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POPULATION ESTIMATES AND YIELD-PER-RECRUIT ANALYSIS FOR THE SPINY LOBSTER, PANULIRUS MARGINATUS, AT NECKER ISLAND

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ABSTRACT

Data from commercial fishermen and research sampling for lobster fishing at Necker Island are examined. The abundance of lobster appears to be very heterogeneous with the greatest abundance in the northwestern part of the Necker bank. Estimates of virgin population size and catchability for this region are 125,000 legal lobsters and 3.94×10^{-5} per trap-night, respectively. The estimated range of sustainable yield from the northwest region based on the minimum legal size of 8.25-cm carapace length and the present population size is 10,000 to 21,000 legal lobsters per year. Yield-per-recruit analysis indicates that substantially greater yields may be possible if the minimum legal size is reduced from 8.25 cm. However, this latter result is based on strong assumptions about recruitment which can only be confirmed by field tests.

Necker Island — sustainable yield
spiny lobsters — yield per recruit

INTRODUCTION

Commercial spiny lobster, *Panulirus marginatus*, fishing began on a regular basis off Necker Island in the Northwestern Hawaiian Islands in November 1976. Seven commercial fishing vessels from Honolulu reported lobster catches during the period from November 1976 through April 1979. Some of these vessels trapped in the area frequently while others trapped only occasionally.

This report analyzes and summarizes commercial and research data for the *P. marginatus* fishery off Necker Island during the period from November 1976 through April 1979. Estimates of virgin population size, catchability, and sustainable yield are obtained and a yield-per-recruit analysis is performed. The commercial data consists of monthly totals of the number of legal lobsters caught and the effort expended (Table 1).

TABLE 1. TOTAL MONTHLY CATCH (IN NUMBERS) AND EFFORT (IN TRAP-NIGHTS) IN THE COMMERCIAL FISHERY FOR LEGAL LOBSTERS AT NECKER ISLAND, OCTOBER 1976-APRIL 1979

Date	Region I		Region II		Total	
	Catch	Effort	Catch	Effort	Catch	Effort
1976						
Oct.	107	73	--	--	107	73
Nov.	616	156	--	--	616	156
Dec.	984	276	--	--	984	276
1977						
Jan.	10,030	1,656	1,599	1,081	11,629	2,737
Feb.	--	--	--	--	--	--
Mar.	--	--	--	--	--	--
Apr.	--	--	--	--	--	--
May	15,588	3,480	67	53	15,655	3,533
June	7,132	1,936	461	122	7,593	2,058
July	9,727	2,447	24	75	9,751	2,522
Aug.	5,404	1,832	678	534	6,082	2,366
Sept.	10,524	2,944	293	120	10,817	3,064
Oct.	2,901	916	58	120	2,959	1,036
Nov.	1,885	600	--	--	1,885	600
Dec.	2,485	824	--	--	2,485	824
1978						
Jan.	1,314	254	203	92	1,517	372
Feb.	978	300	--	--	978	300
Mar.	3,687	1,482	54	60	3,741	1,600
Apr.	3,022	719	398	112	3,420	831
May	3,160	687	--	--	3,160	687[1]
June	2,940	1,260	--	--	3,849	1,724
July	2,167	603	--	--	2,167	603
Aug.	2,014	585	--	--	2,014	585
Sept.	202	246	--	--	202	246
Oct.	1,574	606	1,373	401	2,947	1,007
Nov.	116	56	5,222	2,349	5,338	2,405
Dec.	--	--	7,040	3,139	7,040	3,139
1979						
Mar.	1,563	658	--	--	1,563	658
Apr.	1,925	958	--	--	1,925	958

[1]Two stations with no positions.

A legal lobster is defined as a lobster with a carapace length equal to or exceeding 8.25 cm. These data were collected by National Marine Fisheries Service (NMFS) observers aboard commercial vessels or were reported in catch reports submitted by the vessels' owners. The unit of effort is measured as one baited trap fished on the lobster ground for one night, henceforth referred to as a trap-night. The research data consist of total number and effort, as well as length and sex, for lobsters caught at sampling sites from the RV Townsend Cromwell.

Necker Island is surrounded by a large bank (Figure 1). The commercial catch by position indicates that the fishermen have primarily trapped in the northwest region of this bank, indicated as Region I in Figure 1. There were 90,368 legal lobsters trapped in Region I from January 1977 through April 1979; only 17,740 legal lobsters were trapped on the rest of the bank (Region II) during the same period (Table 2). The catch per unit effort (CPUE) in Region II (Figure 2) shows considerable variation, and some of the more recent values for CPUE approach those for Region I (Figure 3). However, because of the lack of a longer series of catch and effort data for Region II, this report will focus only on Region I. By isolating Region I for study, we are making the assumption that the lobster population in this region is closed. This may not be an unreasonable assumption for adult lobsters because tagging experiments by NMFS indicate minimal migration. However, in the case of larval recruitment this may not be the case and for the long term, the assumption of a closed population in Region I may not be valid.

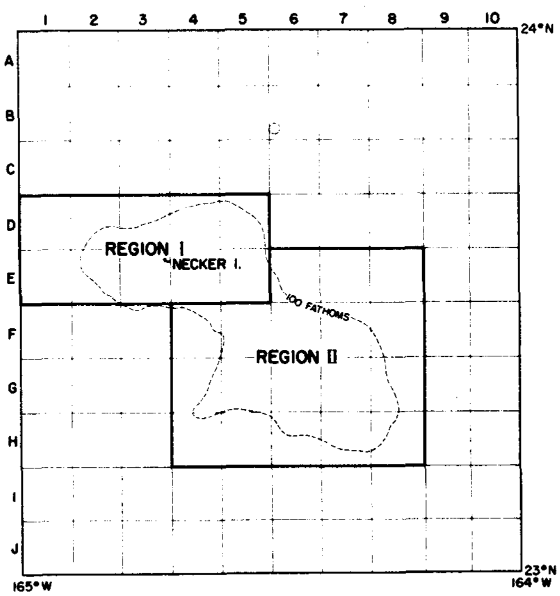

Figure 1. Necker bank

TABLE 2. THE ANNUAL CATCH (IN NUMBERS OF LOBSTERS), EFFORT EXPENDED (IN TRAP-NIGHTS), AND CATCH PER UNIT EFFORT FOR LEGAL LOBSTERS AT NECKER ISLAND BY COMMERCIAL VESSELS FROM JANUARY 1977-APRIL 1979

Year	Catch	Effort	Catch Per Unit Effort
	Region I		
1977	65,676	16,635	3.95
1978	21,201	6,798	3.12
1979 (1/1-4/30)	3,491	1,616	2.16
	Region II		
1977	3,180	2,105	1.51
1978	14,290	6,153	2.32
	Combined (Regions I and II)		
1977	68,856	18,740	3.67
1978	35,491	12,951	2.74

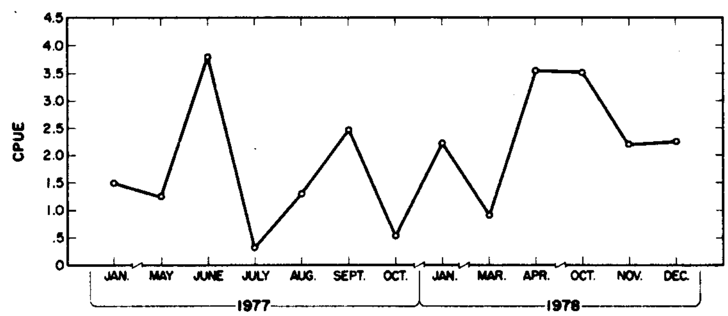

Figure 2. Catch per unit effort (in legal lobsters per trap-night) from Region II at Necker Island

RELATIVE ABUNDANCE

Catch per unit of effort provides a measure of relative abundance. Changes in CPUE over time can result from changes in population structure and size, as well as changes in fishery methods and gear. In the case of the lobster fishery at Necker between November 1976 and April 1979, the changes in fishing methods and gear have been minimal. A graph of CPUE for legal lobsters from Region I on a monthly basis is presented in Figure 3. Considerable month-to-month variation as well as a declining trend is apparent.

One reason for some of the month-to-month variation in CPUE is that the monthly CPUE is computed by pooling the catch and effort for all the

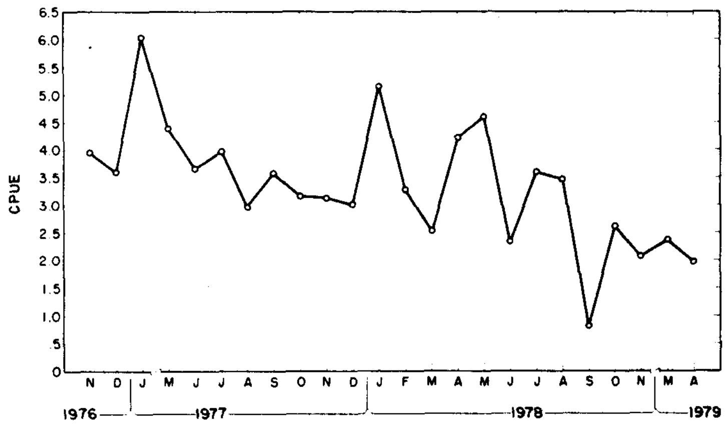

Figure 3. Catch per unit effort (in legal lobsters per trap-night) from Region I at Necker Island

vessels reporting trips to Necker during the month. These vessels are not always the same vessels but a subset of the seven commercial vessels which comprise the fleet.

Catch per unit effort computed on an annual basis has declined each year from 1977 to 1979, although the 1979 figure should be treated with caution because it is based on only an effort of 1,616 trap-nights and may change when more 1979 data are available (Table 2).

A regression of CPUE against month, weighted by effort, indicates that at the 5% level the decreasing trend in CPUE for 1977 is significant while the trend in 1978 is not. The CPUE for January 1977 and January 1978 represents a sharp increase from the preceding and following months indicating a possible seasonal trend which should be examined as more data become available.

The percentage of legal lobsters in the total lobster catch provides an index of the proportion of legal lobsters in the population to the total lobster population. A decrease in this index could mean that the number of legal lobsters in the population has been reduced and/or the number of sublegal lobsters in the population has increased due to increased reproduction, survival, or immigration. We found that the percentage of legal lobsters in the catch for the RV Townsend Cromwell decreased from 54.2% in November 1976 to 23% in May 1979 (Table 3).

POPULATION ESTIMATES

The primary approach we selected to estimate population size was a method proposed by Allen (1966) (see Appendix 1). Basically, this method consists of a least squares procedure which estimates population size and catchability by minimizing the sum of squares between the actual catch and the predicted catch based on effort.

TABLE 3. THE AMOUNT OF EFFORT EXPENDED (IN TRAP-NIGHTS) AND PERCENTAGE OF LEGAL LOBSTERS CAUGHT AT NECKER ISLAND BY THE RV *TOWNSEND CROMWELL*

Date	Effort (Trap-Night)	% Legals in Catch
	Region I	
Oct.-Nov. 1976	145	54.2
May 1977	32	40.0
Oct. 1977	116	42.0
Mar. 1978	57	35.0
Oct.-Nov. 1978	104	37.1
May 1979	48	22.8
	Region II	
Sept.-Oct. 1977	234	62.6
Mar. 1978	61	81.0
Oct. 1978	52	67.0

We used the monthly commercial catch and effort data from November 1976 through April 1979 to estimate population size and catchability. Allen's model assumes natural mortality and recruitment operate in the population. In its most general form, this model assumes that the rate of natural mortality is constant while recruitment may vary over time. This most general form requires that the use supplies estimates of the natural mortality rate and the recruitment rates. We do not have any size and age data which might allow us to estimate these parameters and consequently, we used a simplified version of Allen's model. We assumed that the ratio of the rate of natural mortality to the recruitment rate ($e^{-M}/1-W_i$) in Appendix 1 is constant. Given effort, we then estimated this constant as the value which gave the best fit of predicted catch to actual catch. We feel the assumption that the ratio (rate of natural mortality to recruitment rate into the fishery) is constant may not be unreasonable for the 2-year period of our study. If it takes 6 or more years for a lobster to grow from larval stage to legal size, and if the majority of the mortality occurs during the early years of life, then even an intense reduction of the population of legal lobsters in 1977 will not have a major effect on the ratio of natural mortality rate to recruitment rate until 6 years later.

The plots of actual monthly catch and predicted monthly catch estimated by Allen's method are presented in Figure 4. The fit of the model to the data is good. Based on this method, we estimate that there were 132,406 legal lobsters in Region I at the beginning of November 1976. This number declined to 68,571 legal lobsters by April 1979. A plot of the monthly estimated population size is given in Figure 5. As could be expected from the catch and CPUE data, the population size of legal lobsters dropped severely during 1977 and decreased very slowly during 1978.

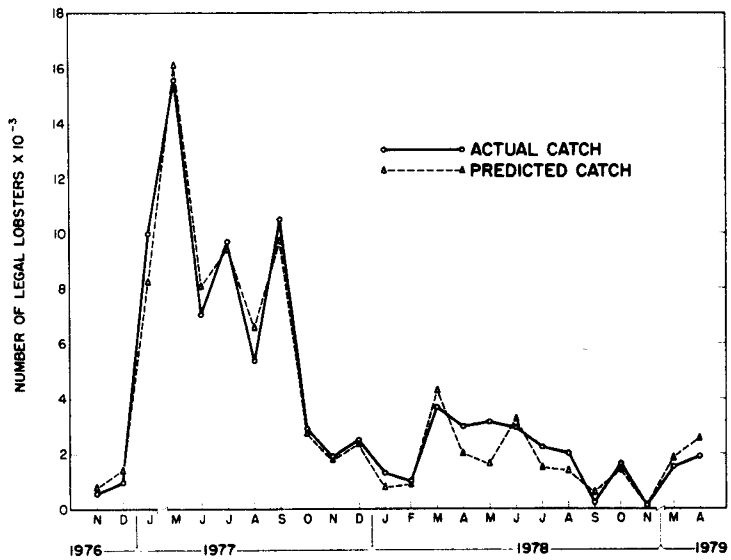

Figure 4. Catch predicted from Allen's model versus actual catch of legal lobsters from Region I at Necker Island

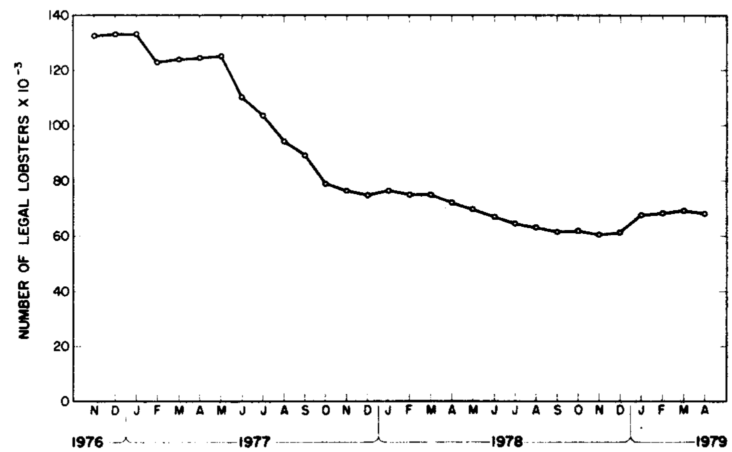

Figure 5. Estimated population size of legal lobsters from Allen's model for Region I at Necker Island

As an independent check on the results obtained by Allen's method, we used Leslie's method of population estimation. This method is used to estimate population size and catchability in situations where there has been intensive fishing of a closed population over a short period of time. Since this method applies to fishing over a short period of time, we assume that natural mortality and recruitment are negligible.

We noticed from Table 1 that trapping was very intense from May through August 1977. We used these data to estimate the population size of legal lobsters at the beginning of May 1977 and the catchability by Leslie's method. The estimated population size and catchability obtained from Leslie's method is in agreement with the estimates obtained by Allen's method (Table 4).

TABLE 4. A COMPARISON OF THE ESTIMATES FROM THE LESLIE AND ALLEN METHODS

	Leslie	Allen
N_{May}	127,000	125,000
q	3.58×10^{-5}	3.94×10^{-5}

N_{May} is an estimate of the number of legal lobsters in Region I beginning May 1977; q is the catchability coefficient.

Lobster yield-per-recruit analysis

We can explore the relationship between size at entry into the fishery (minimum carapace size) and yield with the Beverton-Holt equilibrium yield equation. We will assume that over the range of minimum legal sizes of interest, the number of recruits to a given size is constant, that the lobster growth can be approximated by a von Bertalanffy equation, and that the lobster weight can be expressed as: weight = a $(\text{length})^b$. We then write the yield per recruit into the fishery Y/R as:

$$\frac{Y}{R} = \left(\frac{F}{K}\right)\left(W_\infty\right)\left(e^{Zt_m}\right)\left[B\left(X,\ b,\ \frac{Z}{K}\right)\right]$$

where F is the fishing mortality, K is the growth coefficient for the von Bertalanffy curve, W_∞ is the asymptotic lobster weight, $Z = F + M$, M is the natural mortality, $t_m = t_{min} - t_o$, where t_{min} is the minimum age of entry into the fishery and t_o is the age of zero length in the von Bertalanffy curve, and B(X, b, Z/K) is the incomplete beta function evaluated at $X = e^{-Kt_m}$, and b is the allometric coefficient.

We will evaluate Y/R at several levels of fishing effort and several minimum carapace lengths. We selected fishing effort (f) at the following levels (trap-nights): 2,500, 5,000, 7,500, 10,000, 12,500, and 15,000. Based on these values of f we can estimate F as F = qf where $q = 4 \times 10^{-5}$ from Allen's method. We selected the following values for the minimum legal carapace length: 6.75, 7.25, 7.75, and 8.25 cm. The value of t_m corresponding to these lengths can be estimated from the von Bertalanffy curve. We determined W_∞ to be 3,580 g and the coefficient b in the weight-length relationship as b = 2.6 from data in McGinnis (1972). There is not any one data set for lobster growth which appears sufficiently reliable. Results from tagging and modal analysis by NMFS gives the estimates: K = 0.26/yr and L_∞ = 12.5 cm. Observations by McDonald of an 18-cm carapace curve suggests L_∞ could be as high as 18 cm. We, thus, performed the yield-per-recruit analysis for the following sets of K and L_∞ values: (K = 0.05, L_∞ = 18 cm), (K = 0.1, L_∞ = 15 cm), (K = 0.2, L_∞ = 12 cm). We used the relationship:

$$\frac{F + M}{K} = \frac{(L_\infty - \bar{l})}{\bar{l} - l_{min}}$$

where l_{min} is the minimum carapace length, $\bar{l}$ is the mean carapace length of the population above l_{min}, and F and M are the fishing and natural mortality, respectively (Beverton and Holt, 1956).

We are able to estimate the ratio M/K by taking a length-frequency distribution from a sample of the population taken from Necker Island in November 1976--before any substantial fishing effort was applied to the region. This sample, consisting of 744 lobsters, estimated M/K at approximately 3.5 for L_∞ = 12 cm. For the yield-per-recruit analysis, we used values for M/K as 2, 3, and 4.

From the results of the yield-per-recruit analysis, we determined the carapace length from among the set 6.75, 7.25, 7.75, and 8.25 cm, which gave the greatest yield (Table 5). In most situations, a minimum carapace length of 6.75 cm achieved the maximum yield per recruit. Only when M and M/K are low and L_∞ is large is the yield per recruit achieved with a minimum carapace length greater than 6.75 cm.

TABLE 5. CARAPACE LENGTH (IN CENTIMETERS) AT WHICH THE MAXIMUM YIELD PER RECRUIT (IN GRAMS) IS OBTAINED

		Fishing Effort					
		2,500	5,000	7,500	10,000	12,500	15,000
$\frac{M}{K} = 2$	K = 0.05, L_∞ = 18	7.75	8.25	8.25	8.25	8.25	8.25
	K = 0.1, L_∞ = 15	6.75	6.75	6.75	7.25	7.25	7.75
	K = 0.2, L_∞ = 12	6.75	6.75	6.75	6.75	6.75	6.75
$\frac{M}{K} = 3$	K = 0.05, L_∞ = 18	6.75	6.75	7.25	7.25	7.75	7.75
	K = 0.1, L_∞ = 15	6.75	6.75	6.75	6.75	6.75	6.75
	K = 0.2, L_∞ = 12	6.75	6.75	6.75	6.75	6.75	6.75
$\frac{M}{K} = 4$	K = 0.05, L_∞ = 18	6.75	6.75	6.75	6.75	6.75	6.75
	K = 0.1, L_∞ = 15	6.75	6.75	6.75	6.75	6.75	6.75
	K = 0.2, L_∞ = 12	6.75	6.75	6.75	6.75	6.75	6.75

An examination of the yield-per-recruit results suggest that an adoption of a 6.75-cm minimum carapace length could, in the worst case ($K = 0.05$, $L_\infty = 18$, $M = 0.1$, and $F = 15{,}000$), result in a 15% decrease in yield per recruit from the minimum carapace length of 8.25 cm, and at best ($K = 0.2$, $L_\infty = 12$, $M = 0.8$, $F = 1{,}500$), achieve a 167% increase in yield-per-recruit over an 8.25-cm minimum carapace length (Table 6). Clearly, these results should be interpreted cautiously because we have no evidence to suggest that the level of recruitment will remain unchanged when the minimum carapace length is lowered to 6.75 cm. However, the magnitude of the possible increase in yield which may be achieved with a reduction from the existing minimum carapace length should serve as impetus for further study and testing.

TABLE 6. YIELD-PER-RECRUIT (IN GRAMS) AS A FUNCTION OF FISHING EFFORT (IN TRAP-NIGHTS) AND MINIMUM LEGAL CARAPACE LENGTH (IN CENTIMETERS) FOR SELECTED GROWTH AND MORTALITY PARAMETERS

	Fishing Effort					
l_{min}	2,500	5,000	7,500	10,000	12,500	15,000
			$\frac{M}{K} = 4$, $K = 0.2$, $L_\infty = 12$			
6.75	124	216	287	343	388	425
7.25	90	157	210	252	286	314
7.75	64	112	150	180	205	226
8.25	44	78	105	126	144	159
			$\frac{M}{K} = 3$, $K = 0.1$, $L_\infty = 15$			
6.75	210	305	355	384	402	415
7.25	194	285	334	364	383	397
7.75	177	262	310	340	360	373
8.25	160	239	284	313	332	346
			$\frac{M}{K} = 2$, $K = 0.05$, $L_\infty = 18$			
6.75	318	339	335	327	321	315
7.25	321	351	351	347	342	338
7.75	321	358	363	361	349	356
8.25	319	362	371	372	371	370

CONCLUSIONS

The analysis of commercial catch and effort data indicating the decline in CPUE from 3.95 in 1977 to 3.12 in 1978 strongly suggests that a population size of 65,676 legal lobsters is not sustainable with a CPUE of 3.90. This is further supported by the decline in the percentage of legal lobsters per trap from the Cromwell sampling data. The fact that we do not reject the hypothesis that CPUE did not decline during 1978, based on the test of the slope of the regression line, suggests that a yield of 21,201 legal lobsters per year may be sustainable with a CPUE of about 3.00. We can use the result of Allen's model to compute the surplus production which can be harvested without reducing the population size. This value is obtained by multiplying the population size of legal lobsters by the ratio of the natural mortality rate to the recruitment rate for legal lobsters and subtracting the initial population size. We estimated the population size at the beginning of 1979 to be 67,766 legal lobsters and the ratio of the monthly rate of natural mortality to recruitment to be 1.0116. Consequently, for 1979, we estimate that slightly over 10,000 legal lobsters can be harvested for the year without reducing the population size of legals. Thus, based on the data presented here, the annual surplus production of legal lobsters in 1979 is estimated to be between 10,000 and 21,000.

Finally, due to the results of our theoretical yield-per-recruit analysis, it is suggested that future research undertake field trials to ascertain the impact of a lower legal size on yield per recruit.

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APPENDIX 1

Allen's population estimation procedure

A method developed by Allen (1966) was used to estimate population size at time t (N_t), catchability (q) given effort at time t (X_t), and catch (C_t). M is the natural mortality, W_i is the proportion of the new recruits in the exploited stock for the ith season, and A is the ratio of the number of animals that die per month to the number of animals that are recruited per month. The essential relationships of this model are given below:

Year 1 Initial population $= N_1$

Survival to beginning of next season $= (N_1 - C_1)e^{-M}$

Expected catch $= \left(N_1 - \frac{C_1}{2}\right)qX_1$

Year 2 Initial population $= N_2 = \frac{(N_1 - C_1)e^{-M}}{1 - W_2}$

Survival to beginning of next season $= \left[\frac{(N_1 - C_1)e^{-M}}{1 - W_2} - C_2\right]e^{-M}$

Expected catch $= \left[\frac{(N_1 - C_1)e^{-M}}{1 - W_2} - \frac{C_2}{2}\right]qX_2$

Continuing in this way we can show that at the beginning of year t the population equals

$$N_t = \frac{e^{-(t-1)M}}{\prod_{i=2}^{t}(1-W_i)}\left[N_1 - C_1 - \frac{C_2(1-W_2)}{e^{-M}} \cdots \frac{C_i \prod_{j=2}^{i}(1-W_j)}{e^{-(i-1)M}} \cdots \frac{C_{t-1}\prod_{j=2}^{t-1}(1-W_j)}{e^{-(t-2)M}}\right]$$

$$= A_t\left[N_t - f(C)_{t-1}\right],$$

where

$$A = \frac{e^{-(t-1)M}}{\prod_{i=2}^{t}(1-W_i)}$$

and

$$f(C)_{t-1} = C_1 + \sum_{i=2}^{t-1}\frac{C_i}{A_i}.$$