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The Protection of the Marine Environment and Management of Exploited Stocks

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At a time when marine reserves are appearing almost everywhere, and where many marine and land species are said to be endangered, the time would appear ripe to restate certain basic biological considerations affecting the development of marine species which, in comparison to land species, make it possible to explain some obvious facts, which are generally analysed too superficially, leading to flawed decisions, which unfortunately only appear to be effective.

Measures to protect living populations generally target the protection of adults and, classically, this protection is based on the following truism:

As breeders, adults are the necessary and/or adequate source for population renewal.

Genetically speaking, it would be irrational to deny this. Nowadays everyone knows that it is through the joining of two gametes from adult individuals that living sexually distinguishable beings are born.

The lifespan of an organism is marked by a certain number of events which can be presented in the form of a cycle: fertilised eggs produce juveniles, these juveniles become adults by reaching sexual maturity and these adults then lay more eggs. In their turn these fertilised eggs produce juveniles, etc.

My talk will concentrate on demonstrating that if the qualitative link between parents and their progeny is undeniable, in contrast, it is mistaken to believe that there is for every species a direct and close quantitative relationship between the number of progeny which reach adult age and the number of breeding adults.

Let us begin with something which is familiar to us and which we understand well, i.e. the human species. Everyone knows that demographers determine for each people on the planet a precise rate of demographic growth. Even within one species, in this case humans, it can be noted that population increase depends on population size and the environment. For example, the rate

for French Polynesia is 2.2%. This figure is very precise and since the French Polynesian population is currently known to be 220,000, it allows us to forecast that in 10 years there will be 47,600 additional French Polynesians. The government can thus "administer" due to this very precise forecast and plan the construction of schools, hospitals, etc.

The number of elephants in the Serengeti increases at a rate of 5% per year. Although this figure is less precise than the previous one, it still allows the number of elephants which will need to be sustained by the reserve in the coming years to be forecast accurately. What the two mammal species given in the example, i.e. humans and elephants, have in common is low fertility; very few offspring per female, produced one at a time. In contrast, where they differ is in the degree of ability to protect their offspring and this is reflected in the accuracy of the figure expressing the quantitative link between the size of the breeding population and the number of progeny it produces. If a woman dies just after childbirth, the baby, incapable of surviving alone, will be cared for by human society (family, foster home, orphanages, etc.) and will live. If a female elephant dies just after the birth of the baby elephant, this baby elephant will die. Social structures within elephant society are capable of caring for adolescent elephants but not very young ones.

In general, birds are somewhat more fertile than these mammals. Emperor penguins in the Antarctic live in an extremely harsh environment. The female lays one egg each autumn and gives it to the male who incubates it for nearly four months, without eating and while making every effort to guard it in spite of the extreme cold. Social structures assist each male to survive and protect the egg. The timing between the return of the females in springtime and the males' limit of endurance leaves little leeway. Although nature has allowed some rather clever physiological and social responses in order to preserve the chick, mortality remains high and varies from one year to the other depending on how taxing the weather is. As a result, the number of recruits varies from year to year from 15 to 60%, with an average of 40%. This quantitative link, although imprecise, is still sufficient for estimates, especially over the long-term. Accurate estimates from one year to the next re, however, impossible. For puffins, young adults sometimes "forget" to reproduce and so..e of them need three to four years' experience before being able to successfully incubate their brood. While still low, fertility of the great titmouse is a bit higher than for the two birds cited above with 2 eggs per couple per year. Good parental protection of the nestlings make the number of young surviving each year higher than the number of available nests. The drastic mortality rate among those without shelter leaves just enough survivors to fill the nests left empty by the disappearance of a few of a group of titmouses possessing a nest. The number of available nests then determines the size of the population.

For reptiles, let us take the example of the leatherback turtles whose females lay an average of 135 eggs. Only 54 (on average) will hatch, 18 during the day when the young turtles will be decimated by the birds, 36 during the night when the young turtles will almost all reach the ocean. Survival at these two stages (hatching and reaching the water) thus averages 26%. The precision of this figure masks the hazards of future phases of marine development. Many of the turtles, an unknown number, will be lost, particularly due to predators.

These initial examples show roughly how two reproductive strategies can be distinguished. The first consists of producing a limited number of young and caring for them in order to minimise

infant mortality. The other consists of producing more young and caring less for them or for a shorter length of time. This results, then, in a higher mortality rate among juveniles. A theory can be postulated: "The lower the fertility, the more protection provided for the young and the higher the fertility, the less the parents will protect their offspring". Let us see what happens when fertility increases to the point of being difficult to estimate.

Only a few species of fish protect their eggs, for example the tilapia and some catfish from the *Bagridae* family. In these exceptional cases, fertility is relatively low; a few dozen eggs are laid each spawning period and are often incubated in the mouth of the male. Increased fertility occurs, whenever possible, through an increase in the number of spawning periods per year. Some tilapias spawn every two weeks. However, the females of the very large majority of fishes and marine invertebrates spawn only once per year, producing several hundred thousand eggs at each spawning. For fish, the record must undoubtedly go to the sunfish (*Mola mola*) with up to 4×10^9 eggs per female per spawning! *Lethrinidae, Lutjanidae, Sparidae, Serranidae, Thonidae* or even *Clupeidae* females usually depending on the species, lay from 150,000 to 600,000 eggs.
Immediately after spawning all these eggs are abandoned and will normally develop within the plankton. Before becoming adults, these eggs, then the resulting juveniles, will have to survive a real obstacle course. Some of these obstacles are of the "**restrictive**" type. These are a kind of window or "narrow passages" through which only a limited number of specimens can pass. This number depends on the size of the window and not the quantity of specimens present. This is the case with the amount of food to be found in pelagic or benthic nursery grounds. This limited amount will then determine how many juveniles can feed there and thus survive. For example, the nursery ground for juvenile soles in the north of the Gulf of Gascony can only sustain a certain number of juveniles, fewer than those present, despite the intensive fishing effort on the adult stock. Whereas the density of pelagic larvae varies from one year to another by a factor of 30, the density of the juveniles on the nursery grounds only varies by a factor of 3. Other obstacles are of an "**exponential**" type such as predation. These are called "density dependent" i.e. they depend on the abundance of eggs or larvae – the more there are the more die. This is, for example, the case when the eggs or larvae are the prey of a predator. If in one year the parents have produced a lot of eggs, larvae or juveniles, their very number will make them easy prey and attract predators. In contrast, as soon as they become scarcer, the "cost" of their predation becomes too high and predators will turn away from them to find easier prey. The eggs spawned during annual spawning aggregations in the reef passes by the *Serranidae, Acanthuridae* or *Scaridae* essentially serve as food for pelagic filtering fish like *Chanos chanos* (milk fish) which gather in great numbers at these locations at such times.

All this demonstrates that successful biological development is a highly unpredictable process which can vary within the same species, in significant ratios of a factor of 1000 or more varying from year to year depending on chance meetings or inclement weather.

Stated simply, extension-oriented handbooks mention, for example, that out of 10^7 eggs laid only 2 young will survive to take their place in the population. However, this does not mean that twice as many, i.e. 2×10^7 eggs, is needed to have 4 young recruits or three times as many 3×10^7, in order to have 6, but rather that survival is very low and very risky and, that in a certain sense, spawning serves more as nourishment for predators than as a means to renew the population. The number of eggs is always extremely abundant. Also, if, due to chance or human intervention, not

2 but 4 young recruits survive out of 10^7 eggs, the mortality rate will, practically speaking, be just as great; in contrast, in terms of development, recruitment will, in the second case, be twice that in the first case.

Economic interests related to the exploitation of live oceanic resources have favoured the development of a branch of scientific research, "The Dynamics of Exploited Marine Populations", which is the speciality of fisheries scientists. The bibliography of this science shows historical series of demographic data sometimes covering varying periods sometimes of a hundred years, often more than 20, which have allowed the number of recruits issued from known parent stocks to be calculated for each of these years. The scientific mind's desire for exactness has led to the development of stock recruitment models based on these data, models which lead the reader to believe in the existence of a fine relationship between stock and its recruitment and thus in forecast models. These models, first designed in the 1950s, have since been widely used. Although they are presented as being precise, they often omit to underline the essential point, i.e. that they correspond to fictional balanced situations in a stable environment, that is to say, an environment which would repeat itself exactly every year. But the environment is not stable and these models are just academic hypotheses which can only allow the formulation of reasonable but not completely reliable for fishermen (this in itself is quite an achievement). The same figures reviewed chronologically show stock-recruitment relationships which are much more inconsistent (see figures 1 to 10).
For this reason, quantitatively speaking, for the immense majority of very fertile marine species, the apparent truism of the second paragraph is false. As soon as fertility for a given species is very high and there is then no protection of the young - and this is the case in the ocean for practically all species, especially those which are exploited (crustaceans, mollusks, fish) – there is no simple quantitative relationship between the number of individuals in the breeding portion of a population and the number of recruits originating in this stock which have achieved successful long-term survival. The stock/recruitment relationship is, in fact, a stochastic relationship, in other words a model can be generated by computer but remains, in practice, unpredictable and so unusable for management. No forecast of the abundance of a population or stock, based on knowledge of breeding adults can be made.

Since the beginning of the 1980s, thanks to computers which have allowed biologists to use complex statistical analysis techniques, more and more scientific studies have demonstrated close ties between success in development and the environment of those species which have a very high fertility. Shrimp stocks in Casamance (Senegal) vary with the flooding periods of the river, *Ethmalosa* stocks in the lagoons of the Côte d'Ivoire fluctuate according to the amount of rainfall in the Gulf of Guinea, the abundance of the anchoveta in Chili and Peru is determined by the vagaries of El Nino, etc.

Moreover, the environmental conditions which determine spawning are often not the best for the development of the eggs. There are often important differences. For example, the maximum spawning intensity of soles in the North Atlantic occurs at the beginning of spring, but the largest number of juveniles result from the few eggs laid at the end of the spawning period, that is to say at the end of spring. We have found similar results for two species of lagoon scallops in New Caledonia for which larval development success is highest in winter (August) although spawning is highest in summer (January)! In other words, from the point of view of potential fertility, the

breeding stock is always superabundant and there are always too many eggs spawned.

Thus, actions designed to increase the population do not amount to maximising the number of eggs spawned by protecting the existing breeding stock, but rather involve increasing the number of juvenile individuals which successfully complete their development. This is quite a different approach as its efforts are aimed at the juvenile phase and not at the adult phase. The success of the juvenile phases of development must be favoured, even assisted, and not survival in adult phases, if the aim is to increase or restore the number of recruits in a population. No matter how many eggs are spawned, during their development they will encounter "filters" which will, in any case, only allow survival of a fraction determined by parameters independent of the species. For very fertile species, it is therefore not the quantity of eggs which is important, as this is always sufficient, nor the survival of these eggs because there are always enough which survive, but rather all the later stages of development up to maturity, and especially the last one. Real protection will be not hampering these stages of development and, if possible, favouring the final stages of development or, at the very least, not handicapping them. It is over the course of the stages of development, especially the final stage, where the factors which actually limit the number of marine populations are to be found.

Juveniles must be protected by favouring their survival in breeding grounds. This protection includes the absence of toxic pollution, and the availability of food and shelter. Moreover, human intervention which promotes better survival of juveniles will bring better results because natural biological mechanisms are for the most part exponential in nature. Research must be focused on encouraging studies of the development phases of species and in the identification of nursery sites as well as an understanding of their functioning.

In the Pacific Island region, nursery grounds are usually found throughout the lagoon or coastal area, e.g. the fringing reef, seagrass beds, detrital slopes, soft bottoms, etc., and a single body of water circulates around all these sites. Total protection of the marine environment, especially in the lagoon, is thus the only effective human action. The rest is only an illusion or placebo. Limited protection, temporal or spatial, has only scientific, recreational or educational merit. The cycle of very fertile species shows two distinct groups, which are the adult or parent stock group and the juvenile or pre-recruitment group. If the link between stock and its recruitment is stochastic, the link between the recruitment and the stock is tangible. By knowing the mortality vector of a population or stock, it is possible to predict future numbers and by knowing the growth, it will be possible to predict biomasses.

What is rational stock exploitation?

The adults of exploited populations represent a biomass that must be managed like a commercial stock. However, this "merchandise" has two particular characteristics that distinguish it from tinned goods i.e. each piece of stock grows larger and heavier over time and if they are not consumed, they will in any case be lost to natural mortality.

Suppose we have a certain number of specimens "N" recently recruited into the exploitable stock. A certain portion will disappear at any given moment solely through natural mortality while the survivors will grow larger. But as they age individuals grow less and less and the relative weight

gain of the survivors of the N individuals is, over the course of time, smaller and smaller while the natural mortality eliminates individuals which are bigger and bigger. Thus it is seen that for a group of individuals born from the same spawning, there exists a threshold age at which the momentary quantity of the biomass which disappears from the group through natural mortality is higher than the quantity of biomass which appears at the same moment through individual growth of the survivors and that, of course, the inverse is true before this age. In other words, although numbers decreases more or less regularly with time, in contrast, the biomass of a group of individuals born from the same spawning first increases up to a maximum point then diminishes.

The goal of the rationalisation of the exploitation of a stock is to allow optimal and on-going captures. The work of scientists consists then of two tasks. The first is to make it possible to harvest the maximum biomass of existing individuals. Given the individual growth, calculations will then be based on determining a minimum capture size as influenced by the additional mortality caused by fishing. Concretely, this means determining two values "minimum capture size" and "fishing mortality" which maximise production. These parameters are interdependent but the first depends mostly on the biological characteristics of the species and the second on the technical, social, and economic characteristics of the fishery. This process gives sure and precise results and non-respect of the minimum size calculated will always reduce profits to fishermen.

The second is to allow stock numbers to maintain a level which is compatible with the intensity of its exploitation or the reverse, that is to say, to establish an exploitation intensity that is compatible with the available number of specimens, meaning that the quantity of resources harvested should not exceed the rate of renewal However, the number of replacements is, as we have seen, unpredictable (please refer to the first part). The solution then is to follow the demography of this resource and, if possible, make graphs using the recruitment abundance index and an index of the abundance of stock coming from this recruitment as is practiced, for example, with rock lobsters in New Zealand and Australia. Demographic analysis can reveal signs of over exploitation, a purely economical notion, and graphing will also allow the fishing effort to be adjusted or an adjustment in the catch per unit effort to be made.

The work of the fisheries scientist therefore has two orientations : on the one hand, within the context of fishing effort, which the scientist only records, to determine a minimum capture size, that is to say the minimum size to be respected so that the fisherman's income given the fishing effort is maximised; on the other hand, to determine the maximum number of individuals which can be harvested while ensuring that captures continue.

The two aspects of this work come down to determining fishing mortality (F) by age and by intensity. All management measures have an effect on the value of F and/or on the age at which it is applied. In the area of inshore fisheries, especially for lagoon species in island environments where sizes are quite small, a great deal of attention must be paid to the consequences of measures to limit fishing, especially when these are prohibitions pertaining to species or to periods of the year. For example, if half of the lagoon is closed to fishing, this necessarily implies that the other half will have to sustain the fishing effort of the entire island. If the goal is to maximise captures, this measure is poorly conceived and the result is that it can be expected that neither of the two halves of the lagoon will be very well managed. The overexploited one will

not gain any benefit from the under exploited one. However, if the idea is to promote the protected area through recreational activities, this measure then gains its full value, especially if these activities draw away some of the fishermen towards employment which has added value in the sector of tourism.

In conclusion the protection of the environment and stock management are inextricably linked.

The goal of protection is the health of the natural environment. It must work both at avoiding any harmful effects detrimental to development of the species and seek to initiate all measures aimed at allowing the greatest number of juveniles to become adults. The goal is not to protect adult organisms as breeders, as in fact they represent a potential fertility which is always superabundant. This is the role of stock management measures.

The goal of marine stock management is to use to the best advantage a renewable resource whose members will, in any case, be lost to natural causes beyond our control in spite of our protection efforts. This benefit to be drawn is a human concept i.e. to feed people, develop tourism, contribute to scientific research or serve education and training purposes.

Illustrations:

The following ten illustrations present the chronological evolution of data about the annual abundance of parental stocks of pelagic marine fishes and those related to the recruitment produced annually by this parental stock. Illustrations 1 to 6 describe the evolution of Mediterranean inshore stocks exploited by artisanal inshore techniques. Figures 7 and 8 show cod stocks in the North Atlantic exploited by trawl nets. Illustration 8 corresponds to a bottom-dwelling diadromous species whose parental stock only reproduces once and dies at the end of spawning. Figure 9 corresponds to a pelagic holosaline species whose breeding stock reproduces a great number of times in their lifetime.

It can be noted from these graphs that the evolution of the number of adults shows minor fluctuations without correlation to those of the number of juveniles which fluctuate much more widely.

It can also be noted that the evolution in the number of adults shows certain tendencies, especially when stocks exploited by commercial methods are involved, while the evolution of the number of juveniles appears chaotic and that this is more pronounced for a species with a short adult lifespan for species which are benthic or bottom-dwelling
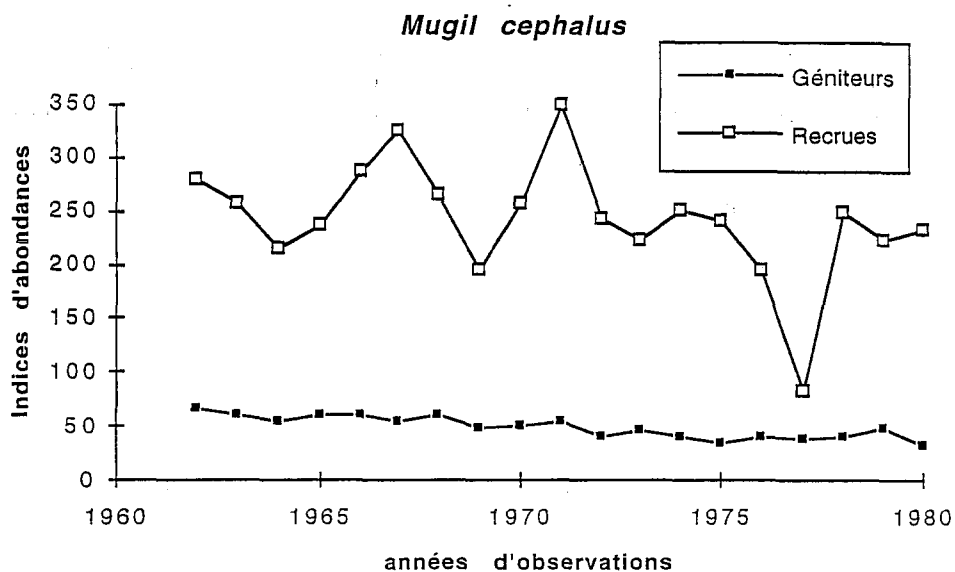
Mugil cephalus

Fig n°1: Evolution du stock Nord-tunisien du muge *Mugil cephalus* (Chauvet, 1986)
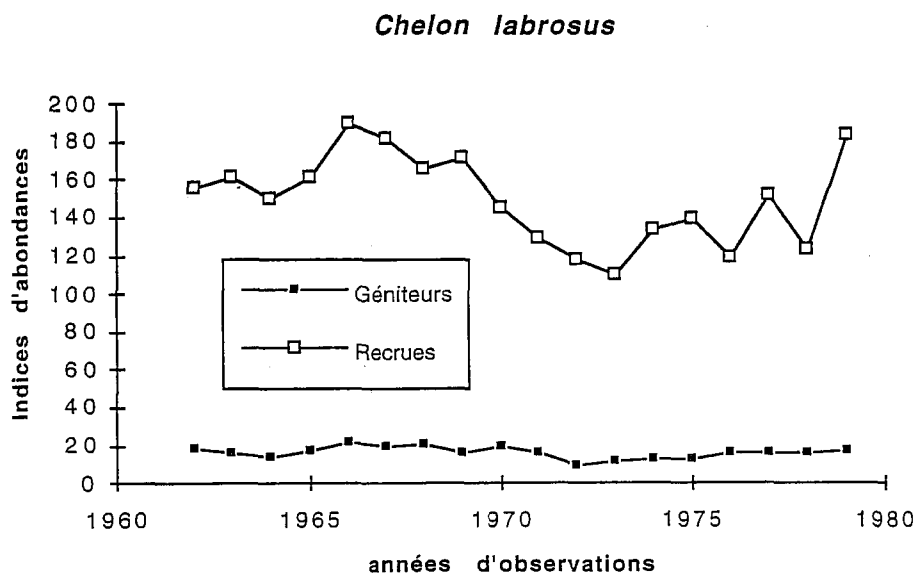
Chelon labrosus

Fig n°2: Evolution du stock Nord-tunisien du muge *Chelon labrosus* (Chauvet, 1986)
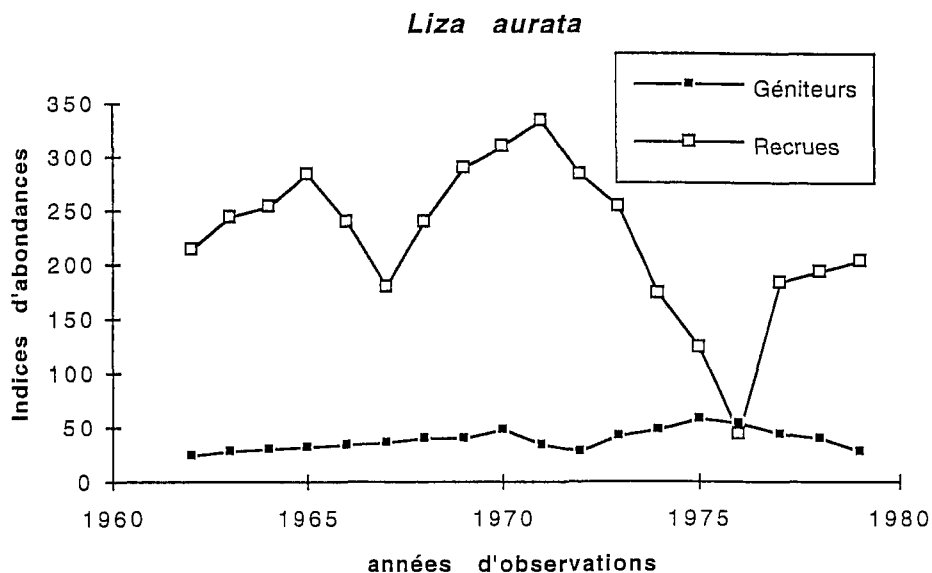
Liza aurata

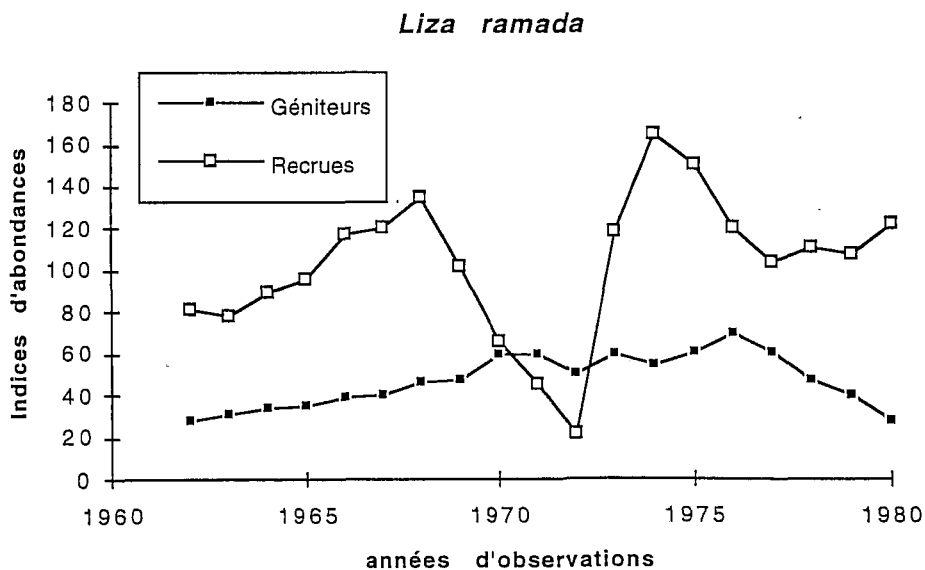Fig n°3: Evolution du stock Nord-tunisien du muge *Liza aurata* (Chauvet, 1986)

Liza ramada

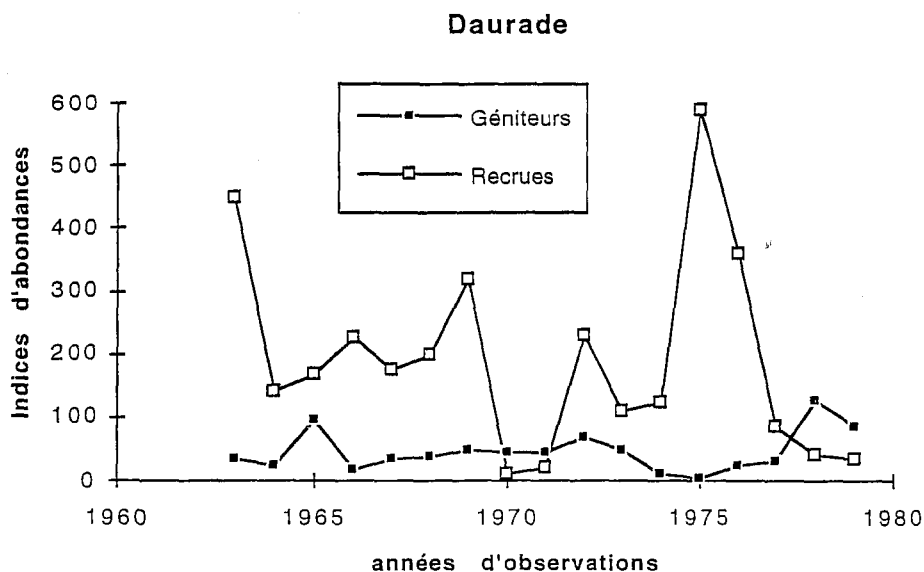Fig n°4: Evolution du stock Nord-tunisien du muge *liza ramada* (Chauvet, 1986)

Daurade

Fig n°5: Evolution du stock Nord-tunisien de la daurade *Sparus aurata* (Chauvet, 1986)

Dicentrarchus labrax
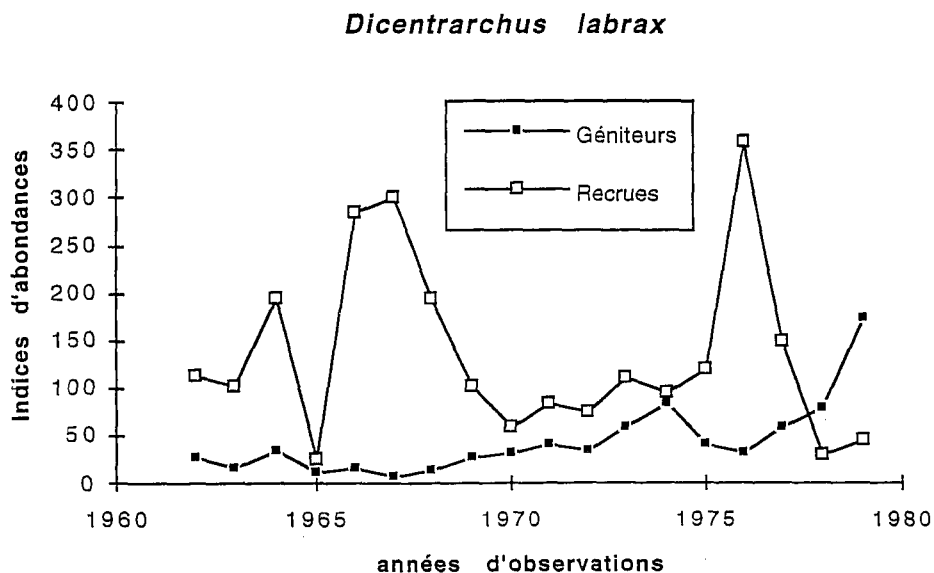
Fig n°6: Evolution du stock Nord-tunisien du loup *Dicentrarchus labrax* (Chauvet, 1986)
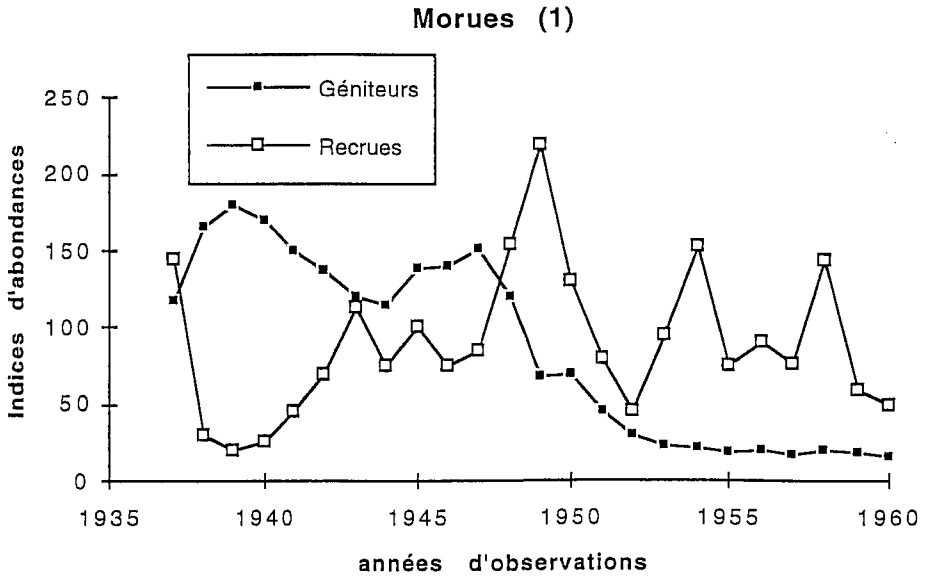
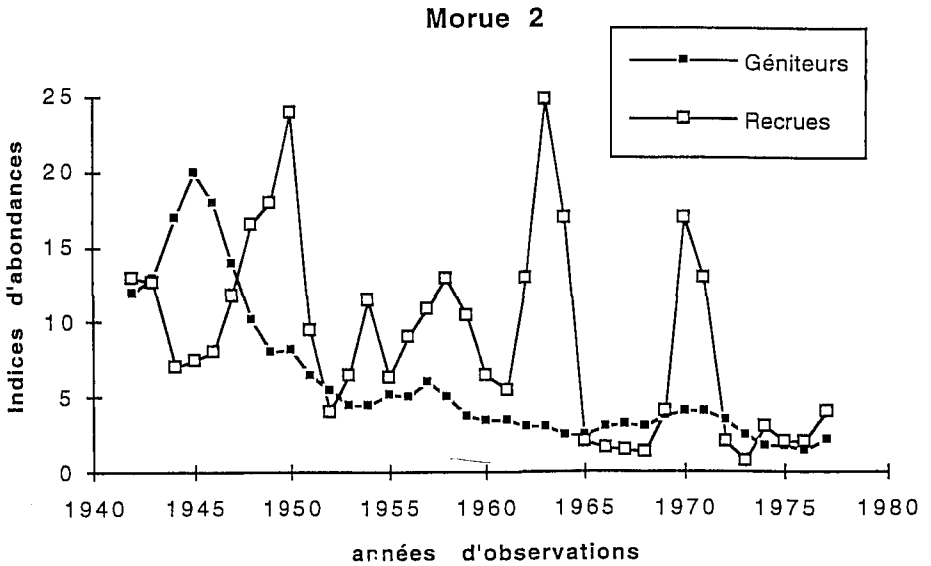Fig n°7: Evolution du stock norvégien de morues (Garrod, 1967)

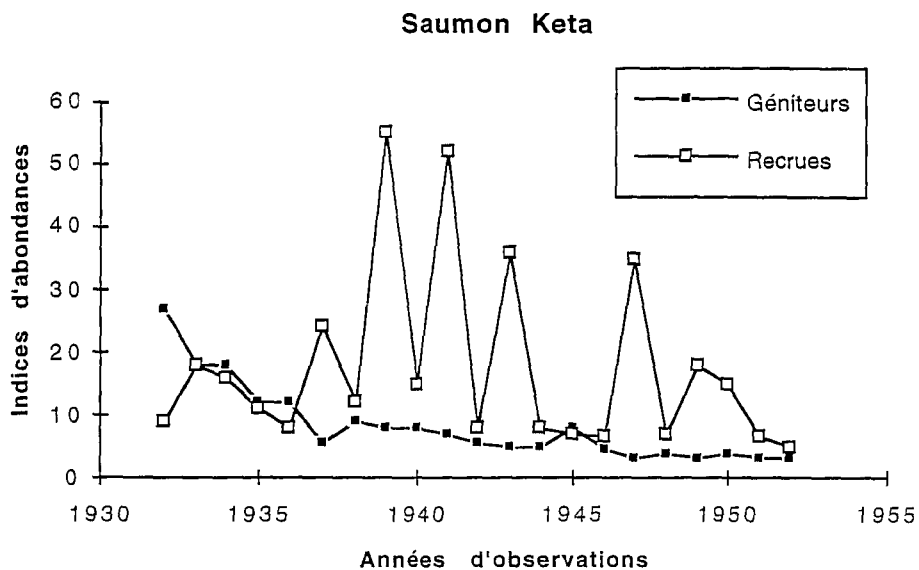Fig n°8: Evolution du stock d'atlantique nord de morues (Cushing, 1981)

Saumon Keta

Fig n°9: Evolution du stock de saumon Keta de la baie de Tillamook (Henry, 1953)
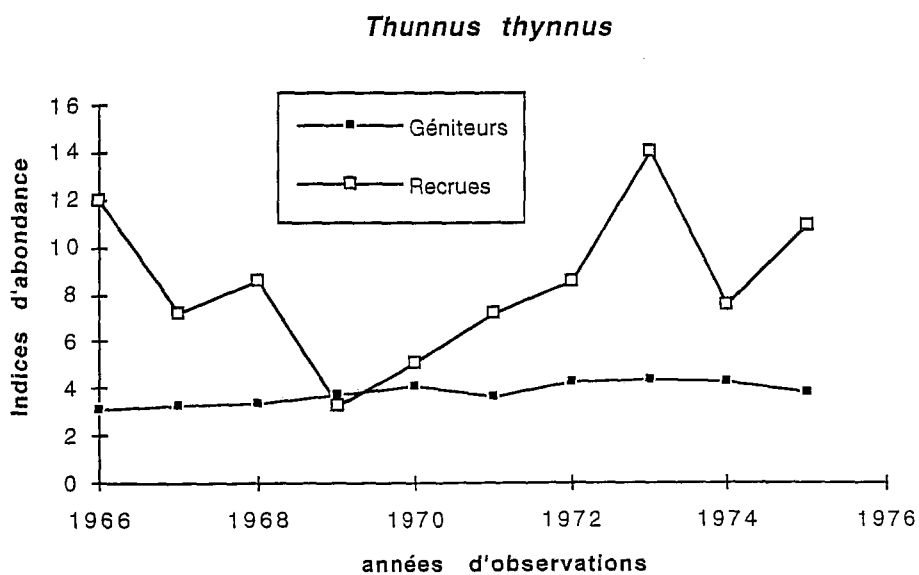
Thunnus thynnus

Fig n°10: Evolution du stock Nord-atlantique du thon rouge *Thunnus thynnus* (Farrugio, 1981)