VIRTUAL POPULATION ANALYSIS

Vivekanand Bharti

Fishery Resources Assessment Division

ICAR-Central Marine Fisheries Research Institute

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Introduction

Virtual population analysis (VPA) is a modeling technique commonly used in fisheries science for reconstructing the historical population structure of a fish stock using information on the deaths of individuals in each time step. The time steps are typically annual (though not necessarily) and the deaths are usually partitioned into mortality due to fishing and natural mortality. VPA therefore looks at a population in an historic perspective. The advantage of doing a VPA is that once the history is known it becomes easier to predict the future catches, which is usually one of the most important tasks of fishery scientists. Virtual population analysis calculates the number of fish alive in each cohort for each past year. It is also called cohort analysis because each cohort is analysed separately. VPA relies on a very simple relationship for each cohort. VPA or Cohort analysis was first developed as age-based methods in temperate regions further developed as length-based methods for tropical regions.

Virtual Population Analysis

Virtual population analysis is basically an analysis of the catches of commercial fisheries, obtained through fishery statistics, combined with detailed information on the contribution of each cohort to the catch, which is usually obtained through sampling programmes and age readings. The word "virtual", introduced by Fry is based on the analogy with the "virtual image", known from physics. A "virtual population" is not the real population, but it is the only one that is seen. It is virtual in the sense that the population size is not observed or measured directly but is inferred or back calculated to have been a certain size in the past. The idea behind the method is to analyse that what can be seen, the catch, in order to calculate the population that must have been in the water to produce this catch. The total landings from a cohort in its lifetime is the first estimate of the numbers of recruits from that cohort. The basic equation for VPA is

Number alive at beginning of this year	=	Number alive at beginning of next year	+	Catch of this year	+	Natural mortality of this year

VPA is based on three equations;

1.1. $C(y,t,t+1) = N(y,t) * \left[\frac{F(y,t,t+1)}{M+F(y,t,t+1)} * \{1 - \exp(-z)\}\right]$

1.2. $C(y,t,t+1) = N(y,t) * \frac{F(y,t,t+1)}{M+F(y,t,t+1)} [\exp\{F(y,t,t+1) + M\} - 1]$

1.3. $N(y,t) = N(y+1,t+1) * \exp\,[F(y,t,t+1) + M]$

Where,

C (y, t, t+1) = number caught between age 't' and age 't+1' in 'y' year

N (y, t) = No. of survivors in the sea with 't' age in starting of 'y' year

N (y+1, t+1) = No. of survivors in the sea with 't+1' age in starting of 'y+1' year

F = Fishing mortality coefficient

M = Natural mortality coefficient

Calculation procedure

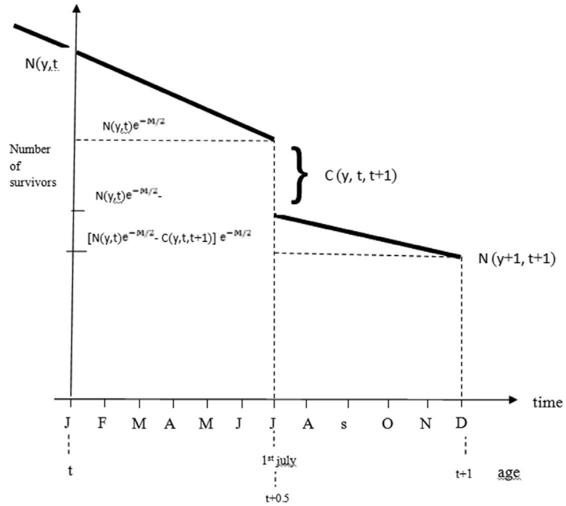
The calculation can be started from the bottom i. e. year of oldest age group for VPA analysis (for example, if VPA analysis is carried out for the time period from 1978 to 1980, the starting of VPA analysis can be begun from the year 1980) using equation-1.1. At first step, the fishing mortality can be chosen on the basis of guess. Second step onward, fishing mortality cannot be taken simply on the basis of guess, but it can be calculated with help of equation-1.2 by some trial and error method. Once, fishing mortality has been estimated, the number of fish in the sea for preceding year can be calculated by using equation-1.3.

Computer Programs

Mensil (1988) presents a package of microcomputer programs, 'ANACO' (ANAlysis of COhort) which can perform the VPA calculations. 'COMPLEAT ELEFAN' package (Gayanilo, Soriano and Pauly, 1988) and FiSAT contain also routines for VPA analysis.

Age-based Cohort Analysis (Pope's Cohort Analysis)

As derived from the catch equation, the VPA implied the solution by some numerical techniques (some trial and error method). This is a minor technical problem when one has access to a computer. However, the problem can be circumvented in an easy way, so that VPA can also be carried out on a pocket calculator. The version of VPA suitable for pocket calculators is the "cohort analysis" developed by Pope (1972). Cohort analysis is conceptually identical to VPA, but the calculation technique is simpler. It is based on an approximation, illustrated which shows the number of survivors of a cohort during one year. The catch is taken continuously during the year, but in cohort analysis the assumption is made that all fish are caught on one single day. Consequently in the first half year the fish suffer only natural mortality so the number of survivors on 1 July becomes:



Diagrammatic representation of age-based cohort analysis

2.1. $N(y, t + 0.5) = N(y, t) * \exp\left(-\frac{M}{2}\right)$

Then, instantaneously, the catch is taken and the number of survivors becomes:

2.2. $N(y, t) * \exp\left(-\frac{M}{2}\right) - C(y, t, t + 1)$

This number of survivors then suffers further only natural mortality in the second half year and finally the number of survivors at the end of the year is:

2.3. $N(y + 1, t + 1) = \left(N(y, t) * \exp\left(-\frac{M}{2}\right) - C(y, t, t + 1)\right) * \exp\left(-\frac{M}{2}\right)$

For convenience of calculation this equation is rearranged as:

2.4. $N(y, t) = \left(N(y + 1, t + 1) * \exp\left(\frac{M}{2}\right) + C(y, t, t + 1)\right) * \exp\left(\frac{M}{2}\right)$

Now from the N's, fishing mortality can be obtained with the help of equation:

2.5. $F(y, t, t + 1) = \ln\left[\frac{N(y,t)}{N(y+1,t+1)}\right] - M$

Note that the F that caused computational problems in the VPA equation does not occur here.

Since catch may be considered for any time period i. e. t to t+Δt. Therefore, the general equation for age-based cohort analysis can be express as:

2.6. $N(t) = \left[N(t + \Delta t) * \exp\left(M * \frac{\Delta t}{2}\right) + C(t, t + \Delta t)\right] * \exp\left(M * \frac{\Delta t}{2}\right)$

Similarly, the general equation to obtain fishing mortality can be express as:

2.7. $$F(t, t+\Delta t) = \frac{1}{\Delta t} * \ln\left[\frac{N(t)}{N(t, t+\Delta t)}\right] - M$$

Calculation procedure

The calculation of cohort analysis can be started similar to VPA analysis by assuming the fishing mortality for the oldest age group. After first step, the number of survivors in the sea in preceding year can be calculated for any time period by using the general equation for age-based cohort analysis given above (equation-2.6). The fishing mortality during the year can also be calculated by using above general equation of fishing mortality (equation-2.7).

Jones' Length-Based Cohort Analysis

Keeping in view the difficulty in determination of ages for certain resources and also the fact that it is rather difficult to obtain age-frequency data for most of the tropical fish, cohort analysis described above is modified to make use of the length frequency data (length composition data for the total fishery are available for one year or the average length composition for a sequence of years). The name "length based cohort analysis" is somewhat misleading, as we are not dealing with real cohorts in the present analysis. The real cohort is replaced by a "pseudo-cohort" which is based on the assumption of a constant parameter system. Thus, it is assumed that the picture presented by all length (or age) classes caught during one year reflects that of a single cohort during its entire life span. Example for length-based cohort analysis is length composition of total catch of hake (*Merluccius merluccius*):

Length group (cm) (L1-L2)	Number caught ('000) C (L1, L2)	Length group (cm) (L1-L2)	Number caught ('000) C (L1, L2)
6-12	1823	48-54	653
12-18	14463	54-60	322
18-24	25227	60-66	228
24-30	8134	60-72	181
30-36	3889	72-78	96
36-42	2959	78-84	16
42-48	1871	84-∞	46

Here length group is converted into age intervals by the inverse Von Bertalanffy equation:

3.1. $$t(L1) = t_0 - \frac{1}{K} * \ln\left[1 - \frac{L1}{L\infty}\right]$$

3.2. $$\Delta t = t(L2) - t(L1) = \frac{1}{K} * \ln\left[\frac{L\infty - L1}{L\infty - L2}\right]$$

To convert the cohort analysis equation into a length-based version, only the term exp [(M* Δt)/2] has to be changed. This is done by substituting Δ t with following equation:

3.3. $$\exp\left[M * \frac{\Delta t}{2}\right] = \exp\left[\frac{M}{2} * \frac{1}{K} * \ln\left(\frac{L\infty - L1}{L\infty - L2}\right)\right] = \exp\left[\ln\left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}\right] = \left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}$$

It is convenient to use a symbol instead of this complicated term, therefore we introduce the symbols:

N (L1) = N [t (L1)]	=	the number of fish that attain length L1
	=	the number of fish that attain age t (L1) (also called the number of survivors)
N (L2) = N (t (L1 + Δt)	=	the number of fish that attain length L2
	=	the number of fish that attain age t (L2)
		[= t (L1) + Δt]
C (L1, L2) = C (t, t + Δt)	=	the number of fish caught of lengths between L1 and L2
	=	the number of fish caught of ages between t (L1) and t (L2)

3.4. $$H(L1, L2) = \left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}$$

Now equation can be rewritten using these length-based symbols, as:

3.5. $$N(L1) = [N(L2) * H(L1, L2) + C(L1, L2)] * H(L1, L2)$$

The equation for length-based cohort analysis for last group:

3.6. $$C(L1, L2) = N(L1) * \frac{F}{Z}[1 - \exp(-z * \Delta t)]$$

The equation for calculation of fishing mortality in length-based cohort analysis can be written as:

3.7. $$F(L1, L2) = M + \frac{F(L1,L2)/Z(L1,L2)}{1 - \left[\frac{F(L_1,L_2)}{Z(L_1,L_2)}\right]}$$

Calculation Procedure

The calculation for length-based cohort analysis is similar to age based cohort analysis. It can be started with last group with the help of equation-3.6. After first step, the number of survivors in the sea in preceding year can be calculated by using equation-3.5. The fishing mortality can also be calculated by using equation of fishing mortality given in equation-3.7.

Limitation

1. Natural mortality of cohort at age 't' (M) is constant.
2. It deals with the population dynamics of single species, whereas natural fish populations almost always interact among themselves and with others.

Suggested Reading

Gulland, J. A. 1983. Fish Stock Assessment: A manual of basic methods: Chichester, U.K. Wiley Interscience, FAO/Wiley Series of Food and Agriculture Vol. 1, 223 pp.

Sparre, P. and Venema, S. C. 1992. Introduction to Tropical Fish Stock Assessment. Part I. Manual. FAO Fisheries Technical paper, No. 306.1. Rev1. Rome. FAO. 376 pp.