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Yield Per Recruit Analysis and Minimum Meat Weight Recommendations for the Bay of Fundy Scallop Fishery

by

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Abstract

A Thompson-Bell Yield per recruit model is used to estimate the optimal minimum size for the Bay of Fundy scallop fishery. The basis for the input parameters are reviewed and seasonal and spatial differences are examined.

The results indicate that a minimum meat weight of 6.3 g and shell height of 84 mm would be the optimal single values for the Bay of Fundy. If separate size restrictions for the winter fishery in the inside zone were to be retained, the spatial and seasonal variations in growth indicate that the sizes for this area could be increased to 10.0 g and 90 mm.

Résumé

On a utilisé un modèle de rendement par recrue Thompson-Bell pour estimer la taille minimale optimale des prises de pétoncles de la baie de Fundy. On examine ici le fondement des paramètres d'entrée ainsi que les différences spatiales et saisonnières.

Les résultats révèlent qu'un poids de chair minimal de 6,3 g et une hauteur de coquille de 84 mm constitueraient des valeurs uniques optimales pour la baie de Fundy. Si, toutefois, on devait adopter des tailles distinctes pour la pêche d'hiver dans la zone intérieure, les différences de croissance spatiales et saisonnières révèlent qu'on pourrait porter ces valeurs à 10 g et 90 mm respectivement.

Introduction

Current management regulations in the Bay of Fundy scallop fishery are directed at reducing the number of small-sized scallops in the catch through minimum ring sizes of the gear, meat count, and minimum shell height regulations. Shell height and meat count regulations, if enforced, have the most effect, as scallop gear is not very selective. The meat count is more practically effective than the shell height regulation as the scallops are shucked at sea and only the meats are landed. There has been a request for advice on a minimum meat weight regulation as opposed to the meat count (minimum individual size compared to minimum average size) to aid in enforcement. In 1993 the minimum meat weight corresponding to the current shell height regulations was determined (Kenchington and Lundy 1993). In this document we present biologically-based shell height, and corresponding meat weight values, to provide a more optimal yield as determined by yield-per-recruit analysis.

Approach

The parameters for a Thompson-Bell yield per recruit analysis are reviewed and used in an analysis for the Digby beds, which traditionally supply most of the landings for this fishery and for which we have the best data series (1982-1989). The resulting age-at-first-capture is defined in terms of shell height, which is the only means of selection available to the fishermen prior to shucking the animal, and meat weight, which would be enforceable at dockside. These minimums are then compared to data from other areas of the Bay of Fundy with different growth rates. The data required for a Yield Per Recruit analysis are: size-at-age (shell height from growth curves, and meat weights from regressions on shell height), selectivity at age, and natural mortality rate. From this analysis the standing stock biomass per recruit can also be obtained. This is of interest as it affects stock levels and thus CPUE. In addition, egg production per recruit can be calculated in the same manner to examine possible influences on spawning potential.

Both shell growth and the relationship between shell height and meat weight are known to vary spatially. The effect of this variation is examined with the use of growth curves from various parts of the Bay of Fundy.

Growth Rate

Scallops are aged with the use of annual rings on the shell (Bourne 1963). This can provide a shell height for each year of its life. This provides more data, and a greater spread of points, than size-at-age from the shells aged, but adds the problem that the curve is being fit to non-independent points and thus biases the fit. There are two sources of bias in the shell height data. The first is that samples for aging are not taken at random, but are selected to cover the full size range encountered. This gives a greater spread of points for the fit, but means that the main modes in the size distribution are under-represented and the tails are over-represented. The second source of bias is that if all rings are used, the older animals are contributing a greater number of points to the fit than the younger animals. In a population that has size selective fishing mortality there may be a Rosa Lee effect (Lee, 1912), i.e., the older, larger animals in the population tend to be animals that have grown slower than average. To examine if this was true for the Digby population, the 1982-1989 aged survey samples were broken down into age groups and the means and standard deviations for the annual rings calculated. This data is shown in Table 1. It can be seen that for the Digby scallop population there is a definite Lee effect in that the older animals do tend to have slower growth rates.

To overcome these biases, the growth curve was fit to all data points but with a two part weighting scheme. The data from 1982 to 1989 was combined and the total weight of each 5 mm size group in the aged sample was set proportional to the percentage contribution of that size class in the 1982-1989 survey length frequencies. This weight was then split evenly between all scallops in the aged size group and each scallop's weighting divided by the number of rings so that each scallop in the group contributed the same total weight to the fit regardless of age. This weighting scheme should thus remove both sources of bias in the fit of the growth curve.

The growth curve was fit to the data in three ways; 1) using this weighting scheme, 2) using all points in an unweighted fit, and 3) using only the last ring for each scallop. The resulting fit is shown in Figure 1. The weighted and unweighted fits are not significantly different. This is probably due to the fact that the sampling scheme used is not strictly a length stratified sample but simply tries to cover the entire size range present in each tow. This results in a distribution close to that which the weighting scheme is designed to provide. Using one point per scallop has not yielded as good a fit, in this case mainly at the bottom of the curve where there are few small scallops to contribute points.

As the Yield Per Recruit analysis will be based on June sizes and the growth curve is based on the annual ring size, the aged June survey data was analyzed for growth from the last ring to the shell edge. This gave an average for ages 4-10 (good fit and n >500) of 70.5% of the annual incremental growth having taken place by June, and so the size-at-ages from the ring based growth curve were adjusted by this amount. For the analysis with separate inside and outside zones the values were 67.7 and 74.5% respectively.

Selectivity

Size selection in the scallop fishery is a combination of gear selectivity, behavior of the scallops and targeting by the fishing fleet. For the purpose of this discussion, the combination of these effects will be referred to as selectivity. The first part of this selectivity is the sorting of scallops that enter the gear, smaller ones which can be pushed out through the rings or the inter-ring spaces are not retained as efficiently as the larger scallops. Scallop behavior also influences selectivity as the smaller scallops have a greater tendency to swim away from the dredge, or be pushed away by the pressure front, than larger ones, and avoid capture by that means. Targeting by the fleet on patches of scallops of differing sizes is a much more complex selectivity process. It depends on such factors as relative catch rates for the patches, and price differences for various sized scallops. This means that selectivity due to targeting will depend on the population structure of the fishing area. If larger scallops are abundant, the denser patches of smaller scallops will not be targeted, however as the catch rates of the areas of larger scallops fall the patches of small scallops become more attractive. If these scallops are very small the fishermen have to fish less abundant large scallops as well in order to meet the average meat count regulations. As this analysis is for a recommended absolute minimum meat weight, the last factor, which is very important under an average meat count regulation, will be altered by any change in regulations. Targeting by the fleet will, therefore, be ignored, and the model will use the gear selectivity.

There have been no recent studies to determine the selectivity curves for the Digby scallop gear. The study used for this analysis is that of Worms and Lanteigne (1986) who used three years of alternate haul data from resource surveys in the Southern Gulf of St. Lawrence. They looked at the selectivity of Digby gear on various bottoms over three years and came up with an overall logistic curve of the form: % retained = 1/(1+exp(-(-9.1975+0.1247*height))), for the selectivity. This gives a size at 50% retention of 74 mm, close to the value used by Dickie (1955) and Jamieson and Lundy (1978), but the curve has a shallower slope.

An aspect of fleet targeting that would not be affected by changes in meat count regulations is that fishing mortality is reduced on older ages. This is because areas with a low abundance of older scallops do not attract much fishing effort. The resulting selectivity curve is dome shaped, as opposed to the asymptotic curve of the gear selectivity. To examine the effect of this selectivity pattern the model was also run with a dome shaped pattern.

Natural Mortality

Natural mortality is taken as 0.1, the value commonly used for scallops in the literature. (Merril and Posgay 1964, Orensanz et al. 1991) It should be noted that the long term average percentage of clappers observed in June surveys is 3% (Kenchington and Lundy 1992)

Weight At Age

The June data for 1991 to 1993 (n = 1,657) was used to give a regression of meat weight on shell height for June. Meat weights for April and October were based on the June weights, adjusted for the seasonal growth pattern from Kenchington *et al.* (1994). The values used for

April and October were 1.03 and 1.23% of June weight for the inside zone, and 1.09 and 1.20% for the outside zone.

Egg Production Per Recruit

To give an index of egg production, the regressions of gonad weight on shell height for Digby in August and November were used to estimate loss in weight due to spawning for each age class. This does not take into account differences in viability of eggs or re-absorption of gametes. These factors are assumed to be negligible. The weight loss was multiplied by 0.5 assuming a 50:50 sex ratio.

Results

Yield Per Recruit Analysis

The results for the Thompson-Bell Yield Per Recruit analysis using the data from Table 2 are shown graphically in Figure 2. There is a maximum yield at an F_{max} of 0.22 and the $F_{0.1}$ value is 0.13. Also shown in the figure are the standing stock biomass per recruit, and the index of egg production per recruit.

Yield isopleths (Figure 3) show the resulting yield at increasing age of first capture. The analysis with a dome shaped selectivity curve is shown in Figure 4.

Discussion

The F_{max} of 0.22 from the Yield Per Recruit analysis is lower than would be expected from the literature, as targeting of the fishing fleet, which would lower the selectivity on the younger ages, is not included. The standing stock biomass and egg production per recruit curves indicate that they will be considerably reduced from virgin stock levels . At the $F_{0.1}$ level both the egg production per recruit and the standing stock biomass, and thus the catch rate, will be about 50% higher than at the F_{max} level.

The yield isopleths (Figure 3) indicate that increasing the age of first capture to 5 increases yield. The small increase in yield that could be obtained by increasing the age of first capture beyond age 5 would require a large increase in effort and thus harvesting costs. In addition to being uneconomical, there would be a negative effect of increased fishing mortality due to incidental mortality on the undersized scallops.

With the dome shaped selectivity pattern (Figure 4), there may be a slight advantage in increasing the age of first capture from five to six. This would result in an 8% increase in the $F_{0.1}$ yield, but would require a 21% increase in F to obtain it.

Minimum Shell Height and Meat Weight

Using the mean sizes and standard deviations from the 1982-89 data set, the modes for age 4, 5 and 6 scallops for June are shown in Figure 5, with the volume of each successive mode declining by 20% to account for mortality. Since the fishermen must rely on shell height to discriminate, the best overall size at which to discard under aged scallops would be 84 mm. This will still not provide a complete separation, as at this point in their growth, the size range of the age classes overlap. This size is larger than the shell height in the present regulations (76 mm) which would result in almost half of the age 4 scallops being legal size in June. The June meat weight corresponding to an 84 mm shell height would be 6.3 g.

Temporal and Spatial Variation

The meat weight for a scallop of a given size has been shown to vary by as much as 30% in concert with the spawning cycle of the scallops, with the maximum weight in December-January and the minimum June-July (Kenchington *et al.* 1994). Using the averages for the Digby bed the meat weight for ages four and five scallops through the year are:

	Meat weight (g)			
Age	April	June	Oct.	Dec.
4	2.5	4.3	5.5	6.0
5	5.4	7.5	9.3	10.3

Thus a minimum meat weight around 6.3 g would selectively harvest scallops age 5 and up for most of the year, but due to the seasonal cycle in meat weights, a portion of the 4 year olds would meet the weight restrictions in the winter, and most would be undersized as five year olds for a period later in the spring after losing weight in late winter.

Figure 6 shows the growth curves for various areas of the Bay, and Figure 7 the modes for ages 4 and 5 from the same areas. Since both shell growth and the relationship between shell height and meat weight are known to vary spatially, the growth curves and a 70.5 % inter-annual growth to June were used to look at the separation between age 4 and 5 for the various areas.

For most areas, 84 mm would be close to the best separation point. The Upper Bay beds would be the most limited, as 84 mm is near the mean size for five year olds. We have meat weight-shell height data for the Annapolis Basin in June, and Brier Island and Lurcher in August, which indicate that the meat weight for an 84 mm shell size would be 11.6 g, 6.6 g and 5.9 g respectively. This means that for the fisherman using an 84 mm shell height as a guide, the meat weights would be above the minimum size for the Basin and Brier Island, but not for Lurcher.

This spatial and temporal variation therefore raises the possibility of varying the minimum size to conform to the optimum for each area and/or season. There is at present a separate meat count for the October 1 to April 30 period, which corresponds to the open season for the inshore zone (<6 miles from shore). This area has both a higher growth rate than the offshore zone, and a larger meat weight for a given shell height. If the past fishing pattern is used as a basis for seasonal size regulations for the inside zone, a five year old would be 89 mm and 9.5 g in June before the inside zone opens, and 93 mm and 11.2 g in April as a six year old by the time it closes. This indicates that minimums of 90 mm and 10 g could be used during this season. For the outside zone a 5 year old would be 79 mm and 5.4 g in April and 88 mm and 7.1 g in June. The 84 mm and 6.3 g division would still be suitable, but again the a portion of the 4 year olds would meet the weight restrictions during the winter.

The optimal yield for most other areas or seasons could be obtained by varying the minimum meat weight and shell height restrictions, but the enforcement problems involved in such a scheme would make it unacceptable except in very restricted areas, i.e., perhaps the Annapolis Basin.

Summary

A minimum shell height of 84 mm and minimum meat weight of 6.3 g would help to optimize the yield per recruit from the Bay of Fundy scallop fishery. A separate winter minimum to optimize the inshore zone would be 90 mm and 10 g. These can be compared to present regulations of 76 mm shell height and meat counts of 72 and 55 meats per 500 g. (Average meat ~6.9 and 9.1 g).

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Table 1. Mean ring heights for scallops of age 3 to 15 from 1982 to 1989 Digby survey data, (n, mean ring height, Std. Deviation of ring height).

Ring	Age 3	4	5	6	7	8	9	10	11	12	13	14	15	Total
2	61	550	920	1084	724	576	367	253	174	100	46	33	34	4922
	19.7	19.3	19.5	20.0	20.3	20.1	19.9	19.7	19.6	19.3	18.9	18.5	19.1	19.8
	3.1	3.2	3.2	3.2	3.0	3.0	2.9	3.2	3.2	3.3	3.4	3.5	2.7	3.1
3	102	1296	2136	2162	1592	1217	782	480	321	168	88	51	64	10459
	49.1	45.7	43.0	42.0	41.8	41.7	41.9	41.6	41.6	41.2	40.9	40.1	39.4	42.6
	4.2	5.2	4.6	4.5	4.6	4.7	5.1	4.7	4.7	4.7	5.3	4.2	4.3	4.9
4	0	1296	2137	2162	1592	1217	783	484	323	168	88	51	64	10365
		70.5	65.3	63.0	62.3	62.0	61.7	60.9	61.0	60.5	59.8	59.4	58.3	63.8
	.00	5.4	5.3	5.2	5.1	5.3	5.7	5.5	5.3	5.1	5.2	5.0	5.0	6.0
5	0	0	2137	2162	1592	1217	783	484	323	168	88	51	64	9069
	.00	.00	83.8	80.5	79.4	78.6	77.9	76.9	76.7	75.9	75.2	74.8	73.4	80.0
	.00	.00	5.3	5.2	5.3	5.5	6.1	6.0	6.1	5.6	6.2	5.5	6.0	6.0
6	0	0	0	2162	1592	1217	783	484	323	168	88	51	64	6932
	.00	.00	.00	93.7	92.4	91.3	90.4	89.2	88.9	88.0	87.2	86.6	84.7	91.7
	.00	.00	.00	5.6	5.5	5.9	6.3	6.5	6.5	5.9	6.6	5.8	6.2	6.2
7	0	0	0	0	1592	1217	783	484	323	168	88	51	64	4770
	.00	.00	.00	.00	102.2	101.1	100.1	99.1	98.3	97.6	96.9	96.5	94.2	100.6
	.00	.00	.00	.00	5.8	6.3	6.7	7.2	7.1	6.5	6.9	6.2	6.7	6.6
8	0	0	0	0	0	1217	783	484	323	168	88	51	64	3178
	.00	.00	.00	.00	.00	108.5	107.6	106.6	105.7	105.1	104.4	104.5	102.2	107.2
	.00	.00	.00	.00	.00	6.8	7.4	8.0	7.8	7.2	7.4	6.7	6.5	7.4
9	0	0	0	0	0	0	783	484	323	168	88	51	64	1961
	.00	.00	.00	.00	.00	.00	113.4	112.4	111.5	111.1	110.5	110.4	108.9	112.3
	.00	.00	.00	.00	.00	.00	7.9	8.5	8.2	7.7	8.0	7.0	6.6	8.1
10	0	0	0	0	0	0	0	484	323	168	88	51	64	1178
	.00	.00	.00	.00	.00	.00	.00	117.1	116.4	116.0	115.6	115.8	114.3	116.4
	.00	.00	.00	.00	.00	.00	.00	9.0	8.7	8.2	8.5	7.3	6.9	8.6
11	0	0	0	0	0	0	0	0	323	168	88	51	64	69
	.00	.00	.00	.00	.00	.00	.00	.00	120.4	120.3	119.9	120.2	119.1	120.2
	.00	.00	.00	.00	.00	.00	.00	.00	9.0	8.8	8.8	7.6	7.5	8.7
12	0	0	0	0	0	0	0	0	0	168	88	51	64	371
	.00	.00	.00	.00	.00	.00	.00	.00	.00	123.8	123.6	123.8	123.1	123.6
	.00	.00	.00	.00	.00	.00	.00	.00	.00	9.0	9.1	8.0	7.7	8.7
13	0	0	0	0	0	0	0	0	0	0	88	51	64	203
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	126.8	127.1	126.9	126.9
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	9.4	8.2	8.1	8.7
14	0	0	0	0	0	0	0	0	0	0	0	51	64	115
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	130.0	130.3	130.1
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	8.5	8.6	8.5
15	0	0	0	0	0	0	0	0	0	0	0	0	64	64
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	133.2	133.2
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	9.0	9.0

Table 2. Parameters used in Yield Per Recruit analysis.

	Height		GonadWeight			Meat	
Age	Ring	June	Aug	Nov	Diff	Weight	Selectivity
1	8.0	15.8	0.0	0.0	0.0	0.03	0.07
2	18.6	36.9	0.1	0.1	0.0	0.32	1.08
3	44.5	58.6	0.6	0.3	0.3	1.72	13.80
4	64.5	75.3	1.7	0.8	0.9	4.26	55.99
5	79.8	88.2	3.2	1.4	1.8	7.54	100.00
6	91.7	98.2	5.0	1.9	3.0	11.08	100.00
7	100.9	105.9	6.8	2.5	4.3	14.54	100.00
8	107.9	111.8	8.5	3.0	5.5	17.69	100.00
9	113.4	116.3	10.0	3.5	6.6	20.44	100.00
10	117.6	119.9	11.4	3.8	7.5	22.77	100.00
11	120.8	122.6	12.5	4.2	8.3	24.68	100.00
12	123.3	124.7	13.4	4.4	9.0	26.24	100.00
13	125.2	126.3	14.1	4.6	9.5	27.49	100.00
14	126.7	127.5	14.7	4.8	9.9	28.48	100.00
15	127.9	128.5	15.1	4.9	10.3	29.26	100.00
16	128.8	129.3	15.5	5.0	10.5	29.87	100.00
17	129.4	129.8	15.8	5.1	10.7	30.35	100.00
18	130.0	130.3	16.0	5.1	10.9	30.73	100.00
19	130.4	130.6	16.2	5.2	11.0	31.02	100.00
20	130.7	130.9	16.3	5.2	11.1	31.24	100.00

Growth curve from Digby surveys 1982-1989 data
Weighted fit, L inf = 131.7473, k= 0.2597, t-zero = 1.4131.

Shell height - meat weight regression from 1991-1993 survey data
a = -14.131, b = 3.605, n=1657.

Selectivity Logistic Curve from Worms and Lanteigne (1986)
a = -9.1975, b = 0.1247 with >86 mm set to 100.

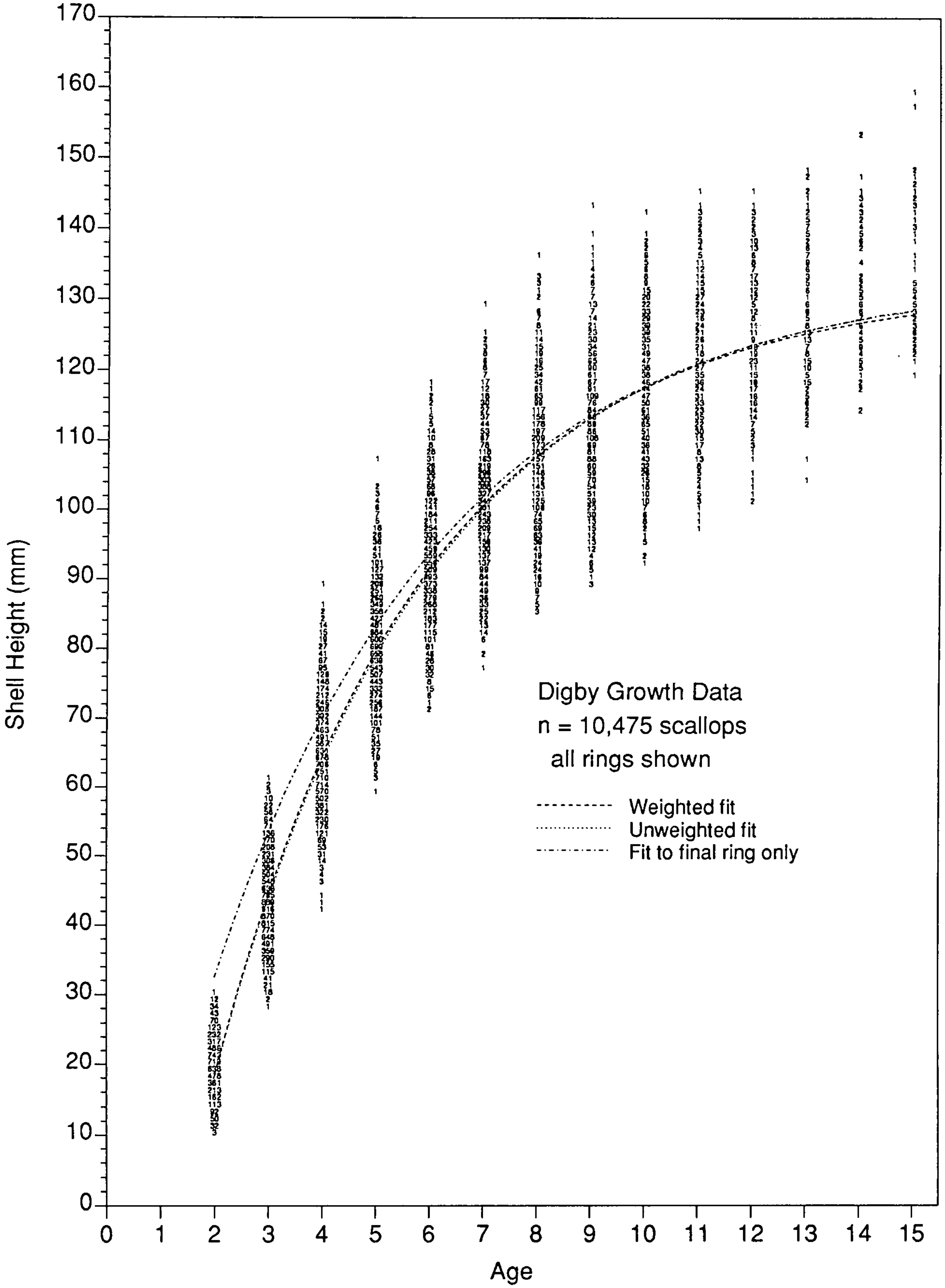


Figure 1. Von Bertalanffy growth curves fit to the 1982-1989 Digby survey samples.

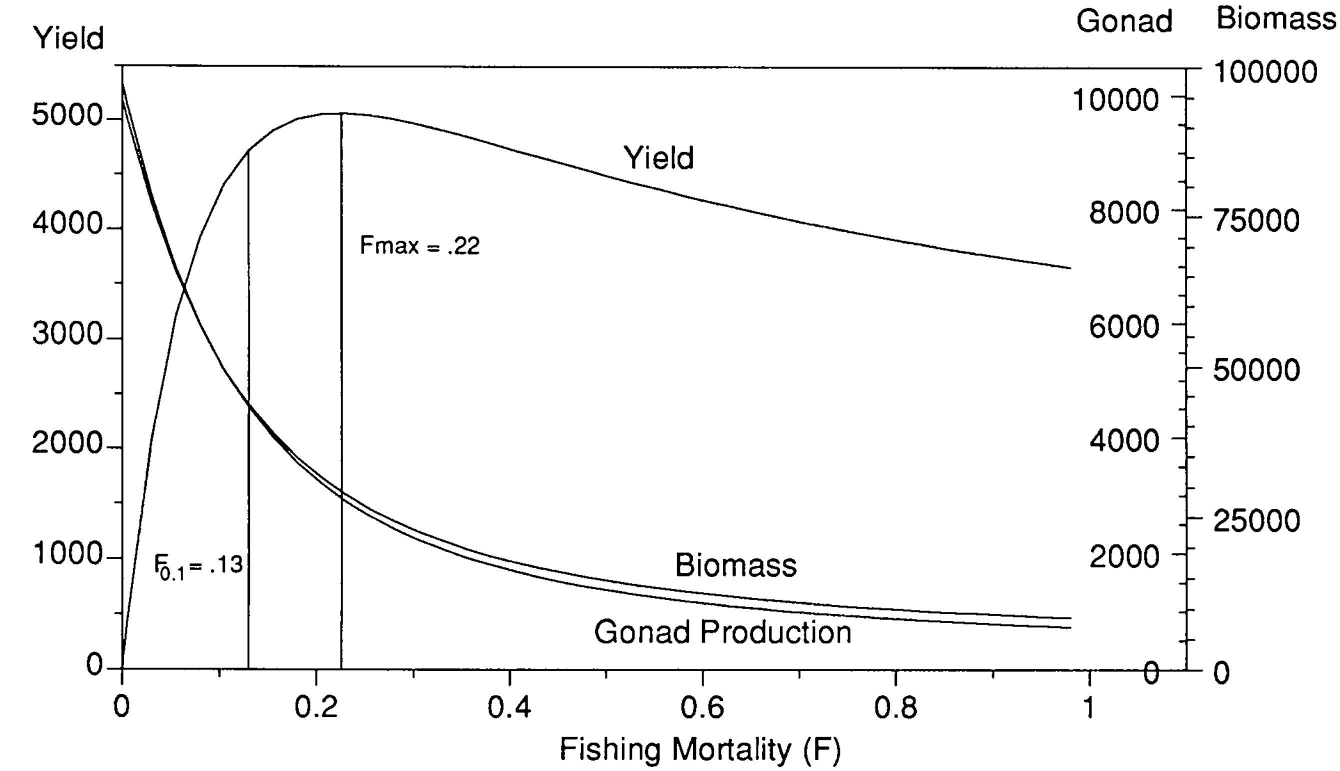


Figure 2. Thompson Bell yield per recruit model for Digby scallops showing yield, standing stock biomass and gonad production in grams per 1000 recruits.

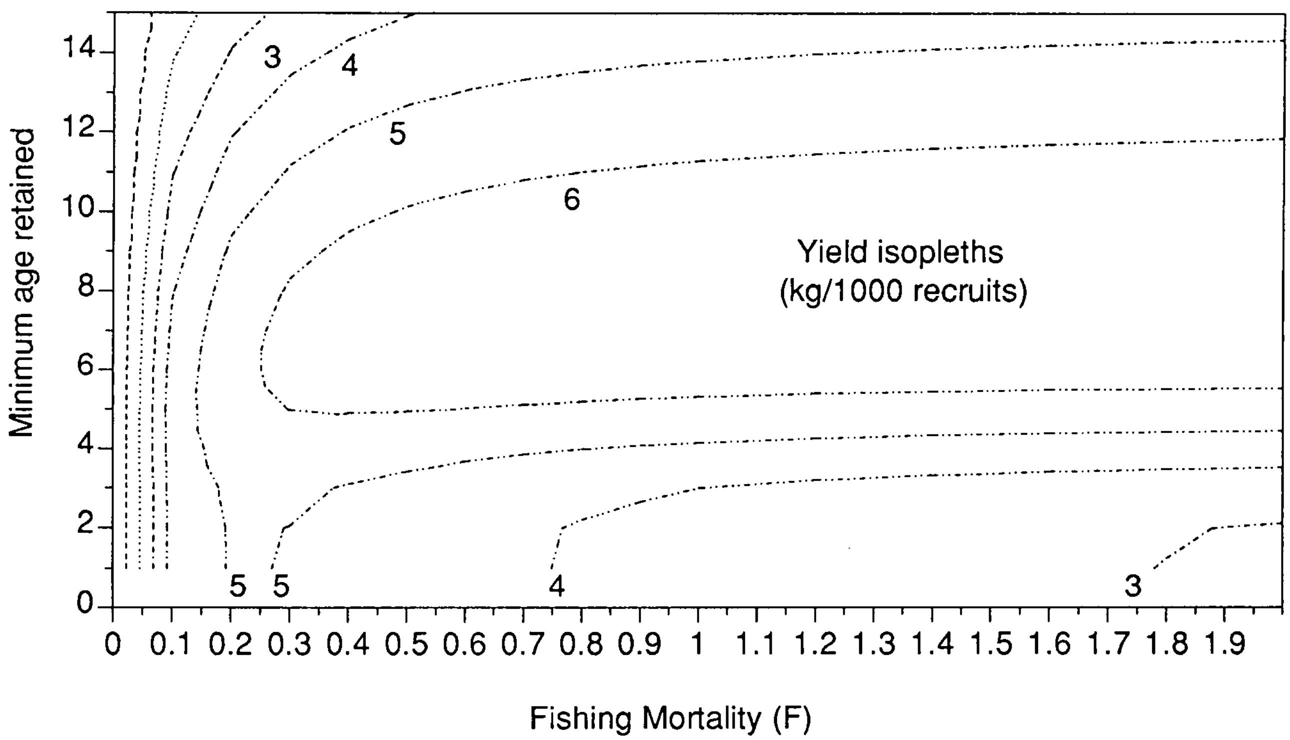
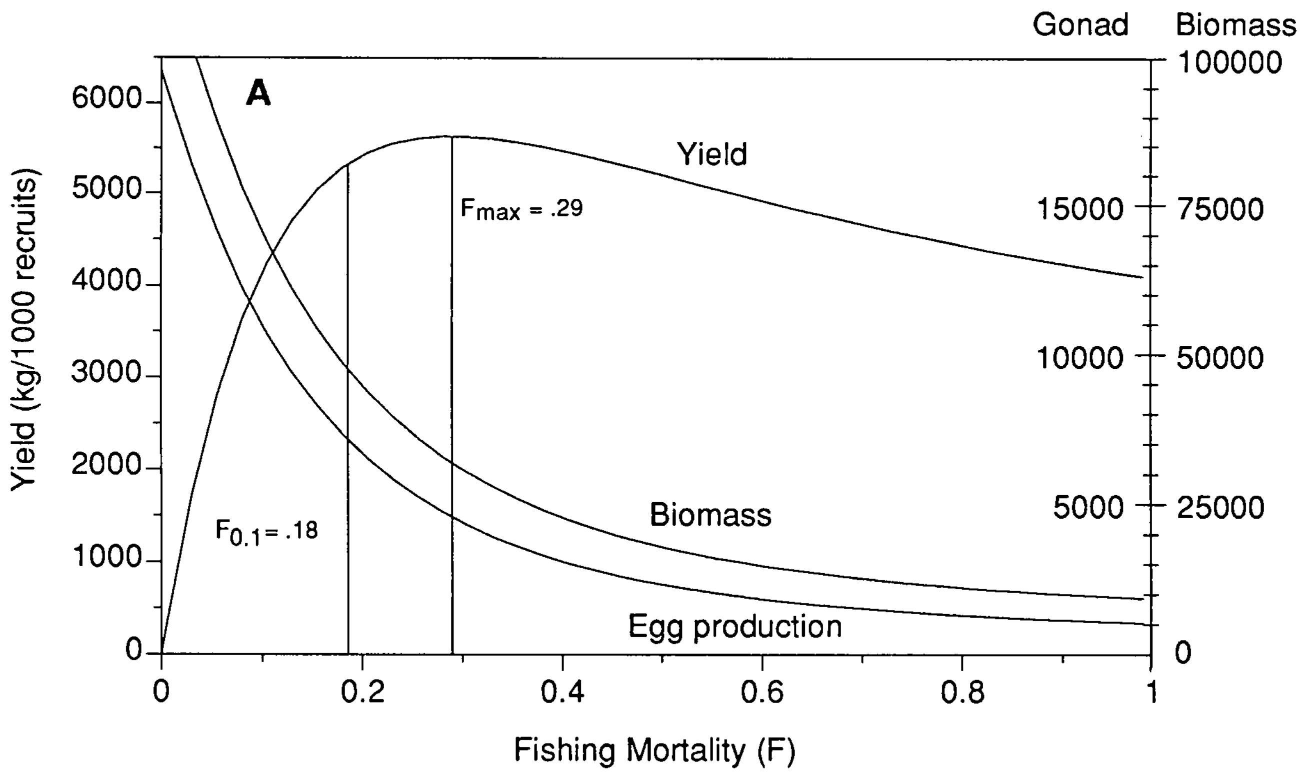


Figure 3. Yield isopleths in kg per 1000 recruits for increasing the age of first capture.



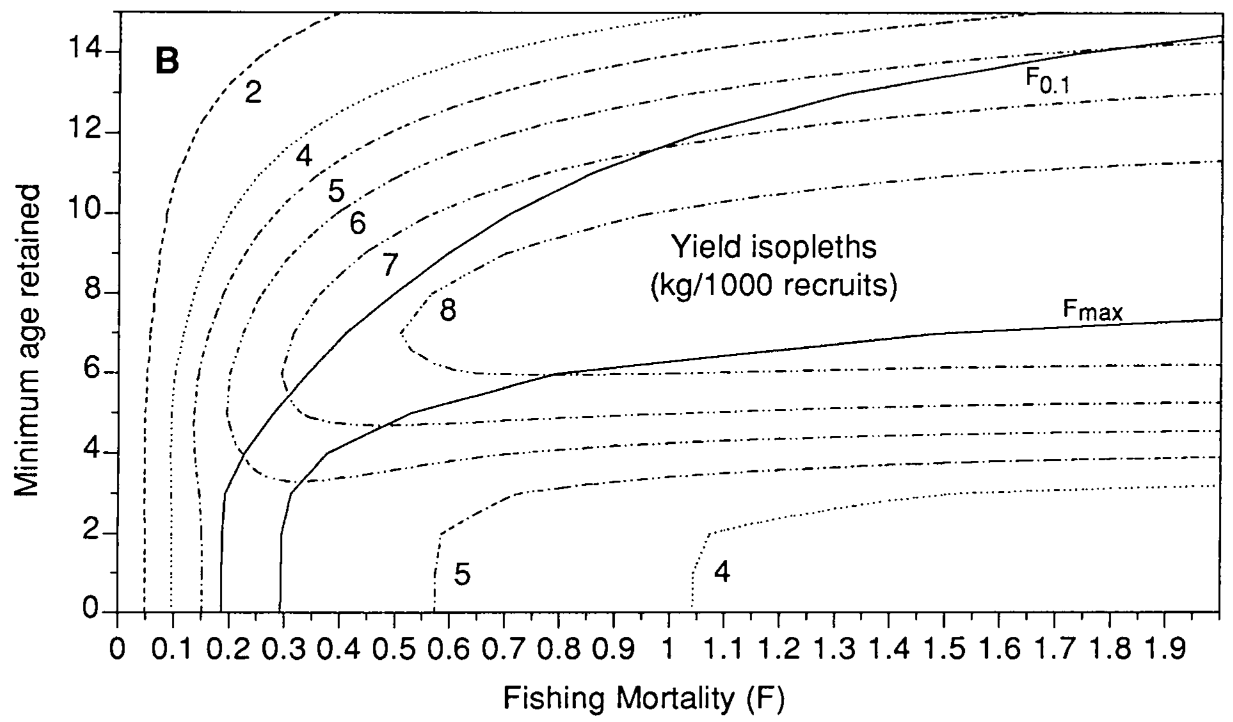


Figure 4. A- Yield per recruit results and B- yield isopleths, for a dome shaped recruitment curve, analysis as in figures 2 and 3.

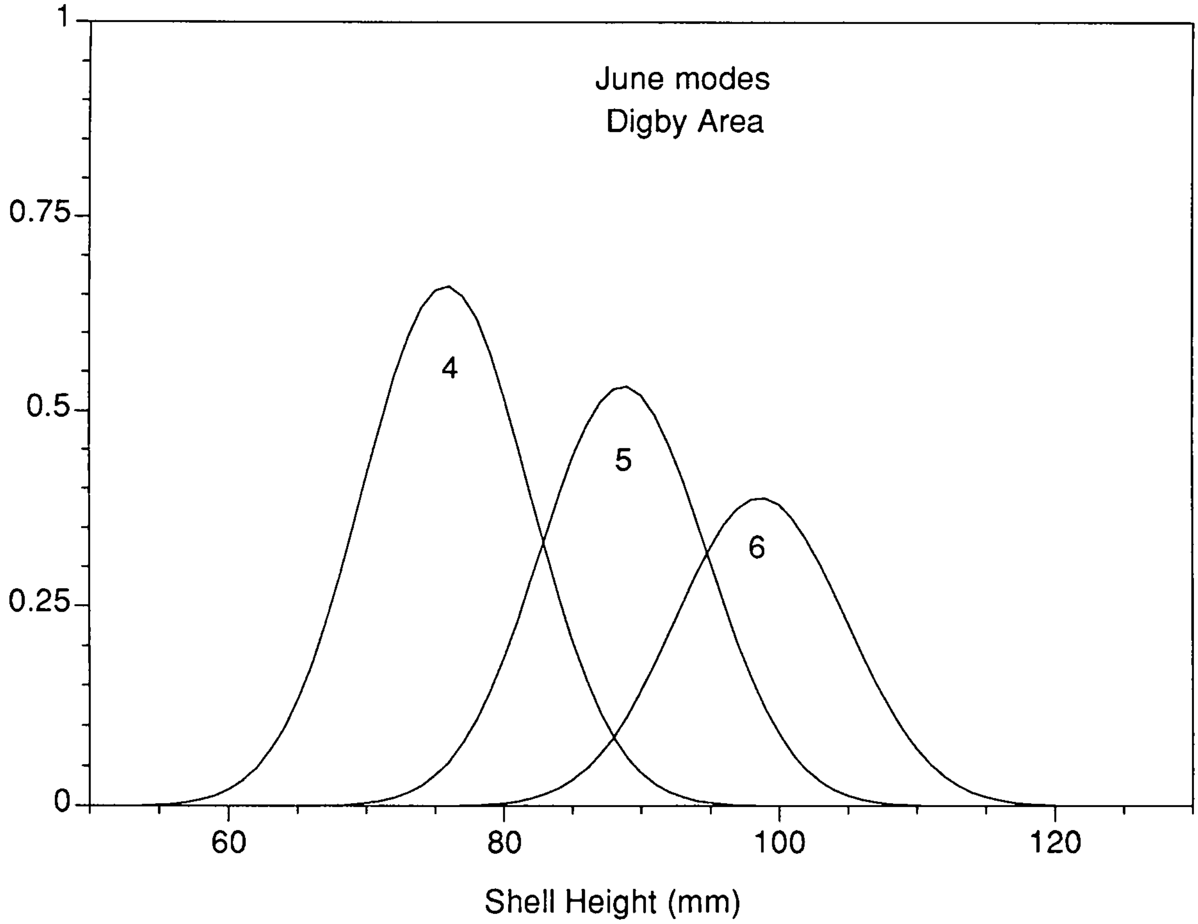


Figure 5. Modes for ages 4, 5 and 6 using mean and standard deviations of shell height from Digby 1982-1989 survey data. Scaled so area under curve is 80% of preceding age.

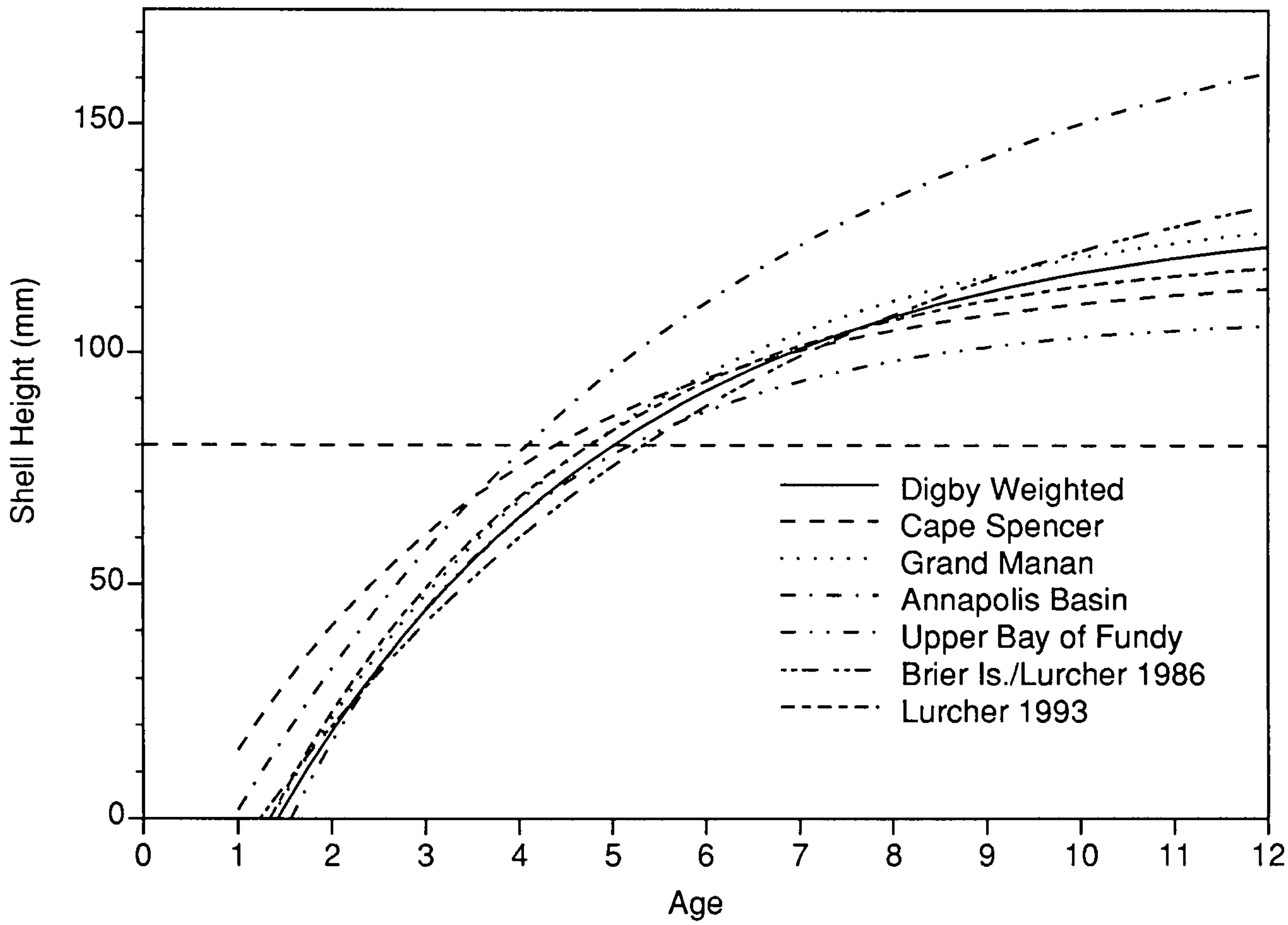


Figure 6. VonBertalanffy growth curves for different areas of the Bay of Fundy.

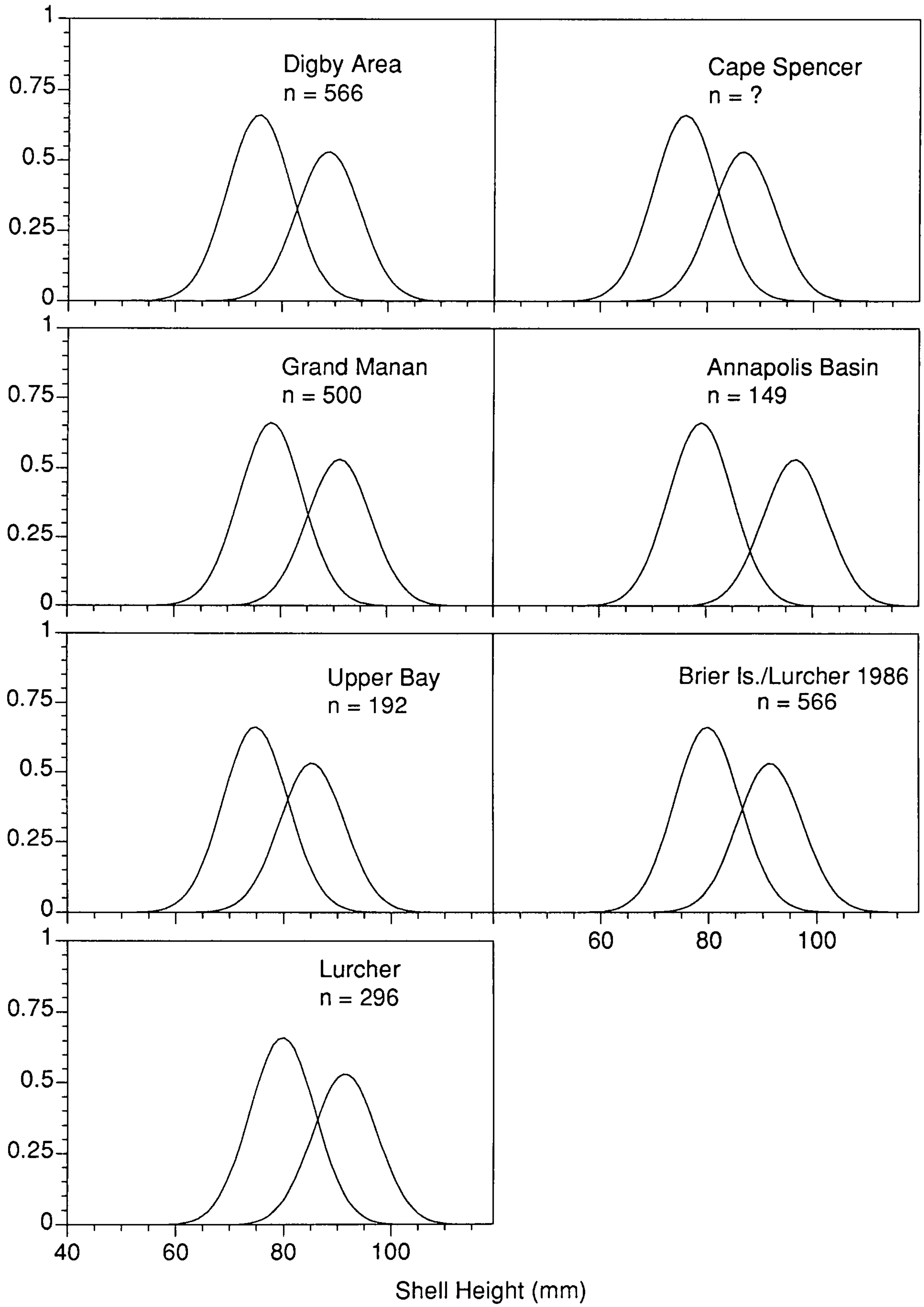


Figure 7. Estimated distribution of shell heights for age 4 and 5 from various localities in the Bay of Fundy.