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Distribution, population structure, growth and reproduction of the razor clam *Ensis arcuatus* (Jeffreys) (Solenaceae) in coastal waters of western Ireland

by

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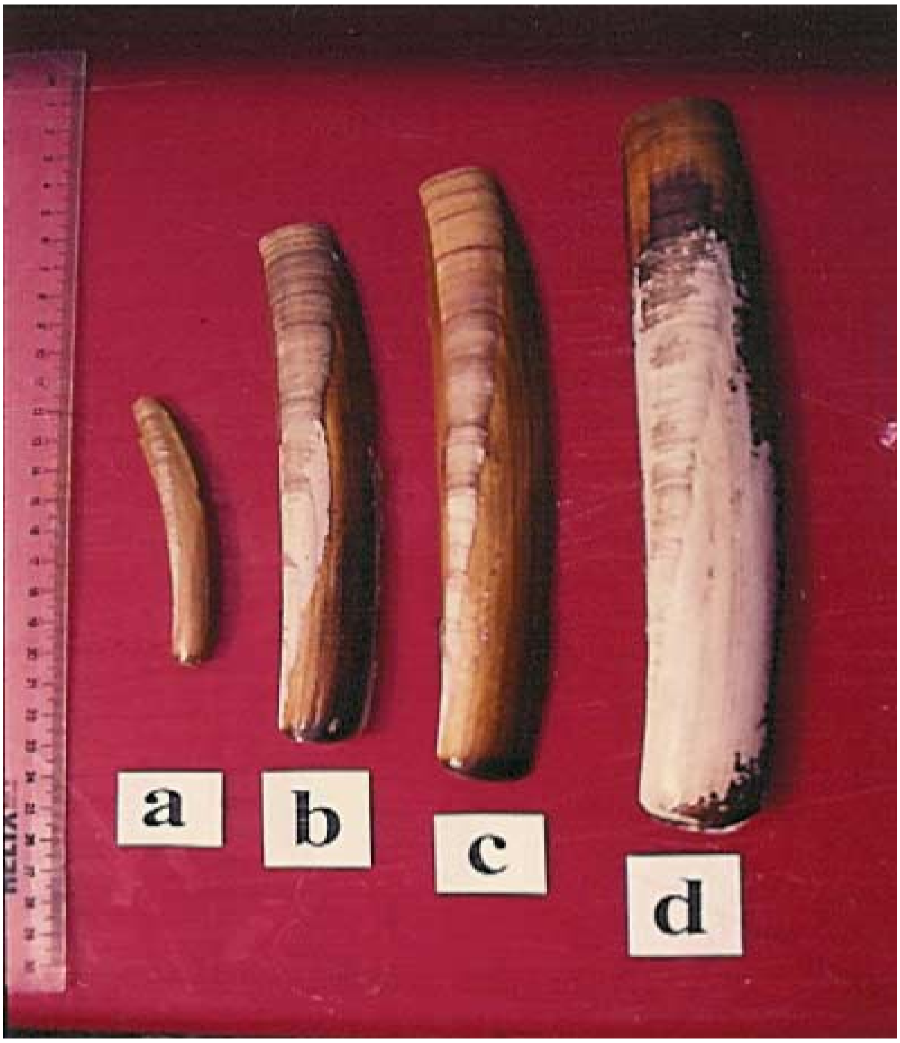

Plate 1. Ensis species from the coast of Co. Galway: a) *E. ensis*, b) *E. arcuatus*, c) *E. arcuatus*, abnormal specimen from Inishbofin and d) *E. siliqua*, a typically large specimen from maërl.

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ABSTRACT

Samples of razor clams, *Ensis arcuatus*, the species which makes up the majority of landings from the west coast of Ireland, were collected by commercial fishery methods, in association with the dredge fishery and by SCUBA diving, from three locations off the coast of Co Galway. *E. arcuatus* occupies coarse sand (of maërl and shell fragments) and rarely co-exists with the other common species of the region, *E. siliqua*. *E. arcuatus* were aged, an age-length-key devised for them, and growth parameters (*Linf*, *k* and *t0*) were calculated. Their maturation state was established by histological examination.

Evidence suggests that *Ensis arcuatus* is mainly a spring spawner, although some spawning appears to take place in most months, with a spatfall in June/July. Maturation commences in its third year. Asymptotic length is achieved at 10 years, approximately, and there was little variability in growth among the three sampling areas or between the sexes. In a small bed of razor clams in Cill Chiarain Bay, Co Galway, there would appear to have been a spatfall in most, if not all, of the past 15 years.

The quantitative distribution of *E. arcuatus* in a single bay within the boundaries of Comharchuman Sliogéisc Chonamara Teó, Co Galway, was estimated by divers salting quadrats of 0.33 m². The razor clam community is divided into a generally distributed fraction occurring at low density (described as the non-bed) and at a relatively higher density (described as the clam bed). The bed was situated in the lee of reefs, which is usually the case for this species along the Atlantic seaboard. More than 90% of the biomass was above the E.U. minimum size limit.

1. INTRODUCTION

Until 1997 razor clams were occasionally harvested in small quantities in the intertidal by salting or digging on Irish coasts. Three common species form large, sparsely populated beds in the lower intertidal and sub-tidal parts of the coast of Britain and Ireland (Holme, 1951 and Tebble, 1966). In 1997 substantial beds of *Ensis siliqua* were discovered off the east coast of Ireland, extending from the inter-tidal into deeper water. Where water quality was unpolluted (Grade A), razor clams were gathered by hydraulic (fluidised bed) dredging (they were fished to a depth of 10 m). The largest exploitable bed, situated off the coast of Co Meath at Gormanstown, extended over 21 km^2; all parts of it were at less than 10 m depth at lowest spring tide. The bed supported an estimated 1,500 tonnes of razor clams (Fahy *et al*, 1999).

Within two years of its discovery more than 1,000 tonnes of *Ensis siliqua* had been removed by commercial fishermen from the Gormanstown bed and additional/alternative beds were actively sought. Inevitably, attention turned to the Irish mid-western seaboard. *Ensis siliqua* occurs there in relatively small numbers; instead, the dominant species is *E. arcuatus*. *E. arcuatus* however, forms relatively smaller patches which are usually situated in the lee of islands, rocks and reefs which shelter the animals from the westerly swell (Fig 1); *E. siliqua* is frequently found in the inter-tidal of westerly or northerly facing shores along the western seaboard, usually in association with very fine sediments. Small percentages of large *E. siliqua* (greater than 220 mm in length) co-exist with *E. arcuatus* in coarser sediments off the west coast. The patches or beds of *E. arcuatus* were located by fishermen dredging in an exploratory way; a vessel of approximately 12 m in length with a crew of 3 men requiring a yield of approximately 300 kg per day to commercially sustain its dredging activity. Where this occurred, razor clams were regarded as being present in harvestable densities and these are the locations marked in Fig 1.

Whereas data are available on the growth and reproduction of *E. siliqua* (Gaspar *et al*, 1994, Gaspar *et al*, 1998, Fahy *et al*, 1999) and Henderson *et al* (1994) made observations on this species and on *E. ensis*, less attention has been paid to *E. arcuatus* which constitutes most of the razor clam landings from the west coast of Ireland. The objective of this investigation of *E. arcuatus* is to describe its growth and reproductive biology in western Ireland. The length and age frequencies of *E. arcuatus* in a single bay are examined to compare the age composition of a clam bed where the animals are clustered at higher density with those of the surrounding area. The biomass of the clam bed is estimated.

The work was undertaken to clarify the biology of *Ensis arcuatus* and to provide information on which it might be exploited in a sustainable way within the boundaries of Comharcuman Sliogéisc Chonnamara Teó (CSC).

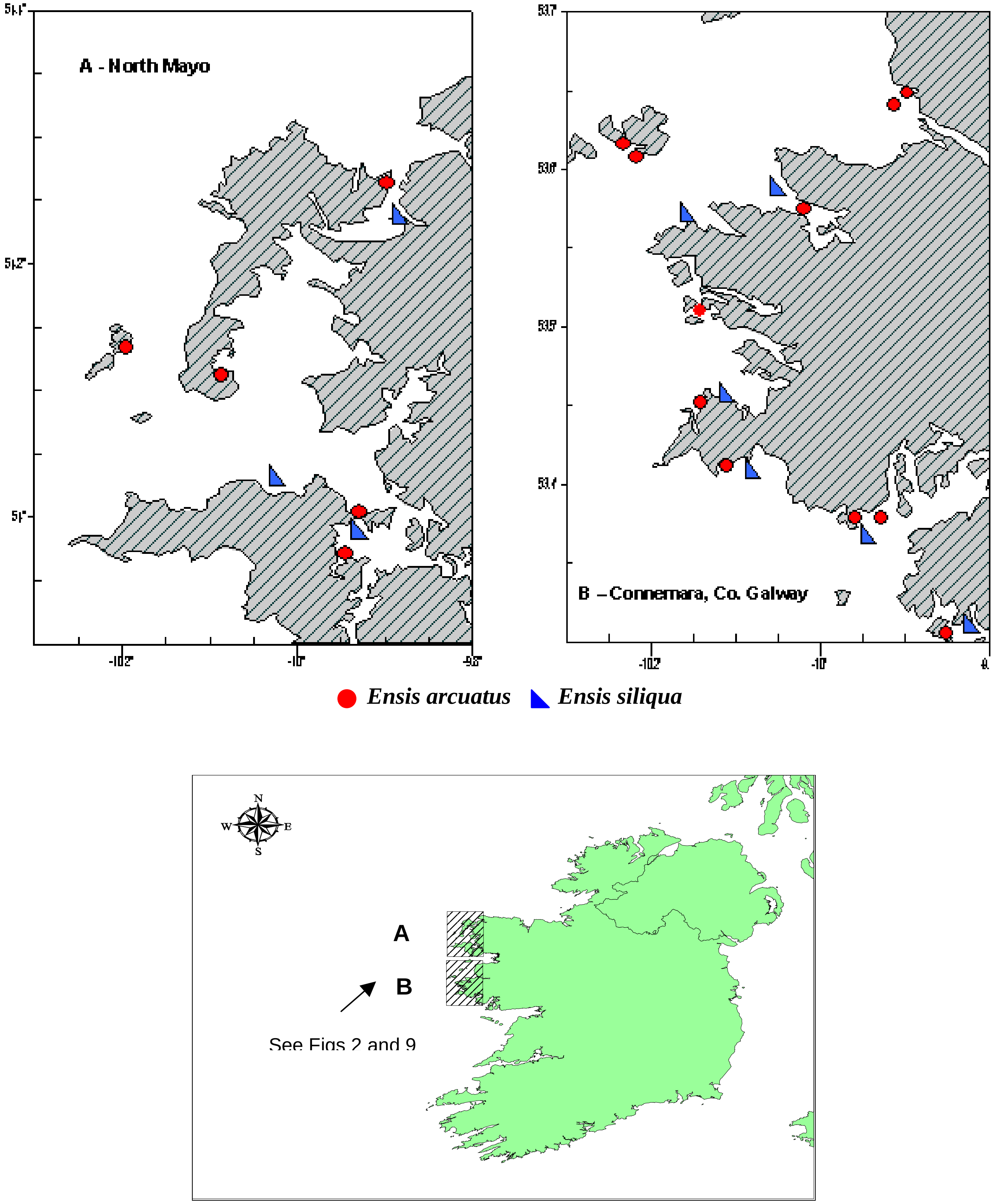

Fig 1. The distribution of concentrations of *Ensis siliqua* and *E. arcuatus* on the coasts of North Co Mayo and Connemara, Go Galway.

2. MATERIALS AND METHODS

2.1. General collections

Investigations into the biology of *E. arcuatus* were conducted from January 2000 to January 2001 in Co Galway. Samples were obtained opportunistically, from material collected by the commercial fishery. Survey work by divers took place in August in an effort to quantify the razor clam populations of an area which is part of Cill Chiaráin Bay. The survey was initiated by in co-operation with the Marine Institute and Taighde Mara Téo, in an area under the control of CSC. CSC is a local community-based shellfish co-operative established in 1984 and it was licensed by the Government Department responsible for fisheries three years later. The objectives of CSC are to "secure and/or provide for, the proper management, protection, maintenance and full development of all shellfish, oysters, prawns, crayfish, mussels, crabs, scallop, lobsters and clams fisheries in Cill Chiaráin and Beirtraghbuí Bays, whether or not known or existing at the formation of the Society" (CSC, 1984).

Razor clams were sub-sampled from the contents of a hydraulic (fluidised bed) dredge, fishing close to Inishbofin (10°15"W 53°36"N) on 26th January, 23rd February and 27th April 2000. The clams were sorted from a portion of the dredge content which, although it had been fished in a metal cage whose bars at 1.5 cm were sufficiently wide to permit smaller animals to drop through, retained quantities of sand which contained 0 group *E. arcuatus*. Samples were collected on 26th October and 13th December 2000 and on 15th January 2001 by a dredge using a propeller to clear away sediment, thus uncovering the razor clams and washing them back into a cage. This operation exploited small patches of clams in the vicinity of Clifden, Co Galway (10°10"W 53°30"N). Specimens were collected during commercial dredging operations. On 7th June razor clams were collected by diver in Greatman's Bay (9°38"W 53°16"N) and on 6th July by the same method in Cill Chiaráin Bay (9°45"W 53°20"N).

2.2. Quantitative sampling

A quantitative assessment by divers of the clam populations in a part of Cill Chiaráin Bay was undertaken from 7th to 11th August 2000. Stations were selected at about 500 m intervals, working seawards approximately along the 9º36" W line from the intertidal. Differential GPS readings were taken at each station. Metal quadrats enclosing 0.33 m^2 were dropped onto the substratum at each station, up to 5 quadrates being placed at each. A second approximate line of stations was selected running west to east at 53º17" N and additional stations were chosen at the margin of the intertidal. When a heavy concentration of razors was located at 9º49"W 53º16"N, more intensive sampling was concentrated on it (Fig 2).

Quadrats were sampled by pouring 1 litre of granular salt (NaCl)[1] over the substratum enclosed by the frame. Within ten minutes all razor clams that had emerged were collected by hand for measurement. Ten stations were sampled by 5 quadrats, 9 by 4, 4 by 3, 2 by 2 and one by a single quadrat. Details of the sites fished are set out in

[1] Hydrosoft granular salt, food purity grade.

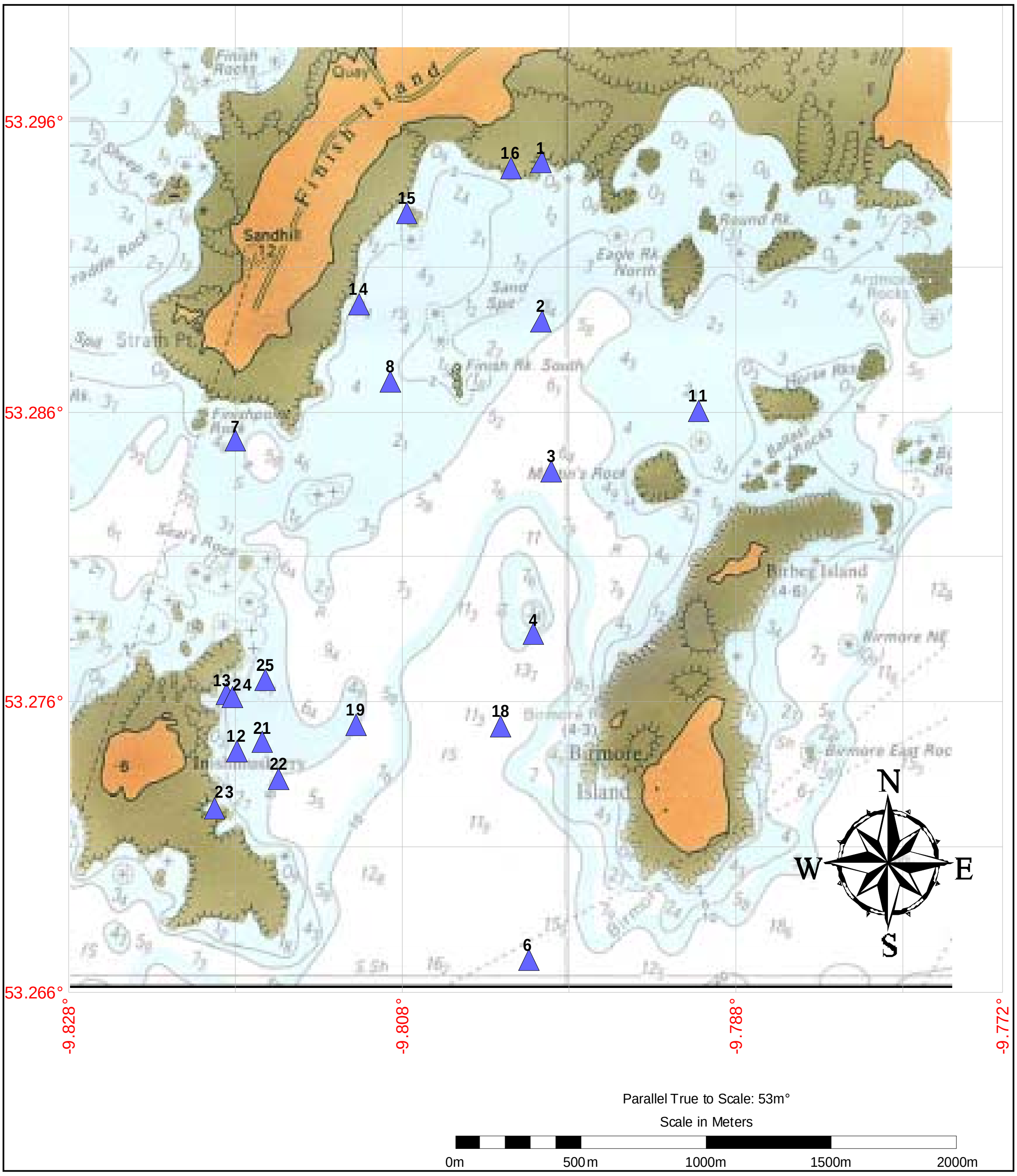

Fig. 2. The distribution of sampling stations in Cill Chiaráin Bay, Co Galway.
The location of the Bay is shown in Fig 1.

Appendix 1. Five stations were, additionally, sampled by Venturi lift (the bag mesh size (2x) being 4 mm.), one of them by two quadrats sampled by this method and one station was sampled by two Venturi lifts only. The contents of the Venturi lift bags were sorted in trays. The Venturi lift yielded large numbers of 0 group razor clams (one sample contained 27 <10 mm / 0.33 m^2) and it is likely the this method gathered animals which divers overlooked. Such was the difference between the two methods that the Venturi samples were not included in quantitative analyses.

2.3. Processing of material

On each occasion when razor clams were harvested, a random sample of landings from the commercial harvesting operation was used to establish the length frequency distribution and to provide material to assess maturation and on which measurements of growth could be made. Whenever sampling took place, particular efforts were made to gather *Ensis* of less than 10 cm in order to trace the progress of the smallest size groups. The lengths of all animals encountered in the course of the diving surveys were measured on a fish measuring board. Sub-samples were removed to the laboratory for additional measurements and weighing.

In the laboratory the razor clams were immersed in fresh water and this was gently agitated for an hour to remove sand; the clams were then left on a draining board for a further hour before examination commenced. The total length (to the nearest 1.0 mm) was noted on a fish measuring board and each clam was weighed to the nearest 0.1 g.

Approximately 30 razor clams ranging from 8 to 17 cm in length were investigated in greater detail on each sampling occasion. Each was split lengthwise and a fragment of gonadal tissue (approximately 0.2 g) was removed and fixed in formaline, later being sectioned and stained in eosin and haemotoxylin. The purpose of this was to ascertain gonadal development. The stage of gonad development was scored according to the conventions of Gaspar *et al* (1998) from 0 in which there was no visible gonadal development and the sexes could not be distinguished, through 1 (where maturation was commencing and the sexes could be distinguished), 2 (where the gonad enlarged), 3 (where the gonads were fully ripe), through 4 (where the release of ova and spermatozoa had commenced and the follicle walls had ruptured) to 5 (where the animal was spent and only occasional resorbing ova and groups of spermatozoa remained).

Additionally, a gonadal smear was examined from a number of animals which were not sectioned, to ascertain the sex for the elucidation of growth rate; males and females of *E. siliqua* were shown to grow at different rates on the east coast of Ireland (Fahy *et al*, 1999). A single valve of each of these individuals was numbered and dried.

Measurement of growth length took place along the hinge margin of the shell, the origin being the corner of the shell at the base of the hinge. The numbered valves were examined under the microscope and aged from the numbers of growth annuli; annual growth features were marked and the length intervals were measured using Vernier callipers[2]. In total 512 *E. arcuatus* were aged; efforts were made to age some from each sampling, once the specimens in question had been sexed. In June, July and August however, most individuals were in the resting stage (0) and hence, few which were aged in those months could be sexed.

[2] "Total length" was measured on a fish measuring board and "growth length" was measured using Vernier callipers. On average, growth length is 5% less than total length, a consequence of shell curvature.

Estimates were made of the length growth coefficient and parameters from the von Bertalanffy growth equation (Ricker, 1979):

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

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

The total lengths of aged individuals were assembled in age-length-keys (ALKs) which were used to allocate ages among length frequencies of measured-only samples.

Occasional substrate samples were collected in the course of sampling operations. Usually they accompanied biological materials in the dredge or they were collected in the course of diving operations. In the laboratory the sediment samples were dried and screened though a series of sieves ranging from 16.0 to 0.063 mm, the weight of each fraction to the nearest 0.1 mm being noted.

Other bivalve species associated with *E. arcuatus* were listed.

3. RESULTS

3.1. Associated bivalve species

Spisula solida (L) was locally common in the vicinity of Clifden and *Dosinia exoleta* (L) formed large beds there, which had occasionally been commercially exploited. *Lutraria lutraria* (L) occurred at the three locations, Clifden, Inishbofin and Cill Chiaráin Bay. *Venus verrucosa* L and *Tapes rhomboides* (Pennant) were infrequently present at the Clifden site.

Glycymeris glycymeris (L) and *Arctica islandica* (L) were occasional at all sites and *Laevocardium crassum* (Gmelia) was common in Cill Chiaráin Bay. Other species taken particularly in Clifden Bay were *Gari depressa* (Pennant) and *Angulus squalidus* (Pulteney).

3.2. The substratum

Large concentrations of *E. siliqua* on the east coast of Ireland (Fig 3) were particularly associated with fine sediment (According to the American Geophysical Union descriptive scale, more than 90% of the grain size at Gormanstown and more than 70% in Cill Chiaráin, is “fine sand”, corresponding with a rating of –3 on the θ scale

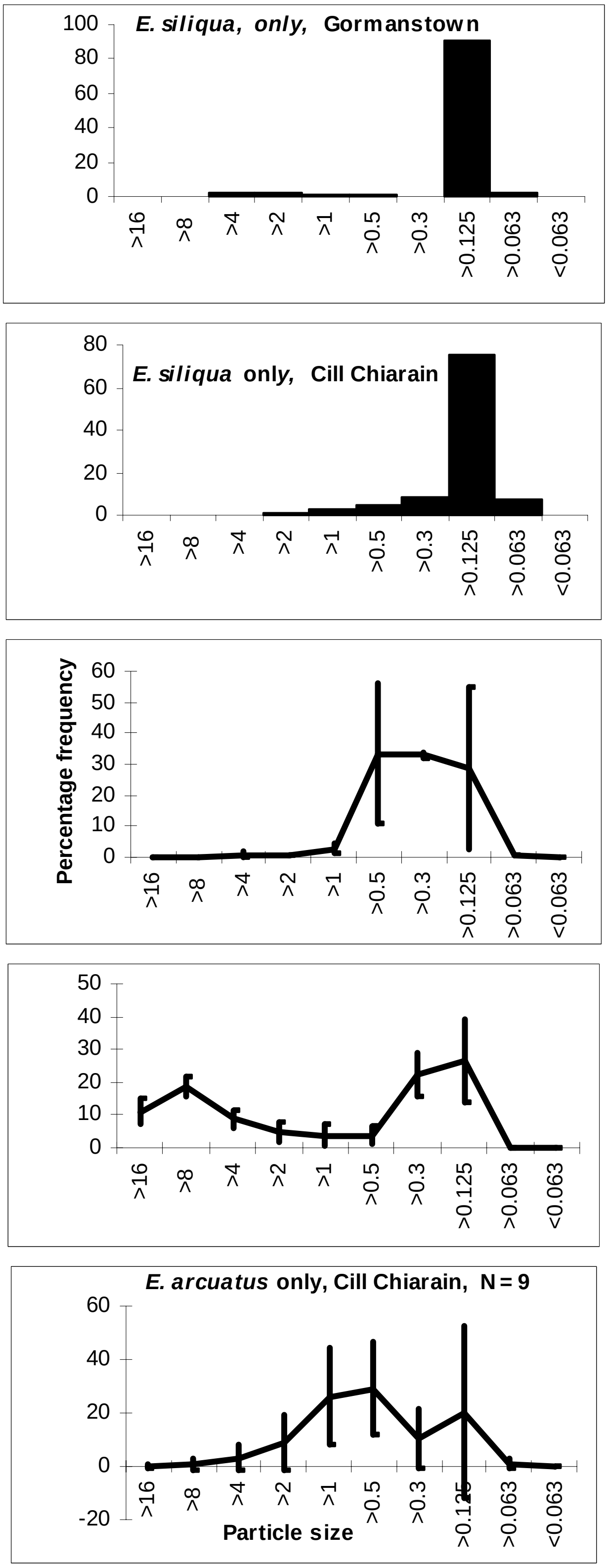

Fig. 3. Analysis of particle size associated with *E. siliqua* and *E. arcuatus* and both species together, on the east (Gormanstown) and west (Cill Chiaráin) coasts of Ireland. The top two histograms are each calculated from a single sample; the next two represent the mean and range of values and the bottom diagram is drawn from the mean +/- 1 standard deviation.

(Fluskey, 1989)). Wherever the two species occurred in the same vicinity off the west coast, smaller *E. siliqua* (<150 mm total length) were usually found in association with fine sand. *E. arcuatus* usually occurred in shell sand or in algal gravel (maërl) which is common along the Co Galway shoreline (de Grave *et al*, 2000) (corresponding with "coarse" and "very coarse sand" on the American Geophysical Union descriptive scale or with values of –1 to 0 on the θ scale). Occasional very large *E. siliqua* (210 – 230 mm total length) occurred among these larger particles at the Inishbofin site. The largest particles encountered at Inishbofin were more usually shell fragments rather than stones.

3.3. Size range of *E. arcuatus* from the sampling areas

Length frequency distributions of the sampled razor clams are set out in Fig 4. Their composition is not entirely randomly chosen (except in the case of Cill Chiaráin Bay), smaller individuals were disproportionately gathered to clarify the early growth stages.

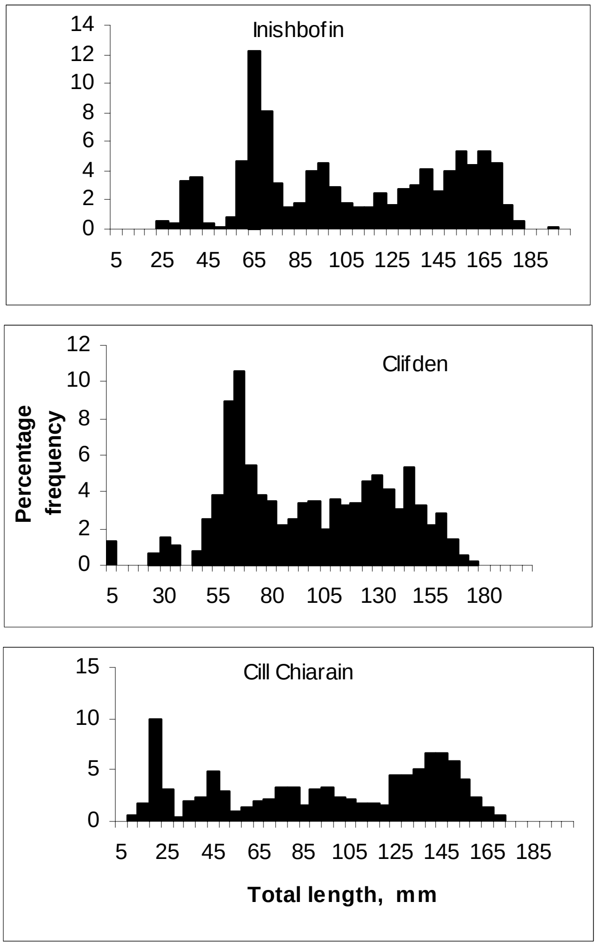

Fig 4. Length frequency (total lengths) of razor clams (*E. arcuatus*) sampled from Inishbofin, Clifden and Cill Chiaráin in 2000.

Holme (1951) gave length measurements (corresponding with total lengths as used here) for *E. arcuatus* intermediate between those of *E. siliqua* and *E. ensis*. Holme's dimensions for *E. siliqua* are smaller than recorded in Ireland (Fahy *et al*, 1999) and *E. arcuatus* recorded here are also larger than reported by Holme. Tebble (1966) reported that large specimens of *E. arcuatus* could reach 152.4 mm. The largest total lengths of *E. arcuatus* exceeded 170 mm and, in Inishbofin, whose samples contained the largest specimens, one was greater than 190 mm. This single specimen was, however, regarded as abnormal.

Length frequencies of all *E. arcuatus* less than 100 mm from all sites are set out by month in Fig 5. Discrete, separable modes are numbered and sliced from their neighbours at the lowest intervening length frequency. The data contributing to them are averaged and expressed as mean values +/- 1 standard deviation and re-arranged in sequence over a notional time scale (Fig 6). All data from January 2000 and January 2001 are combined. Between December and February, the lowest point of the standard deviation was 24 mm in year 1 and 49 mm in year 2; the upper point in the standard deviation was 39 mm in year 1 and 69 mm in year 2. There would appear to be one spatfall annually, probably in June-July.

3.4. Growth

Growth length is shorter than total length and, in the case of western *E. arcuatus*, is in closer agreement with the maximum lengths reported by Holme, 1951 and Tebble, 1966. The various populations from three areas in Western Ireland, had *Linfs* which ranged from 145 to 159 mm; a single individual from Inishbofin was considerably larger, its *Linf* was 212 mm (Table 1; Fig 7). For comparison, a calculated growth curve for *E. arcuatus*, based on material collected in Clifden and another in Cill Chiaráin (Table 1) is also presented in Fig 7. Unlike *E. siliqua*, whose growth rates are higher for males than females (Fahy *et al*, 1999), both sexes of *E. arcuatus* have similar asymptotic lengths.

The total lengths of all aged *E arcuatus* were arranged in an ALK which was used to distribute length frequencies among ages (Table 2). According to a calculated growth curve which incorporated all length at age data for the species, the mean length at 1 year is 28.2 mm (+/- 7.18 mm); at 2 it is 55.3 mm (+/- 8.42 mm). These calculations are in approximate agreement with the lengths at age shown in Fig 6.

3.5 Maturation

As has previously been observed, razor clam gonads usually contain more than one developmental stage during maturation and, in this case, the presence of these was noted as a percentage; for example, a section might have contained 30% stage 2 and 70% stage 3. All of these percentages were totalled on each sampling date, and the percentage frequency occurrence of all stages (Table 3) was expressed in histogram form (Fig 8).

The smallest mature *E. arcuatus*, a male of 85 mm total length, corresponded with an age of 2 – 3 years. Small numbers of *E. arcuatus* spawn during a large part of the year. However, the 0 stage occupied a progressively larger number of gonads as the year progresses from winter.

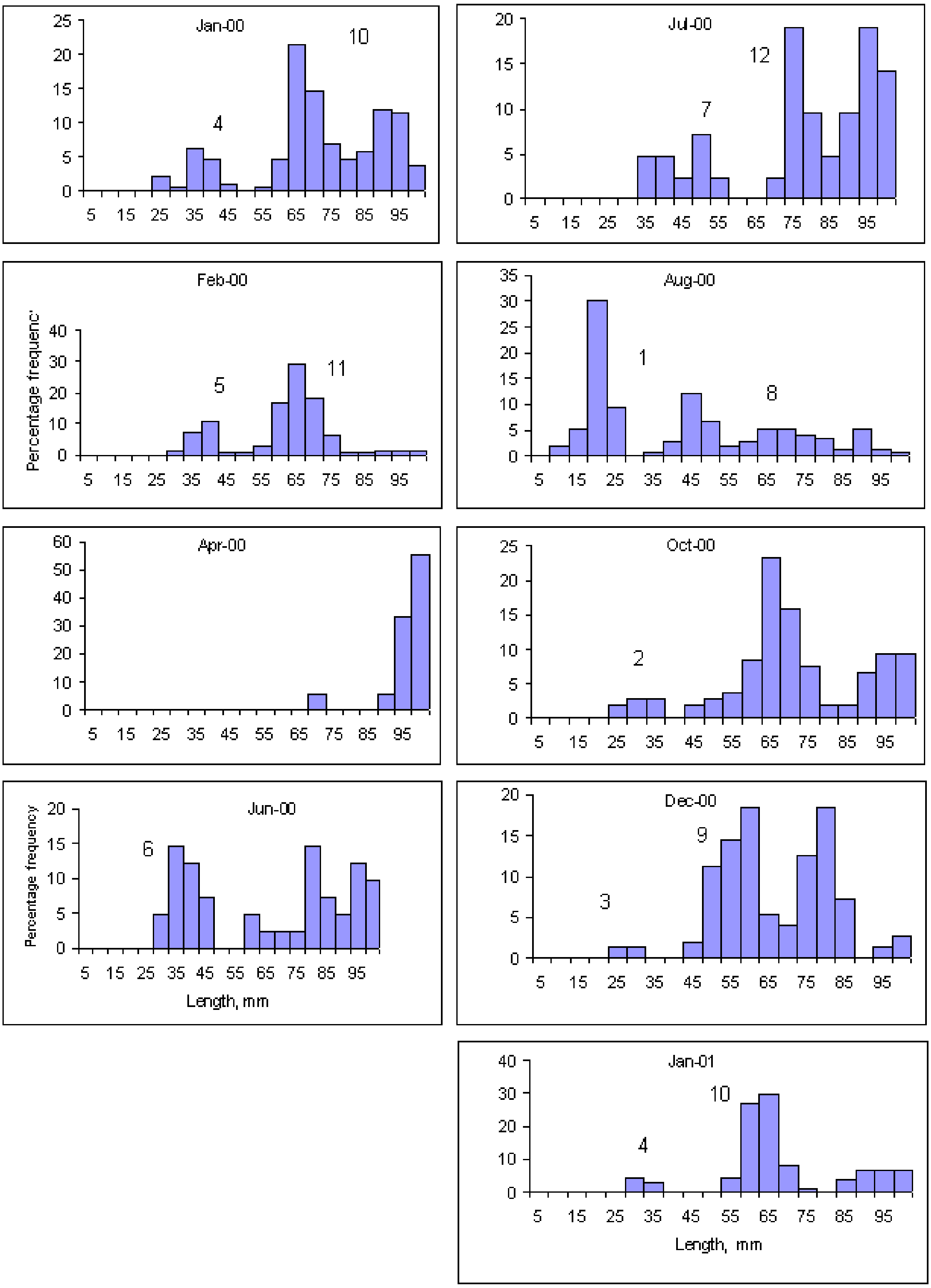

Fig 5. Monthly percentage length frequencies of *E arcuatus* less than 100 mm, total length. Separable cohorts are identified by number.

3.6 Weight at length relationships

For *E. arcuatus*: LNweight (g) regressed on LNtotal length (mm) with the following outcome: intercept = -12.8665; x-variable = 3.2863 (N=1892; r^2=0.9854). A similar regression was calculated for *E. siliqua* from the Gormanstown bed, on the east coast of Ireland, with the following outcome: intercept=-4.2267; x-variable = 2.9150 (N = 51; r^2=0.9377). These calculations are used to estimate biomass of the species in Cill Chiaráin Bay.

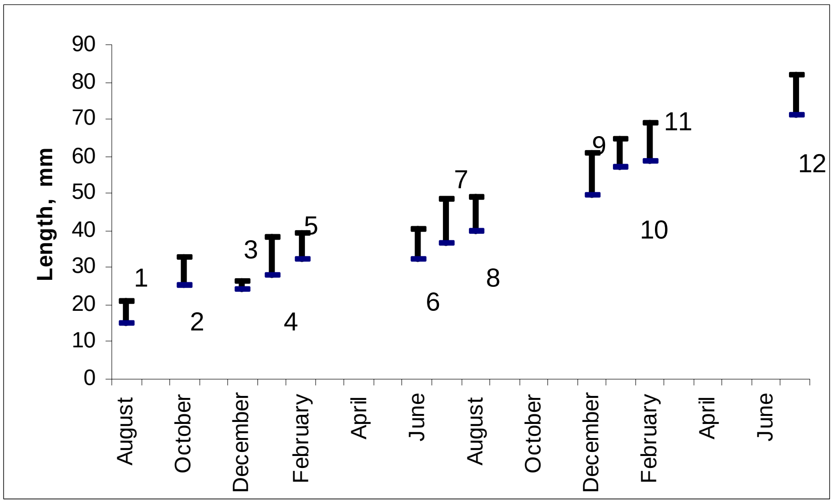

Fig 6. The mean +/- 1 standard deviation of separable cohorts of *E. arcuatus* (from Fig 5) rearranged in sequence over a notional time scale of two years.

3.7 Ecology of an *E. arcuatus* bed in Co Galway

E. arcuatus is widespread in Cill Chiaráin Bay, Co Galway where it is the more abundant of the larger bivalves; the bay is also well known for its commercial production of a variety of other shellfish species including oysters and scallops.

Along the shore of Cill Chiaráin Bay the substratum is of fine sand (in which there are sparse numbers [<1/m²] of *E. siliqua*) which, further seawards, is replaced by coarse or very coarse particle sizes which consist largely of maërl intermixed with shell sand. Concentrations *of E. arcuatus* accumulate in the lee of islands, reefs and rocks. Patches of *Zostera* spp. occur in the vicinity but they are not favoured by *E. arcuatus*, probably because its roots obstruct burrowing.

A survey of *E. arcuatus* in August 2000 revealed the distribution of biomass shown in Fig 9. Clusters of sites having relatively high razor biomass (consisting of E. arcuatus only) are referred to as the clam "bed". *E. arcuatus* in Cill Chiaráin Bay was considered as two groups: those within the bed (the highest concentration of the species) and those in the surrounding substratum (the non-bed).

The length frequency distributions of both groups contrast most markedly in the large numbers of clams of less than 10 mm which occurred outside the bed (Fig 10). However, after omitting the smallest clams (<10 mm) from further consideration (samples taken by Venturi lift suggested that these may not have been efficiently collected by hand), comparison of the relative occurrence of size groups within the bed and outside it, by Chi-square, reveals significant differences (Table 4) between the length frequencies. The smaller individuals (up to 70 mm total length) were mainly outside the bed as were the very largest (140 -160 mm total length), those in the intermediate range being mainly on the bed.

Converting the length to age frequencies by ALK reveals a similar pattern: the youngest animals were proportionally more frequent outside the clam bed, as were the oldest, those animals of intermediate age being relatively more frequent in the clam bed. In this case however, there was no significant difference in the two age distributions (P>0.05).

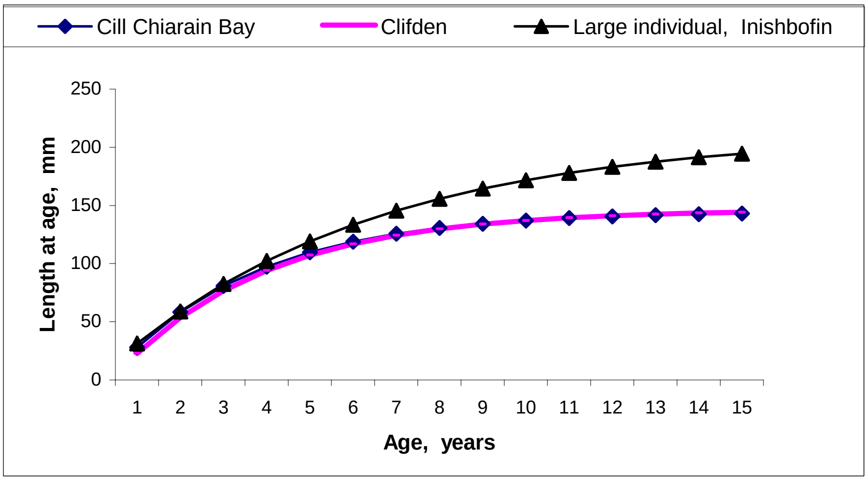

Fig. 7. Calculated growth curves for *E. arcuatus* in Clifden and Cill Chiaráin compared with a curve for a single exceptionally large individual taken at Inishbofin. Curves are fitted using the von Bertalannfy growth equation.

3.8 Area and biomass of the clam bed

The extent of the bed was identified by including adjacent stations in which the biomass of razor clams was high (Fig 9). Its area was calculated by GIS using the unprojected Lat/Long method as 183,226 m2.

A low tide survey of the substratum by boat using differential GPS to mark the position of rocks, concentrations of *Zostera* and clear sandy areas, confirmed that the highest density of razor clams occurred on a sand substratum among occasional seaweed covered rocks which, while they are likely to provide valuable shelter against the Atlantic swell for *E. arcuatus*, also obscure a proportion of the clam habitat. The boat survey suggested that 88% of the area characterised by high clam densities actually supported razor clams.

The biomass of razor clams within the area described as the bed is estimated at 247.6 g per 0.33 m² (Standard deviation = +/- 135.2 g). Outside the bed, the average razor clam

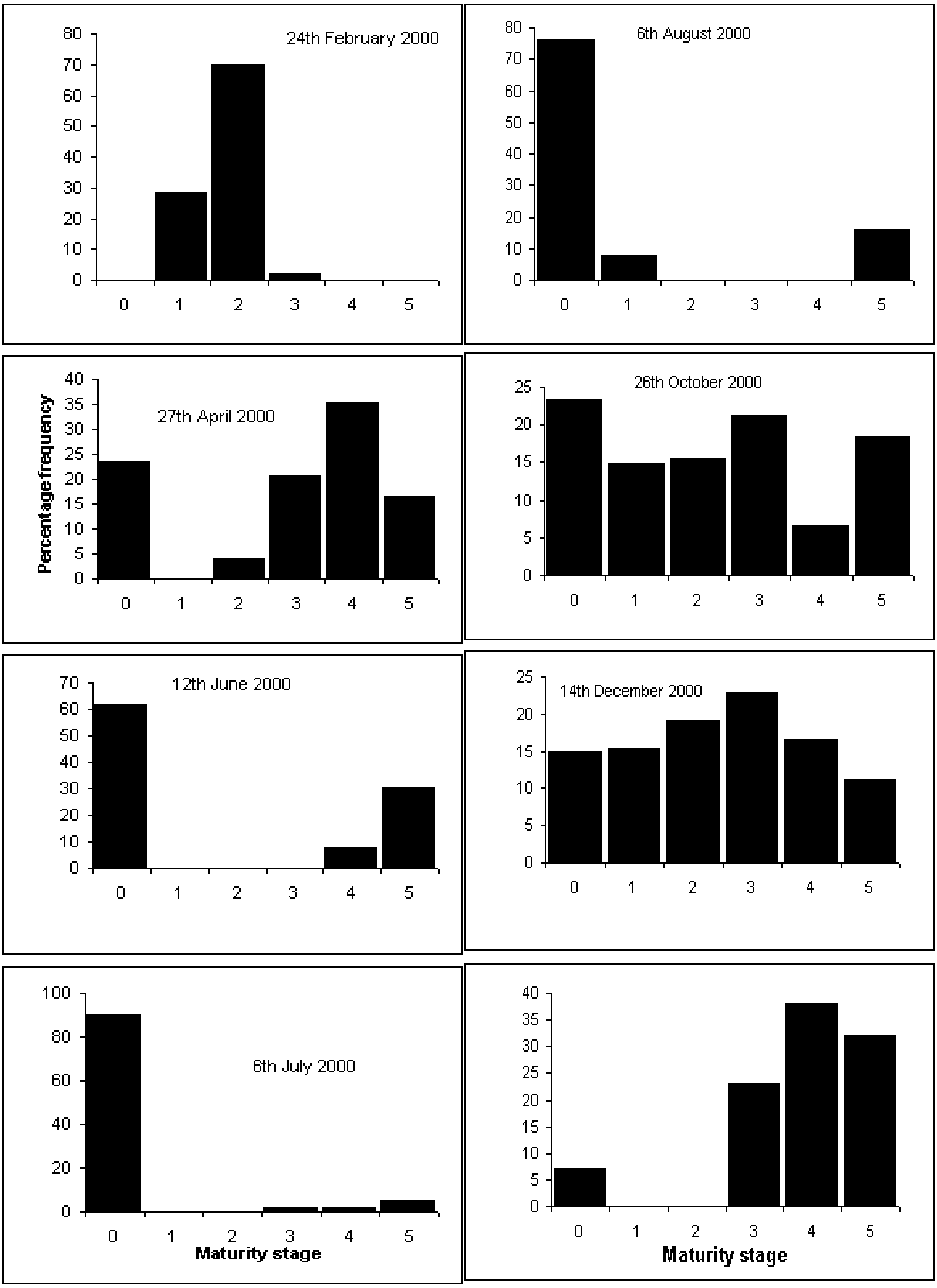

Fig. 8. Percentage frequency histograms of maturation in *E. arcuatus* from the estimated occurrence of developmental stages in histological preparations of gonads. Details of the samples are in Table 3.

biomass, which included *E. siliqua* closer to shore, was lower at 35 g / 0.33 m² and the standard deviation larger (+/- 101 g).

Harvestable biomass consists of clams larger than 100 mm (the E.U. size limit). Applying the weight at length relationship to the length frequency of *E. arcuatus* on the bed, suggests that some 92% of the clams may be legally harvested. The figure might be adjusted because of the possibly low collection rate of the smallest clams but, in view of their low weight, it is unlikely to be a major alteration.

The estimated harvestable biomass of the clam bed in Cill Chiaráin Bay is estimated at 110 tonnes, ranging between 50 – 170 tonnes (Table 5).

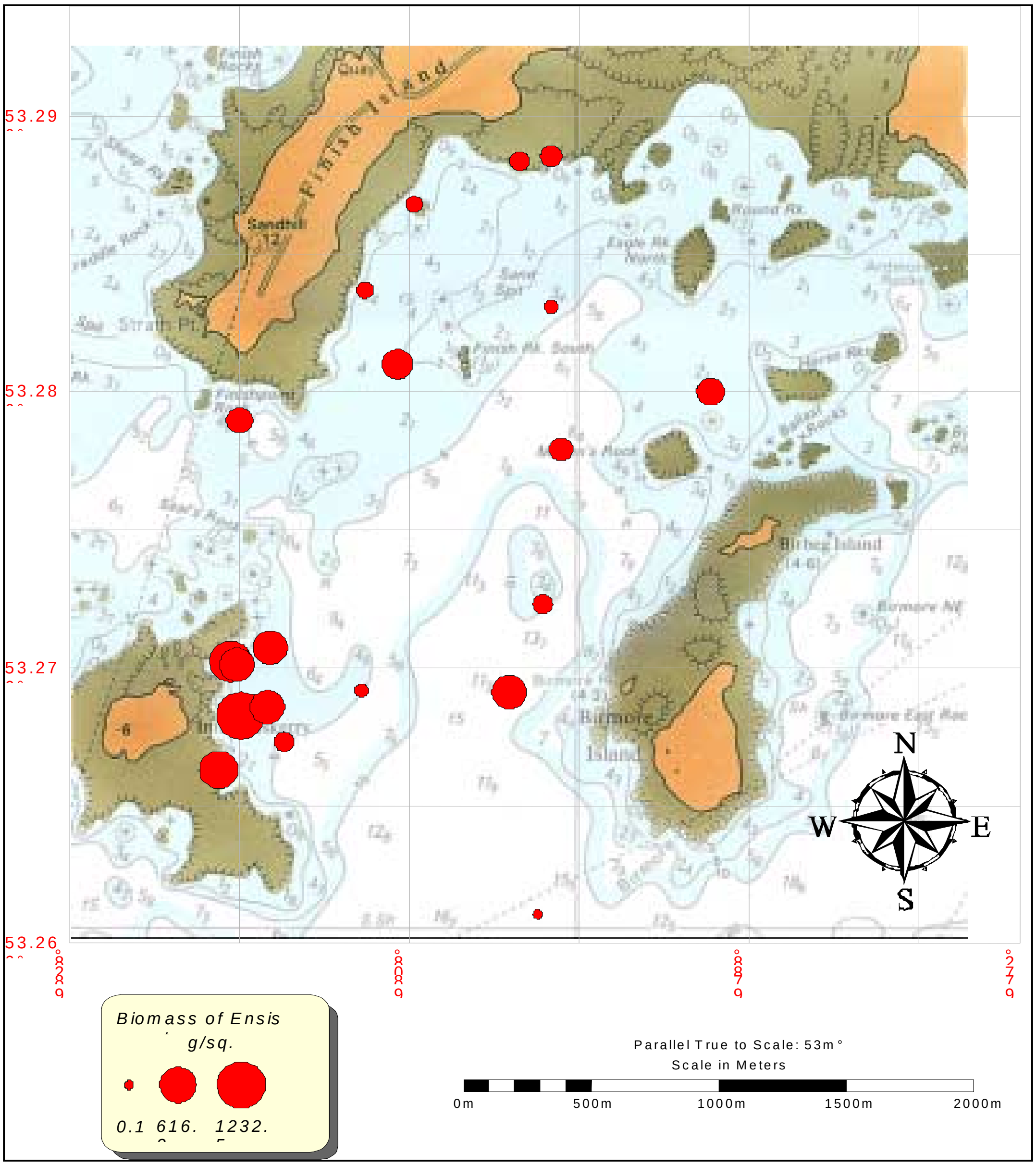

Fig. 9. Biomass per station in Cill Chiaráin Bay.

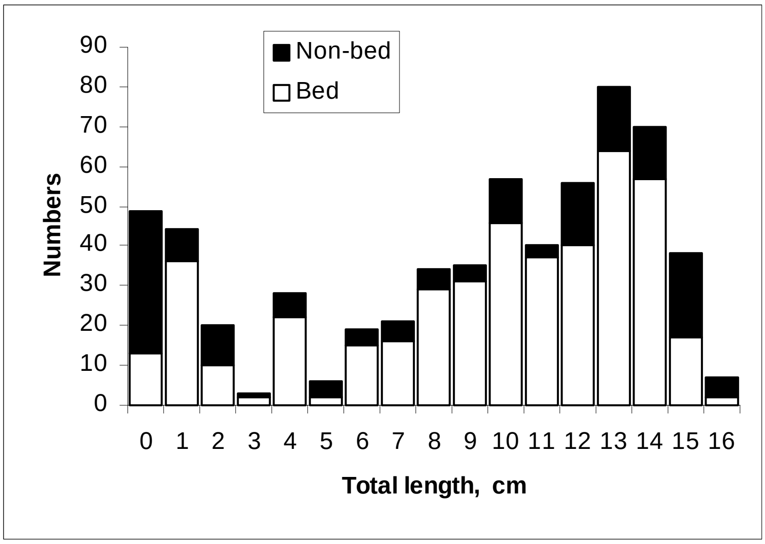

Fig.10.The length frequency distribution of *E. arcuatus* in Cill Chiaráin Bay, visualised as being concentrated in a clam "bed" and dispersed at lower density ("non-bed")

4. DISCUSSION

E. arcuatus colonizes a substratum consisting of a coarser grade size than *E. siliqua*; only very large specimens of the latter appear capable of occupying maërl/shell sands. *E. arcuatus* is the most abundant of the larger bivalves in these areas and it co-exists with a number of other species, some of which have commercial potential. *E. arcuatus* forms concentrations or beds in the lee of sheltering rocks and reefs which provide protection from the westerly swell. The species would appear to be dependent on shelter and its beds/patches of relatively high concentration are small, when compared with, say beds of *E. siliqua* on the east coast of Ireland.

Little is known of the frequency of recruitment in *E. arcuatus*, but it would appear that in one instance (Cill Chiaráin Bay), there has been a spatfall in most, if not all, of the past 15 years (Table 4).

Maturation in *E. arcuatus* appears to commence at the age of 2-3 years (probably by a small proportion of the population), slightly younger than in *E. siliqua* on the east coast. Growth becomes asymptotic after 10 years and the calculated growth curves from several localities were closely similar. Male and female *E. arcuatus* have similar growth curves, unlike *E. siliqua* where males grow at a faster rate and achieve a larger asymptotic length than females.

Active gonad development took place between October and April, making this species a winter-spring spawner. In this respect *E. arcuatus* contrasts with *E. siliqua* which, although it is variable, appears to spawn mainly in the spring and summer months (Gaspar *et al*, 1998, Fahy *et al*, 1999). However, there appears to be some discrepancy between February 2000 and January 2001 so the annual maturation cycle may be variable. The appearance of small razor clams of 10 – 25 mm in August 2000 would suggest their settlement in June/July from a likely spawning in April. There was no evidence of two spat falls in the year. The consequence of a winter spawning is not evident.

Estimating the size of a razor clam patch can be approached in several ways. Monitoring dredging records to compile a record of depletion rates and harvest has been done (Fahy *et al*, 1999) but it is essentially destructive. The approach in this case was to attempt a census of the animals before harvesting commenced.

The estimation of razor clam biomass using divers is expensive. Variance within and among stations was large in this assessment and confidence limits were correspondingly wide. The age composition of the clams within a "bed" was not unlike that of the more dispersed population in surrounding areas and it is probable that there is movement of animals between the two. Razor clams are known to be active swimmers (Fahy *et al*, 1999) and fishermen have remarked on the rapid recolonisation of razor beds after dredging, either by the redistribution of animals within the fished area or by migration of others onto the clam bed. But recolonisation cannot be an indefinite process; eventually all stocklets within an area will be fished down and the surrounding areas which are uneconomic to dredge, may also be depleted in the process because their occupants have moved away into the exploited areas.

E. arcuatus appears to produce gametes over a long period in the year: stages 4 and 5 in the gonads, associated with the release of eggs and spermatozoa, were recorded in 6 of the 8 months in which gonads were sampled and recommendation of a close season to allow spawning or spatting would be unwise until more is known about these processes. Observations made in the course of this work favour spring as an important spawning time, followed by settlement in June and July.

Fallowing, leaving razor clam beds to recuperate after harvesting, would seem to be an option, in which case the recommended period should probably allow the juveniles of the year to reach first maturation (three years later).

So little is known about the dynamics of razor clam beds that any prudent course of extraction will have to be carefully monitored and frequently assessed. Sustainable management of these resources is always going to be problematical; in circumstances where there are no official obstacles to fishing for a fresh fish market – provided water quality is adequate – the only possible controlled environment is likely to be that provided by controlled exploitation of an enclosed area within a management arrangement such as that of CSC.

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David Palmer of CEFAS, Lowestoft, confirmed the identity of a single large individual of *E. arcuatus* from Inishbofin. Darrel Clinton of the Fish Health Unit of the Marine Institute at Abbotstown prepared the histology sections of razor clam gonad.

Chris Richardson of the School of Ocean Sciences, University of Wales, Bangor, read the MS and made a number of valuable suggestions for its improvement.

Figs 2 and 9 are reproduced with the permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office from chart number 2096, Republic of Ireland – west coast, Cashla Bay to Kilkieran Bay (licence number HO 688/990406/01).

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Table 1. Growth coefficients and associated data used in the calculation of growth curves for *Ensis arcuatus*.

Population	Number of length at age points used	Age range	Growth coefficients Linf (mm)	k	t0	Ford-Walford plot r2
Cill Chiarain Bay, both sexes	7	1-7	144.9	-0.3005	0.2864	0.9940
Clifden Bay, both sexes	11	1-11	146.5	0.2865	0.4082	0.9980
Inishbofin, both sexes	14	1-14	158.6	-0.2625	0.2038	0.9990
Males only, all locations	11	1-11	154.0	-0.2695	0.1919	0.9980
Females only, all locations	12	1-12	154.0	-0.2695	0.4313	0.9980
One large individual from Inishbofin	12	1-12	212.3	-0.1661	0.0411	0.9980

Table 2. Age length key (ALK) for Ensis arcuatus, all data pooled.

Length Group mm	Age 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	TOTALS
0-9	7																			**7**
10-19	12																			**12**
20-29	4																			**4**
30-39	12	21	1																	**34**
40-49	2	3	1																	**6**
50-59		10	8	1																**19**
60-69		43	24	2																**69**
70-79		6	14	2																**22**
80-89			7	4																**11**
90-99			14	8																**22**
100-109			3	9	6	2														**20**
110-119				13	9		1													**23**
120-129					12	6	5	4	3	1										**31**
130-139					4	10	6	11	6	1	2	5	3							**48**
140-149						5	11	6	11	3	7	5	3	1	2					**54**
150-159						1		3	4	9	10	6	5	9	3	4				**54**
160-169									1	3	7	11	8	6	9	8	4		1	**58**
170-179												2	3	3	3	2	3	1		**17**
180-189																				
190-199													1							**1**
																Total				**512**

Table 3. Percentage frequency of maturation stages in *E. arcuatus* from various dates.

	Numbers examined	Percentage stages					
		0	1	2	3	4	5
24-Feb-00	28	0	29	70	2	0	0
27-Apr-00	34	24	0	4	21	35	17
12-Jun-00	13	62	0	0	0	8	31
06-Jul-00	20	90	0	0	3	3	5
06-Aug-00	25	76	8	0	0	0	16
26-Oct-00	30	23	15	16	21	7	18
14-Dec-00	27	15	15	19	23	17	11
18-Jan-01	29	7	0	0	23	38	32

Table 4. Percentage length and age frequencies of *E. arcuatus* on the bed and outside it (non-bed) in Cill Chiarain Bay. Animals of less than 10 mm in length are omitted from the calculations.

Length group (cm)	Non-bed	Bed
1	6.1	8.5
2-4	12.9	8.0
5-7	9.8	7.7
8-9	6.8	14.1
10	8.3	10.8
11-12	14.4	18.1
13	12.1	15.0
14-16	29.5	17.8
Totals	**100.0**	**100.0**
Numbers on which totals are based	*170*	*439*

(including animals less than 10 mm omitted from the calculations)

Chi-square = 17.55; 7 degs of freedom, significant at 14.1. P < 0.05

Age group (years)	Non-bed	Bed
1	12.2	10.4
2	10.7	8.9
3	6.7	10.4
4	6.0	10.2
5-6	8.4	11.2
7-8	8.6	11.1
9-10	9.0	10.6
11	6.8	6.7
12	10.4	5.7
13-14	12.1	9.1
15-18	9.1	5.7
Totals	**100.0**	**100.0**

Chi-square is 12.063; 10 degs of freedom, significant at 18.3 P>0.05, not significant.

Table 5. Calculation of the biomass of *E. arcuatus* on a clam bed in Cill Chiarain Bay.

		Minimum	Mean	Maximum
a	Area of the clam bed (m2)			183,226
b	Proportion likely to support razor clams (percentile fraction)			0.88
c	Area likely to support razor clams [a*b] (m2)			161,239
d	Biomass (g) per quadrat			248
e	Standard deviation			135
f	Biomass (g) per m2 [(d-e)*3] [d*3] [(d+e)*3]	337	743	1,148
g	Percentile fraction to be harvested			0.92
h	Biomass per m2 to be harvested [f*g]	310	683	1,057
I	**Potential clam yield (kg)** [c*h]	**50,020**	**110,187**	**170,353**

Appendix 1. Survey details from Kilkieran Bay.

Station number	Bed (B) or general dispersion (N)	Latitude	Longitude	Sample diver/ Venturi	Depth (m)	Comments on Substrate	Total razor biomass g per 0.33 m2
1.1	N	53.29477	-9.80052	Dive	3.5	Sand	48.3
1.2	N	53.29477	-9.80052	Dive	3.5	Sand	0.0
1.3	N	53.29477	-9.80052	Dive	3.5	Sand	93.2
1.4	N	53.29477	-9.80052	Dive	3.5	Sand	56.4
1.5	N	53.29477	-9.80052	Venturi	3.5	Sand	0.0
2.1	N	53.28930	-9.80052	Dive	8	Sand	0.0
2.2	N	53.28930	-9.80052	Dive	8	Sand	21.3
2.3	N	53.28930	-9.80052	Dive	8	Sand	0.0
2.4	N	53.28930	-9.80052	Dive	8	Sand	0.0
3.1	N	53.28413	-9.79993	Dive	10	Maerl	54.8
3.2	N	53.28413	-9.79993	Dive	10	Maerl	17.4
3.3	N	53.28413	-9.79993	Dive	10	Maerl	40.4
3.4	N	53.28413	-9.79993	Dive	10	Maerl	99.1
4.1	N	53.27852	-9.80100	Dive	13.3	Sand & Maerl	21.3
4.2	N	53.27852	-9.80100	Dive	13.3		21.3
4.3	N	53.27852	-9.80100	Dive	13.3		15.2
4.4	N	53.27852	-9.80100	Dive	13.3		54.2
5.1	N	53.27245	-9.80300	Dive	13.3	Coarse sand	0.1
5.2	N	53.27245	-9.80300	Dive	13.3		0.0
5.3	N	53.27245	-9.80300	Dive	13.3		0.0
5.4	N	53.27245	-9.80300	Dive	13.3		0.0
6.1	N	53.26727	-9.80130	Dive	16.9	Sand patches/rock	0.1
6.2	N	53.26727	-9.80130	Dive	16.9		0.0
6.3	N	53.26727	-9.80130	Dive	16.9		0.0
6.4	N	53.26727	-9.80130	Dive	16.9		0.0
7.1	N	53.28518	-9.81885	Dive	8.4		58.5
7.2	N	53.28518	-9.81885	Dive	8.4		76.0
7.3	N	53.28518	-9.81885	Dive	8.4		96.2
8.1	N	53.28722	-9.80955	venturi	4.1		0.4
8.2	N	53.28722	-9.80955	Dive	4.1		8.1
8.3	N	53.28722	-9.80955	Dive	4.1		274.6
8.4	N	53.28722	-9.80955	Dive	4.1		207.0
9.1	N	53.28773	-9.80418	venturi	7		0.0
9.2	N	53.28773	-9.80418	venturi	7		0.0
9.3	N	53.28773	-9.80418	Dive	7		0.0
9.4	N	53.28773	-9.80418	Dive	7		0.0
9.5	N	53.28773	-9.80418	Dive	7		0.0
10.1	N	53.28792	-9.80023	Dive	7.8	Maerl	0.0
10,2	N	53.28792	-9.80023	Dive	7.8		0.0
10.3	N	53.28792	-9.80023	Dive	7.8		0.0

10.4	N	53.28792	-9.80023	Dive	7.8		0.0
11.1	N	53.28622	-9.79113	Venturi	5.5	Sand/Zostera	107.3
11.2	N	53.28622	-9.79113	Dive	5.5		48.4
11.3	N	53.28622	-9.79113	Dive	5.5		123.6
14.1	N	53.28990	-9.81148	Dive	6.5	Zostera	73.6
14.2	N	53.28990	-9.81148	Dive	6.5		0.0
14.3	N	53.28990	-9.81148	Dive	6.5		0.0
14.4	N	53.28990	-9.81148	Dive	6.5		0.0
14.5	N	53.28990	-9.81148	Dive	6.5		0.0
15.1	N	53.29302	-9.80858	Dive	6.1	Fine sand	0.0
15.2	N	53.29302	-9.80858	Dive	6.1		0.0
15.3	N	53.29302	-9.80858	Dive	6.1		0.0
15.4	N	53.29302	-9.80858	Dive	6.1		56.1
16.1	N	53.29458	-9.80237	Dive	4.2	Sand patches/rock	42.0
16.2	N	53.29458	-9.80237	Dive	4.2		42.0
16.3	N	53.29458	-9.80237	Dive	4.2		0.0
17.1	N	53.28707	-9.77852	Dive	10.5	Maerl, sand cobble	0.0
17.2	N	53.28707	-9.77852	Dive	10.5		0.0
18.1	N	53.27532	-9.80298	Dive	6.5	Coarse shell sand	131.8
18.2	N	53.27532	-9.80298	Dive	6.5	Coarse shell sand	152.1
18.3	N	53.27532	-9.80298	Dive	6.5	Coarse shell sand	471.5
18.4	N	53.27532	-9.80298	Dive	6.5	Fine sand	84.0
18.5	N	53.27532	-9.80298	Dive	6.5	Fine sand	27.1
19.1	N	53.27538	-9.81167	Dive	9.3		0.3
19.2	N	53.27538	-9.81167	Dive	9.3		0.0
19.3	N	53.27538	-9.81167	Dive	9.3		21.3
19.4	N	53.27538	-9.81167	Dive	9.3		0.0
19.5	N	53.27538	-9.81167	Dive	9.3		0.0
20.1	N	53.27485	-9.81575	Dive	8.4		0.0
22.1	N	53.27352	-9.81623	Dive	7.2	Sand without ripples	128.5
22.2	N	53.27352	-9.81623	Dive	7.2		22.7
22.3	N	53.27352	-9.81623	Dive	7.2		1.8
22.4	N	53.27352	-9.81623	Dive	7.2	Sand with ripples	0.3
22.5	N	53.27352	-9.81623	Dive	7.2		0.0
26.1	N	53.27675	-9.81495	Dive	10.7	Coarse broken shell	0.0
26.2	N	53.27675	-9.81495	Dive	10.7		0.0
26.3	N	53.27675	-9.81495	Dive	10.7		0.0
26.4	N	53.27675	-9.81495	Dive	10.7		0.0
26.5	N	53.27675	-9.81495	Dive	10.7		0.0
27.1	N	53.27478	-9.81688	venturi	8.3		0.0
27.2	N	53.27478	-9.81688	venturi	8.3		0.0
12.1	B	53.27447	-9.81880	Dive	5.2	Sand	402.2

12.2	B	53.27447	-9.81880	Dive	5.2		369.2
12.3	B	53.27447	-9.81880	Dive	5.2		511.8
12.4	B	53.27447	-9.81880	Dive	5.2		487.9
12.5	B	53.27447	-9.81880	Dive	5.2		444.7
12.6	B	53.27447	-9.81880	venturi	5.2		249.1
13.1	B	53.27643	-9.81938	Dive	5.8	Zostera	73.6
13.2	B	53.27643	-9.81938	Dive	5.8		364.6
13.3	B	53.27643	-9.81938	Dive	5.8		336.3
13.4	B	53.27643	-9.81938	Dive	5.8		385.0
13.5	B	53.27643	-9.81938	Dive	5.8		288.1
21.1	B	53.27478	-9.81722	Dive	6.8		334.1
21.2	B	53.27478	-9.81722	Dive	6.8		173.1
21.3	B	53.27478	-9.81722	Dive	6.8		64.3
21.4	B	53.27478	-9.81722	Dive	6.8		129.9
21.5	B	53.27478	-9.81722	Dive	6.8		129.0
23.1	B	53.27250	-9.82008	Dive	5.2	Stony ground	0.0
23.2	B	53.27250	-9.82008	Dive	5.2		359.7
23.3	B	53.27250	-9.82008	Dive	5.2		326.2
23.5	B	53.27250	-9.82008	Dive	5.2		231.7
24.1	B	53.27632	-9.81902	Dive	5.5		112.4
24.2	B	53.27632	-9.81902	Dive	5.5		103.2
24.3	B	53.27632	-9.81902	Dive	5.5		141.0
24.4	B	53.27632	-9.81902	Dive	5.5		253.1
24.5	B	53.27632	-9.81902	Dive	5.5		227.9
25.1	B	53.27698	-9.81705	Dive	9.5		197.5
25.2	B	53.27697	-9.81705	Dive	9.5		111.9
25.3	B	53.27695	-9.81705	Dive	9.5		185.6
25.4	B	53.27693	-9.81705	Dive	9.5		187.7