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Yield per Recruit Analysis of 4VWX Squid by Simulation

by

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INTRODUCTION

The traditional yield per recruit models are based on three sorts of data: growth, fishing and natural mortalities as functions of age. It is also assumed that the population is closed. Growth at age is fairly well known for Scotian Shelf squid. Fishing mortality is also estimable from the selectivity of the trawls used and the historical patterns of effort, both of which are reported in the literature.

Natural mortality, which we define as all causes of removal from the population except catch shall be broken into three categories: cannibalism, migration and all other noncatch factors are pooled into conventional natural mortality. In this paper sources of mortality are investigated and their implications to a yield per recruit analysis explored.

METHODS

A simulation of the life cycle of the Illex from recruitment onto the shelf until spawning is undertaken. Each component of the life cycle and the data base and assumptions used for the simulation are presented in turn.

The basic equation for the simulation is the catch equation with natural mortality having three components:

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dN/dT = -2N,
where Z is the total mortality Z = F + M
and M = MC + MM + MN
MC - cannibalism mortality
MM - migration mortality
MN - natural mortality
and the catch is
C = FN(1-e<sup>-Z</sup>)/Z
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Growth

The von Bertalanffy growth parameters presented in Amaratunga (1980) for the years 1977, 1978 and 1979 are compared to the average bottom temperatures from the spring groundfish cruises. The relationship between <u>Illex</u> growth and temperature has been noted in Koeller (1980) wherein a correlation coefficient of .88 was reported between mean length and mean bottom temperature for the Canadian Research Vessel surveys. Also O'Dor et al. (1980) report an increase of growth rate with temperature for <u>Illex</u> kept in laboratory studies. The July 1978 mean bottom temperature was 5.8. The 1977 and 1979 temperatures were relatively warmer and similar, 6.4 and 6.5 degrees respectively. The mean on these values of parameters and temperatures are pooled for these two years and then compared to the values for 1978 in Table 1.

The differences show similar patterns for both males and females. In the model the temperature is constrained between 5 and 7 degrees and the growth parameters are assumed to act in a linear fashion.

 $P(T) = P(5.8) + \Delta P / \Delta T(5.8)$

Weights at age are calculated from the lengths by means of the relation

 $W = 8.43 \times 10^{-6} L^{3.16}$

These values are the means for males and females for 1978 and 1979. The lengths are calculated for each two week period in the simulation for both males and females, then averaged to give a length at the onset of the period.

Migration

It is assumed that the onset of stage 3 of maturity is coordinated with migration for spawning. Using the same approach as above for growth to relate the onset of stage 3 with temperature did not produce a consistent pattern (see Table 2). The data are for 1978 and 1979 and are from Amaratunga (1980a).

As a first approximation to emigration a sigmoid curve is used which is the integral of a normal distribution with its mean on December 1 and a standard deviation of 1 period. Thus on Dec. 1 the emigration rate is half its maximum value. The maximum is chosen to be an instantaneous rate of .2. This value was taken from the assessment of Hurley and Beck (1979) where they derived a late season rate of .31 but did not include cannialism into their calculations, and from Waldron (1979) who presents C/E for the Scotian Shelf. The late season, from week 42 to week 52 show a Z of .68 per two week period. Migration is treated as a mortality because it removes animals from the population without contributing to the catch. As is seen in Equation 1 it is implicitly assumed that the loss from migration is proportional to the abundance.

Cannibalism

Two approaches are used to estimate the effects of cannibalism. One is based on unpublished report by Caddy (1979) in which the loss due to cannibalism is estimated from the efficiency of food utilization for growth. The second approach is simpler and requires an estimate of the feeding frequency instead of the metabolic efficiency. The data for the rate of cannibalism are from Amaratunga (1980b) and Ennis and Collins (1979). These studies show the percentage of squid in the stomach contents throughout the season. The following two approaches convert the percentage into mortality rates.

In the first approach we assume an efficiency of conver-

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sion of food into somatic growth. This rate is denoted by E. The percentage of squid in the stomach, which varies as the animal grows, is called H. The weight gain of the predator and the average prey weight over one period are ΔW and \overline{W} respectively. The following relationship gives the mortality from cannibalism over a period:

 $M_{C} = LN(K\overline{W}E/K\overline{W}E - \Delta WH)$

See Appendix A for a derivation of this relationship.

The value for the conversion efficiency is set at .25 throughout the simulation (O'Dor et al. 1980). Because the prey squid in the tank studies were less than 25% of the predators weight K is set at 20%. These two values are slightly lower than O'Dor's as food is presumably less abundant in the wild than it was for the tank studies. The final version of the above relationship used in the yield/ recruit is:

MC = ln (.05 \overline{W} /.05 \overline{W} - ΔWH)

The second approach is conceptually and mathematically simpler but it requires a value for the animals' feeding rate. In the absence of other sources of mortality, if 1 unit of animals enter a feeding period and Y of them are alive at the end of the period HY of which were eaten by their cohorts we have:

```
1 = Y + HY
or
Y = 1/1 + H
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As was mentioned above H as a function of size is available in the literature. In a simulated time step (two weeks in this study) there will be on the average a number, say NFP, of feeding periods. Thus the mortality due to cannibalism over one simulated time step is

 $MC = NFP \ell n (1 + H)$

NFP was chosen to have a maximum value of 5 at the first of the season and drop to three by the following January.

The feeding rate is less well known than the efficiency of conversion, and neither is well defined for natural populations. The feeding rate is assumed to drop throughout the season. Based upon the increased incidence of empty stomachs seen later in the season and O'Dor et al. (1980) observation that the growth rate falls relative to the theoretical rate which is a consequence of starvation. The mortalities generated from this approach are generally higher than those from the food conversion approach.

Natural Mortality

The remaining contributing factors to mortality, starvation, disease predation by other species, etc., are pooled into this parameter. The Z values from the C/E data for the last four years do not give any insight into determining its value (see Figure 1). With an assumed life span of the order of one year and following the arguments of Au (1975), Hurley and Beck (1979) and Waldron (1980), this value is chosen to be .06/period and is held constant.

Fishing Mortality

The effort pattern used is an average pattern from the last three years international fleet in SA4 (Amaratunga, 1981). The effort pattern was extended to include June as the data for the last three years has a July 1 starting date. This is combined with the selectivity pattern for a 60 mm mesh reported in Amaratunga et al. (1979). The ogive for this mesh is idealized to have a 50% retention at 122 mm and a 33 mm standard deviation.

Structure of Model

The yield/recruit model is an extension of the method of Thompson and Bell (Ricker, 1975). Because of the relatively high mortalities a million recruits are assumed for the first of April. These recruits are followed for 21 two week periods. The parameters controlling the yield are the temperature, choice of cannibalism model and the intensity and pattern of fishing. As well as the yield an estimation of the escapement is produced to assess the damage to the stock of the various strategies. As there is no known mechanism of recruitment the escapement cannot be used to predict the subsequent year class strength. It is included only as an indication of the impact of fishing effort.

RESULTS

Simulation runs for both approaches to estimating mortality due to cannibalism are shown in Tables 3 and 4. These tables show population size, growth, catch and mortalities as a function of time throughout one season. The catches and yields are totaled in the last row and the average mortalities are also given in the last row. The yields have units of kilograms and the mortalities are per two week period.

Table 5 contains yield per recruit results for three combinations of bottom temperature and method of estimating mortality due to cannibalism effect while the 6.5° "frequency" method has the most. In all cases Y/R increases with earlier period and more intense fishing.

Table 6 is analogous to Table 5 except it shows escapements to a spawning population. This escapement is sum of the animals migrating and those left after the last period of the simulation.

DISCUSSION

This simulation is an attempt to coordinate biological information in order to see its implications to the animal's life cycle. Without a recruitment relationship it is impossible to use the simulation for more than a single season. The most significant effect is the mortality due to cannibalism. The models to estimate the impact of cannibalism contradict one another in terms of the severity of the impact and appear to contradict historical commercial catch and effort data. Except for the early periods which show rapid growth, the frequency of feeding approach shows a much higher mortality than do the estimates from the efficiency of food conversion information. This is evident even late in the year when the frequency of feeding in the model drops to three times per two week period. This is equivalent to eating less often than once every four days. This seems like a long period to fast for an animal as active as the squid. Ennis and Collins (1978) reported that up to 70% of the animals late in the season had empty stomachs. If one accepts 36 hours as the time for complete digestion (Wallace et al. 1981) this implies feeding on the average of every five days. Amaratunga (1980b) presents similar data which show the percentage of recently fed animals falling to 20-30% late in the year. The inference is then that the efficiencies of conversion are too high or that the feeding rate is too high. It would appear that the efficiencies of food conversion into growth measured in the laboratory (O'Dor et al. 1980) are not directly applicable to the wild population. The level of efficiency in the wild would have to be considerably lower than the 25% used. A lower value would reflect greater metabolic requirements for maintenance in the wild.

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The other implications of the modelling of cannibalism are with regard to the total mortality. As seen in Tables 3 and 4 the mortality due to cannibalism dominates (greater than 60%) the total mortality. This dominance increases with increasing bottom temperature. The other sources of non-catch mortality (migration and natural) are poorly known but are presumably of a reasonable magnitude. The sum of these three mortalities exceeds the slopes of the log of the commercial catch per unit effort shown in Figure 1. Either a portion or portions of the model are in error or the stock exploited by the offshore fleet in SA4 cannot be considered as a closed stock which was recruited as a unit. If the recruitment were protracted the catch/effort would remain high compared to the model because of the new recruits. Other possibilities to be explored are the degree of schooling and the fishing practices of the fleet which would keep the catch/effort from falling as' fast as predicted by the model.

It is interesting to note that the cannibalism effects predict a faster rate of decline in abundance during the warmer years and that this prediction is born out in Figure 1 in which 1977 and 1979 are the warmer years.

The yield per recruit results (Table 5) show increasing yield with increasing effort and earlier start of season. Using the simulated growth data for a 6.5 degree year with mortality effects predicted from efficiency of food conversion no F_{max} could be found with F levels up to 10 per period and the historical fishing pattern. $F_{0.1}$ was also unrealistically high at 1.6 per period (these results are not included). This is because the mortality rate is greater than the growth rate throughout the fishing season and thus the sooner harvested the better.

There is approximately a 50 to 170% increase, depending on the scenario used, in the yield per recruit when the fishing commences on week 28 (approximately July 1) as opposed to a week 32 (August 1) starting date. The warmer the weather the more the increase. While the impact of the start of season on the predicted escapement values is less than 30% for all but the highest F-levels tried. These results are expected as the F to Z ratio is small and the Z to growth ratio is large.

It is also predicted that the yield per recruit will be less in warm years than cool years. This does not contradict recent catch statistics, as it must be kept in mind that this is the yield per recruit and that the recruitment is greatly enhanced during the warmer years.

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The model displays cumulated mortalities for a season and the scenarios presented from 5.5 to 12.4. This implies that the recruiments onto the shelf are very large. These mortalities would also have a considerable impact on published virtual population analyses which use lower mortalities.

The management implications of this study from a yield per recruit point of view could be expressed as its best to catch them before they die. Less damage is done per ton caught early in the season. $F_{0.1}$ is at an unrealistically high level. If the non-catch mortalities combined average .33 (6.5 bottom temperature and "efficiency" cannibalism) and one accepts the suggestion of the special STACRES meeting in February, 1978 (ICNAF Summ. Doc. 78/VI/3) the resulting F level is approximately .2/period.

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	1	977-1979	1978	3	ΔP	∆P/∆	T
Females	L_{∞}	294	347		-53	-81.	5
	Т _О	6.8	-2	.5	9.3	14.	3
	K	0.054	C	0.025	0.029	0.	045
Males	L_{∞}	239.9	278	а } — с — с — с — с — с — с — с — с — с —	38.1	-58.	6
	Т _О	9.3		1.1	9.4	14	• 5
	К	0.09	C	.036	0.054	0.	.083
Bottom Tempe	erature	6.45	5	.8	- • •	-	-

Table 1. Growth parameters compared to bottom temperatures.

Table 2. Maturity stage compare to bottom temperature.

		1978	1979	Р
Males	Stage l	156	146	-10
	2	209	188	-21
	3	220	228	8
Females	Stage 1	174	195	21
	2	250	258	8
	3	271	267	-4
Bottom Temp	perature	5.8	6.5	· .

WEEK	N UM B E R S	LENGTH	WE I GH T	CATCH	YIELD	M CANA	M MIGR	N NATL	M FISH	EFFORT
14	1000000	81	9	0	0	0.00	0.00	0.06	0.00	0.00
16	940270	106	21	0	0	0.05	0.00	0.06	0.00	0.00
18	843541	1 27	38	0	0	0.29	0.00	0.06	0.00	0.00
2,0	592981	145	58	0	0	0.38	0.00	0.06	0.00	0.00
22	382279	161	81	0	0	0.40	0.00	0.06	0.00	0.00
24	240240	174	104	0	0	0.40	0.00	0.06	0.00	0.00
26	151438	186	1 27	0	0	0.38	0.00	0.06	0.00	0.00
28	97130	196	150	4179	673	0.36	0.00	0.06	0.05	0.05
30	60483	205	172	4456	812	0.33	0.00	0.06	0.09	0.09
32	37237	212	193	2974	601	0.30	0.00	0.06	0.10	0.10
34	23428	219	212	1492	329	0.28	0.00	0.06	0.08	0.08
36	15497	224	229	933	222	0.25	0.00	0.06	0.07	0.07
38	10585	229	2 46	616	156	0.22	0.00	0.06	0.07	0.07
40	7439	233	260	355	95	0.20	0.00	0.06	0.06	0.06
42	5422	237	273	258	72	0.18	0.00	0.06	0.05	0.06
44	4022	240	285	179	52	0.16	0.03	0.06	0.05	0.05
46	2970	243	296	53	16	0.14	0.10	0.06	0.02	0.02
48	2150	245	305	18	6	0.13	0.17	0.06	0.01	0.01
50	1493	248	314	12	4	0.11	0.19	0.06	0.01	0.01
52	1023	249	322	0	0	0.10	0.20	0.06	0.00	0.00
				$15527^{\rm T}$	3037 ^T	0.23 ^A	0.03 ^A	0.06 ^A	0.03 ^A	

Table 3. Simulation with mortality due to cannibalism estimated from conversion efficiency (bottom temperature 6.5°).

T = total

A = average

VE EK	NUMBERS	LENGTH	WEIGHT	CATCH	YIELD	M CANA	M MIGR	N NATL	M FISH	EFFORT
14	1000000	81	9	0	0	0.00	0.00	0.06	0.00	0.00
16	941317	106	21	0	0	0.02	0.00	0.06	0.00	0.00
18	868543	1 27	38	0	· 0	0.18	0.00	0.06	0.00	0.00
20	683264	145	58	0	0	0.30	0.00	0.06	0.00	0.00
22	474656	161	81	0	0	0.40	. 0.00	0.06	0.00	0.00
24	299408	174	104	0	0	0.47	0.00	0.06	0.00	0.00
26	175363	186	1 27	0	0	0.53	0.00	0.06	0.00	0.00
28	97103	196	150	3795	611	0.57	0.00	0.06	0.05	0.05
30	48872	205	172	3190	581	0.60	0.00	0.06	0.09	0.09
32	22971	212	193	1591	322	0.62	0.00	0.06	0.10	0.10
34	10515	219	212	570	126	0.63	0.00	0.06	0.08	0.08
36	4865	224	2 2 9	2 46	58	0.64	0.00	0.06	0.07	0.07
38	2252	229	246	109	27	0.64	0.00	0.06	0.07	0.07
40	1047	233	260	41	11	0.63	0.00	0.06	0.06	0.06
42	496	237	273	19	5	0.62	0.00	0.06	0.05	0.06
44	236	240	285	9	2	0.61	0.03	0.06	0.05	0.05
46	111	2 4 3	296	2	0	0.59	0.10	0.06	0.02	0.02
48	51	245	305	0	0	0.57	0.17	0.06	0.01	0.01
50	23	248	314	0	0	0.55	0.19	0.06	0.01	0.01
52	10	249	322	0	0	0.53	0.20	0.06	0.00	0.00
			-	9571 ^T	1745^{T}	0.49 ^A	0.03A	0.06 ^A	0.03 ^A	

T = total A = average - 12 -

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	1.1								
Bottom temperature		5 .8°			6.5°		6	•2°	
Cannibalism estimate type	"ef	ficien	су"	"ef	ficien	су"	"frequ	ency"	
Onset (week)	24	28	32	24	28	32	24	28	32
F									
.02 .05 .10 .20 .40	1336 3131 5654 9403 13888	1144 2683 4851 8070 11867	686 1625 2986 5100 7762	867 2037 3695 6205 9344	715 1678 3037 5072 7523	414 980 1798 3064 4652	564 1361 2571 4631 7742	386 928 1745 3114 5107	140 338 640 1157 1933
Table 6	. Esc	apement	per m	illion	recrui	ts.			

Table 5. Yield per recruit analyses (kg/million recruits).

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Bottom temperature		5.8°			6.5°			6.5	0
Cannibalism estimate type	"ef	ficienc	У"	"ef	ficien	су"	"fre	quen	су"
Onset (week)	24	28	32	24	28	32	24	28	32
F									
.02 .05 .10 .20 .40	3920 3188 2258 1134 287	3951 3251 2349 1227 336	4068 3496 2717 1641 600	3051 2475 1747 871 217	3076 2526 1820 945 255	3168 2719 2108 1267 459	49 40 29 15 4	50 41 30 16 4	51 44 34 21 8



Figure 1. Natural log of commercial data, catch is in units of numbers of animals $x = 10^{4}$.



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Figure 1. cont.

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Determination of Mortality Due to Cannibalism Given the Efficiency of Food Utilization

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Consider a unit squid entering a period at weight W_1 . At the end of this period a portion Y of these have survived and have a weight W_2 . During this period the proportion of animals have squid in their stomachs and the efficiency of food conversion to somatic growth is E. Mortality is portioned into two components, M_C for cannibalism and all other sources are combined into M.

1-Y	number lost throug	h all causes		
<u>(1-Y)M_C</u> M+M _C	number cannibalize	đ		
(1-Y) <u>M</u> KW M+M _C	biomass cannibaliz weight of survivor relating the small	ed where \overline{W} is s and K is a factor of the size of the	the mean actor prey.	
(1-Y) M KW M+M _C H	total biomass cons	umed		
$\frac{(1-Y) M EK\overline{W}}{M+M_{C} HY} =$	$\Delta W = W - W$ weight	gain/survivor	Al	
$\frac{(1-Y)}{Y} = \frac{\bigwedge W(M+M)}{MKWE}$	<u>,) H</u>		A2	
$Y = \frac{MK\overline{W}E}{MK\overline{W}E + \Delta WH(1)}$	<u>4</u> +M _C)		A3	
$M_{C} = lnY = ln$	(<u></u>	с)	Α4	

This is a non-linear equation for M_C and requires a numerical solution. This expression can be simplified assuming $M < M_C$ which leads to the following approximation:

 $M_{c} = \ln \left(\frac{K\overline{W}E}{(K\overline{W}E + \Delta WH)} \right)$ The mean weight for the period, W, can be estimated as:

 $\overline{W} = (W_1 + W_2) + 2$

When the following values are used:

K = .2 $W_1 = 50$ $W_2 = 60$ E = .25H = .15M = .06

A4 gives the result $M_c = .38$ and the approximation A5 the result $M_c = .44$.

