

Extinction Revisited: “Allee Effect” and Irreversibility in “Schooling” Fisheries

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Abstract - Important results of Colin Clark’s research in the 70s are used again in the discussion of the limits to the privatization of the fisheries. Those results highlighted the possibility of species extinction motivated by special forms of the natural growth function. This paper revisits the situation in which the growth function exhibits a non-feedback, or depensation, curve. The existence of non-shrinkage curves poses problems in determining the sustainable yield and has important implications for resource management. The so-called “Allee Effect” may explain the difficulties of recovery of certain stocks, even when there are a set of limitations to the fishing effort. Ultimately, it explains the extinction of some species: if we face a situation of non-critical feedback, an effect of irreversibility is introduced. These effects are considered in the schooling species fisheries case.

Keywords - *Natural Growth Law, “Allee Effect”, Irreversibility, “Schooling” Fisheries*”.

1. Introduction

After almost four decades, important results of Colin Clark’s (1973, 1974) research are used again in the discussion of the limits to the privatization of the fisheries as a means of introducing more efficiency in fisheries operations (Clark, Munro & Sumaila (2008, 2010)). Those results highlighted the possibility of species extinction motivated by special forms of the natural growth function of species.

This paper revisits the situation in which the growth function exhibits a non-feedback, or depensation, curve. The existence of non-shrinkage curves poses problems in determining the sustainable yield and has important implications for resource management.

The structure of the paper is the following:

In the first point we present the basic model of fisheries management, the so-called Gordon /Schaefer model. This bio-economic model introduces an equation that reflects the natural growth of the species and describes their biological dynamics.

The second point introduces different forms of this equation and investigates the impacts of non-feedback characteristics of growth functions on the management and conservation policy. In this context, the so-called “Allee Effect” may explain the difficulties of recovery of certain stocks, even when there are a set of limitations to the fishing effort.

In the third point the effects of irreversibility are considered and the possibility of species extinction is discussed. The schooling species fisheries case is used as an example of this kind of preoccupations.

2. The underlying Biological Dynamics of Gordon/Schaefer Model

To design an acceptable bio-economic model of fishing, we must introduce, in its foundation, a biological model of fishing resources growth. In the Gordon (1954) article, the underlying biological foundation is a variant of Schaefer (1957). The populations’ dynamics can be easily described with a “Macro-biological Approach”. A fish resource population or biomass will, if not subject to human capture, grow in terms of weight, both as a consequence of recruitment of new individuals and as the result of the growth of individual fish in the population. Natural mortality will act as a check on

growth. If we assume stable environmental conditions (especially, if we do not introduce men as predators), along the time, the biomass will approach a natural equilibrium level at which net growth is zero (Coelho, 1989; Coelho, 1999; Smith, 1968).

We define the Law of the Natural Growth as the specific form by each species or resource is regenerated. In fact, each specie regeneration capacity is affected by biological characteristics (birth rate, mortality rate, age structure, etc.) and environmental characteristics (nutrients abundance, temperature, habitat, existence and efficiency of the predators, etc). It was interesting to evaluate all of the factors but difficult. So, when introducing into the model the biological characteristics, we must consider restrictive hypothesis.

If we do not attempt to distinguish among the factors influencing net growth, the growth of the biomass can be viewed as a function of the biomass itself and the population dynamics can be modelled by a very simple differential equation:

$$F(x) = dx/dt$$

x denotes the biomass and F(x) represents the regeneration capacity associated with every level of the stock.

The relation between the rate of growth and the level of the stock is not monotonic. In the Schaefer model, we'll have a quadratic function:

$$F(x) = r x (1 - x/K)$$

K denotes the carrying capacity and r, constant, denotes the intrinsic growth rate. When integrated, we are facing the popular Lotka/Volterra logistic equation of population dynamics (Neher, 1974; Wilen, 1985).

When we introduce men action of fishing, the first equation is modified:

$$dx/dt = F(x) - H(t)$$

H(t) denotes the capture rate.

The production function is given by:

$$H(t) = h E(t) x(t)$$

where E(t) denotes the fishing effort at time t (a kind of "capital-jelly" measure of the flow of labour and capital services devoted to fishing; this could be evaluated, for example, in terms of fishing hours), and h, constant, denotes a capture-ability coefficient

measuring the different capture conditions between fishing grounds.

If the resources are being captured in a sustainable basis, then $dx/dt = 0$ and $H(t) = F(x)$. Hence, F(x) can be viewed as the sustainable yield associated with a given biomass level. Since H(t) is a function of E, as well as x, one can establish the sustainable yield/fishing effort relationship:

$$Y = \alpha E - \beta E^2,$$

where Y denotes sustainable physical yield, with $\alpha = h K$ and $\beta = h^2 K/r$.

With the biological model complete, we can introduce prices and costs. We assume that both the demand for captured resources and the supply of fishing effort are perfectly elastic. The cost function can be expressed as the simple equation:

$$C = c E$$

We assume that the total cost is linear with effort. The constant c denotes unit cost of effort.

Sustainable revenue is represented by pY, where p is the unit price of fishing. It has, also, a quadratic form.

We can now solve the model and analyse the behaviour of the "industry".

The main conclusions can be summarized as follows: If fishing was managed by a "sole owner", it would be stabilised at the point where sustainable resource rent - sustainable revenue less total cost - is maximised. In this situation, fisheries are managed in a socially optimal manner. If fishing effort expands beyond this point, overexploitation of the resources occurs.

But, as fishing activities take place in a regime of open access, there is no landlord to appropriate the resource rents generated by fishing. Thus, if fishing was at the point where resource rents are maximised, the "industry" would be enjoying super-normal returns and new fishermen would be attracted to enter the fishing ground. If fishing is unregulated and competitive, fishing effort will expand, leading to overexploitation of biomass. In this case, fisheries would not be in equilibrium until it had expanded to the point where total costs are equal to total revenues, that is, until resource rent had been fully dissipated. This "bionomic equilibrium" reflects the existence of

externalities in the capture process and it's a case of market failure (Filipe et al, 2007; Coelho, 2011).

Besides the relevance of the conclusions, we have to underline the role of the biological model when constructing such a bio-economic model of fisheries management. In fact, the potency of explanation of the basic model depends on the capacity of the growth equation that is introduced, to catch the fundamental characteristics of biological dynamics of the species considered. At the same time, if we do not want to introduce too much mathematical complexity in the model, we must take care of the efficacy/ feasibility of the model and of the biological information needs to estimate the bio-economic model.

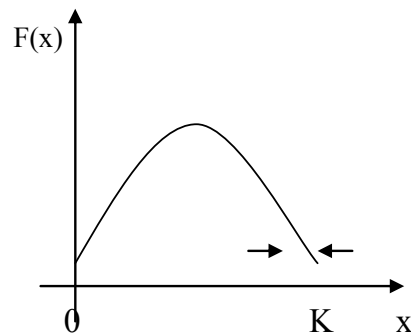
3. Compensation and Non-feedback Control in Biological Models

Also problematic is the possibility that $F(x)$ does not have the usual form. Several alternative forms for the logistic model have been proposed.

The logistic model itself and, in general, models with a growth function such as the first figure - so that the proportional rate of growth

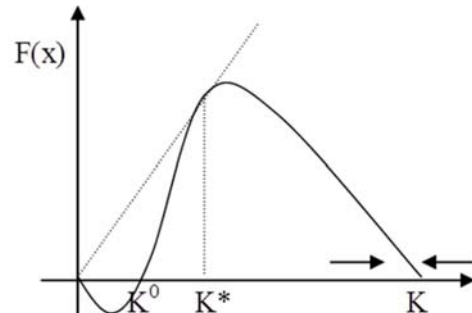
$$r(x) = \frac{F(x)}{x}$$

is decreasing with x - are called models of pure compensation.



On the other hand, if $r(x)$ is an increasing function of x , for certain values of x , it is said that there is a process of non-feedback or "depensation". For example, there are curves that shows non-feedback for $0 < x < K^*$ and compensation for $x > K^*$. These types of curves are the so-called non-feedback curves.

Also, we can use the expression "curve of non-critical feedback" to refer non-feedback curves with the property $F(x) < 0$ for certain values of x , near $x = 0$, as in the second figure.



The existence of non-shrinkage curves poses problems in determining the sustainable yield, y , and has important implications for resource management. The first aspect can be seen as follows. Assuming that the stock is subject to a given capture with a constant effort, we have:

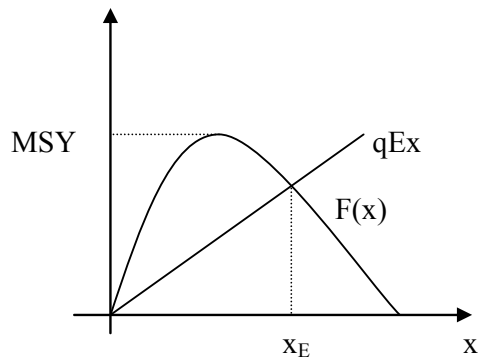
$$\frac{dx}{dt} = F(x) - qEx$$

Suppose that we want to build the Yield-Effort curve: $y = y(E)$.

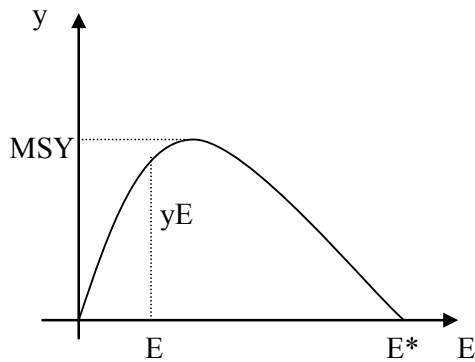
In the case of pure compensation, each level of space (E) produces a unique and stable solution for the population balance X_E and the corresponding yield Y_E is:

$$y_E = f(x_E)$$

Therefore, the curve Yield-Effort rises to a maximum (MSY) and then decreases slowly as the effort is being increased. The sustained yield is zero for values of $E \geq E^*$, where $qE^* = F'(0) = \max r(x) = r^*$. As in the logistic model, the resource stock is driven asymptotically to zero if the catch rate is maintained at a level higher than the intrinsic growth rate r^* .



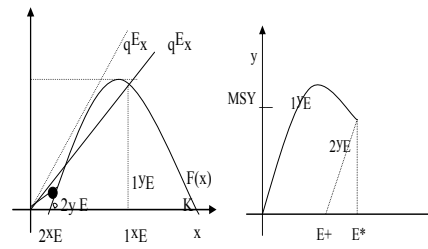
Natural Growth Curve



Yield-Effort Curve

In the absence of feedback effect we face the problem of the existence of multiple equilibrium solutions. For each level of effort $E < E^* = \max r(x)/q$ there is a population of stable equilibrium $1x_E$ and a yield equilibrium $1y_E$, equally stable. But, for values of $E > E^* = F'(0)/q$, there is also a population of unstable equilibrium, $2x_E$.

If the initial level of the population $x(0)$ is higher than $2x_E$, the equilibrium level is established at $x = 1x_E$; however, if $x(0) < 2x_E$, equilibrium is established at $x = 0$, assuming that E is constant. Thus, there remains a critical effort E^* such that $y(E) = 0$, but the yield curve-effort is different from pure compensation model, now forming a discontinuity at $E = E^*$, where the yield curve reaches zero if E exceeds the critical level.



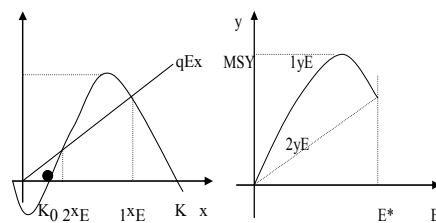
The implications for the management policy are very relevant:

First, the incremental approach of Schaefer model is not appropriate, since a slight increase of E can lead the population to collapse. It reminds us the "butterfly effect": a simple variation in E conducts the population to a possible disaster.

Furthermore, the model introduces a special effect. Suppose that the effort is approaching the level $E > E^*$ and $x(t)$ approaches zero (while x is still positive). If E is reduced to a level below E^* , this does not imply that the system returns to $1y_E$. In fact, one can demonstrate that if the reduction is not below $2x_E$, the population will continue to decline. That is, to return to $1y_E$ may be necessary to reduce the effort until E^+ .

In short: to bring the population to acceptable levels, the reduction in fishing effort may be much higher than desirable. This "Allee Effect", as it is known in Anglo-Saxon literature (see, for example, Southey (1972) and Larkin, Raleigh & Wilimovsky (1964)), may explain the difficulties of recovery of certain stocks, even when there were a set of limitations to the fishing effort. Ultimately, it explains the extinction of some species.

Worse, if we face a situation of non-critical feedback. A new effect is introduced - that of irreversibility.



In this case, it can be seen that each level of effort $E \geq 0$ gives rise to two equilibrium solutions

($1xE$ and $2xE$) and that $x = 0$ is a stable equilibrium solution for any E . If effort goes beyond a supercritical level, the population may find itself reduced to a level lower than K_0 (the minimum viable population). So, we find ourselves in a situation of irreversible extinction.

4. Non-critical Feedback and Species Extinction

In the world's fisheries there are some studied cases of this situation of non-feedback control. These studies also have important practical indications about resource management and conservation measures.

An example is the so-called "Schooling fisheries" case. These species, like sardine, tend to live in large schools. The existence of large schools provides a means of defense against large predators. The mathematical theory that studies the relationships between schools and predators, due to Brock and Riffenburgh (see Clark, 1974) indicates that the detection by predators is an inverse function of the size of the shoal. Since the amount of fish that a predator can consume has an average threshold, when exceeding this limit, the growth of the school implies a reduction of consumption by the predator. Also, other defensive aspects of the school, such as bullying or confusion of predators, are elements of more effective "schools".

However, this type of large schools behavior has allowed the development of highly efficient fishing techniques. With modern fish finding equipment by satellite, with modern nets of fibers, strong and easy to handle, fishing can remain profitable, even for small stocks (Bjorndal (1987), Neher (1990), Mangel and Clark (1983)). Of course, as these stocks are getting scarce they become even less protected.

Furthermore, the existence of these techniques prevents a stock effect on business costs, as opposed to the so-called "search fisheries." For "search" species, the fishing action implies search and detention. The existence of larger populations is essential for fishermen because it reduces the costs of detection (see Neher, 1974). But now, the high capacity of detection of new technology means that costs are no more sensitive to the size of stock, even for schooling fisheries (Bjorndal and Conrad, 1987). This situation is extremely dangerous because of the low biotic potential of some species. The reproductive capacity requires a minimum value below which extinction is inevitable. Since the

efficiency of the school is reduced, the losses due to the effects of predation are relatively large at low stock levels. Clark (1974) states this turns into a situation of non-feedback in the stock-recruitment relationship. And that implies a discontinuity in the curves of yield-effort, so that an infinitesimal increase in stress, below a certain threshold, leads to an unstable state which can lead to extinction.

In the case of non-critical feedback, the path to extinction may be irreversible. According to Clark (1974), a necessary and sufficient condition for the existence of non-critical feedback is that the average fertility is too small to balance the high mortality of some low levels of population, for which the school becomes inefficient. So, the fishing communities can face a possible sudden collapse in the exploitation of small schooling species subject to strong capture. These breakdowns can directly result from overfishing or can be indirectly induced by environmental fluctuations operating on a population of excessive exploitation and decreased resistance.

Bjorndal, Conrad and Salvanes (1993), in a study on the capture of seals in the area of Newfoundland, concluded that, although the stock had not reached the danger of extinction, the existence of a feedback-like effect could be appropriate to describe the dynamic behavior of this specie. The same way, the poor biotic potential of species like whales, especially when subject to severe operating conditions, together with the existence of an intertemporal discount rate higher than the natural growth rate of the species, may be explanatory factors for the near extinction of this species and the need of establishing a "moratorium" on whaling by the International Whaling Commission. On this issue, see, for example, the studies of Conrad (1989) and Clark (1987).

5. Final Remarks

The widespread implementation of rights based management (RBM) schemes in fisheries management, as ITQs, increased the opportunity for private sector groups to influence fisheries management. This development has given rise to a debate over the extent to which should be encouraged this private influence.

In a provocative paper, Grafton, Kompas & Hilborn (2007) state, on the basis of empirical investigation, that the results of Clark (1973, 1974) are really no more than a theoretical curiosity with no

practical significance. But, other important investigations' results highlight that the conclusions of Clark cannot be safely dismissed. See, for example, the study of Dulvy, Sadovy & Reynolds (2003). The authors point that the possibility of extinction is relevant. In fact, the extinction occurred in about 100 marine fisheries (most of all, it is expected, in situations of positive minimum viable population levels – see Hutchings (2000)). That indicates that there is substantial scientific evidence that we can find several species with positive minimum viable population levels, and that there exist population levels below which the resources cannot replace their original levels of abundance even if we reduce the fishing effort.

According to Clark, Munro & Sumaila (2010) this should imply that there are limits to the privatization of fisheries: there are situations in which the communities should not put under private hands the defense of the common interest. In situations of “depensation” growth curves and of little growth rate of renewal, compared to the existing interest rate, the private management should lead (“efficiently-seeming”) to species extinction.

We go further: in situations like this we should also not purely confide in public policy. The management of such situations imposes an important restriction to the managers and underlines the fundamental idea that, in these types of industries, there is more than simply Economics. In fact, Nature and her laws impose a necessary humility to political devisors. A principle of precaution in the definition of total authorized capture levels and in the formulation of other command and control, or economic, tools is simply a question of good sense and ethical posture.

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