Time Recovery for Exploited Fish Populations Based on Surplus Yield Models

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Abstract

A new method to estimate the time recovery of exploited populations based on M.B. Schaefer's theory is proposed. The parameters used are as follows: current population size (αP_∞), target population level (βP_∞), and an estimate of population growth rate. The exploitation and survival rates are described and used to obtain a time-recovery isopleth diagram for a range of population size and exploitation rates. This method is applied to the octopus (*Octopus maya*) and the red grouper (*Epinephelus morio*) fisheries on Campeche Bank and to the yellow abalone (*Haliotis corrugata*) fishery on the central coast of Baja California, in Mexico.

The Model

The Schaefer model (1954, 1957) is described by the equation

$$(1/P)(dP/dt) = r\{1 - (P/P_\infty)\} - qf \qquad ...1)$$

Under equilibrium ($dP/dt = 0$), yield (Y_E) can be expressed as a function of fishing effort

$$Y_E = qfP_\infty\{1 - (qf/r)\}$$

where population biomass declines due to fishing intensity following the linear function

$$P_E = (P_\infty/r)(r-qf)$$

Equation (1), without fishing, can be solved for population size P_t, as:

$$P_t = P_\infty/(1 + (P_\infty/P_0 - 1)e^{-rt}) \qquad ...2)$$

This equation represents a function increasing monotonically from P_0 to P_∞. Taking $P_0 = \alpha P_\infty$ as the current population size and $P_t = \beta P_\infty$ as a *target* population size, then

$$\beta P_\infty = P_\infty/(1 + (P_\infty/\alpha P_\infty - 1)e^{-rt})$$

and solving for t the equation gives an estimate of the time of recovery for the unexploited population from αP_∞ to βP_∞, i.e.,

$$t = (1/r)\log_e((1-\alpha)\beta)/(1-\beta)\alpha) \qquad ...3)$$

Under equlibrium, and assuming qf to be constant, the exploited population increases toward P'_∞, which ultimately depends on fishing effort. In the sabsence of fishing $P'_\infty = P_\infty$. Thus, the population biomass decrement can be expressed as a function of fishing effort, as follows:

$$P'_\infty = (P_\infty/r)(r-qf)$$

and $P'_\infty = P_\infty(S)$

where $S = (r-qf)/r = P'_\infty/P_\infty$

which is a function expressing the population remaining after fishing; this has the properties:

1) when $f = 0$ then $S = 1$, i.e., in the absence of fishing, $P'_\infty = P_\infty$;
2) If $f>0$ then S decreases. When $S = 0$, we have $r = qf$ (i.e., a surplus biomass does not exist);
3) $qf>r$ describes overfishing, with negative values for S (which implies an extinction of the stock).

The exploitation ratio (E') represents the population biomass caught as a fraction of the current population, αP_∞:

$$E' = 1 - (P'_\infty/P_\infty)$$

$$E' = 1 - (r - qf)/r$$

and $E' = (qf/r) = (1 - S)$

The exploitation ratio, applied to the current population, can be included in equation (2), where $\alpha(1\text{-}E)P'_\infty$ is the population size after fishing; from this level, the population increases toward P'_∞.

Because $S = (1\text{-}E')$

and $P'_\infty = SP_\infty$, then $\alpha(1\text{-}E')P'_\infty = \alpha S^2 P_\infty$;

and $$\beta' SP_\infty = SP_\infty/(1+((SP_\infty/\alpha S^2P_\infty)-1)e^{-rSt}) \qquad ...4)$$

where βSP_∞ is the target population size under exploitation solving for t gives:

$$t = (1/rS)\log_e((1-\alpha S)\beta'/(1-\beta')\alpha S) \quad \text{...5)}$$

If $\beta' = 0.5$, the equation (5) gives an estimation of the time to recover from the current (exploited) population, αSP_∞, until the population level corresponding $0.5P'_\infty$, which depends on the population size P'_∞ and the amount of fishing applied.

On the other hand, MSY can be represented for the population level $0.5P_\infty$, where P_∞ is the maximum population size as determined by the environmental carrying capacity. This may be set equal to the average unexploited population size. If the goal of management is MSY, equation (4) changes as follows:

$$\beta P_\infty = P_\infty/(1+((P_\infty/\alpha S^2 P_\infty)-1)e^{-rSt}) \quad \text{...6)}$$

and for t:

$$t = (1/rS)\log_e(((1-\alpha S)\beta)/((1-\beta)\alpha S)) \quad \text{...7)}$$

which is similar to equation (5), except that β and β' are not necessarily equal, as they refer to P_∞ and P'_∞, respectively.

Table 1. Time of recovery (years) for some demersal stocks, from a population level of $\alpha P'_\infty$ until $0.5P'_\infty$.

Population	αP_∞ (yr)	r	t(E'±0)	t(E'=0)
Octopus maya[a] (octopus)	$0.296P_\infty$ (1984)	0.57[d]	5	0.6
Epinephelus morio[a] (red grouper)	$0.28P_\infty$ (1985)	0.21[d]	12	7
Haliotis corrugata[b] (yellow abalone)		0.11[b]		
I	$0.228P_\infty$ (1981)		34	17
IIa	$0.255P_\infty$ (1981)		25	14
IIb	$0.185P_\infty$ (1981)		30	14
III	$0.115P_\infty$ (1981)		45	20

yr = current year (last year analyzed).
αP_∞ = current population level.
r = population growth rate (year^{-1}).
t(E'±0) = time of recovery under the current exploitation rate.
t(E'=0) = time of recovery without exploitation.

[a]Campeche Bank, Gulf of Mexico.
[b]West Central Coast of Baja California, Mexico (Arreguín-Sánchez 1987a).
[c]Estimated from Solis and Arreguín-Sánchez (1984).
[d]From Arreguín-Sanchez (1987b, 1989).
I, IIa,b and III: indices of fishing grounds.

Application Examples

Equation (4) was applied to three fishing resources:

a) the artisanal octopus (*Octopus maya*) fishery on Campeche Bank;

b) the red grouper (*Epinephelus morio*) fishery on Campeche Bank;

c) the yellow abalone (*Haliotis corrugata*) fishery along the central Pacific coast of the Peninsula of Baja California.

Table 1 gives the basic parameters of the yield curve and population statistics for these three fisheries. Fig. 1 shows the corresponding time isopleth diagrams, taking the *target population level* as $0.5P'_\infty$. Fig. 1A shows that in absence of fishing the octopus population requires two years to reach $0.5P'_\infty$. Under a continuation of the current exploitation rate, the time recovery to that level is nearly five years. For the red grouper fishery (Fig. 1B), and in the absence of fishing, the time of recovery is nearly five years. Under the current exploitation level, the time of recovery was around ten years.

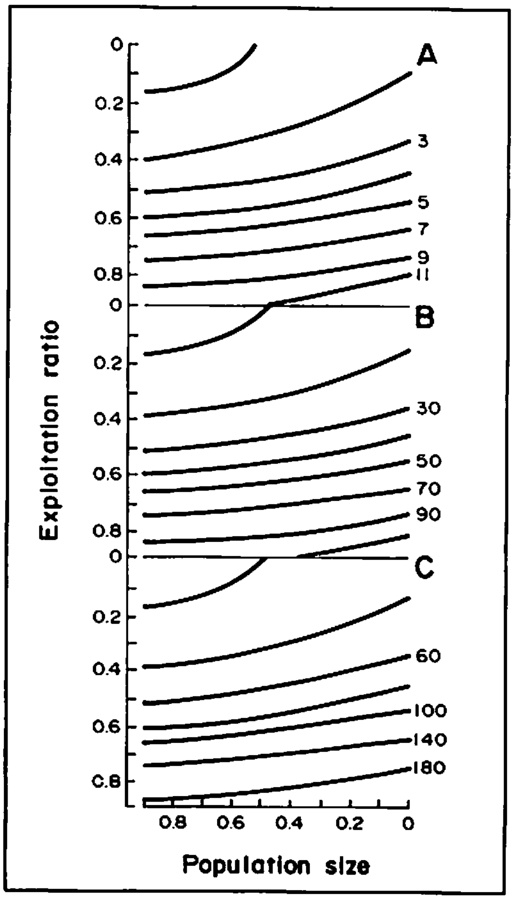

Fig. 1. Time of recovery for ((A) the octopus (*Octopus maya*) and (B) the red grouper (*Epinephelus morio*) fisheries from the Campeche Bank; and (C) the yellow abalone (*Haliotis corrugata*) fishery from the central Pacific coast of Baja California, under different combinations of population size (αP_∞) and exploitation rate (E').

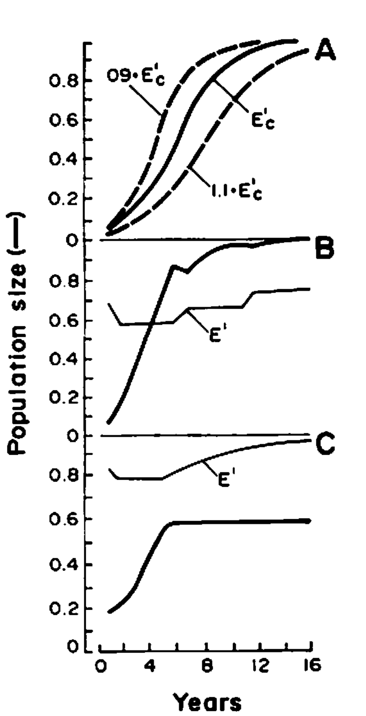

Fig. 2. Estimated trends for the octopus population (A) under three different levels of exploitation rate; (B) simulation based on a time-variable exploitation rate; and (C) experimental management strategy whose objective is to maintain a constant population level based on the regulation of the fishing effort.

The yellow abalone fishery is a case which was previously studied by Arreguín-Sánchez (1987a). For all the fishing grounds the current population level ($\alpha P'_\infty$) is very small as a consequence of an intensive overexploitation (Doi et al. 1976; Mimbela 1984; Walter 1986; Rocha and Arreguín-Sánchez 1987). Time of recovery in absence of fishing is extremely high, over 40 years under the current exploitation rate (Fig. 1C). Obviously, equation (4) assumes that the remaining population, after fishing, has the possibility for recovery of the losses after a unit of time (one year). For the abalone, reproductive biology and its associated behavior are important features to be considered. Abalone are species with external fecundation, and for the reproductive success a certain level of population density is required to guarantee the fecundation. Although there are few studies on these aspects for the regional abalone grounds, it is possible (according to Table 1) that some population densities are lower than those required for fecundation (Rocha and Arreguín-Sánchez 1987).

Conclusion

Despite equilibrium assumptions, for some practical uses, the knowledge of the current status of populations and the time required for their recovery until a certain population level could be useful in fisheries management.

Obviously, because the proposed equations for time of recovery estimations are based on Schaefer's theory, they are subjected to the same original assumptions; however, an additional constraint about $r \geq qf$ is imposed for their application, because under this condition, the population will never increase, but its tendency will be to extinction.

An additional consideration could be made about the time of recovery. Equations (4) to (7) could be used in a fishery simulation experiment in order to assess the population tendencies and the impact of the alternative management options, changing, or not, the exploitation rate on time according to the population changes observed and the objectives to be reached. As an example, Figs. 2A and 2B show the population trends under different levels of exploitation rates for the octopus fishery; and Fig. 2C, a strategy whose objective is to maintain a constant population level through regulation of the exploitation rate.

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References

Arreguín-Sánchez, F. 1987a. Tiempo de recuperación de los bancos de abulón amarillo de la costa centro-occidental de la Península de Baja California, México. julio 1987 CINVESTAV-IPN, Unidad Mérida, México.

Arreguín-Sánchez, F. 1987b. Estado actual de la explotación del mero (*Epinephelus morio*) del Banco de Campeche. 25 Aniversario del Instituto Nacional de Pesca, CRIP-Yucalpetén, SEPESCA. CINVESTAV-IPN, Unidad Mérida, México.

Arreguín-Sánchez, F. 1989. Present status of the red grouper fishery from the Campeche Bank. Proc. 38th Annual Session of the Gulf and Caribbean Fisheries Institute. Martinique, 11-15 November 1985.

Doi, T., D. Mendizabal and M. Contreras. 1976. Análisis preliminar de la población de mero, *Epinephelus morio* (Valenciennes) en el Banco de Campeche. Ciencia Pesquera. Inst. Nac. Pesca. DEPESCA. México 1(1): 1-16.

Mimbela, R. 1984. Situación actual de la pesquería del abulón y alternativas para su regulación. Dir. Gral. Admon. Pesq. SEPESCA. México.

Rocha, E. and F. Arreguín-Sánchez. 1987. Diagnóstico de la pesquería del abulón (*Haliotis* spp.) de la Península de Baja California, México. Investigaciones Marinas CICIMAR. México 3(2): 65-77.

Schaefer, M.B. 1954. Fisheries dynamics and the concept of maximum equilibrium catch, p. 53-63. *In* Proc. 6th Annual Session Gulf and Caribbean Fisheries Institute.

Schaefer, M.B. 1957. A study of the dynamic of the fishery for yellowfin tuna in the Eastern Tropical Pacific Ocean. Inter-Am. Trop. Tuna Comm. 2(6): 247-285.

Solís, M.J. and F. Arreguín-Sánchez. 1984. Anàlisis bioeconómico de la pesquería de pulpo del Banco de Campeche. Mem. 9a. Conferencia MEXUS-Gofo. Cancún Q. Roo. México, 11 al 16 de noviembre de 1984.

Walter, G.G. 1986. A robust approach to equilibrium yield curve. Can. J. Fish. Aquat. Sci. 43(7): 1332-1339.