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in

Lleonart J. (ed.).
Dynamique des populations marines

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 35

1998
pages 135-137

Modelling the trawl catching process for fish

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SUMMARY - This research is aimed at demonstrating, both analytically and experimentally, that the trawl fishing is size-selective, not only due to mechanical causes (meshes) or specific avoidance reactions but also (and mainly) because the physiological processes of fish endurance are size-dependent. In the classical model, doubling fishing time doubles the catch, while it will appear that in reality the doubling of time does more than double the catch. Given the assumption that speed and stamina are positively related to size, this suggests that the largest size classes are the ones that substantially contribute to the more-than-proportional-to-time catches. The overall result of this process should be similar to fishing the smaller fish longer than the bigger ones, since small fish would be tired faster. A new conceptual model taking into account a size-dependent time-lag in the process has been envisaged. Under the assumptions of the model, it appears that (length) frequency distributions from short trawl surveys are not comparable to those coming from much longer commercial hauls, and that population parameters estimated from surveys are potentially biased (proposing a worse scenario than the true situation). In fact, using actual data from Italian trawl surveys, it significantly appears that at least the hake, *Merluccius merluccius*, behaves as the model suggests.

Key words: Modelling, bias correction, trawl fisheries, stamina, hake, *Merluccius.*

RESUME - *"Modélisation du processus de capture des poissons par chalutage". Cette étude a pour but de démontrer, au niveau analytique et expérimental, que le chalutage est sélectif pour la taille, non seulement pour des causes mécaniques (maillage) ou des réactions spécifiques d'évitement mais aussi (et surtout) en raison du fait que les processus physiologiques liés à l'endurance des poissons sont proportionnels à la taille. Dans le modèle classique, le doublement des temps de pêche double les captures alors qu'il apparaît en réalité qu'en doublant le temps de pêche, les captures sont plus que doublement proportionnelles. Si l'on suppose que la vitesse et l'endurance sont positivement liées à la taille, il en résulte que l'excédent de captures en sus de celles qui sont proportionnelles au temps est dû essentiellement aux classes de plus grandes dimensions. Le résultat global de ce processus devrait être le même que si l'effort de pêche des poissons de petite taille était plus prolongé que pour ceux de grande taille, les premiers ayant moins d'endurance. Un nouveau modèle conceptuel qui tient compte d'un temps de pêche différent en fonction de la taille a été envisagé. Au titre des hypothèses de ce modèle, il apparaît que les distributions de fréquence (longueur) issues de chalutages de brève durée ne sont pas comparables avec celles qui résultent d'opérations commerciales plus prolongées et que les paramètres de population estimés à partir des études sont potentiellement faussés (donnant un scénario plus mauvais que la situation réelle). En effet, les données effectives d'essais de chalutage en Italie, montrent de manière significative qu'une espèce au moins, le colin (*Merluccius merluccius*), a un comportement conforme à ce modèle.*

Mots-clés : *Modélisation, correction du biais, chalutage, endurance, colin,* Merluccius.

It is well known that many fishing gear operate in selective ways relatively to fish size. That is not usually the case of fishing trawls, where the catchability coefficient is generally considered fixed.

How gear selection operates differently on sizes might be understood by intuitive reasoning. The small fish whose maximum speed is lower than the boat speed are taken first. The others are herded in front of the net mouth and swim until they become anaerobically exhausted and slowly fall back into the net bag. Medium size fish can not sustain the speed of the boat for long time while larger animals having higher (aerobic) sustainable speed and/or higher energy reserves (for anaerobic work) can keep going longer, and thus escape capture altogether.

The research is aimed at demonstrating, both analytically and experimentally, that the trawl fishing is size-selective, not only by mechanical causes (meshes) or specific avoidance reactions but also (and mainly) because the physiological processes of fish endurance are size-dependent.

In the classical model, doubling fishing time doubles the catch, while it shall appear that in reality the doubling of time does more than double the catch.

The following statements will lay down the bases of a "new" conceptual model on catchability, that takes into account a constant and a size-dependent time-lag in the fishing process.

A sustainable speed higher than the boat speed will make the fish practically unavailable to the trawl gear.

The majority of the fish, i.e., the medium sized, to stay in the front of the net mouth, shall keep a speed between sustainable (aerobic) and maximum (anaerobic) speed.

In this way fish accumulate an oxygen debt over time: when (and if) the debt reaches the maximum allowed, they slow down to the sustainable speed (or less), and are captured.

Of course, the actual behaviour of fish during the fishing process is so various that some sort of simplifying assumptions will be needed to start to build up the theory.

Let draw a few essential constraints: (i) only the fish in the net path react to the approaching of the gear; (ii) reaction is of avoidance, and fish tend to be herded in front of the net mouth; (iii) some distance occurs between the point of disturbance and the mouth of the net; and (iv) given a species, there is a direct relation between sustained speed and stamina.

A formal treatment shows that in the "classical" model

$$Catch_{a0t} / Catch_{b0t} = a_0 / b_0$$

while in the "new" model

$$Catch_{a1t} / Catch_{b1t} \neq a_1 / b_1$$

in fact if $a_1 < b_1$, then $C_{a1t} / C_{b1t} < a_1 / b_1$

The assumption that stamina (and speed too) is positively related to size suggests that the largest size-classes are the ones that substantially contribute to the more-than-proportional-to-T' catches.

The overall result of this process is similar to fishing the smaller fish longer than the bigger ones, since small fish would be tired faster.

Under the assumptions of the model, it appears that (length) frequency distributions from short trawl surveys are not comparable to those coming from much longer commercial hauls, and that population parameters estimated from surveys are potentially biased (proposing a worse scenario than the true situation).

Fish has been given an initial density (of 1 fish/frontal m, homogeneous), a survival-by-size negative-exponential function, a stamina-by-size function and a weight-by-size function (both potential).

The number and weight of fish "caught" in each length-class after 1, 2, 3, 4, 5 km (or after 12, 24, 36, 48, 60 min equivalently) has been calculated and plotted.

More interesting for research applications, also the number and weight of fish encountered by the gear but "still swimming" in front of the net (i.e., still not captured) has been calculated and plotted too.

The differences among the initial size proportions and the pie-charts are easily seen, and are due to the accumulation of larger fish in front of the net (and not in the bag), while the absolute value of still-swimming smaller fish stabilizes very early.

The relative importance of small fish in the catch (by weight) reduces with towing time. It can be noted that, once a size-class is "recruited" to the net, its capture is thereafter linear with time.

In general, it appears clearly that, in trawling, shorter hauls give strongly biased estimates of the real population size-distribution.

It is quite difficult, without performing an *ad hoc* experiment, to obtain data that are suitable for implementing the model; in fact, it is necessary:

(i) An abnormal-time haul, i.e., one-hour plus or minus 5, 10, or 15 minutes (no more, to have the same fishing process operating).

(ii) At least one related normal haul, i.e., in the same days, in comparable light condition, at similar depth, by the same gear/boat.

(iii) The presence in the catch of an abundant species, distributed over an ample range of length.

On over 500 hauls examined, only 36 trawling "sets" have been found in the databases of 4 fishery research institutions.

Using a Kolmogorov-Smirnov approach, it significantly appears that actual trawling data on hake, *Merluccius merluccius*, behave as the model suggests; even a simple regression analysis shows a favourable trend.

Of course, notwithstanding the better-than-expected results, it is certainly too early to say that the model has been validated, and more research is needed.

Moreover, for the future, to overcome the limitation of a deterministic model, a stochastic procedure has been developed to better simulate the trawling process.