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Preliminary examination of egg per recruit estimates in the Canadian lobster fishery

By

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Abstract

The present Egg Production per Recruit (E/R) levels in the Canadian lobster fishery is assessed in reference to the American biological reference point of 10% of maximum E/R and comment on its appropriateness to the Canadian fishery are provided. Under the USA definition lobsters are said to be overfished when the estimated E/R is 10% or less than that of an unfished population. Results of E/R calculations are presented for Lobster Fishing Areas (LFA) in Scotia-Fundy, Gulf, Quebec and Newfoundland regions using an E/R model developed by Fogarty and Idoine (NMFS USA). The model was run with minimum modifications to allow comparison with USA results. E/R has been looked at as a potential biological reference point because of the difficulty in estimating standing stock, spawning biomass or stock recruitment relationships. However, E/R does not take into account actual population size and thus ignores the 2-3 fold increase in lobster population size regionally that appears to have occurred during the 1980's and the resulting greater egg production. It remains to be established if E/R levels may be useful as a biological reference points.

Initial analysis suggests that a single value could be inappropriate for areas with diverse productivity levels. Extremely low E/R levels were found in the highly productive and historically stable area in the Gulf of Maine (LFA 34) while higher E/R values were found in the lower productivity and less stable eastern shore of Nova Scotia (LFA 31-32). Maintaining adequate egg production has been a consistent consideration in lobster research and management, the concern being to ensure that egg production will be sufficient to obtain good recruitment. The results suggest that E/R for Canadian stocks may be very low and therefore the fisheries may be in a high risk situation.

An examination of a relationship between stock and recruitment for lobster at Arnold's Cove, Placentia Bay, Newfoundland suggests that recruitment may become impaired only at very low egg production. It suggest a stock-recruitment relationship with a very steep ascending limb, reaching a plateau at the low end of the egg production range beyond which recruitment is independent of egg production. Though we cannot determine how close we are to that point, the current extremely low egg production per recruit and the resulting potential risks to the resource suggest a conservative approach would be prudent.

Résumé

On évalue la production d'oeufs par recrue (O/R) actuelle dans la pêche canadienne du homard par rapport au point de référence biologique des Américains, qui est établi à 10 % du niveau maximal d'O/R et on discute de sa pertinence pour la pêche canadienne. Selon la définition des Américains, il y a surpêche du homard quand le niveau O/R estimé est égal ou inférieur à celui d'une population inexploitée. On présente les résultats des calculs d'O/R pour les zones de pêche du homard des régions de Scotia-Fundy, du Golfe, de Québec et de Terre-Neuve effectués au moyen d'un modèle créé par Fogarty et Idoine (NMFS, É.-U.). Ce modèle a été exploité sans grande modification pour permettre une comparaison avec les résultats obtenus aux États-Unis. La production d'oeufs par recrue a été envisagée comme point de référence biologique possible en raison des difficultés à estimer le stock actuel, la biomasse de reproducteurs ou les liens avec le recrutement. Toutefois, elle ne tient pas compte de l'effectif réel de la population et par conséquent de l'augmentation, du simple au double ou au triple, de la population régionale de homard qui semble s'être produite au cours des années 1980, ainsi que de la plus grande production d'oeufs correspondante. Il reste à déterminer si les niveaux O/R peuvent constituer des points de référence biologique utiles.

Les analyses initiales semblent indiquer qu'une seule valeur ne conviendrait pas à des régions qui ont des productivités diverses. Les niveaux O/R étaient extrêmement bas dans la région très productive et traditionnellement stable du golfe du Maine (ZPH 34), alors qu'ils étaient très élevés sur la côte est de la Nouvelle-Écosse (ZPH 31-32), où la productivité et la stabilité du stock sont moindres. Le maintien d'une bonne ponte a toujours été un élément crucial dans la recherche sur le homard et la gestion de cette espèce, le but recherché étant de faire en sorte que la production d'oeufs soit suffisante pour permettre un bon recrutement. D'après les résultats obtenus, la production d'oeufs par recrue serait apparemment très basse dans les stocks canadiens et ceux-ci seraient donc en situation de haut risque.

Un examen des liens entre le stock et le recrutement du homard de Arnold's Cove, à Placentia (Terre-Neuve), révèle que le recrutement ne souffrirait que lorsque la production d'oeufs est extrêmement basse. Il apparaît que le rapport stock-recrutement se présente comme une courbe rapidement ascendante, atteignant un plateau aux valeurs basses de la gamme des niveaux de production d'oeufs, au-delà desquelles le recrutement est indépendant de cette production. Quoique nous ne puissions déterminer dans quelle mesure nous nous approchons de cette situation, la très faible production actuelle d'oeufs par recrue et les risques qui en résultent pour la ressource militent en faveur de la prudence.

Introduction

Various national and international organizations use biological reference points to describe the status of stocks compared with some desired values. The USA definition of overfishing for lobster is specifically based on the estimated egg production per recruit (E/R) at the present exploitation rate, size at maturity and minimum legal size compared with the estimated egg production per recruit of a theoretical unfished population, referred to hereafter as %E/R. Lobster are said to be overfished when the estimated egg production per recruit under current conditions is 10% or less than that of an unfished population. This definition assumes that there is a minimum %E/R below which the resource is unlikely to be able to maintain itself. Therefore, %E/R should be kept well above that minimum.

The same concept was used to define overfishing for finfish and scallop stocks in the United States. Egg per recruit (or in the case of fish spawner per recruit) calculations are an extension of yield per recruit calculations which tabulate surviving recruits as they become mature. Egg per recruit presents the same concept as spawner per recruit when the number of eggs per unit of biomass is constant. Maintaining adequate egg production has been a consistent consideration in lobster research and management, the concern being to ensure that egg production will be sufficient to obtain good recruitment. However, because the total population abundance is not known, egg per recruit production was considered.

In defining overfishing, the concept of spawner per recruit or egg per recruit is used to find a fishing mortality rate which will allow recruits to replace their parents. This is different from the way the concept was used for lobster where the main concern was to ensure that there will be enough parents to produce a good number of recruits. For lobster, there is no *a priori* basis to choose what level of fishing mortality will allow recruits to replace their parents nor how many parents are required to produce a good number of recruits.

Combining spawner per recruit calculations with a stock recruitment scatter plot provides graphical empirical estimates of recruits per spawner. If the axes on this graph are inverted, the points become estimates of spawner per recruit and provide (assuming environmental variability remains within the bounds of past observations) a series of possible future spawner per recruit ratios. The bisecting line leaving half of the points above the line and half below the line corresponds to a fishing mortality where recruits will replace their parents on average. Points above the line will allow the stock to increase on average, while points below the line will cause it to decline.

The ratio of spawner per recruit at a given fishing mortality to the spawner per recruit in an unfished stock can be used to make comparisons between stocks. This ratio has been calculated for several groundfish stocks (Mace and Sissenwine, 1993) and it was found that stocks would be expected to decline when the ratio is less than 20%. The ratio was also calculated for one scallop stock where declines would be expected when the ratio was 5% or less (Mace and Sissenwine 1993). These ratios could be considered as indices of the resiliency of the species and would suggest that scallops are more resilient than groundfish.

The long time series of stock recruitment information needed to do those analyses are not available for lobster. Using a comparative approach, US scientists hypothesized that lobster are probably more resilient than groundfish, but less so than scallops and they proposed that a reasonable guideline would be that lobster are overfished when the spawner per recruit (or egg production per recruit) is less than 10% of that of an unfished population (Anon, 1993).

The present E/R levels in the Canadian lobster fishery were assessed in reference to the American biological reference point of 10% of maximum E/R and comment on its appropriateness to the Canadian fishery are provided. Results of E/R calculations were presented for Lobster Fishing Areas (LFA) in Scotia-Fundy, Gulf and Quebec regions using an E/R model developed by Fogarty and Idoine (NMFS USA; Fogarty and Idoine 1988). This was the same model used in recent American lobster assessments (Anon, 1993). The model was run with minimum modifications to allow comparison with USA results.

Model and Input Data

Egg per recruit values were calculated using an E/R model (Fogarty and Idoine 1988; Anon, 1993) modified to accept various input formats and a minimum size less than 81 mm CL. Input parameters were obtained from DFO biologists in each region (Figure 1). Newfoundland data were analysed using a similar model and the results were discussed.

The input parameters required to run the model are described in the following paragraphs.

Molt Increment

Molt increments (the increase in carapace length with a molt) are entered as a probability distribution for three size groups, <85 mm, 85-105 mm and >105 mm CL. Molt increment values provided by biologists varied more widely than expected and a review of current data sets on lobster growth may be useful to verify if the differences are real.

Intermolt period

The intermolt period (the time between molts) at a given size is the inverse of the annual proportion molting, typically determined from mark recapture data. Accurate estimates of the proportion molting are difficult to obtain for larger lobsters which are less common in the catch, may have lower catchability and have intermolt periods longer than 3 years. The proportion molting at size was fit to either an exponential function (most of Scotia-Fundy stocks), probit function (for Newfoundland stocks) or a logistic function (Quebec, Gulf, LFA 34, 41 and USA). The effect of the different functions on E/R estimates was not tested in this study.

Curves were fit to available data to calculate intermolt periods (Figure 2). The results were unrealistic for some areas and the intermolt period was set to range from 1 year to a maximum of 20 years (proportion molting equal to 5%) but it is felt that intermolt periods greater than 5 years are unlikely to occur. The effect of a 5 year maximum intermolt period would differ depending upon the molt probability function used. Areas using the exponential function would be least affected since the intermolt period rarely exceeded 5 years. However the effect could be large for areas that used the logistic (default for the model) or probit functions. These functions result in intermolt periods greater than 5 years over a wide range of larger sizes. The shorter intermolt period would increase the growth rate and allow more lobsters to reach these larger sizes, thus increasing the E/R values.

Double molts (two molts a year) are allowed in the model and have the potential of increasing growth rates at smaller sizes in the warmer water areas. For the purpose of the present work, double molts were only used in LFA 27, but in any future analysis, it should be used for other areas where double molting is suspected.

Size at Maturity

Size at maturity was incorporated into the model as a logistic function (Figure 3). The original model uses a set value that is not appropriate for the range of values in the Canadian fishing areas. While size at maturity has been determined using similar methods in each region (Aiken and Waddy 1982), there was not full agreement on the interpretation of the technique. It is suggested that the application of the method be reviewed to ensure it is applied consistently for all LFAs.

Fecundity/length relationships

In the present analysis, a single fecundity at length relationship (Campbell and Robinson 1983) was used rather than those supplied by each region. Comparisons of the fecundity/length relationship from each region showed good agreement at small sizes but the values diverged at larger sizes with up to a 3 fold difference in lobsters over 180 mm carapace length (Figure 4). While fecundity will vary from area to area, the large differences may have been caused by extrapolating results beyond the range of the data, rather than due to true biological differences. The Campbell and Robinson (1983) relationship pooled data from the Bay of Fundy, Eastern Shore of Nova Scotia and Northumberland Strait and was based on a wide range of sizes, from 50 mm to 143 mm CL.

Length Weight relationships

There is ample information on the relationship between length and weight and little variation was observed between regions (Figure 5).

Estimates of F

Estimates of F ranged between 0.6 -1.8 in inshore fisheries and 0.2-0.4 in the offshore (LFA 41). Estimates of F for Scotia-Fundy and Québec are based on exploitation rates calculated from size frequency data from commercial trap samples. (Miller, et al. 1987) The method gives a reasonable approximation of exploitation rate but is influenced by variations in size related catchability, changes in recruitment levels and sampling methods. Estimates of F for Newfoundland and Gulf were from mark recapture data.

Although the estimates of F were sufficient for the present study (range and best estimate of F given), more work is needed to improve the estimates, especially in calculating F for females in the context of egg per recruit calculations

Other model assumptions

The maximum size is set at 310 mm CL. While this may be suitable for the Gulf of Maine it was not appropriate for Newfoundland or the Gulf of St. Lawrence. With a maximum intermolt of 20 years, only a very small percentage of lobsters reach this size even with F=0. However, at more realistic intermolt periods, this could have a large effect on E/R in unexploited or lightly exploited populations and should be looked at in any subsequent analysis. Natural mortality was assumed to be M=0.10

Results

The relationship between egg and yield per recruit are presented for representative LFAs in Figures 6-17.

At the estimated F values, the E/R in all lobster areas, except for the offshore (LFA 41) where it was 10% (Fig. 7), were between 0.1 and 3.5% of the maximum at F=0. This is well below the 10% level adopted by the USA. Higher E/R estimates in the offshore region were due to low fishing mortality estimated to be between 0.2 -0.4. Using a different version of the same model, the E/R level for Arnold's Cove in Newfoundland was 1.7% (Fig. 17).

Estimates of the percentage of maximum E/R at different exploitation levels are given in Table 1 and Figure 18.

The estimate of E/R at F=0 is critical in estimating the percentage E/R of the current situation. The E/R at F=0 is influenced by several assumptions and because no lobster populations remain which are lightly exploited, few data are available on growth and maximum size at low exploitation to verify if the assumptions are reasonable. Too large a maximum size would result in high egg production from very large females which in reality would not be present in the population.

There was also concern over the data, calculations and underlying relationships used to estimate some of the model's parameters. In particular the statistical approaches and assumptions used to estimate growth increment, intermolt period, size at maturity, and double molts need to be reassessed. It was also felt that the model should be modified to better reflect the various conditions in the Canadian fishery. Other models have been used in the past and appear to give similar results, some of these simpler models may allow more flexible input and output.

However, even with the suggested changes to the model and input parameters the E/R levels would probably still be well below the 10% level, unless fishing mortality on females were in fact substantially lower than used here. For example data from the southern Gulf showed that a size increase from 63 mm carapace length to 70 mm carapace length at F=1.45 increased the actual E/R production by 1.7 times which increased the %E/R from 0.4 to 0.8 % (Figure 19).

Discussion

Initial analysis suggests that a single value could be inappropriate for areas with diverse productivity levels. Extremely low E/R levels were found in the highly productive and historically stable area (Pezzack 1993) in the Gulf of Maine (LFA 34) while higher E/R values were found in the lower productivity and less stable eastern shore of Nova Scotia (LFA 31-32). It is difficult to reconcile the continued stability and high productivity in areas such as southwest Nova Scotia with lower E/R.

The possibility that refuge areas exist where fishing mortality is lower was discussed. Except for some small deep water areas of the Gulf of Maine it was felt that there were no significant unfished grounds. Even in the Gulf of Maine, most of the deep water areas are fished to some degree. Refugia in time are possible where the fishing season and availability of different sized animals do not match. Seasonal movements and behaviour can make certain groups less vulnerable to fishing during part or all of the fishing season.

E/R has been looked at as a potential biological reference point for defining lobster conservation because of the difficulty in estimating standing stock, spawning biomass or stock recruitment relationships. However, E/R does not take into account actual population size and thus ignores the 2-3 fold increase in lobster population size regionally that appears to have occurred during the 1980's and the resulting greater egg production.

Nonetheless, biologists remain as concerned as before (e.g. Anonymous 1977, 1989; 1993; Campbell and Robinson 1983; Miller et al. 1987; Pringle and Burke 1993) about the general state of lobster stocks. E/R is very low which puts the fishery in a high risk situation. However, examination of a relationship between stock and recruitment for lobster at Arnold's Cove, Placentia Bay, Newfoundland suggests that recruitment may become impaired only at very low egg production. A 19-year series of estimates of annual standing stock, recruitment and egg production was examined (Fig. 20). Using a 9-year lag between egg production and subsequent recruitment to the standing stock, the series yields 10 data points. They suggest a stock-recruitment relationship with a very steep ascending limb, reaching a plateau at the low end of the egg production range beyond which recruitment is independent of egg production. If the egg production is near the descending limb, the stocks would be highly susceptible to environmental variability leading to more variable productivity and increased probability of stock collapse. Though we cannot determine how close we are to that point, the current extremely low egg production per recruit and the resulting potential risks to the resource suggest a more conservative approach would be prudent.

It remains to be established if E/R levels may be useful as a biological reference points. The concept should be further evaluated, taking into account the uncertainties in the present model and data. It was thus recommended that a workshop be convened to examine the data sets in more detail and apply them to a new or modified E/R model.

Workshop on American Lobster

Draft Terms of Reference

The USA defines that American lobsters are overfished when the current egg per recruit production is less than 10% of the egg per recruit production estimated for an unfished population. Egg per recruit calculations done on Canadian lobsters stocks indicate that in most cases, the current egg per recruit production is less than 1% of the egg per recruit production in the unfished populations. However, the model used makes a number of assumptions which are reasonable for lobster in US waters but may not be for those in Canadian waters. In addition, data available for use in models may be somewhat inconsistent between regions and interpretation may differ among biologists, such as in the determination of maturation stages. In order to better estimate current egg production per recruit for Canadian lobster, a workshop will be convened to:

1. Review and choose, including sensitivity analyses, appropriate assumptions and input parameter values for the calculation of lobster yield per recruit and egg per recruit in eastern Canada with regards to:

    a) maximum size,

    b) molting increment,

    c) molting frequency,

    d) size at maturity,

    e) fecundity at size, and

    f) weight at size.

2. Provide estimates of current fishing mortality exerted on the female lobsters in each LFA taking into account possible variable availability by size, or refugia etc.

3. Estimate biological reference points from spawning per recruit calculations, discuss their relevance to lobster and compare them with alternate reference points.

4. If it is concluded that spawning per recruit is a useful reference point, and if it is found that spawning per recruit needs to be increased for Canadian lobsters, suggest the best means to increase spawning per recruit.

5. Review possible alternative criteria or reference points.

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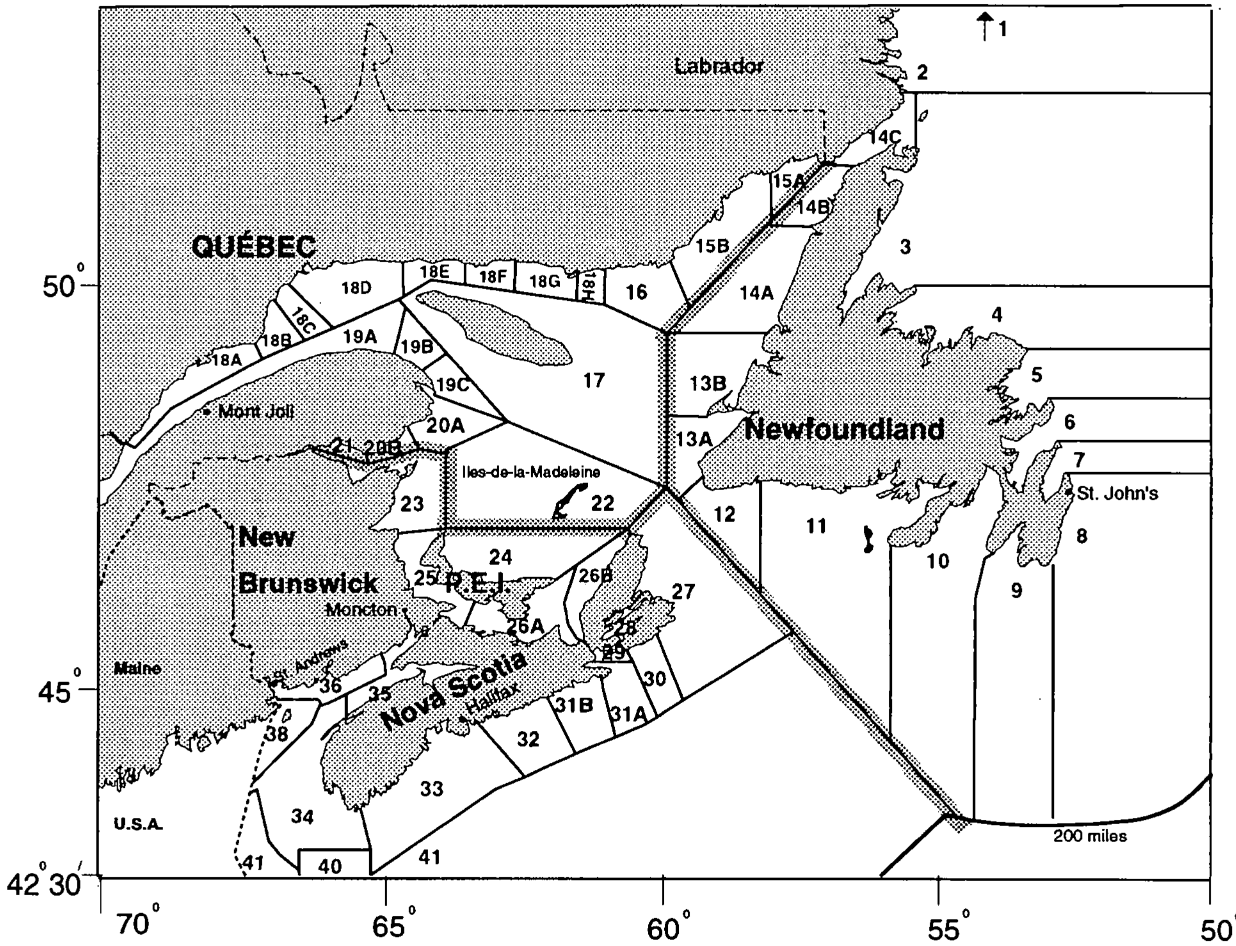
Table 1 Summary of the percentage of maximum E/R (F=0.0) at F for all LFAs used in the present report

F	Exploit.	20	22n	22s	23	24	25	26a	26b	27	28-30	31-32	33	34	35-38	41
		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
0.05	4.9%	65.2%	69.2%	59.6%	65.1%	66.0%	65.1%	64.9%	66.7%	58.0%	60.7%	56.0%	53.8%	63.8%	49.5%	63.8%
0.10	9.5%	49.7%	54.3%	36.3%	47.5%	46.9%	47.5%	47.3%	48.6%	37.9%	41.5%	35.6%	32.4%	44.2%	27.9%	44.2%
0.15	13.9%	40.5%	44.9%	22.8%	35.6%	35.0%	35.6%	35.4%	36.9%	26.6%	30.4%	24.4%	21.2%	32.1%	17.2%	32.1%
0.20	18.1%	34.3%	38.1%	14.8%	27.5%	26.8%	27.5%	27.2%	28.8%	19.5%	23.3%	17.6%	14.6%	24.1%	11.2%	24.1%
0.25	22.1%	29.6%	33.0%	10.0%	21.6%	21.0%	21.6%	21.4%	23.0%	14.9%	18.5%	13.2%	10.6%	18.5%	7.7%	18.5%
0.30	25.9%	25.9%	28.8%	7.0%	17.3%	16.7%	17.3%	17.0%	18.6%	11.6%	15.0%	10.2%	7.9%	14.6%	5.4%	14.6%
0.35	29.5%	22.9%	25.4%	5.0%	14.0%	13.4%	14.0%	13.8%	15.3%	9.2%	12.4%	8.1%	6.0%	11.6%	3.9%	11.6%
0.40	33.0%	20.4%	22.5%	3.7%	11.5%	10.9%	11.5%	11.2%	12.7%	7.5%	10.5%	6.5%	4.7%	9.4%	2.9%	9.4%
0.45	36.2%	18.3%	20.1%	2.8%	9.5%	9.0%	9.5%	9.3%	10.6%	6.2%	9.0%	5.3%	3.8%	7.7%	2.2%	7.7%
0.50	39.3%	16.4%	18.1%	2.2%	7.9%	7.4%	7.9%	7.7%	9.0%	5.1%	7.7%	4.4%	3.0%	6.4%	1.7%	6.4%
0.55	42.3%	14.9%	16.3%	1.8%	6.6%	6.2%	6.6%	6.5%	7.6%	4.3%	6.7%	3.7%	2.5%	5.3%	1.3%	5.3%
0.60	45.1%	13.5%	14.7%	1.5%	5.6%	5.2%	5.6%	5.4%	6.5%	3.7%	5.9%	3.2%	2.1%	4.5%	1.0%	4.5%
0.65	47.8%	12.3%	13.3%	1.2%	4.8%	4.4%	4.8%	4.6%	5.6%	3.1%	5.2%	2.7%	1.7%	3.8%	0.8%	3.8%
0.70	50.3%	11.2%	12.1%	1.0%	4.1%	3.7%	4.1%	3.9%	4.9%	2.7%	4.7%	2.3%	1.5%	3.3%	0.6%	3.3%
0.75	52.8%	10.2%	11.1%	0.9%	3.5%	3.2%	3.5%	3.4%	4.2%	2.3%	4.2%	2.0%	1.2%	2.8%	0.5%	2.8%
0.80	55.1%	9.4%	10.1%	0.8%	3.0%	2.7%	3.0%	2.9%	3.7%	2.0%	3.8%	1.8%	1.1%	2.4%	0.4%	2.4%
0.85	57.3%	8.6%	9.2%	0.7%	2.6%	2.4%	2.6%	2.5%	3.3%	1.8%	3.4%	1.6%	0.9%	2.1%	0.3%	2.1%
0.90	59.3%	7.9%	8.5%	0.6%	2.3%	2.0%	2.3%	2.2%	2.9%	1.6%	3.1%	1.4%	0.8%	1.9%	0.3%	1.9%
0.95	61.3%	7.3%	7.8%	0.5%	2.0%	1.8%	2.0%	1.9%	2.6%	1.4%	2.8%	1.2%	0.7%	1.6%	0.2%	1.6%
1.00	63.2%	6.7%	7.2%	0.5%	1.8%	1.5%	1.8%	1.7%	2.3%	1.2%	2.6%	1.1%	0.6%	1.4%	0.2%	1.4%
1.05	65.0%	6.2%	6.6%	0.4%	1.5%	1.3%	1.5%	1.5%	2.0%	1.1%	2.3%	1.0%	0.5%	1.3%	0.2%	1.3%
1.10	66.7%	5.8%	6.1%	0.4%	1.4%	1.2%	1.4%	1.3%	1.8%	1.0%	2.2%	0.9%	0.5%	1.1%	0.1%	1.1%
1.15	68.3%	5.4%	5.7%	0.3%	1.2%	1.0%	1.2%	1.1%	1.6%	0.9%	2.0%	0.8%	0.4%	1.0%	0.1%	1.0%
1.20	69.9%	5.0%	5.2%	0.3%	1.1%	0.9%	1.1%	1.0%	1.5%	0.8%	1.8%	0.7%	0.4%	0.9%	0.1%	0.9%
1.25	71.3%	4.6%	4.9%	0.3%	1.0%	0.8%	1.0%	0.9%	1.3%	0.7%	1.7%	0.7%	0.3%	0.8%	0.1%	0.8%
1.30	72.7%	4.3%	4.5%	0.2%	0.9%	0.7%	0.9%	0.8%	1.2%	0.6%	1.6%	0.6%	0.3%	0.7%	0.1%	0.7%
1.35	74.1%	4.0%	4.2%	0.2%	0.8%	0.6%	0.8%	0.7%	1.1%	0.6%	1.4%	0.6%	0.3%	0.7%	0.1%	0.7%
1.40	75.3%	3.8%	3.9%	0.2%	0.7%	0.6%	0.7%	0.6%	1.0%	0.5%	1.3%	0.5%	0.3%	0.6%	0.0%	0.6%
1.45	76.5%	3.5%	3.6%	0.2%	0.6%	0.5%	0.6%	0.6%	0.9%	0.5%	1.3%	0.5%	0.2%	0.6%	0.0%	0.6%
1.50	77.7%	3.3%	3.4%	0.2%	0.6%	0.4%	0.6%	0.5%	0.8%	0.4%	1.2%	0.4%	0.2%	0.5%	0.0%	0.5%
1.55	78.8%	3.1%	3.2%	0.2%	0.5%	0.4%	0.5%	0.5%	0.7%	0.4%	1.1%	0.4%	0.2%	0.5%	0.0%	0.5%
1.60	79.8%	2.9%	3.0%	0.1%	0.5%	0.4%	0.5%	0.4%	0.7%	0.4%	1.0%	0.4%	0.2%	0.4%	0.0%	0.4%
1.65	80.8%	2.7%	2.8%	0.1%	0.4%	0.3%	0.4%	0.4%	0.6%	0.3%	1.0%	0.3%	0.2%	0.4%	0.0%	0.4%
1.70	81.7%	2.5%	2.6%	0.1%	0.4%	0.3%	0.4%	0.3%	0.6%	0.3%	0.9%	0.3%	0.1%	0.4%	0.0%	0.4%
1.75	82.6%	2.4%	2.4%	0.1%	0.3%	0.3%	0.3%	0.3%	0.5%	0.3%	0.8%	0.3%	0.1%	0.3%	0.0%	0.3%
1.80	83.5%	2.2%	2.3%	0.1%	0.3%	0.2%	0.3%	0.3%	0.5%	0.3%	0.8%	0.3%	0.1%	0.3%	0.0%	0.3%
1.85	84.3%	2.1%	2.1%	0.1%	0.3%	0.2%	0.3%	0.3%	0.5%	0.2%	0.7%	0.3%	0.1%	0.3%	0.0%	0.3%
1.90	85.0%	2.0%	2.0%	0.1%	0.3%	0.2%	0.3%	0.2%	0.4%	0.2%	0.7%	0.2%	0.1%	0.3%	0.0%	0.3%
1.95	85.8%	1.9%	1.9%	0.1%	0.2%	0.2%	0.2%	0.2%	0.4%	0.2%	0.7%	0.2%	0.1%	0.2%	0.0%	0.2%
2.00	86.5%	1.7%	1.8%	0.1%	0.2%	0.2%	0.2%	0.2%	0.4%	0.2%	0.6%	0.2%	0.1%	0.2%	0.0%	0.2%
2.05	87.1%	1.7%	1.7%	0.1%	0.2%	0.1%	0.2%	0.2%	0.3%	0.2%	0.6%	0.2%	0.1%	0.2%	0.0%	0.2%
2.10	87.8%	1.6%	1.6%	0.1%	0.2%	0.1%	0.2%	0.2%	0.3%	0.2%	0.5%	0.2%	0.1%	0.2%	0.0%	0.2%
2.15	88.4%	1.5%	1.5%	0.1%	0.2%	0.1%	0.2%	0.2%	0.3%	0.1%	0.5%	0.2%	0.1%	0.2%	0.0%	0.2%
2.20	88.9%	1.4%	1.4%	0.1%	0.2%	0.1%	0.2%	0.1%	0.3%	0.1%	0.5%	0.2%	0.1%	0.2%	0.0%	0.2%
2.25	89.5%	1.3%	1.3%	0.1%	0.1%	0.1%	0.1%	0.1%	0.3%	0.1%	0.5%	0.2%	0.1%	0.2%	0.0%	0.2%
2.30	90.0%	1.2%	1.3%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.4%	0.1%	0.1%	0.1%	0.0%	0.1%

Canadian Lobster Fishing Areas (LFA)



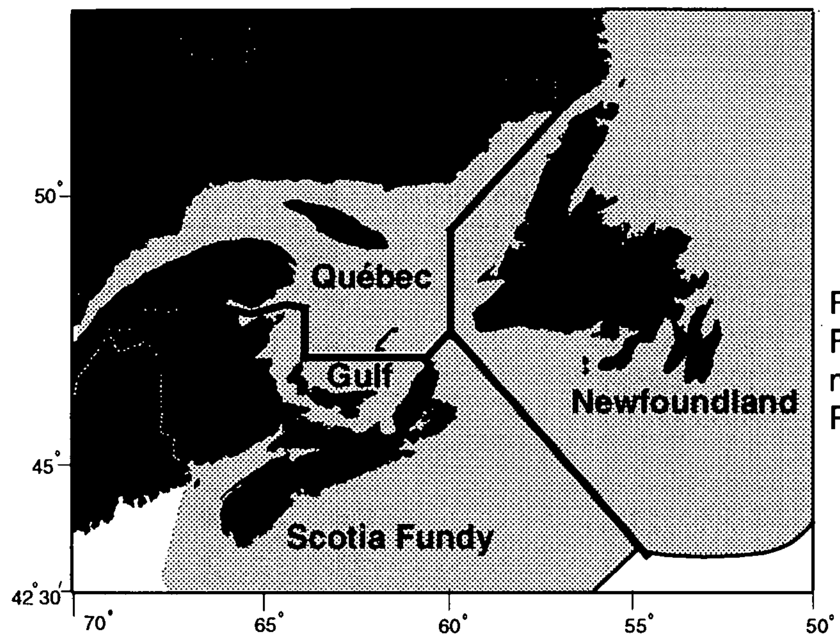
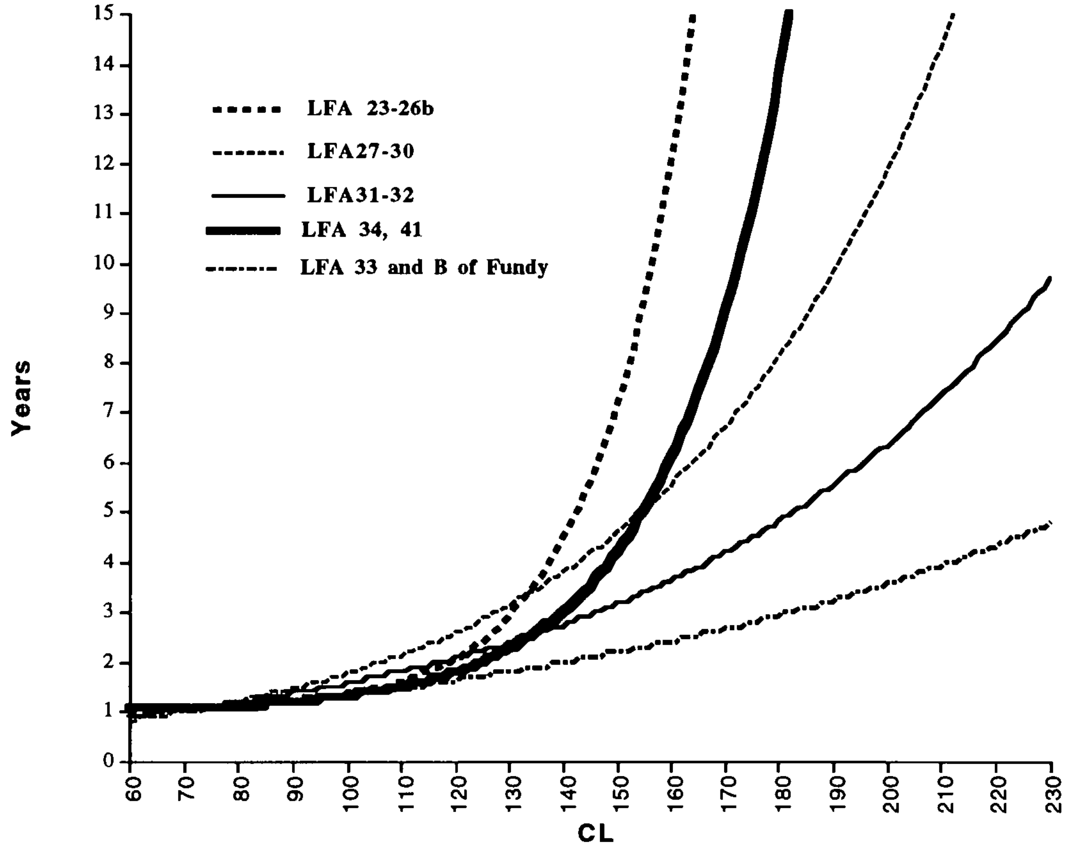


Figure 1: Canadian Lobster Fishing Areas (LFA) and Department of Fisheries and Oceans Regions.

Intermolt Period : Gulf & Scotia Fundy Region



Intermolt Period : Quebec Region

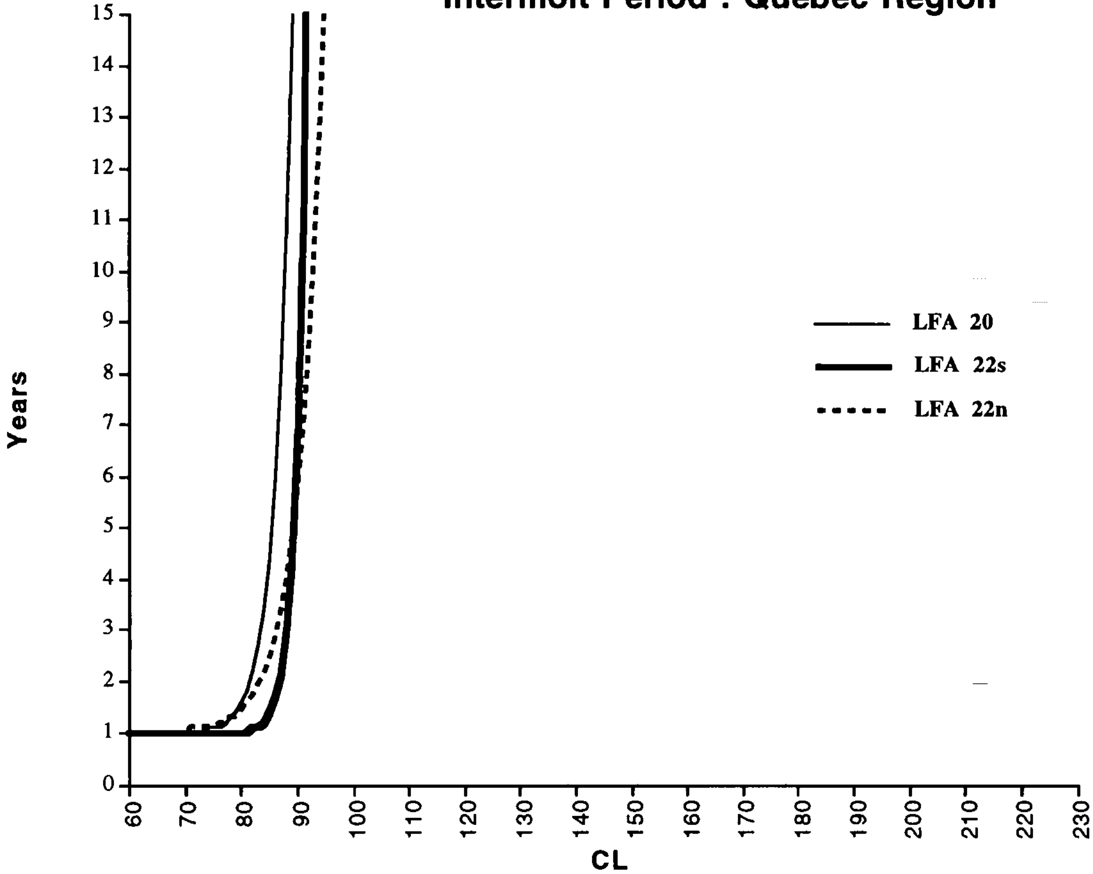
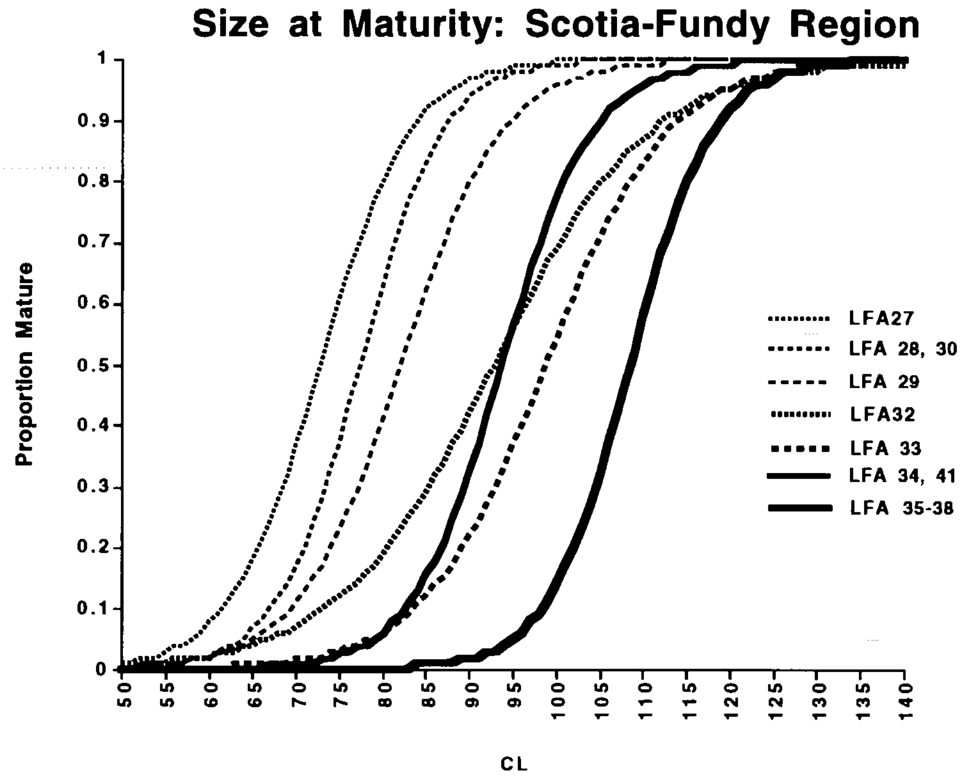


Figure 2: Intermolt periods calculated as the inverse of the annual proportion molting [(annual proportion molting^{-1}] based on mark-recapture data



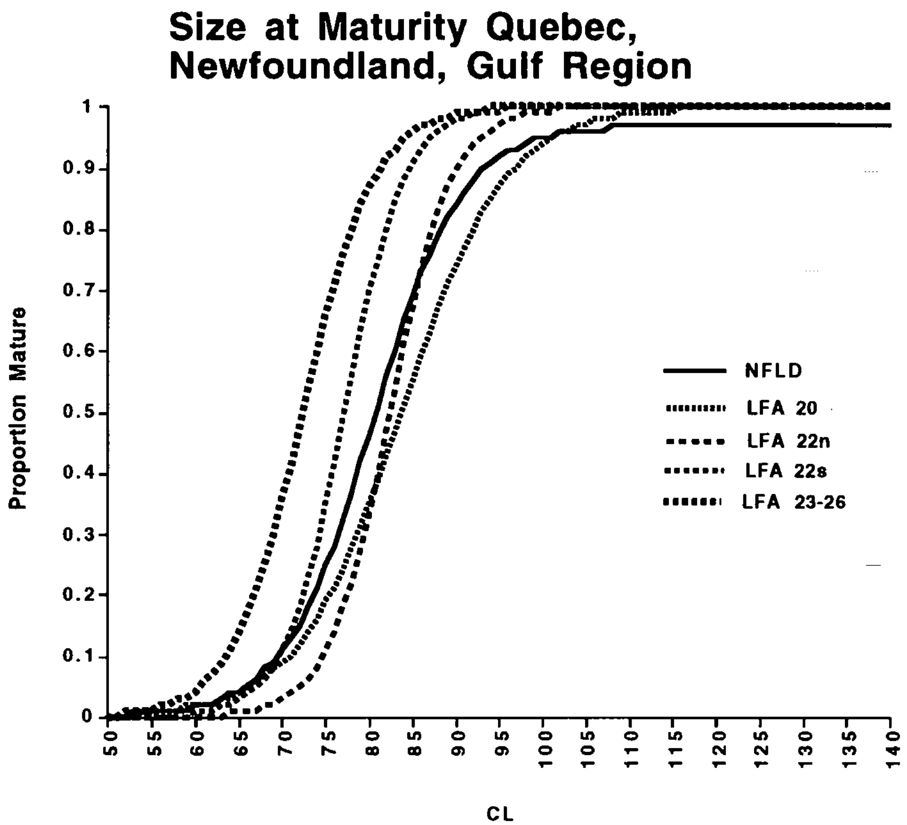


Figure 3: Size at maturity curves based on data fit to logistic function

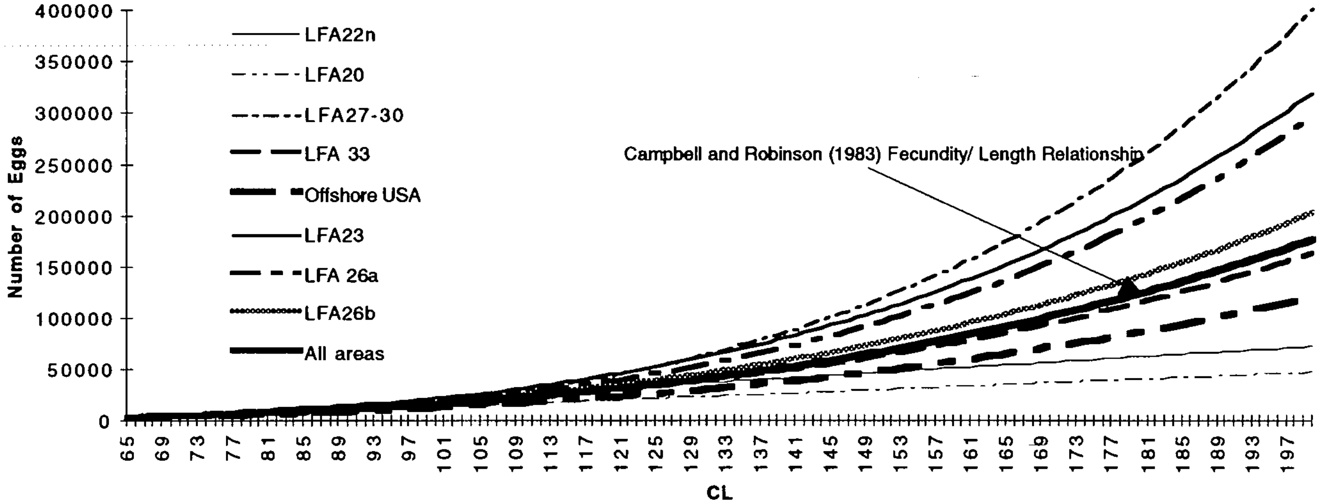


Figure 4: Fecundity at length relationships for various LFAs and the Campbell and Robinson (1983) relationship calculated from Bay of Fundy (LFA 35-38), Eastern Nova Scotia (LFA 31-32) and Northumberland Strait (LFA 24-25) and used in the present E/R calculations

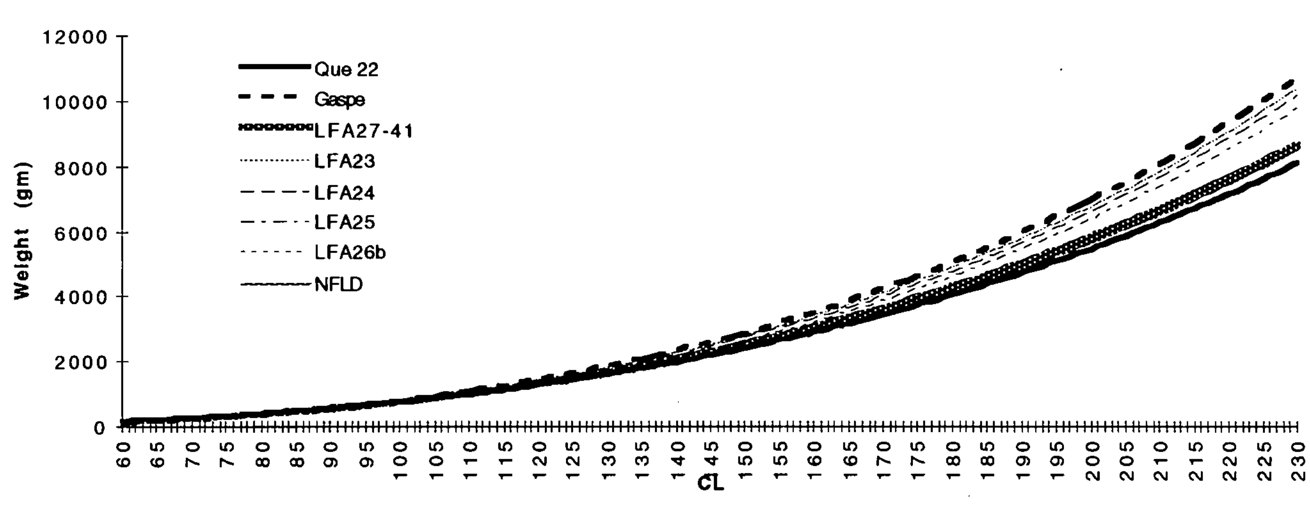
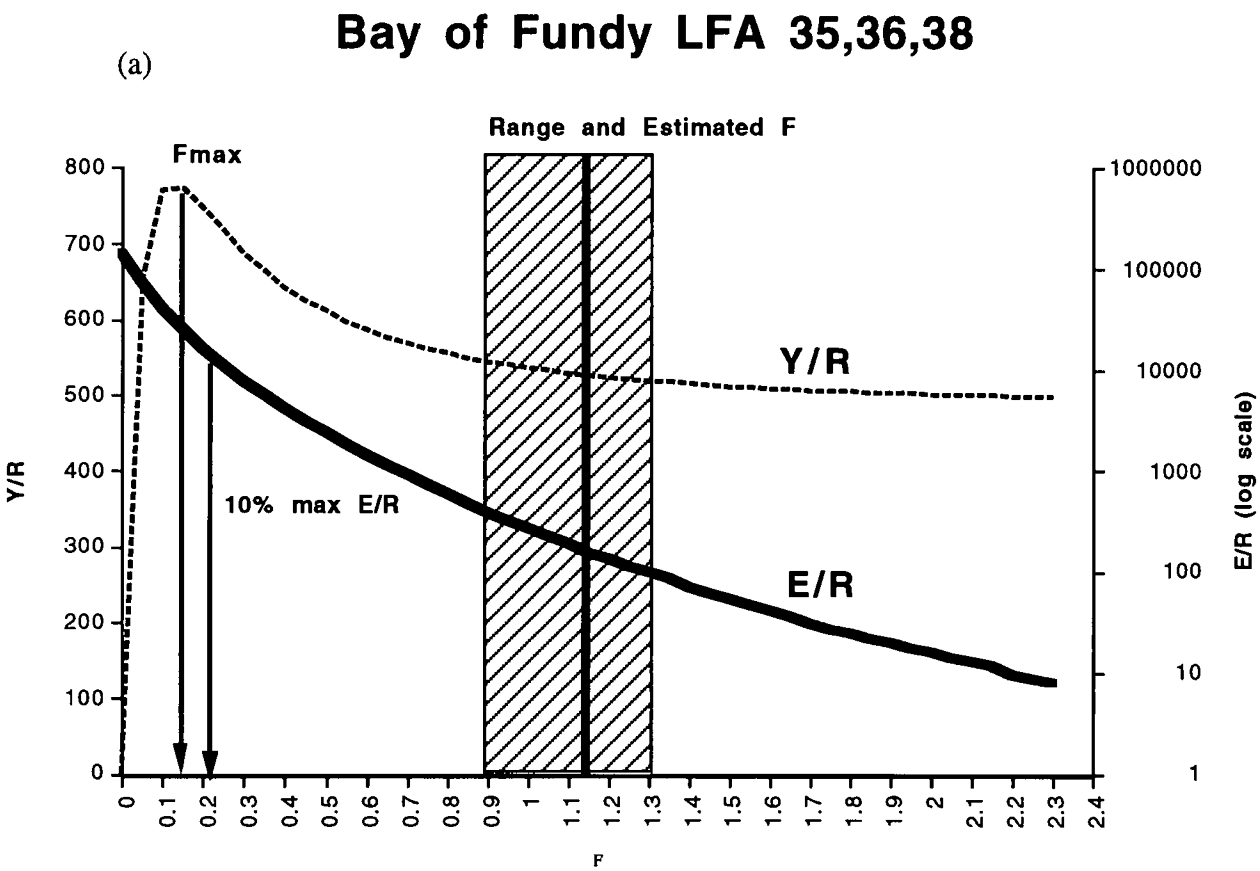


Figure 5: Weight at length relationship for various LFAs and regions.



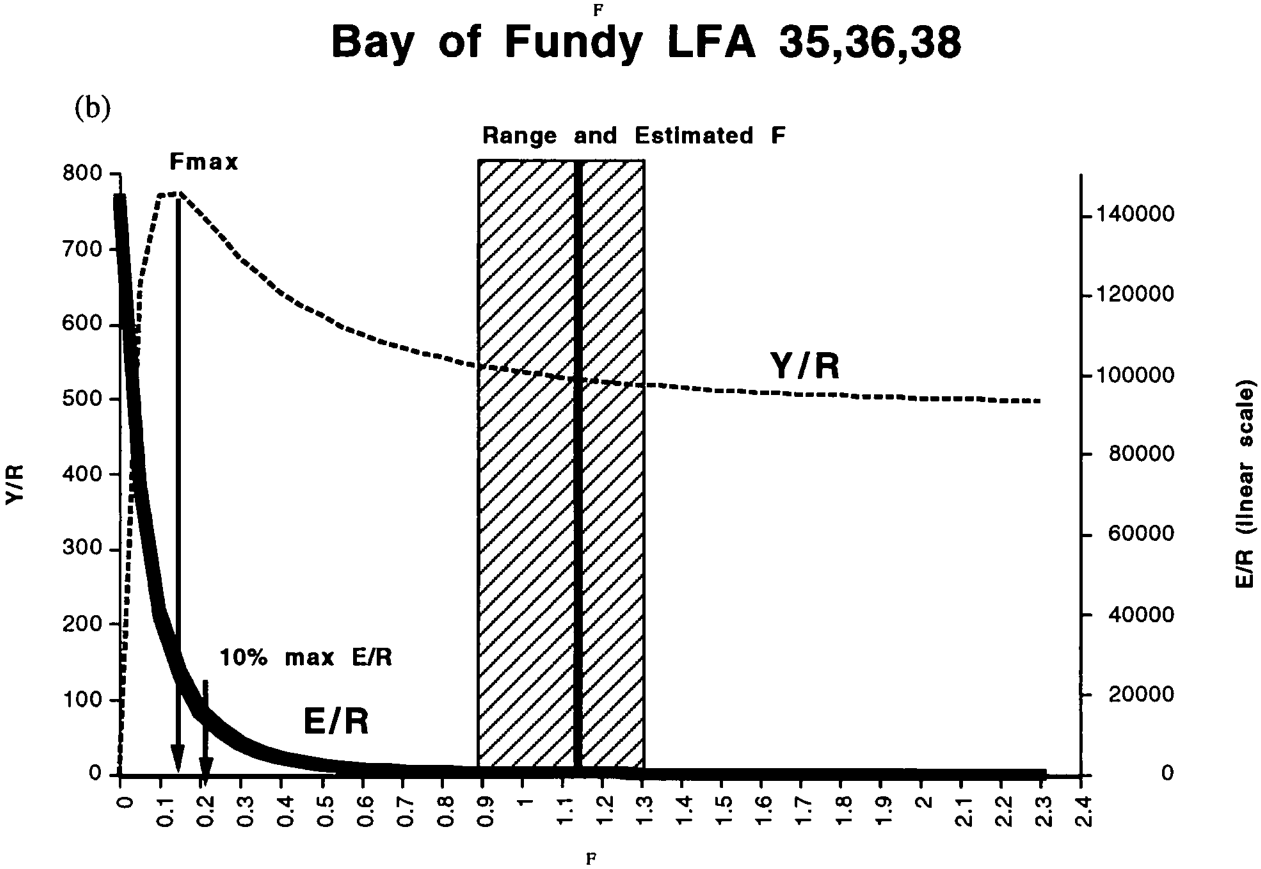


Figure 6: Egg and Yield per recruit for LFA 35-38, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F. (a) E/R plotted on log scale; (b) E/R plotted on linear scale

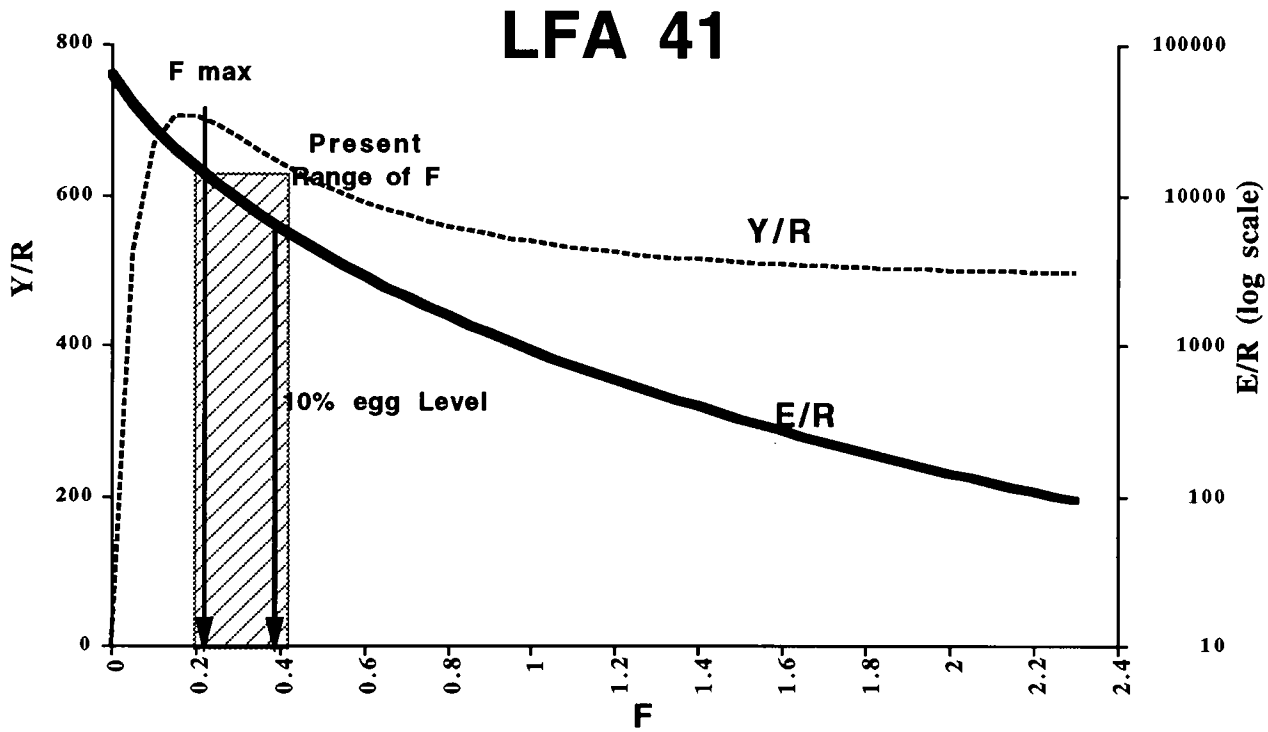


Figure 7: Egg and Yield per recruit (E/R plotted on log scale) for LFA 41, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

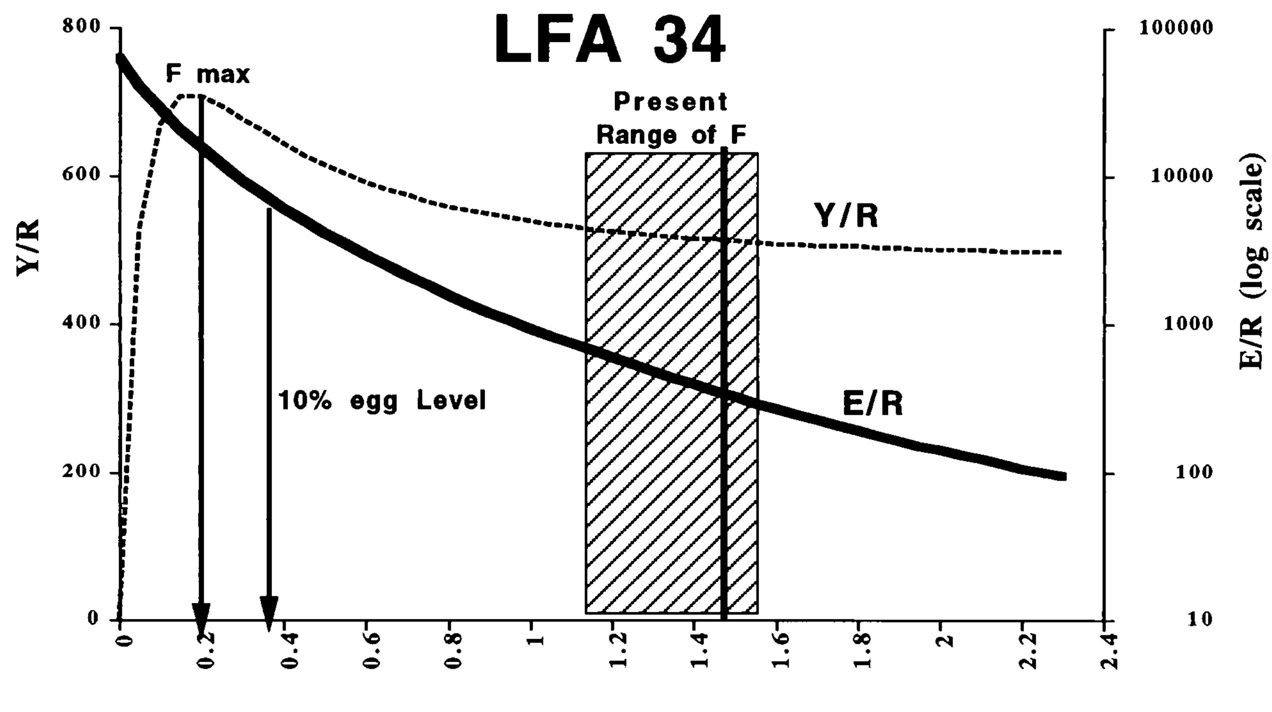


Figure 8: Egg and Yield per recruit (E/R plotted on log scale) for LFA 34, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

LFA 32

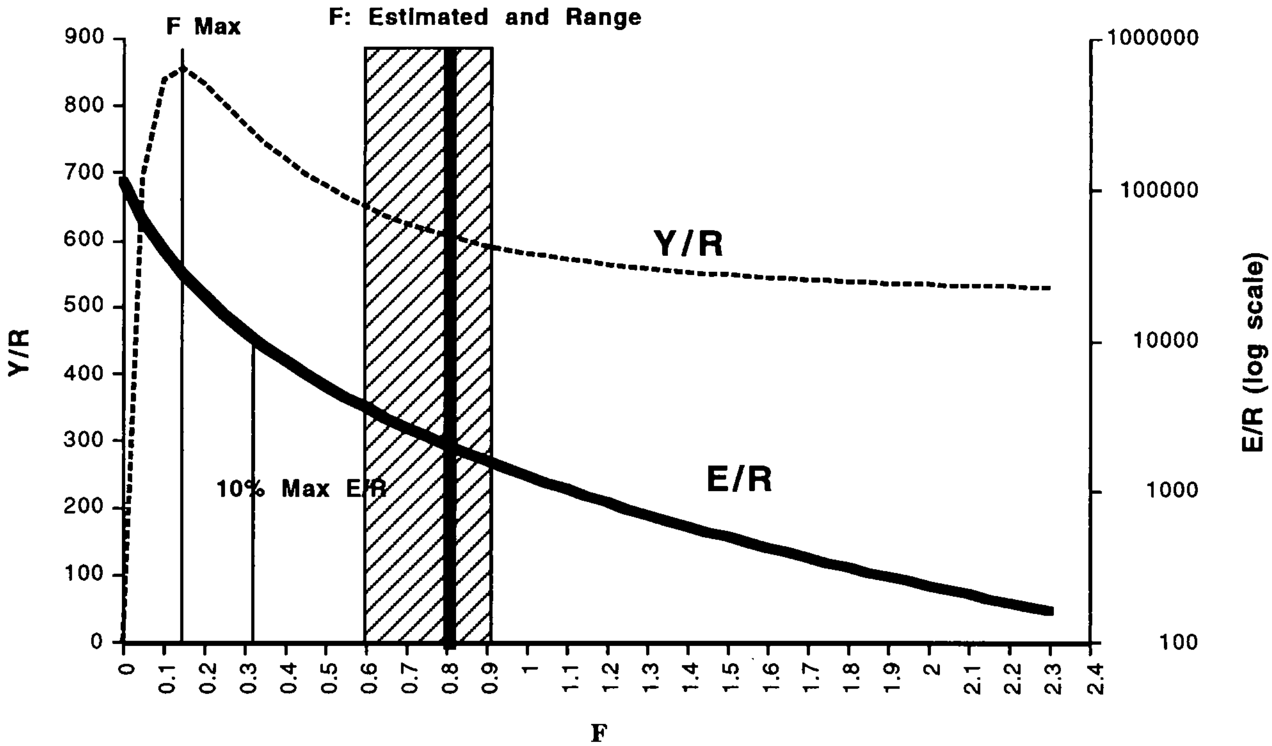


Figure 9: Egg and Yield per recruit (E/R plotted on log scale) for LFA 32, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

LFA 23, 25

Minimum size 66.7mm CL

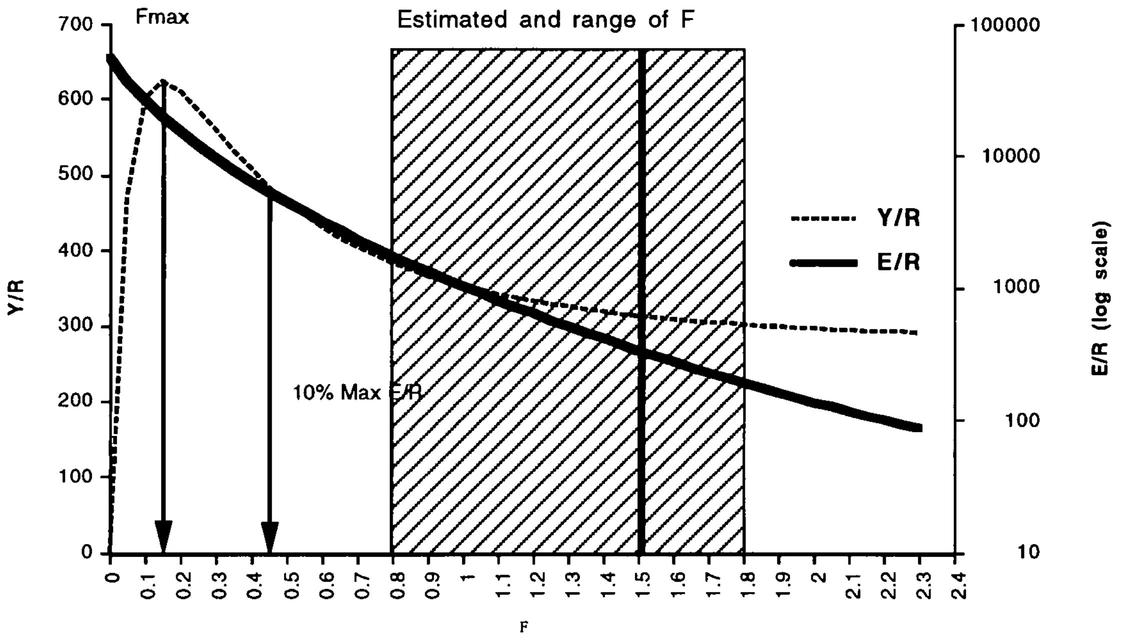


Figure 10: Egg and Yield per recruit (E/R plotted on log scale) for LFA 23, 25, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

LFA 24

Minimum size 63.5mm CL

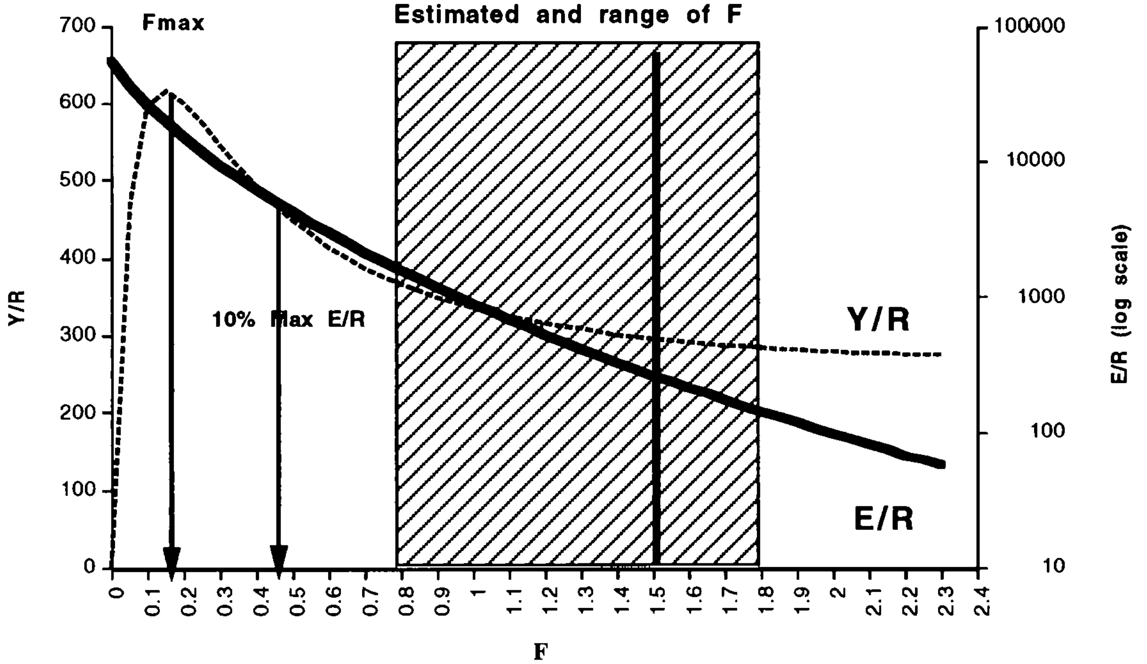


Figure 11: Egg and Yield per recruit (E/R plotted on log scale) for LFA 25, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

LFA 26A

Minimum size 65.1mm CL

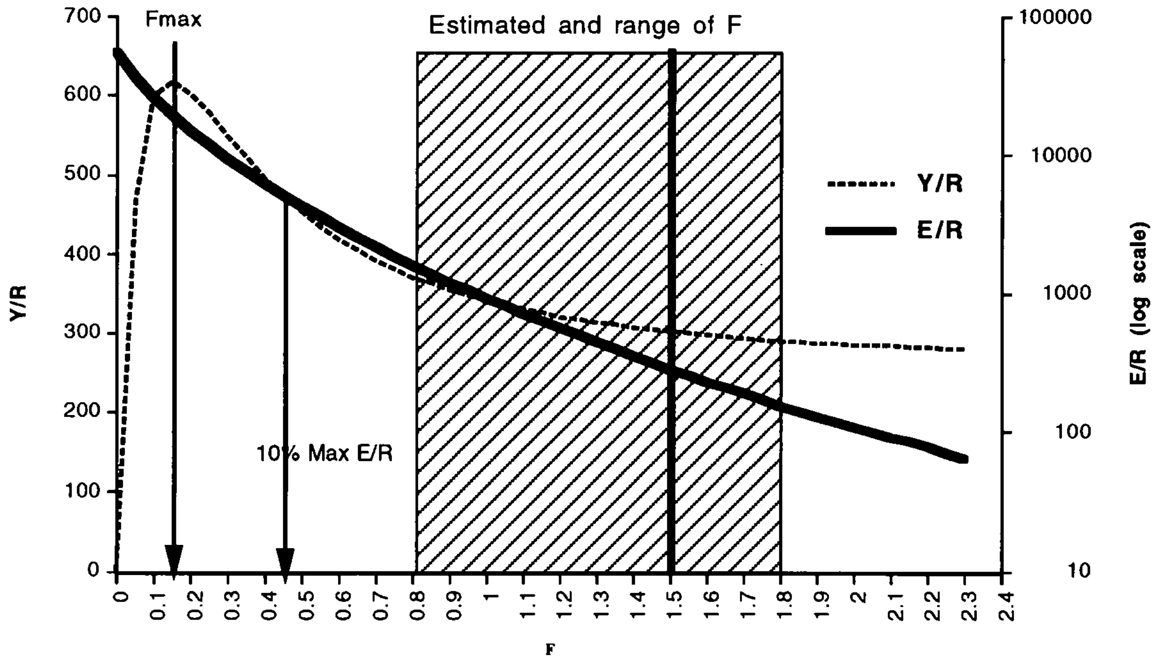


Figure 12: Egg and Yield per recruit (E/R plotted on log scale) for LFA 26a, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

LFA 26B

Minimum size 70mm CL

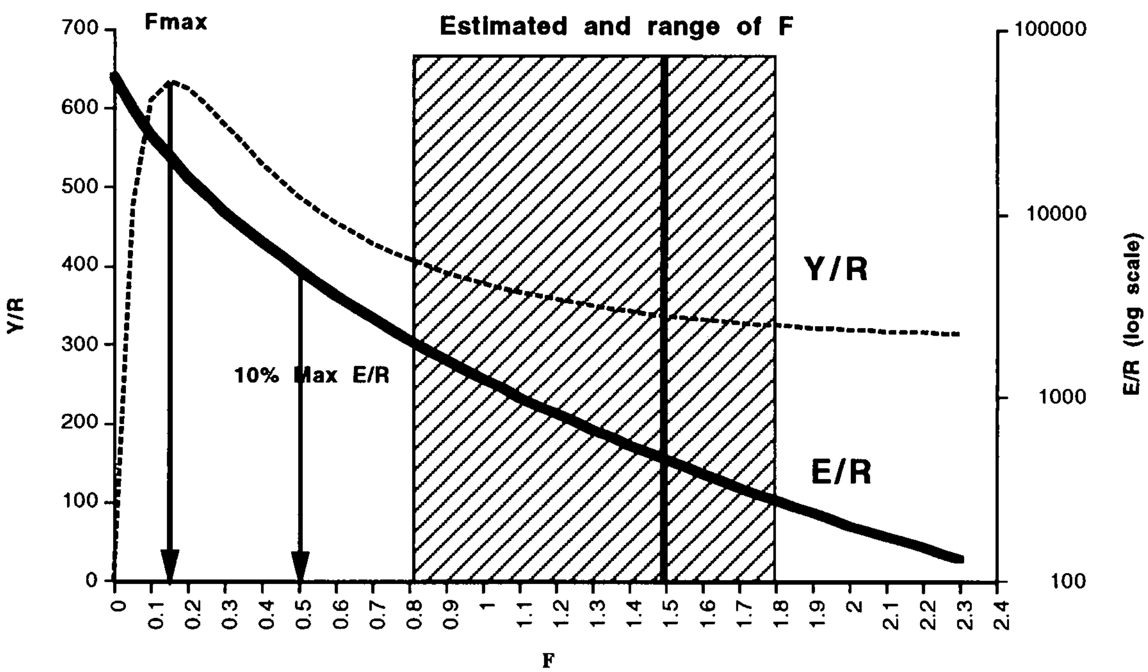


Figure 13: Egg and Yield per recruit (E/R plotted on log scale) for LFA 26b, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

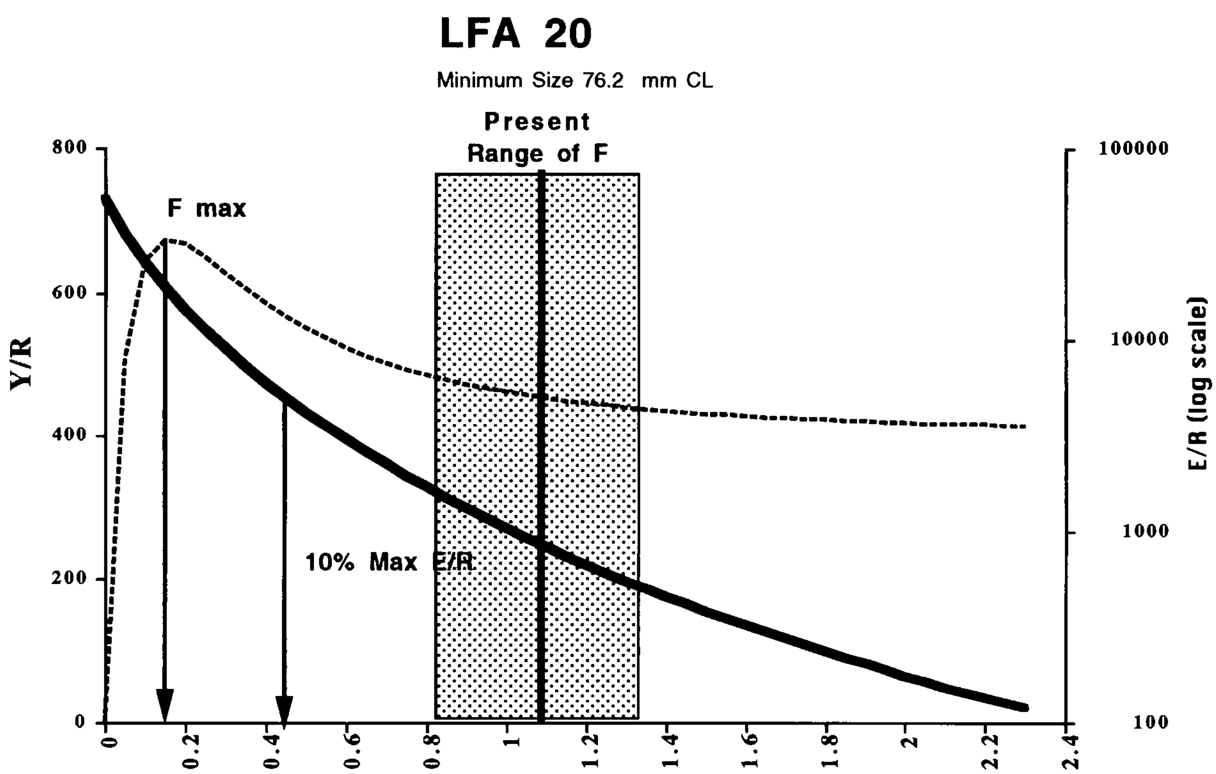


Figure 14: Egg and Yield per recruit (E/R plotted on log scale) for LFA 20, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

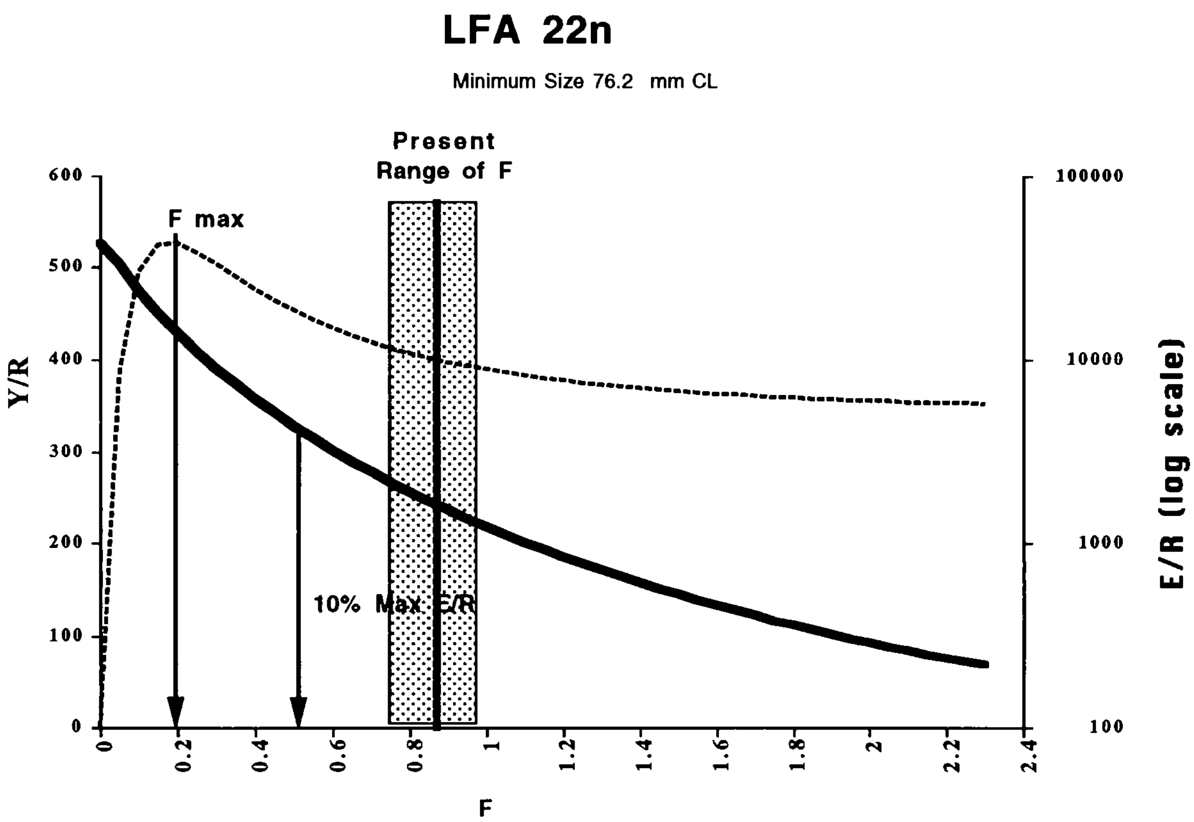


Figure 15: Egg and Yield per recruit (E/R plotted on log scale) for LFA 22n, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

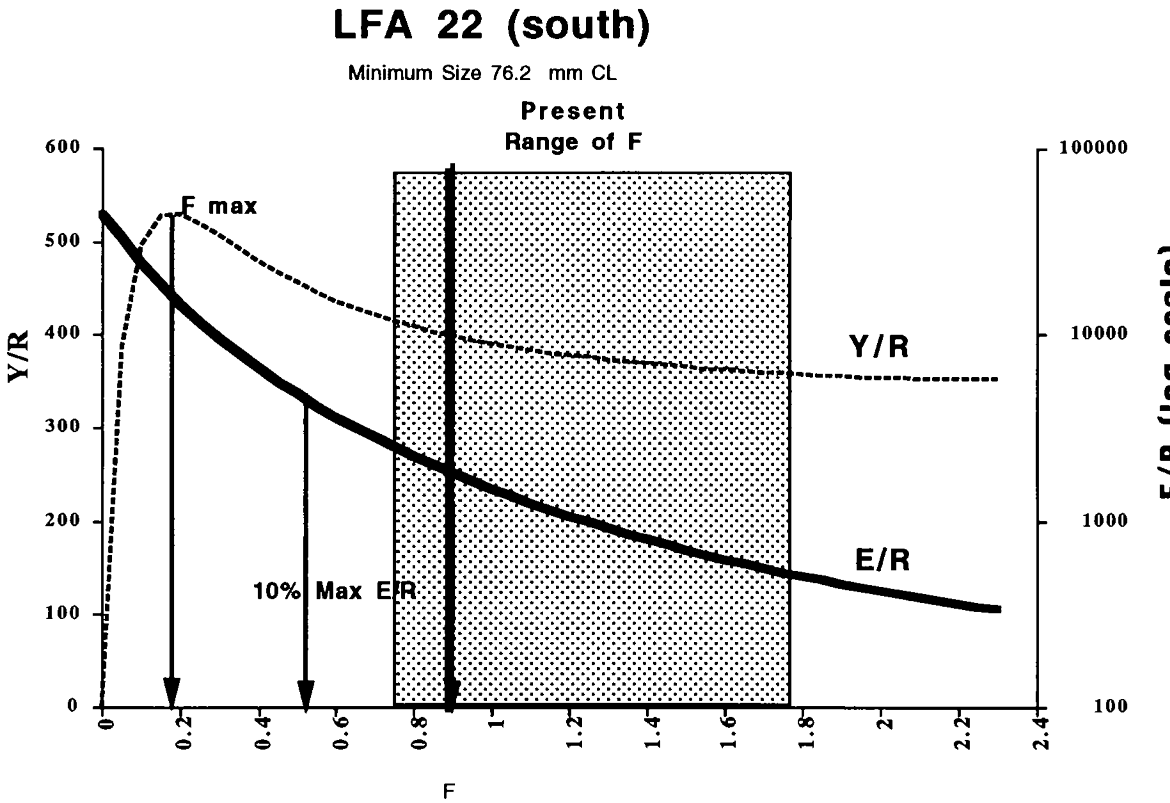


Figure 16: Egg and Yield per recruit (E/R plotted on log scale) for LFA 22s, showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

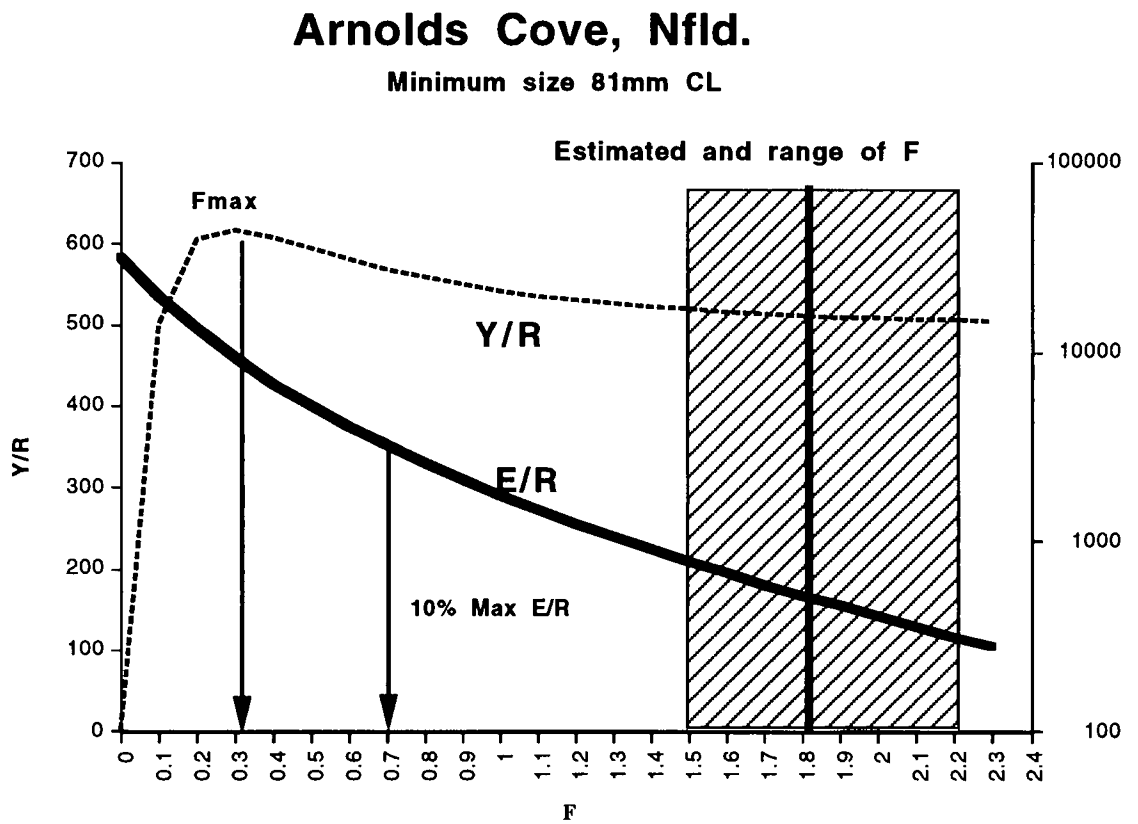


Figure 17: Egg and Yield per recruit (E/R plotted on log scale) for Arnold's Cove, Nfld. showing F at maximum Y/R, F at 10% of the maximum E/R, and present estimated F.

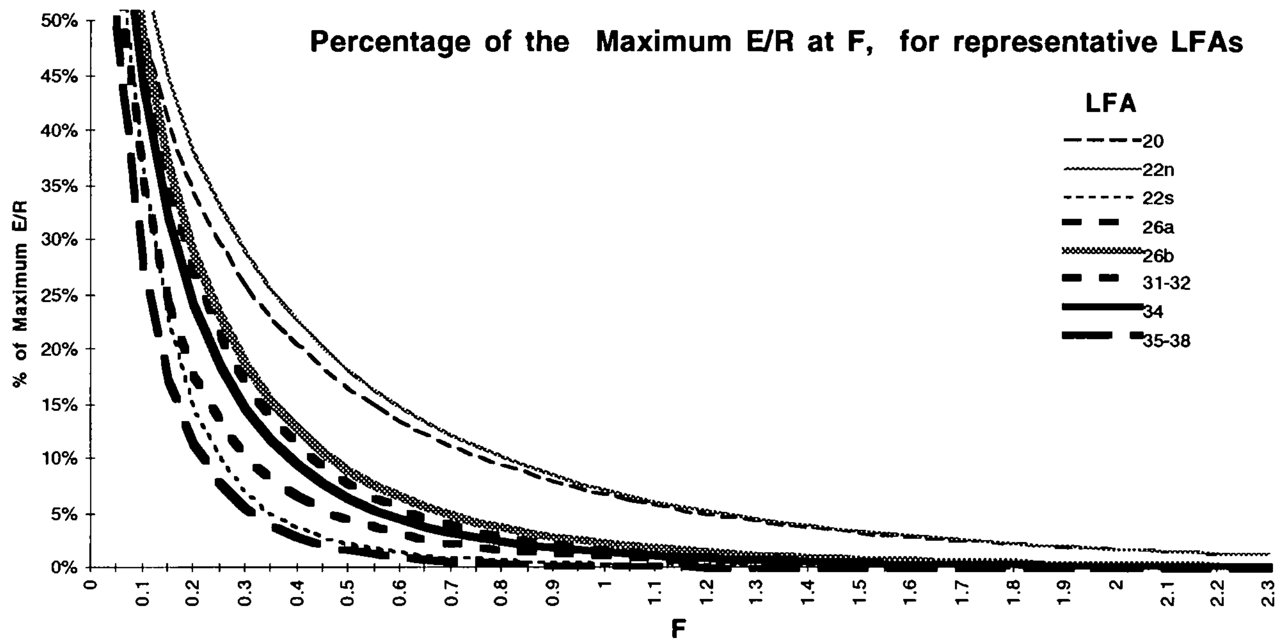
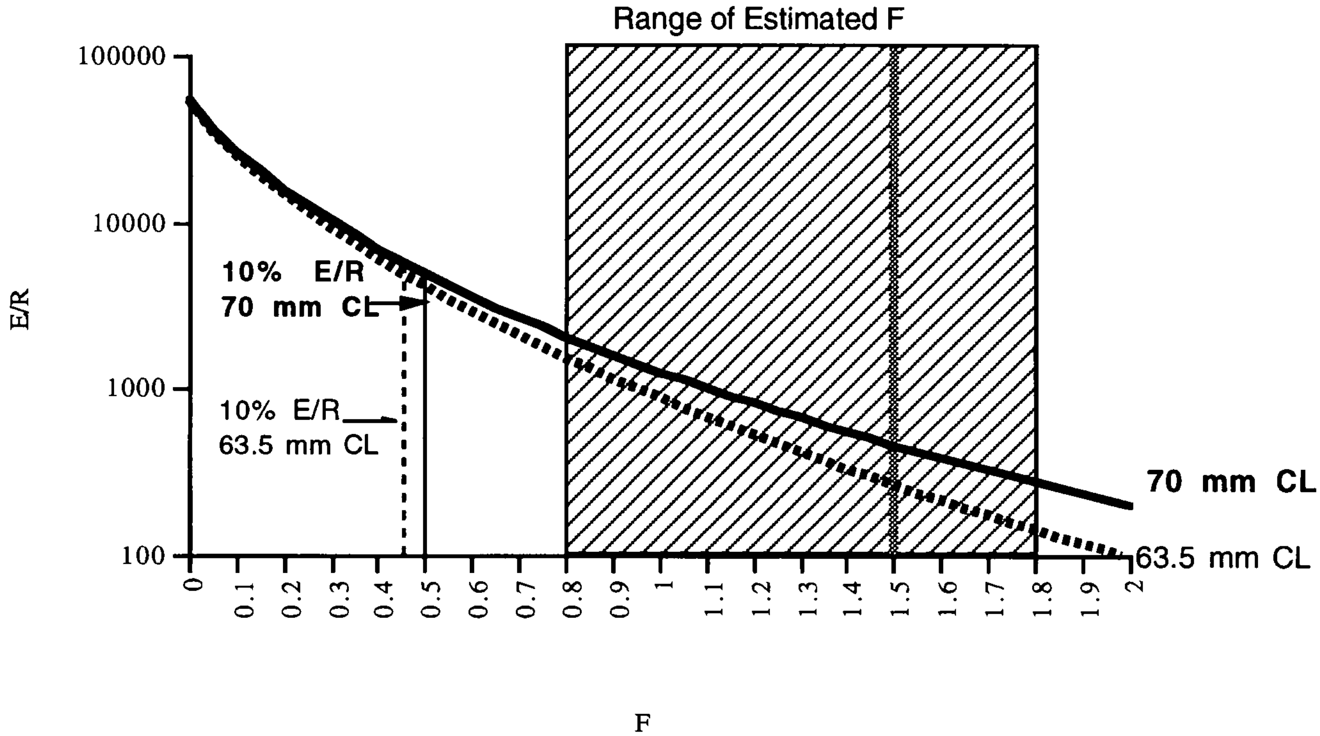


Figure 18: Percentage of maximum E/R at F levels for representative areas and LFAs.



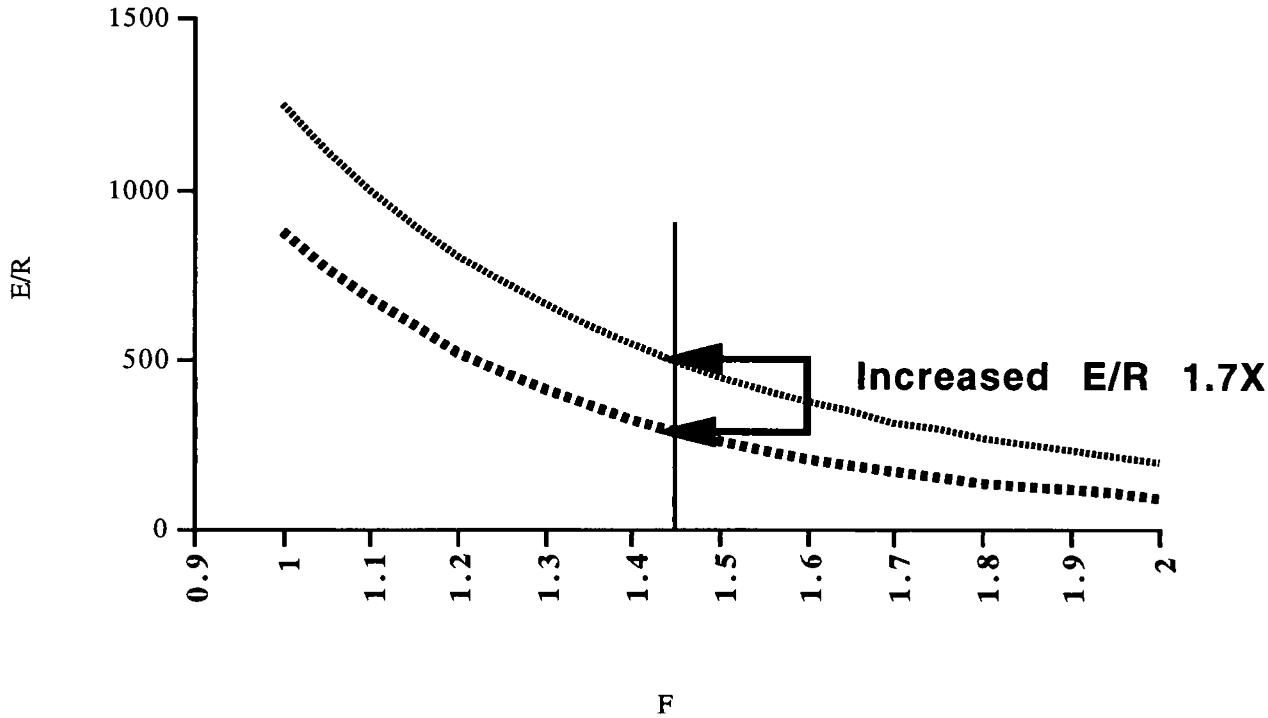


Figure 19: Effect on E/R of increasing the minimum legal size from 63.5mm to 70 mm CL in the southern Gulf of St. Lawrence a) changes in the F at which 10% of the maximum E/R occurs; b) changes in E/R at F=1.45

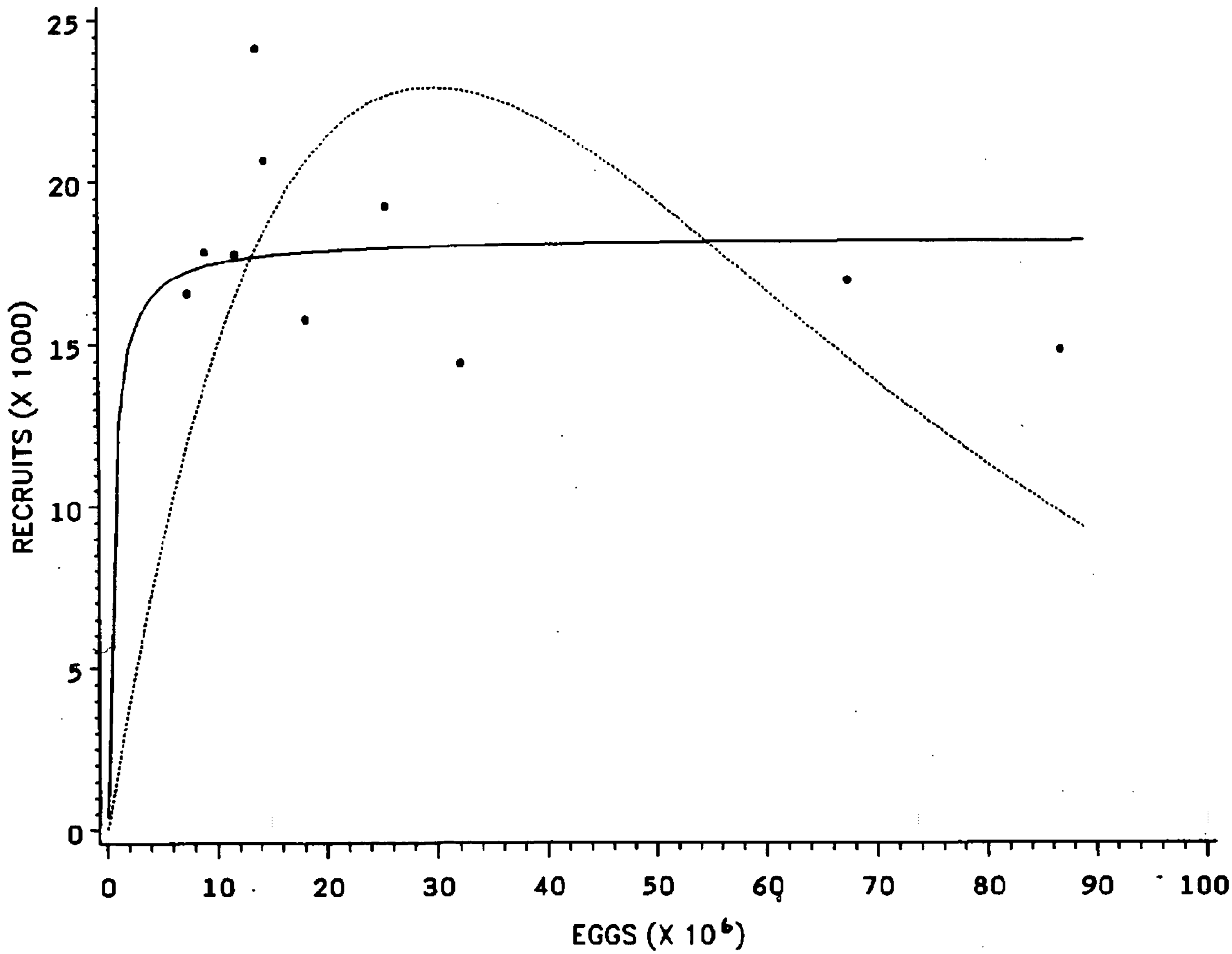


Figure 20: The estimates of egg production and recruitment to the standing stock 9 years later for Arnold's Cove lobster population (G.P. Ennis, Unpublished data) fitted to the Ricker and the Beverton and Holt stock-recruitment models (the Beverton and Holt fit is forced)