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Further yield per recruit analyses for Newfoundland lobsters

by

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ABSTRACT

Growth data for one Newfoundland area were run on the Ennis and Akenhead lobster yield per recruit model at different natural mortality rates. Even at the highest level of natural mortality considered, the model predicts increases in yield per recruit for increases in recruitment length above the present 81 mm carapace length and for decreases in exploitation rate from current levels (around 80%). Yield per recruit curves from this model and those from the Beverton and Holt model using the same growth data are compared. Yield per recruit increases with increasing recruitment length for both models but more rapidly for the Ennis and Akenhead model. In the case of the Beverton and Holt model, however, yield per recruit decreases at recruitment lengths beyond about 95 mm. Long-term changes in yield per recruit predicted by these two models and the Jones model using three different sets of growth data are compared. All three models predict increases in yield per recruit for increases in recruitment length and reductions in exploitation rate considered feasible for the Newfoundland fishery, however, percentage increases are highest for the Ennis and Akenhead model and lowest for the Jones model. Fecundity-maturity data for one area were run on the Jones model as well. Indications are that a substantial increase in egg production would also result from an increase in recruitment length.

Résumé

Le modèle de rendement par recrue à différents taux de mortalité naturelle de Ennis et Akenhead a été appliqué aux données de croissance du homard d'une région de Terre-Neuve. Même au plus haut niveau de mortalité naturelle, le modèle prédit des augmentations de rendement par recrue pour des augmentations de longueur de recrutement au-dessus de la présente longueur de carapace de 81 mm et pour des diminutions de taux d'exploitation au-dessous des niveaux actuels (approximativement 80%). Nous comparons les courbes de rendement par recrue dérivées de ce modèle avec celles obtenues, avec les mêmes données, à l'aide du modèle de Beverton et Holt. Dans les deux cas, le rendement par recrue augmente en fonction de l'augmentation de longueur de recrutement, mais l'augmentation est plus rapide avec le modèle de Ennis et Akenhead. Dans le modèle de Beverton et Holt, cependant, le rendement par recrue diminue à des longueurs de recrutement dépassant environ 95 mm. Nous comparons les variations à long terme du rendement par recrue prédit par ces deux modèles avec celles obtenues avec le modèle de Jones utilisant trois séries differentes de données sur la croissance. Les trois modèles s'accordent à prédire des augmentations de rendement par recrue en fonction d'augmentations de longueur de recrutement et de diminutions de taux d'exploitation considérés possibles dans la pêcherie de Terre-Neuve. Cependant, les pourcentages sont les plus élevés dans le modèle de Ennis et Akenhead et les moins éléves dans celui de Jones. Les données de fecondité-maturité d'une région ont été également appliquées au modèle de Jones. On a des indications qu'une augmentation de longueur de recrutment résulterait en une augmentation substantielle de production d'oeufs.

INTRODUCTION

Yield per recruit assessments for Newfoundland lobsters (Ennis 1978a) were based on a model (Ennis and Akenhead 1978) developed to utilize estimates of the two components of lobster growth (molt increment and proportion molting) separately and to cope with some special features of lobster biology and the lobster fishery which the established models do not provide for. In the model the annual natural mortality rate used was 10% for lobsters that molted during the year and 5% for those that did not molt. Bennett (1976) demonstrated that a generalized crustacean yield model was very sensitive to changes in the value of M and Shelton et al. (1978) showed that lobster (*H. gammarus*) yield per recruit assessments using the Jones (1974) cohort analysis on length composition were also sensitive to changes in M. The purpose of this paper is to determine the sensitivity of the Ennis/Akenhead model to changes in annual natural mortality rate, to compare yield per recruit curves from this model with those from the Beverton and Holt (1957) model, and to compare long term changes in yield per recruit predicted by these and the Jones model using essentially the same data. In addition, using the Jones model, an estimate is provided of the effect on egg production of an increase in recruitment length and a reduction in exploitation rate.

MATERIALS AND METHODS

The Ennis and Akenhead (1978) lobster yield per recruit model was run at annual natural mortality rates ranging from a low of 5% for molters and 0% for non-molters, each rate increasing in steps of 2.5%, to a high of 15% and 10% respectively. Molt increment data and proportions molting data for the years 1975-78 combined (see Ennis 1978b for details) for Arnold's Cove, Placentia Bay were used. These data were combined as described by Ennis (1978b) to produce growth curves. In constructing these growth curves ages 6 and 7 for males and females respectively were assigned to the starting size of 61 mm carapace length (Ennis 1978b). Estimates of mean lengths at successive ages thus obtained were run on a version of the Allen (1966) program to obtain estimates of the parameters of the von Bertalanffy growth equation. These parameters were then utilized in a Beverton and Holt yield per recruit program with M =.1 and a range of t_c and F values encompassing the range of recruitment lengths and exploitation rates used in the Ennis/Akenhead program.

The von Bertalanffy parameters obtained from Arnold's Cove data and those obtained in the same manner from similar data for Comfort Cove, Notre Dame Bay, along with commercial catch length frequencies obtained during the 1976-78 seasons in each area, were also used in a Jones (1974) program.

RESULTS AND DISCUSSION

Sensitivity of the Ennis/Akenhead Model to Natural Mortality Rate

At an 80% exploitation rate, yield per recruit increased with increasing recruitment length at all levels of natural mortality considered in the Ennis/Akenhead program (Fig. 1). Percentage increase in yield per recruit (males and females combined) that would result from an increase in recruitment length from 81 mm (existing size limit) to 89 mm (size limit recommended by Ennis (1978a)) ranged from 11% at the highest level of natural mortality to 25% at the lowest level (Table 1).

Yield per recruit also increased with decreasing exploitation rate at a recruitment length of 81 mm (Fig. 2). However, at high levels of natural mortality it decreased at exploitation rates lower than 40%. Percentage increase in yield per recruit (males and females combined) that would result from a decrease in exploitation rate from 80% to 50% ranged from 4% at the highest level of natural mortality to 17% at the lowest level (Table 1).

The Ennis/Akenhead model is obviously very sensitive to changes in natural mortality rate. However, even at the highest rate considered (15% for molters and 10% for non-molters), which is almost certain to be too high, the recommended size limit increase would improve yield per recruit. At this level of natural mortality though, the increase in yield per recruit as a result of a decrease in exploitation rate would be negligible. However, a reduction in exploitation rate, besides improving the economics of the fishery, would, over the long term, lead to increased abundance.

It seems more likely that the rate of annual natural mortality of lobsters over the range of sizes considered in these assessments is lower than that (10% for molters and 5% for non-molters) used by Ennis (1978a) instead of higher. Ennis (1979) estimated an annual natural mortality rate of only 2.2% for commercial size male lobsters in a Newfoundland population. While the methodology used is such that this estimate can only be taken as a ball-park figure, the estimate does provide a measure of confidence in yield per recruit assessments based on a much higher level of natural mortality.

Yield per Recruit Curves Compared

Yield per recruit curves from the Ennis/Akenhead program run with the Arnold's Cove growth data and natural mortality rates of 10% for molters and 5% for non-molters are compared with those from a Beverton and Holt program run with von Bertalanffy parameters derived from the same growth data and $M = .1$ (Fig. 3 and 4). Yield per recruit increases with increasing recruitment length at 60% and 80% rates of exploitation for both models, but, in the case of the Beverton and Holt model it decreases at recruitment lengths beyond about 95 mm. Yield per recruit increases only slightly with decreases in exploitation rate at recruitment lengths of 81 and 89 mm but decreases at exploitation rates less than 30-40%. Increases in yield per recruit are more rapid in the Ennis/Akenhead curves mainly because of the somewhat lower natural mortality rate used. However, the biggest difference between the two sets of curves is the much higher yield per recruit value at any given recruitment length (t_c) and exploitation rate (F). The different natural mortality rates used would account for some of the difference but the main cause is the different definitions of recruits. The Ennis/Akenhead model starts with 1000 recruits evenly distributed over the 60-69 mm carapace length range whereas the Beverton and Holt model (as used here) starts with 1000 recruits at age 4 (= 9.8 mm carapace length for males and 9.0 mm for females). Yield per recruit values increase substantially in the Beverton and Holt model if t_r is increased, however, the percentage change in yield per recruit with changing recruitment length (age) is unaffected. The same affect is obtained if ages 5 and 6 (instead of 6 and 7 for males and females respectively) are assigned to the starting size (61 mm) from which the growth curves are produced. The resulting von Bertalaffy parameters give higher estimates of size at age and the sizes at $t_r = 4$ increase from 9.8 to 38.1 mm for males and from 9.0 to 30.1 mm for females.

Comparison of Percentage Change in Yield per Recruit

For the three sets of data considered, each of the models demonstrates that yield per recruit is more sensitive to changes in recruitment length than to changes in exploitatin rate (Table 2). Percentage increases in yield per recruit are highest for the Ennis/Akenhead model and lowest for the Jones model for given increases in recruitment length and reductions in exploitation rate (F). The differences between these two models is much greater for female data than for male data whereas for the Ennis/Akenhead and Beverton and Holt models, differences are similar for both male and female data. The lower rate of natural mortality used in the Ennis/Akenhead model accounts for some of the difference but another factor complicating these comparisons is the fact that the Ennis/Akenhead model uses exploitation rate and the others use fishing mortality (F). Exploitation rate is the more appropriate term to use in the case of Newfoundland lobsters because of the relatively short, intense annual fishery and the fact that no recruitment and negligible natural mortality are occurring during the fishing season. Estimates of exploitation rate (for males and non-ovigerous females of commercial size combined) in the Arnold's Cove and Comfort Cove fisheries for recent years are available from tagging studies (Ennis, unpublished data). The estimates for the 1978 season are 84% for Arnold's Cove and 91% for Comfort Cove. The equivalent F values were determined from the relationship $\mu = 1\text{-}e^{F}$. The F values were reduced by the percentage to be considered (Table 2) and the equivalent exploitation rates determined. Comparisons between the Ennis/Akenhead model and the Beverton and Holt model are considered valid. However, the Jones model derives its own estimate of the current F value from the size frequency distribution. The equivalent exploitation rates for the F values it derived for the sets of data considered here are as follows: 51% for Arnold's Cove females, 67% for Comfort Cove males, and 48% for Comfort Cove females. These estimates are considerably lower than those obtained from tagging studies. This explains why the percentage changes in yield per recruit for the Jones model (Table 2) are quite low especially for the female data. The protection of egg-bearing females from exploitation is undoubtedly reflected in the female size frequency distributions. This would explain the lower F value derived by the Jones model for Comfort Cove females compared to that derived for the males. These same sets of data were run on the Jones model with different K and L_∞ values. For each set of data, substituting K and L_∞ values which give higher estimates of mean length-at-age results in a higher estimate of F. The converse is also true. This suggests that the methodology discribed by Ennis (1978b) results in an underestimate of growth rate. If this is true, it means that the percentage increases in yield per recruit reported here for given increases in recruitment length and reductions in exploitation rate are conservative.

The Ennis/Akenhead model also provides special treatment for egg-bearing females whereas each of the other models treats males and females identically.

The result of this special treatment is that yield per recruit values are higher for almost all combinations of recruitment length and exploitation rate (Table 3) compared to values obtained when the female data are subjected to male treatment, but only at the smaller and larger recruitment lengths at low exploitation rates are the values very much higher. This special treatment also results in larger percentage changes in yield per recruit for given changes in recruitment length and exploitation rate. For example, at an 80% exploitation rate an increase in recruitment length from 81 to 89 mm gives a 15.5% increase in yield per recruit for the Arnold's Cove female data compared to 13.7% increase for the same data subjected to male treatment, and at a recruitment length of 81 mm a decrease in exploitation rate from 80% to 50% gives a 9.8% increase in yield per recruit for these data compared to 5.4% when the data are subjected to male treatment. The effect of the special treatment afforded females, however, is not reflected in a greater difference in percentage change in yield per recruit for female data than for male data between the Ennis/Akenhead model and the Beverton and Holt model (Table 2).

For the sets of data considered each of the three models predicts increases in yield per recruit with increases in recruitment length up to 15 mm (above the present 81 mm) and with up to 50% reduction in fishing mortality (except for the female data for Comfort Cove where the Jones model predicts - 1% change with a 15 mm increase in recruitment length and a - 2% change with a 50% reduction in fishing mortality).

Percentage Change in Egg Production

The program used here for the Jones model also provides estimates of percentage change in egg production (population fecundity) with changes in recruitment length and fishing mortality. Fecundity data for Arnold's Cove lobsters (Ennis, unpublished data) were run on the program. An increase in egg producton of 39% was estimated for an increase in recruitment length from 81 to 89 mm at the current fishing mortality rate and an increase of 35% for a 50% reduction in fishing mortality at the current 81 mm recruitment length. These should be taken as minimum estimates because the low F value derived by the Jones model and the fact that this model does not provide for protection of egg bearing females would tend to underestimate the effect on egg production of changes in recruitment length or fishing mortality.

While parent stock-recruitment relationships are unknown for lobsters, it seems quite reasonable to assume that at the present low level of abundance, as indicated by comparing current with historical landings, an increase in egg production would result in an increase in recruitment. The above results indicate that the recommended size limit increase for Newfoundland lobsters, in addition to increasing yields by increasing yield per recruit, would also tend to increase yields through increased recruitment.

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Table 1. Percentage increase in yield per recruit (males and females combined) predicted by the Ennis/Akenhead model using Arnold's Cove growth data and different natural mortality rates for (A) an increase in recruitment length from 81 to 89 mm at an 80% exploitation rate and (B) a decrease in exploitation rate from 80% to 50% at a recruitment length of 81 mm.

	Natural mortality rates				
	15 and 10	12.5 and 7.5	10 and 5	7.5 and 2.5	5 and 0
A	11	14	18	21	25
B	4	6	10	13	17

Table 2. Percentage change in yield per recruit resulting from given changes in recruitment length and fishing mortality predicted by A (Ennis/Akenhead model), B (Beverton and Holt model), and C (Jones model) using the same sets of data.

	1 5 mm increase in recruit. length			2 10 mm increase in recruit. length			3 15 mm increase in recruit. length			4 25% reduction in μ			5 50% reduction in μ			6 2 + 4			7 2 + 5		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Comfort Cove (Males)	12	10	6	24	19	15	37	27	25	2	2	3	6	6	6	25	20	17	28	22	16
Comfort Cove (Females)	11	9	4	20	16	6	29	21	-1	2	1	1	6	4	-2	22	17	1	26	17	-10
Arnold's Cove (Females)	10	8	4	19	15	9	26	19	10	3	2	1	8	5	1	20	15	8	25	16	4

Table 3. Yield per recruit values from the Ennis/Akenhead program using growth data for Arnold's Cove females and in brackets () yield per recruit values for the same data run on the male portion of the program.

Exploitation rates %	Recruitment lengths 71	76	81	89	95	102
100	284 (284)	324 (324)	364 (363)	422 (419)	462 (452)	504 (472)
90	291 (290)	330 (329)	369 (367)	428 (421)	466 (453)	507 (472)
80	299 (298)	339 (336)	378 (373)	435 (424)	473 (454)	511 (470)
70	310 (306)	349 (343)	388 (379)	442 (427)	480 (454)	517 (469)
60	324 (317)	362 (352)	399 (385)	453 (430)	489 (455)	524 (467)
50	342 (330)	379 (362)	415 (393)	465 (434)	499 (455)	531 (464)
40	365 (345)	401 (375)	434 (402)	479 (436)	508 (454)	536 (458)
30	394 (363)	424 (388)	453 (410)	490 (437)	512 (449)	532 (449)
20	417 (380)	439 (398)	458 (413)	481 (430)	493 (435)	501 (429)

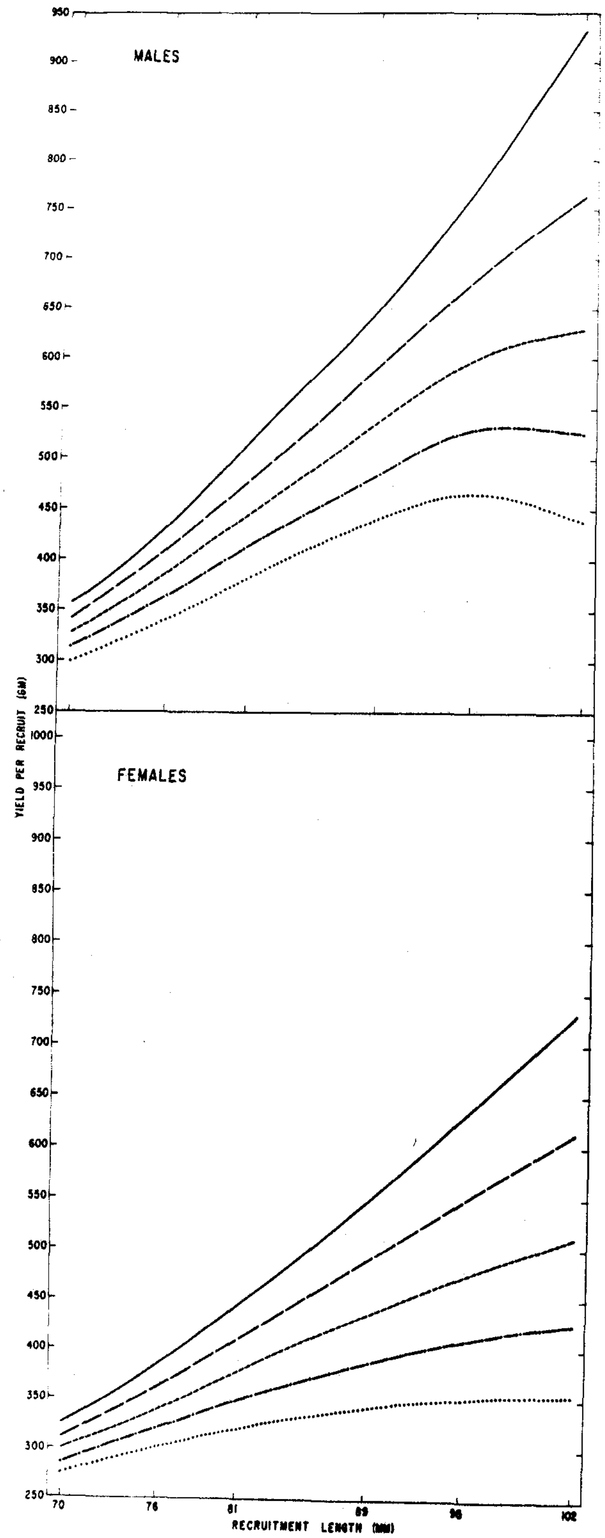

Fig. 1. Curves of yield per recruit against recruitment length at an 80% exploitaton rate for Arnold's Cove growth data run on the Ennis/Akenhead program at natural mortality rates as follows:
——5/0, – – 7.5/2.5, ----10/5, ·–·– 12.5/7.5, ...15/10.

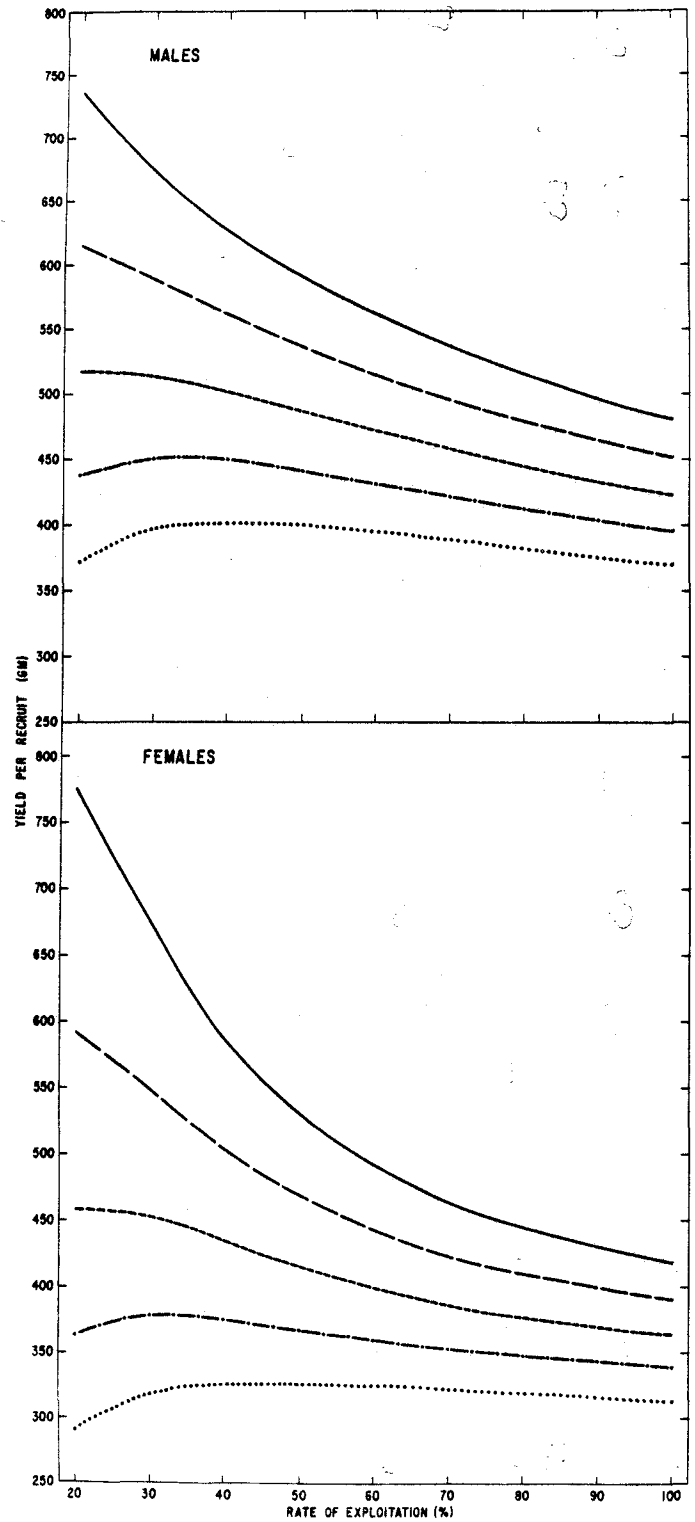

Fig. 2. Curves of yield per recruit against exploitation rate at a recruitment length of 81 mm for Arnold's Cove growth data run on the Ennis/Akenhead program at natural mortality rates as follows:
——5/10, -- 7.5/2.5, ----10/5, ·-·-12/5/7.5, ...15/10.

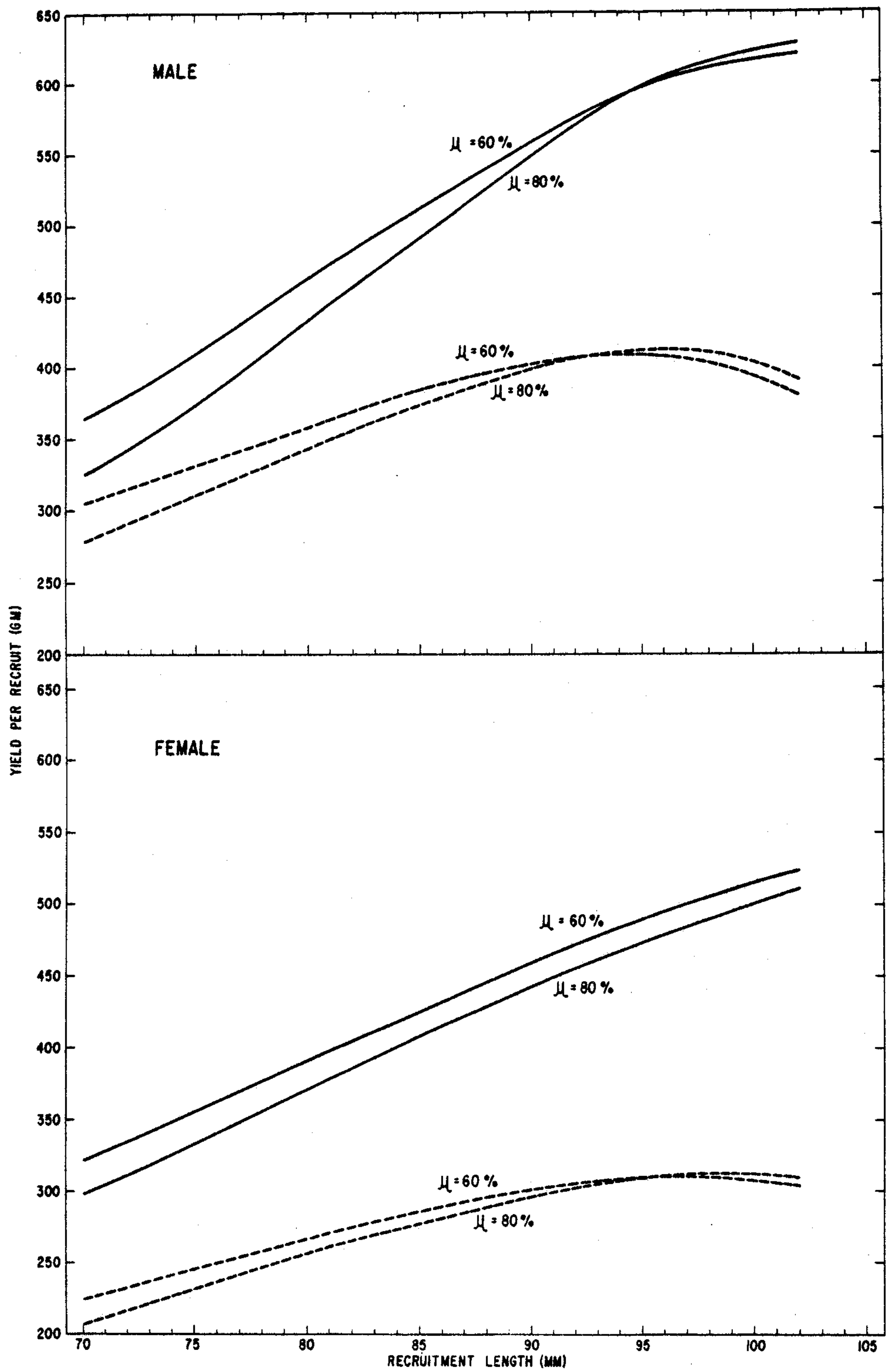

Fig. 3. Curves of yield per recruit agaist recruitment length for Arnold's Cove growth data run on the Ennis/Akenhead program (solid lines) and the Beverton and Holt program (dashed lines).

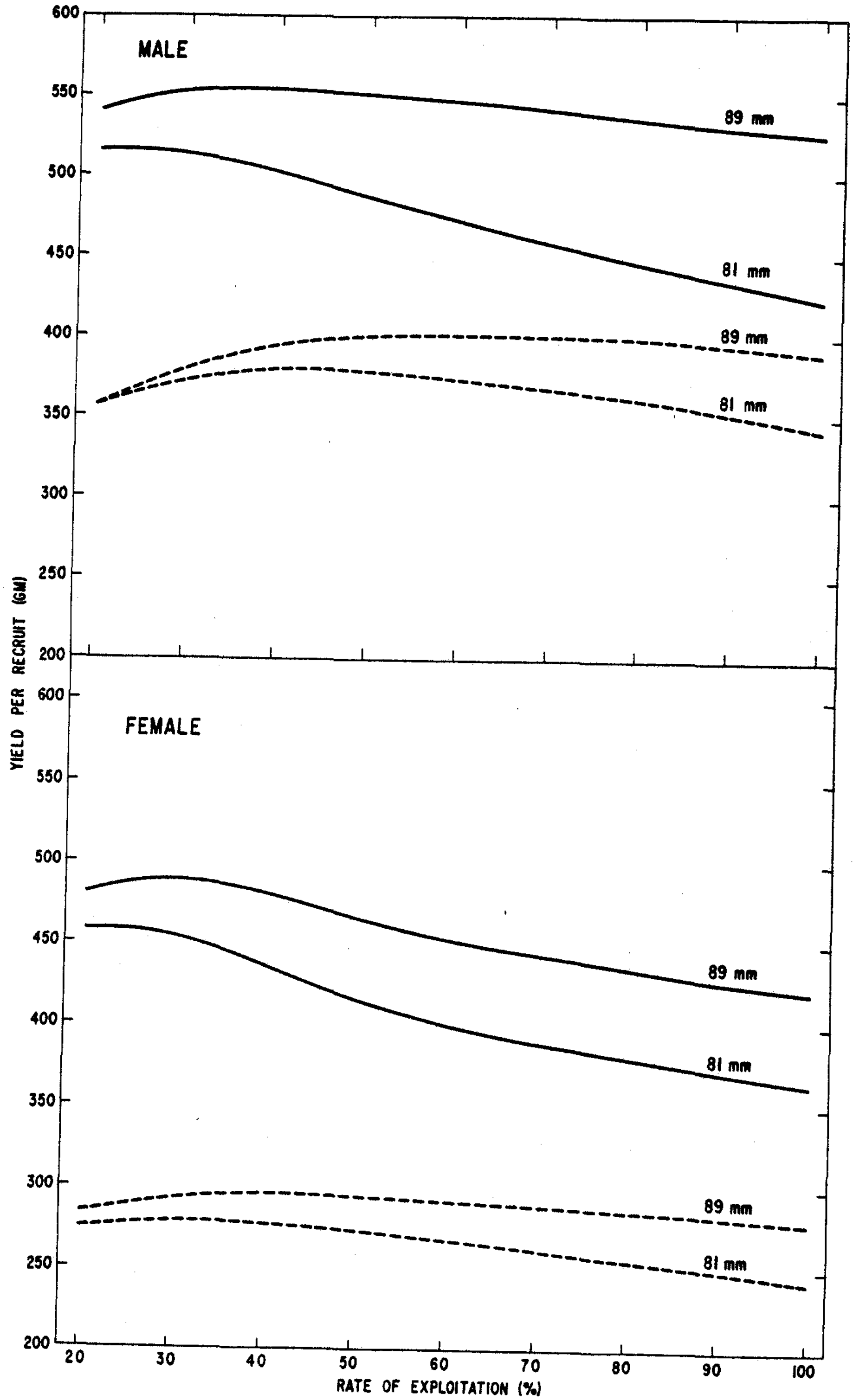

Fig. 4. Curves of yield per recruit against exploitation rate for Arnold's Cove growth data run on the Ennis/Akenhead program (solid lines) and the Beverton and Holt program (dashed lines).