FISH POPULATION DYNAMICS

FIS 507
LECTURE GUIDE

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FISH POPULATION DYNAMICS

Definition:

Population is a group of interbreeding organs of the same species whose breeding is localized in time and space such that they are substantially reproductively isolated from other geographically isolated individuals.

Characteristics of fish population:

i. Presence of birth and death rates
ii. Presence of growth rate – number of biomass
iii. Presence of age class structure
iv. Presence of sex ratio
v. Presence of density
vi. Presence of pattern of distribution during its life span spawning ground nursery, feeding ground, etc

For a proper management of the fishery, there is a need for knowledge of the dynamics of fish population being managed.

There are various methods of fish population estimation and the use of anyone of the methods will depend on a number of factors which include:

i. The biology of fish
ii. The characteristics of the habitat
iii. The resources available
iv. Objectives of the study

States of fish stocks:

i. Steady: fish population is the same year after year
ii. Cyclical: fish population is variable but catches are predictable
iii. Irregular: catches of fish are very unpredictable
iv. Spasmodic: stocks develop and collapse and reappear some other time.

Primary objective of fish stock Assessment.

The basic is to provide advice on the optimum exploitation of aquatic living resources e.g. fish

Since living resources are limited but renewable, therefore fish stock assessment (FSA) is the search for the exploitation level which in the long-run gives the maximum yield in weight from the fishery?

The concept of stock dynamics:

When describing the dynamics of an exploited aquatic resource, a fundamental concept is that of the stock

STOCK. is a subset of a species, which is generally considered as the basic taxonomic unit.

i.e a sub-set of one species having the same growth and mortality parameters, and inhabiting a particular geographical area.

Stock shows the following features;

I. Little mixing with the adjacent groups

ii . Growth and mortality parameters remain

iii. Belongs to the race within the species i.e share a common gene pool

A **Growth parameters;**

There are numerical values in an equation by which we can predict the body size of a fish when it reaches a certain age.

B **Mortality parameters;**

The rate at which the animals die i.e the number of death per time unit. e.g fishing and natural mortalities

MODELS

A fishery consists of three(3) basic elements.

i the input (the fishing effort e.g number of fishing days)

ii the output (the fish landed) and

iii the process which links input and output

Types of models;

i Analytical models

ii Holistic models

Analytical models

These models require the age composition of catches to be known e.g the numbers of 1 year old with caught, the number of 2year old fish caught, e.t.c

The basic ideas of the models may be expressed as follows;

i If there are 'too few old fish' the stock is overfished and the fishing pressure on the stock should be reduced.

ii If there are 'very many old fish' the stock is underfished and more fish should be caught in order to maximize the yield.

Therefore, one can say analytical models are age structured models working with concepts such as mortality rates and individual body growth rates.

While the basic concept in age-structured models is that of a COHORT.

A COHORT of fish is a group of fish all of the same age belongings to the same stock.

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Holistic models

These are less data demanding methods of assessing fish stocks. These methods disregard many of the details of the analytical models. They do not use age or length structures in the description of the stocks but consider a stock as a homogeneous biomass

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Types of holistic models

i. Swept area model

ii. Surplus production model

The swept area model:

This model is based on research trawl survey catches per unit of area. From the densities of fish observed (the weight of the fish caught in the area swept by the trawl) we obtain an estimate of the biomass in the sea from which an estimate of the MSY is obtained.

The surplus production model:

This uses catch per unit effort (e.g. Kg of fish caught per hour trawling) as input. The data usually represent a time series of years.

ESTIMATION OF FISH ABUNDANCE

Estimation of abundance is one of the most interesting aspects of fish biology. The mobility of the fishes, coupled with their invisibility" due to cover, habitat preference or occupation of spaces or water bodies that can only be surveyed on a piecemeal basis, presents an enormous challenge to the biologist who must know how many fishes are present in a given population. Because direct enumeration is rarely possible, biologists generally use estimates of population size based upon some kinds of survey procedures rather than a census. The diversity of life histories, social and behavioural habits of the fishes often present special opportunities for the biologists to estimate population size. Often too, these characteristics intervene to make population estimation particularly biased or imprecise.

GENERAL METHODS OF ESTIMATING NUMERIC ABUNDANCE OF FISH

1. Estimation from catch statistics
2. Correlated population method
3. Direct enumeration
4. Change-in-ratio-methods (survey-removal methods)
5. Mark-recapture methods

1. ESTIMATE FROM CATCH STATISTICS

Imagine a fishery in which a sequence of identical fishing operations successively removes catches of fish from the population. These catches should decline in a regular manner (i.e. apart from random variation due to “Sampling”)

If q^1 is the probability of individual fish being captured, then $(1 – q^1)$ is the probability of escaping capture. In this case a fishing event is considered a “trial” then, a proportion of the original stock will be captured in the first trial, and a proportion will survive. Then the “expected” catches will be:

* $E(C_1) = Nq^1$ Survivors $= N(1 – q^1)$
* $E(C_2) = Nq^1(1 – q^1)$ Survivors $= N(1 – q^1)(1 – q^1)$
* $E(C_3) = Nq^1(1 – q^1)^2$ Survivors $= N(1 – q^1)(1 – q^1)$

Therefore, $E(Cn) = Nq^1(1 – q^1)^{n-1}$ Survivors $= \pm N(1 – q^1)(1 – q^1)^n$

This is the sequence of expected catches assuming that the fisherman does not change tactics from one trial to the next and that the fish react independently to each trial

Setting up the expected catches in a ratio, we have:

$$\frac{[E(C_1)]^2}{E(C1) - E(C_2)} = \frac{N^2(1 - q^1)}{Nq^1 - N q^1 (1 - q^1)}$$

The final equation represents a useful formulation of the population estimate, given any two catches in succession

II. ABUNDANCE ESTIMATED BY CHANGE IN CATCH PER UNIT OF EFFORT

The basic assumption is that the fishing mortality coefficient is proportional to the fishing effort.

$$F = qf.$$

The constant of proportionality, is called the catchability coefficient.

In general, a population is fished until enough fish are removed to significantly reduce the catch per unit of effort, C/F, or, CPUE.

Example: If removal of 10tons of fish reduces C/F by a quarter, the original stock must have been 10/0.25 or 40tons.

METHODS:

1. Leslie– plots of CPUE against cumulative catch, and
2. Delury – log of CPUE is plotted against cumulative effort.

Leslie Derivation:

$$\frac{C_t}{F_t} = qN^t \text{ by definition} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

At the time K_t fish have been caught, the population N_t is:

$$N_t = No - K_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

$$\frac{C_t}{F_t} = qNo - qKt$$

where q is the catchability coefficient.

This is the basic Leslie formulation use to estimate initial population size (x – intercept) and catchability coefficient.

From Y = a + bX (linear model)

The equation above when rewritten becomes……………………….(iii)

$$\frac{C_t}{F_t} = qN_o \left(\frac{N_t}{N_o}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iv)}$$

From which the $\log_e$ form

$$\text{Log}_e \left(\frac{C_t}{F_t}\right) = \text{Log}_e (qN_o) + \text{Loge} \left(\frac{N_t}{N_o}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(v)$$

Delury Derivation:

When the fraction of the stock taken by a single unit of effort in small (say less than 2%0 it can be used as an exponential index to show the fraction of the stock remaining after E_t units (of effort) have been expended.

$$\frac{N_t}{No} = e^{-qEt}$$

Substituting into the logarithmic equation above……………………………..(v)

$$\text{Log}_e \left(\frac{Ct}{Ft}\right) = \text{loge} (qN_o) - qE_t$$

From this both q and N_o may be estimated.

III. CORRELATED POPULATION METHOD:

In this method, it may be possible to estimate population size from the production of eggs or the number of nexts. For some species of fish, the tecundity of the species together with the size of femelas and sex composition of the population, and an estimate of the number of eggs deposited would provide the basic information required to estimate population size. The simplest models is:

$$N = \frac{r_n \hat{E}}{\hat{e}} \quad \text{and} \quad r_n = \frac{Nf + Nm + N_1}{Nf}$$

Where: Nf, Nm, N_1 are the numbers of mature fish of each sex and the number of immature fish beyond a certain age or size, E is the total number of eggs spawned in the season and **e** is the mean number of eggs spawned per mature female.

This estimation procedure requires that the ratio (r_n) be obtained from an experimental survey or from sampling the commercial catch. The total number of eggs spawned involves taking samples of known volumes of water (for pelagic eggs or of known areas of bottom (for benthic eggs)

IV. ESTIMATION BY DIRECT ENUMERATION:

Suppose we know the boundaries of a total population space, but we do not know how the population is distributed in this space. We arbitrarily divide the space into A equal spaces and select “a” of these to enumerate completely. The experiment yields error free numbers.

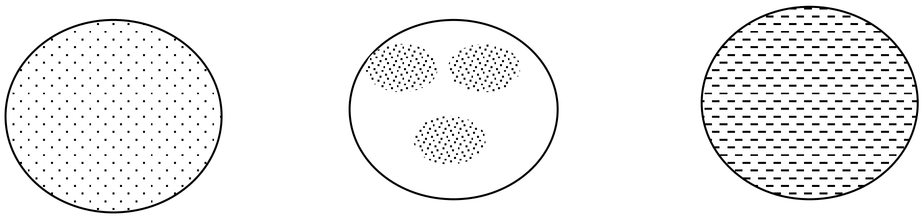
N_1, N_2, N_3 ……………………. Na for the spaces 1, 2, 3…………………..a

Where $$N = \sum_{i=1}^{A} Ni$$

Our estimate of N becomes:

Where $$N = \sum_{i=1}^{A} \frac{Ni}{a}$$

This estimate is valid whether the population is randomly dispersed is space or contagiously distributed (i.e. – “over – dispersed”) or uniformly distributed (“under – dispersed”)



Two applications of this method are used in fisheries using acoustic methods:

(a) Mobile sector – scanning sonar – may be applied by running the vessel along randomly chosen transects and enumerating the sonar blips

(b) Sonar Scanner – placing sonar scanners in migration path and enumerate the blips as the fish pass the station.

V. CHANGE-IN-RATIO ESTIMATORS

Methods of this type have been variously known as change-of-composition, survey-removal or dichotomy methods. The basis for the methods is an observed change in the relative abundance of two classes of animals within a population. The classes may be naturally occurring groups such as age, species, or sex classes, or they may be artificially constructed classes change-in-ratio of the classes allows us to estimate population abundance and survived.

Example:

In a situation where males or females might be selectively removed is evident here in the equation.

Proportion males in (# males before removal) – (#males removed)
Population after removal = (Pop. Size before removal) – (Total # animals removed0

Note that the signs in the word equation depend upon whether fish are entering or leaving the population.

$$N_1 = \frac{R_x - P_2R}{P_2 - P_1}$$ for estimate population abundance

Number of X-type fish in the population at t_1.

$$X = \frac{P_1 (Rx - P_2R)}{P_2 - P_1}$$

Where P_1 – proportion of X – types of fish at time t (1, 2) which is equal to

$$Pi = \frac{Yi}{Ni}$$ where $Ni = Xi + Yi$

N_i = total no of all fish, X_i = total number of X- fish

R_X = Net change in numbers of X – type of fish in the population between t_1 and t_2
R = Rx + Ry = Net removal (–) or addition (f) to the population between t_1 and t_2

VI. MARK – RECAPTURE METHODS:

In 1896, C.G.T. Petersen (Danish biologist) used this method to compute the rate of exploitation and, subsequently the total population of a group of fish. Ten years later Knut Dahl employed the method to estimate a trout population in Norway.

General Considerations:

Mark recapture models for estimating abundance depend upon capturing a portion of a stock, marking it and releasing the marked fish, some of which are subsequently caught in the next capture event.

Factors to consider include:

1. How many fish can be marked in a single event?
2. How many can be recaptured?
3. Are Unique identifiers required or will batch – marked do an well.
4. Will there be losses on capture?

There are two types of mark-recapture methods

i. Single mark – recapture.

ii. Multiple mark – recapture

Single Mark-recapture

$$N = \frac{MC}{r}$$

Where: N is the total population

m = number of marked fish in population

c = number of fish in the sample of population

r = number of marked fish in C

$$V(N) = \sqrt{\frac{N^2(N - m)(N - C)}{mc(N - 1)}}$$

at 95% Cl . P = N + 1.96V (N)

Multiple mark – Recapture method

$$N = \frac{\sum mici}{\sum Ri}$$

i	mi	ci	Ri	Newly marked& released	mici
1	O	44	0	44	0
2	44	53	4	49	2332
3	93	58	4	49	5394
4	145	47	11	36	6815
5	181	52	17	35	9412
6	216	46	18	28	9936
Total		56		33889	

$$N = \quad N = \frac{\sum mici}{\sum Ri} = 33889 / 56 = 605.2$$

Class work:

300 fish were marked and released in June 1. on September 25, 75 were marked differently and released. On October. 1, 250 fish were caught of which 35 bore the June mark and 12 bone the September mark. Estimate the survival of this MR survey.

Solution

$$N_1 = \frac{300 \times 250}{35} = 2143$$

$$N_2 = \frac{75 \times 250}{12} = \frac{1563}{580}$$

$$\frac{580}{2143} \times \frac{100}{1} = 27\% \text{ mortality}$$

Therefore, survival is 73%.

ESTIMATION OF GROWTH PARAMETERS

The study of growth means basically the determination of the body size as a function of age. Therefore all stock assessment methods work essentially with age composition data. In temperate waters such data can usually be obtained through the counting of year rings on hard parts such as scales and otoliths. These rings are formed due to strong fluctuations in environmental conditions from summer to winter and vice versa. In tropical areas such drastic changes do not occur and it is therefore very difficult, if not impossible to use this kind of seasonal rings for age determination.

Only recently methods have been developed to use much finer structures, so-called daily rings, to count the age of the fish in number of days. These methods, however, require special expensive equipment and a lot of manpower, and it is therefore not likely that they will be applied on a routine basis in many places.

Fortunately several numerical methods have been developed which allow the conversion of length-frequency data into age composition. Although these methods do not require the reading of rings on hard parts, the final interpretation of the results becomes much more reliable if at least some direct age readings are available. The best compromise for stock assessment of tropical species is therefore an analysis of a large number of length-frequency data combined with a small number of age readings on the basis of daily rings.

Mathematically von Bertalanffy equation expresses the length, L, as a function of the age of the fish, t:

$$L(t) = L_\infty * [1 - \exp(-K*(t-t_0))]$$

The parameters can to some extent be interpreted biologically. L_∞ is interpreted as "*the mean length of very old (strictly: infinitely old) fish*", it is also called the "*asymptotic length*". K is a "*curvature parameter*" (Figure 1) which determines how fast the fish approaches its L_∞ . Some species, most of them short-lived, almost reach their L_∞ in a year or two and have a high value of K. Other species have a flat growth curve with a low K-value and need many years to reach anything like their L_∞ . The third parameter, t_0, sometimes called "*the initial condition parameter*", determines the point in time when the fish has zero length. Biologically, this has no meaning, because the growth begins at hatching when the larva already has a certain length, which may be called L(0) when we put t = 0 at the day of birth.

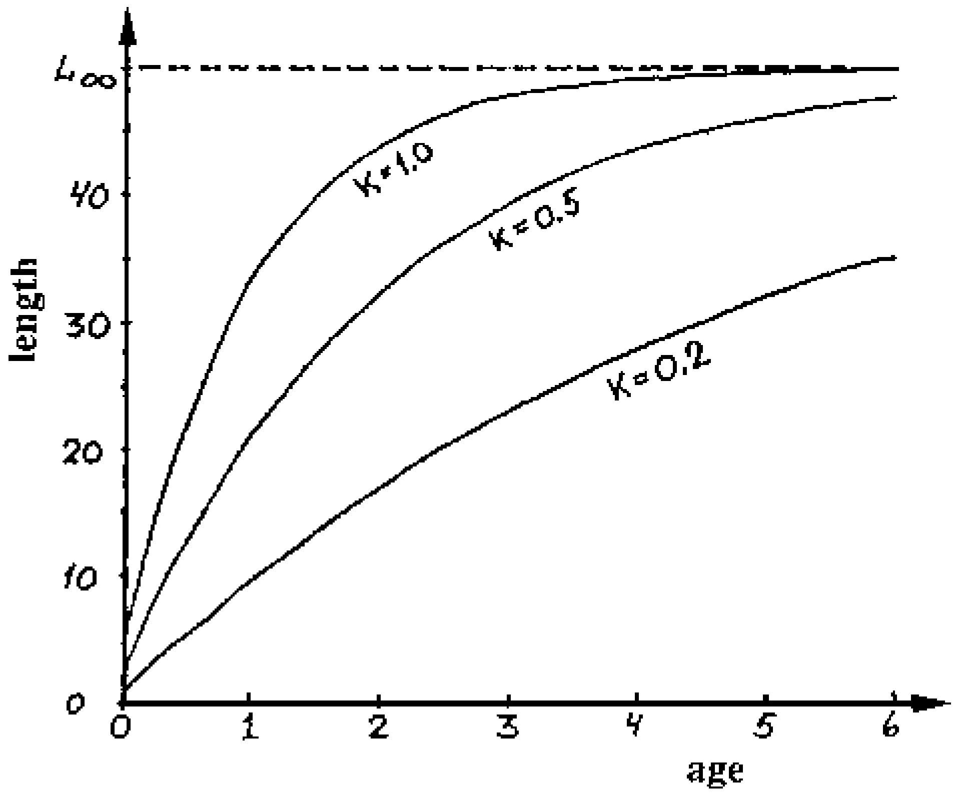


Figure 1: Growth curves with different curvature parameters, different K values

Variability and applicability of growth parameters

Growth parameters, of course, differ from species to species, but they may also vary from stock to stock within the same species, i.e. growth parameters of a particular species may take different values in different parts of its range. Also successive cohorts may grow differently depending on environmental conditions. Further growth parameters often take different values for the two sexes. If there are pronounced differences between the sexes in their growth parameters, the input data should be separated by sex and values of K, L_∞ and t_0 should be estimated for each sex separately.

The weight-based von Bertalanffy growth equation

Combining the von Bertalanffy growth equation

$L(t) = L_\infty *[1 - \exp(-K*(t-t_0))]$

with the length/weight relationship

$W(t) = q*L^3(t)$

One can deduce the weight of a fish as a function of age as:

$$W(t) = q * L_\infty^3 * [1 - \exp(-K * (t - t_0))]^3$$

$$\mathbf{W(t) = W_\infty *[1 - \exp(-K*(t-t_0))]^3.}$$

ESTIMATING THE GROWTH PARAMETERS

The Gulland and Holt plot

$\Delta L/\Delta t = a + b* \bar{L}(t)$

The growth parameters K and L_∞ are obtained from:

$K = -b$ and $L_\infty = -a/b$

The Ford-Walford plot and Chapman's method

$L(t+\Delta t) = a + b*L(t)$

where

$a = L_\infty *(1-b)$ and $b = exp(-K*\Delta t)$

Since K and L_∞ are constants, a and also b become constants **if Δ t is a constant**. The growth parameters K and L_∞ are derived from:

$$K = -\frac{1}{\Delta t} * \ln b \text{ and } L_\infty = \frac{a}{1-b}$$

For Chapman

$L(t+\Delta t) - L(t) = c*L_\infty - c*L(t)$.

where

$c = 1 - exp(-K*\Delta t)$

Thus, since K and L_∞ are constants, and if Δ t remains constant, c will remain constant and consequently the equation becomes a linear regression

y = a + bx

where

$y = L(t+\Delta t)-L(t)$, $a = c*L_\infty$, $b = -c$ and $x = L(t)$

Note that the slope is negative and also that on the abscissa (x-axis) the smaller of the two lengths is used, instead of the mean value.

The growth parameters are derived from

$K = -(1/\Delta t)*ln(1+b)$ and $L_\infty = -a/b$ or a/c

Inverse equation of VBGF for estimating t_o

$t(L) = t_o -1/K* In(1 - L/L_\infty)$

MORTALITY RATES

Mortality is caused by either fishing or through natural phenomena such as old age, disease and predation.The key parameters used when describing death are called mortality rate.

Natural mortality rate, M: This can be estimated using Pauly's empirical model or equation:

$In\ M = -0.0152 - 0.279 * In\ L\infty + 0.6543 * InK + 0.463 * InT$

Where T = mean annual water temperature

Total mortality rate, Z: can be **e**stimated in various ways among which is the linearised length-converted catch curve

$$In\ \ C[L1, L2]/\Delta t[L1, L2] = C - Z * t[L1+ L2] /2$$

From here, fishing mortality,F, can be estimated as

$$F = Z - M$$

And exploitation rate, E, as

$$E = F/Z$$

E ranges from 0 to 1. It is optimum at 0.5, under-exploitation when it is less than 0.5, and over-exploitation when the estimate is above 0.5.

YIELD PER RECRUIT MODEL

This model is used to assess the effect of mesh size regulations. Beverton and Holt developed a relative yield per recruit model which can provide the kind of information needed for management.

This is defined as:

$(Y/R)^1 = E * U^{M/K} * [1- 3U/1+m + 3U^2/1+2m - U^3/1+3m]$

Where m = 1 – E / M/K = K/Z

U = 1 – Lc/L∞ the fraction of growth to be completed after entry into the exploitation phase.

E = F/Z fraction of death caused by fishing

Lc = the length of the smallest fish in the sample

$(Y/R)^1$ can be calculated for a given input values of M/K, L∞ and Lc for values of E ranging from 0 to 1, corresponding to F values ranging from 0 to ∞.

The plot of $(Y/R)^1$ against E gives a curve with a maximum value, E_{MSY}, for a given value of Lc. Thus, when Lc, F and Z are known for a certain fishery, the actual exploitation can be compared with the E_{MSY} level and management measures be proposed as required.

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