Chapter 23

Fishing Gear Selectivity

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1.0 Introduction

Selection of fish by a fishing gear can be considered to be the process which causes the catch of the gear to have a different composition to that of the fish population in the area in which the gear was used. Selectivity of fishing gear is the measurement of this selection process. Chance is one of the most important factors that cause this selection process and hence selectivity describes the relative likelihood that different sizes and species of fish would have been caught by the gear if there were equal numbers of each, in the population.

The knowledge of selectivity of commercially important gears is vital for effective monitoring, management and for sustainable exploitation of fishery resources. Using selective gears help to minimize the capture of juveniles by regulating the length at first capture, increasing the yield per recruit of targeted species and reducing the discards generated by the fishery.

2.0 Definitions of selection curve

The selection process can be partitioned into three definitions based on the population from which the fishes are being selected as

1. Population-selection curve: This is the relative probability of capture of a fish of length l from the entire population.
2. Available-selection curve: is the relative probability of capture of total fish of length l

that was available to the gear (but possibly escaped the gear).

3. Contact-selection curve: is the relative probability of capture of fish with length l that comes into contact with the gear. This curve is often defined as the selection curve, since it is this curve that quantifies the difference in length distribution between the populations coming into contact with the gear.

Parameters of the selection curve for fishing gears

Selection length or L50 is the length at which 50% of the fish of the total fish entering the net either escapes or retained. Selection range is the difference between the length at 25% and 75% retention probability of a particular species. Selection factor (SF) is the factor that shows the relationship between the selection length and the mesh size for the species.

3.0 Selectivity experiments

A selectivity experiment is called direct, when the length frequencies of the population where the fishing is done is known but, estimating the entire population is impossible and hence selectivity studies are called indirect, and the nature of the population has to be derived from experiments involving repeated fishing in the area with different variants of the gear (mesh and shape variants and usually with very low selectivity). The maximum likelihood method is now widely used for all the parameter estimation since the approximate unbiasedness and the variance of the parameter estimates can also be worked out. The log-likelihood of n_{lj} is $\sum_{l}\sum_{j}\{n_{lj}\log e[p_j\lambda_l r_j(l)] - p_j\lambda_l r_j(l)\}$ This function has unknown parameters p_j, j and λ_l and the parameters defining the curve. The maximum likelihood estimates of the parameters are those values maximizing n_{ij}. However due to over-parameterization, it is not always possible to find values for the parameters. But by specifying the population length distribution, assuming geometric similarity in case of gillnets and by using log-linear models, the parameters of the selection curve like L50, selection range, selection ration and the selection factor for the gear can be estimated.

3.1 Gillnet selectivity

Gillnet capture is often interpreted as a mechanical process that depends on the relative geometry of the mesh and the fish. The capture in gillnets could be by any of the following methods (Fig. 1):

1. *Wedging:* The fish is meshed around the body behind the gill cover
2. *Gilling:* The fish is meshed immediately behind the gill cover.
3. *Snagging:* The fish is meshed at the head region.

4. *Entangling:* The fish is held in the net as a result of entangling by teeth, fins, spines or any other projection on the body of the fish.

The selection curves for passive gears are often bell-shapedand fitted by a normal distribution and represented as $S(L) = \exp[-(L-Lm)^2/2s^2]$, where S (L) is the length based gear selectivity;

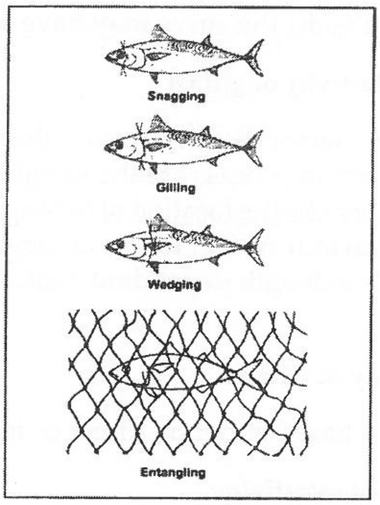

Fig. 1.Schematic diagram of the catching process in gillnets

L is the midpoint of the length class interval; Lm is the optimum length of fish to be caught; s is the standard deviation of the normal distribution (Fig.2). The width of the normal curve represents the selection range of the gear and the maximum height corresponds to the optimum length of the fish captured by the gear. The capture process by gillnets are often

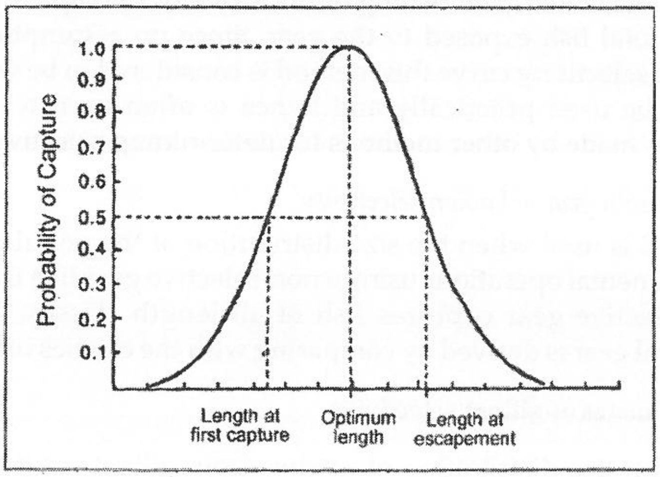

Fig. 2.Typical selection curve for gillnet

dependent on the shape of the fish captured. If the capture process is by tangling, then it may not be possible to model using a normal curve, since tangling is more dependent on factors other than the mesh size. Gillnet selection curves are more skewed to the right when fishes are mostly caught by tangling and approach the bell-shaped curve when most fishes are wedged. The combined selectivity curve for gilling, wedging and tangling would become a uni-model curve skewed to the right hand side and when fish capture is concentrated at more than one position on the body, the curve may have more than one mode.

3.1.1 Factors influencing the selectivity of gillnet

Mesh size is the most important factor that determines the selection length of gillnets. Other factors that determine the selection process are the hanging ratio, visibility of the material, stretchability, operational factors like the location of fishing, depth and orientation of fishing, shape of the fish and the behaviour of fish to the netting which is usually species and/or size specific which often leads to length dependent avoidance, differences in visual acuity, ability to wriggle away etc.

3.1.2 Determination of selectivity in gillnets

Determination of selectivity is based either on direct or indirect method.

3.1.2.1. Direct estimates of gillnet selectivity

This method is employed when the size distribution of the population in known and can be classified into two

1. *Fishing a known population*

   If the size distribution of the population from which the sample is taken is known, then the proportion of fish caught in each length class captured by the experimental gear can be estimated. The fishing effort is one of the inputs required to assess the number of total fish exposed to the gear. Since no assumption is required on the shape of the selectivity curve this method is considered to be very reliable but is very difficult to be used practically and hence is often used to check the validity of assumptions made by other methods for determining selectivity.

2. *Comparison with gear of known selectivity*

   This method is used when the size distribution of the population is usually known from experimental operations using a non-selective gear like trawl, and assumed that the non-selective gear captures fish of all length classes. The selectivity of the experimental gear is derived by comparing with the catches of the non-selective gear.

3.1.2.2. Indirect estimates of gillnet selectivity

In this method, the size distribution of catches from gillnets of different mesh sizes are compared. The indirect estimates can be grouped into two based on the assumptions

1. *Using type B curves as intermediaries*

   In this method, the type B selectivity curve (selectivity of different mesh sizes to one length/size class of fish) is plotted first and from them, Type A curve (selectivity of one mesh size to different length/sizes of fish) is estimated. Type B curve is estimated by comparing the catch of one size class of fish from nets of several mesh sizes, based on the assumption that under the same effort using different mesh sizes, the fishes have equal encounter probability and hence the catch is proportional to the mesh size and plotting the catches against the mesh size will generate the type B curve for a particular length class. This is done for all possible length classes and a 3 way graph representing selectivity as a function of mesh size and fish length can be generated, from which the type A curve can be generated.

2. *Fitting a pre-determined distribution*

   In this method, the type A curve is estimated mathematically without plotting the intermediate type B curves. But the accuracy is more when the selection curve approaches normality. The method proposed by Holt (1963), which compares the catches C1j and C2j in two slightly different mesh sizes m1 and m2 assuming the selection curves to be normal and the variance to be the same and the modes l1 and l2 to be same for the curves is the most widely used due to its conceptual simplicity and ease of experimentation. The nets with the different mesh sizes are fished in the same area at the same time and the length and total number of each species in the gillnets is measured. The assumption is that the natural logarithm of the ratio of catches in numbers for the two nets with different mesh sizes has overlapping selection curves which are linearly related to the fish length.

The procedure involves the calculation of proportions of fish of a particular length class retained in gillnets of larger mesh size. Cb = total fish of length l, in net with larger mesh size $m2$. Ca = total fish of length l in net with smaller mesh size $m1$. The log ratio for each length class is $Y= \ln(Cb/Ca)$ and can be expressed as per the linear regression equation $Y=a+bL$. Where L is the mid-point of the length class and a and b are constants. The selection factor(SF) is calculated as $SF= (-2a)/ [b (m1+m2)]$. The optimum selection length for each gillnets is calculated as $L1=SF*m1$ and $L2=SF*m2$. The standard deviation (S) of each probability function is calculated as $S=(L2-L1)^{0.5}/b$. Using the values for L1, L2 and S, the probability (P1) of capture for a given length L in a gillnet having a mesh size $m1$ can be calculated as $P1=\exp[(-(L-L1)^2)/(2S^2)]$ and for the mesh size m^2, the probability (P2) of capture for a given length class L is $P2=\exp[(-(L-L1)^2)/(2S^2)]$.

3.1.2.3 Estimates using girth measurements

This method is based on the assumption that to be gilled or wedged, the fish has to pass through the mesh beyond the gill cover and as far restricted by maximum girth. By measuring the head girth and the maximum girth for a given fish, the selectivity for a particular mesh can be determined. The peak of the selectivity curve can be estimated based on the assumption that the girths of the fish caught are proportional to the mesh size. Maximum girth=k*mesh perimeter, where the modal girth/mesh perimeter ration k is a constant and the estimated values for k is near 1.25 ranging from 1.08-1.35 depending on the shape of the fish. Modal lengths of fish caught are estimated from the girths and the modal length is the length at which maximum girth is 1.25 times the mesh perimeter. If it is assumed that the girth is proportional to length, the selection factor can be estimated.

3.1.2.4 Estimates using length based assessment

This method is based on the assumption by Baranov (1948) that the mesh size is proportional to the length of fish caught in it and the relationship is $a=k*l$, where a is the mesh bar in mm, k is a constant derived by experimenting with more than one mesh bar, and l is the modal length in mm. Two methods often used to determine the value of k for a species are i) *Length-based measurement:* $k = 2(a1*a2)/l_0(a1+a2)$, where a1 and a2 are the two mesh bars and l_0 is the length of fish caught in equal proportion by both the nets.ii) *Modal length method:* This method involves taking the modal length for each mesh size and deriving the arithmetic mean k=a1/l1, k=a2/l2, where a1 and a2 are the mesh bars in mm for net 1 and 2 respectively and l1 and l2 are the modal length for the respective mesh bars.

3.2 Hook selectivity

Hook selectivity is based on the model developed for gillnets, where the distance of the gape is taken as the critical dimension corresponding to the mesh size of gillnets. The determination of selectivity curve parameters is through experimental fishing using different sizes of hooks with the assumption that the gape differs for each pair of hook, the selection curves are approximately normal and with equal variance and the mean or mode of the selection curve is proportional to the hook size.

3.3 Trap selectivity

Traps and pots have openings which make entry easier for the targeted species, and difficult for the entered species to escape. Once inside the trap, the size selectivity is determined by the ability of fish to pass through the meshes of through the exit openings (which are much smaller than the main opening). The selection curve would be similar to that of a towed fishing gear, which is a sigmoid curve, meaning that smaller individuals have better chances of escapement and the proportion retained goes on increasing with the size of the captured animal in the trap.

3.4 Trawl codend selectivity

Based on the methodology used and the assumptions made, the trawl selectivity estimates are often made by different methods

Covered codend method

In this method, to understand the population structure, a small mesh cover is used over the codend which is sufficiently larger and wider than the codend to minimize the masking effect.

The total population is the catch in the codend and cover taken together and the relative fishing intensity of the codend is 1 because all fish enters the codend and simultaneously the fishing intensity of the cover will be 1 minus the retention probability of the codend. But the retention probability of the cover also needs to be taken into account. When fitting the logistic selection curve to covered codend data, the parameters a and b have to be estimated.The general model can take into account the different variants of the gears and model accordingly, but it is necessary to make assumptions regarding the population length frequency, selection properties of the codend and cover, fishing intensity, fit the model and then select the best fit by comparing the residual plot and goodness-of-fit statistics (Fig. 3.).

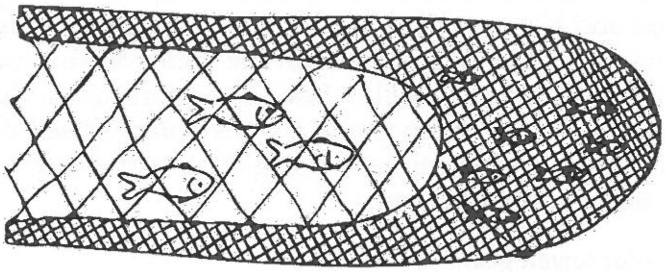

Fig. 3. Schematic diagram of codend and cover

Trouser trawl method

In this method the standard trawl codend is modified in which one codend is of the experimental mesh size and the other is small mesh codend which gives an estimate of the population available.

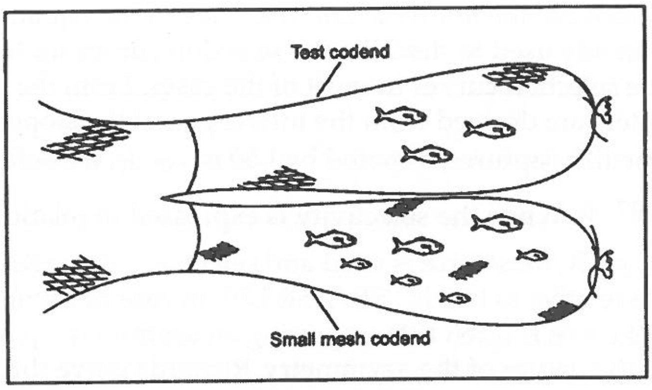

Fig. 4. Schematic diagram of trouser trawl codend

Comparison of length distributions of the fish in each codend allows the estimation of codend selectivity. In case of trouser trawls apart from the parameters a and b, the relative fishing intensity p has also to be estimated.Assumption of equal split is made for deriving the selection parameters, and the model will have three parameters defining the selection curve (Fig. 4.).

Twin trawl method

The twin trawl method uses two trawl nets, one from the star board and other being towed from the port side of the vessel. Here one of the trawlnet carries the experimental codend and the other a small meshed codend used to estimate population. The assumption of equal split of fish between the codends is often not followed and the method depends on assuming equal splits, which have sometimes shown to affect the selectivity parameters estimates.

The most commonly used and reliable method is the covered codend method which retains all the fish that escapes the codend and thus represents the fish encountered by the trawlnet. However, the cover can affect the behaviour of the fishes by masking the mesh opening in the codend and hence the estimates of selectivity. Different methods like, use of long and wider covers, hoops and kites attached to the cover, arefound to reduce the masking effect and improve accuracy of estimates. Among all the methods, the covered-codend method was found to give results that are well defined and more stable than the other methods because it is accepted that the codend with cover stabilizes itself during the fishing and hauling and the total population estimates using this method are more precise than other methods used for selectivity estimation.

3.4.1 Selection curve for towed gears

Size selection quantifies the relative capture probability of a size class of fish, usually represented in terms of length of the fish, since length is the easiest measurable quantity and is related to gape or girth of the fish. The logistic curve which is represented as $r(l)=\frac{\exp(a+bl)}{1+\exp(a+bl)}$ (where r(l) is the probability that a fish of length l retained in the codend, a and b which are the intercept and the slope of the equation have to be estimated), is commonly used to describe the selection curves for towed gears like trawls and found to fit the selection curves in most of the cases. From the above equation the selectivity parameters are derived from the intercept and the slope values (Fig.5). The length at 50% of the fish captured denoted by L50 is $-a/b$, the selection range SR is $=2\log_e(3)/b=2.197/b$. When the selectivity is expressed in relation to mesh size, the selection factor (SF)=L50/Mesh size is used and selection ratio (SRA), is used to express the selection range relative to L50 ie., SRA=SR/L50. In case of asymmetric selection process, a Richards curve is often fitted by using an asymmetric parameter, the value of which determines the nature of the asymmetry. Richards curve thus can be represented as $r(l)=\left(\frac{\exp(a+bl)}{1+\exp(a+bl)}\right)^{1/\delta}$ Where $\delta>1$ indicates that the curve has a longer tail to the left of L50 and with $0<\delta<1$ it has longer tail to the right. When $\delta=1$, it follows the symmetric logistic curve. Being a generalization of the logistic curve, the null hypothesis of a logistic selection curve can therefore be tested against the asymmetric Richards alternative by a

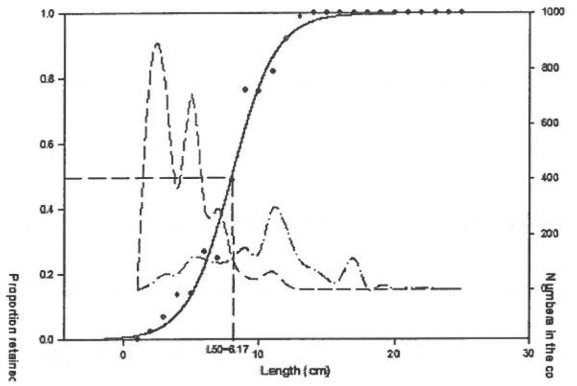

Fig. 5. Typical selection curve of trawl codend

statistical test of the hypothesis Ho: $\delta = 1$. The form of the logistic curve can then be written as $a+bl = \text{logit}(r(l)\delta)$ and hence $L50=\text{logit}(0.5\delta)-a/b$ and $SR = \text{logit}(0.75\delta)-\text{logit}(0.25\delta)/b$.

Other statistical functions like the probit function and non-parametric fit using a Gaussian Kernel-smoother with boot-strapping were tried to model selectivity curve, but the results do not differ significantly from the logistic curve or there were problems comparing the results with other studies using the standard method. Non-statistical models like three-point moving average and fit by eye were also used but the results of these could not be statistically determined since the variance estimates of the parameters are not available in these methods.

SELECT methodology

The method that is acknowledged as the standard for estimating the selectivity parameters is the SELECT model proposed by Millar. This is now being used as a standard for both the towed gears and other static gears. This model does not require the quantification of the length frequency of the population λ_l and is dependent on the proportion of catch of a particular length class retained by the experimental gear. There are a set of assumptions made for estimating the contact-selection curve and the factors that affect the selection curve can be modeled as follows: Let $r_j l$ be the contact selection curve for the gear j. Let n_{lj} be the total number of fish of length l caught by the gear j will be Poisson distributed with mean $p_j(l)\lambda_l r_j(l)$ i.e. the expected number of contacts to gear j, $p_j(l)\lambda_l$, multiplied by the retention probability of $r_j(l)$ This can be denoted by $n_{lj} \sim \text{Pois}\ (p_j(l)\lambda_l r_j(l))$. In practice the contact selection curve $r_j(l)$ and the relative fishing intensity $p_j(l)$ cannot be determined by data and assumptions are usually made regarding the fishing intensity by keeping this a constant irrespective of the length of the fish. So the final selection curve equation can be written as $n_{lj} \sim \text{Pois}\ (p_j \lambda_l r_j(l))$ and this is the general model for analyzing data for all comparative selection studies.

From the general model the expected value of a particular length class l in j hauls may be modeled as $\phi_{lj} = E(y_{lj}) = \frac{p_j \lambda_j(l)}{\sum_j p_j r_j(l)}$, which is equal to $= \frac{\mathrm{p_j r_j(l)}}{\sum_j \mathrm{p_j r_j(l)}}$, where j is the number of hauls and y_{lj} is the proportion of the length class l taken in the j hauls. Here the probability does not depend on λ_l and the log-likelihood for the data y_{lj} is $\sum_l \sum_j n_{lj} \text{Log}_e(\phi_{lj})$ and maximizing the log-likelihood gives the selectivity parameters estimates and the parameters defining the selection curve. This methodology is regarded as superior to the scaled data fit, and it makes use of likelihood ratio test for model selection, and obtains an appropriate covariance matrix for the estimated parameters from the second derivative matrix of the log-likelihood. When the catch data are Poisson distributed, and then the estimators are known to be approximately unbiased and they considered, being the best estimators in terms of having minimum variance. If the Poisson distribution assumption is violated because the data have variance proportional to the expected value (rather than equal to), then SELECT retains these properties and can be considered as quasi-likelihood. The SELECT methodology can also be extended to many challenging questions in selectivity like consideration of geometric similarity, bimodal selection curves, variable fishing power, sampling of catches and between-haul/set variations. Bayesian methodology, which utilizes prior information and model-induced likelihood function, in increasing being used in different quantitative fisheries applications and SELECT can be extended to Bayesian modeling of gear selectivity.

4.0 Studies required

The areas that require further study so that the size selection of fishing gear could be better modeled are

1. Better understanding of fish behaviour and hence the relationship between population selectivity and contact selectivity
2. Effect of commercial trawling conditions like the sea state, catch size, vessel conditions etc. on the selection process.

5.0 Further reading

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