

## Chapter 13

# Fisheries In Coastal Lagoons

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The 'four factors' — recruitment, growth, natural and fishing mortalities — viewed in classical fish dynamics as needed for predicting future from present stock sizes, are reviewed in the context of lagoon fisheries, whose worldwide catches and management are briefly discussed. Emphasis is given herein to the bordigue, a form of tidal trap used in the western Mediterranean area to harvest fish previously recruited to a lagoon, and/or retain undersized fish for another growth cycle. This form of harvest/management, which requires complex social arrangements, may, short of aquaculture, represent the optimum way of utilizing a lagoon to produce fish.

## Introduction

We shall briefly review the factors which determine fisheries yield in coastal lagoons, which have been defined by Ardizzone *et al.* (1988) as "bodies of waters (from brackish to hypersaline) partially separated from an adjacent sea by barriers of sand or other sediment, with openings through which seawater can flow" (see Kjerfve, this volume, for other definitions). 'Fisheries' refers to harvesting of fish and aquatic invertebrates and hence, excludes aquaculture.

The literature on coastal lagoons is immense; that on lagoon fisheries is also too large for a balanced review to fit into the space available for this chapter. We shall, therefore, concentrate on a few themes which we think are of special relevance to lagoon fisheries, yield prediction and management and to fishes only. Our examples will focus on one lagoon of the Gulf of Mexico, and West African and Mediterranean lagoons. We chose the first two locations because we worked there; and the Mediterranean cases,

TABLE 13.1

Fisheries yields of coastal lagoons (all groups included) as compared with the yields of other aquatic ecosystems<sup>a</sup>

Systems	Yields (t km <sup>-2</sup> year <sup>-1</sup> )		
	Median	Mean	<i>n</i>
Coastal lagoons	5.1	11.3	107
Continental shelves	4.8	5.9	20
African/Asian reservoirs	4.2	7.5	41
Coral reefs	4.1	4.9	15
River floodplains	3.2	4.0	33
Reservoirs (U.S.A.)	1.3	2.4	148
Natural lakes	0.5	2.8	43

<sup>a</sup>From Kapetsky (1984)

because this is where the management scheme emerged to which we would like to point the readers' attention. Except for a few references, we shall thus not cover the important lagoon fisheries of the Indo-Pacific area. These lagoons are included, however, in the compilation of lagoon fisheries catches discussed below.

### Fisheries Catches From Coastal Lagoons

Kapetsky (1984) presented the largest data set on catches from coastal lagoons assembled to date, and compared these with catches from other exploited marine and freshwater ecosystems.

As can be seen from Table 13.1, coastal lagoons are, overall, more productive than other ecosystems in terms of fisheries yield, whether one uses the mean or the median as a measure of central tendency. This can ultimately be accounted for by the generally high primary production in coastal lagoons (Nixon, 1982), for which three reasons may be suggested:

- availability of organic matter inputs via rivers (Kapetsky, 1984; Yáñez-Arancibia and Aguirre-León, 1988);
- shallowness, conducive to rapid remobilization of nutrients (Qasim, 1973a, 1973b; Jones, 1982; Nixon, 1982; Quignard, 1984);
- velocity and volume of water exchanges between the sea and the lagoon (which also directly affects fish production via recruitment (cf. Bourquard and Quignard, 1984).

However, coastal lagoons do not have uniformly high yields and indeed, the frequency distribution of Kapetsky's yield data is strongly skewed (Fig.

13.1). Some factors leading to this nearly log-normal distribution are, with regard to the numerous occurrences of unproductive lagoons:

- extreme salinities and temperature fluctuations, turbidity, anoxic conditions or toxic discharges (Gunter, 1967);
- very shallow sills, preventing sufficient recruitment;
- excessive illumination or turbidity, of which either can lead to reduced primary productivity (Qasim, 1973a, 1973b);
- lack of sufficient fishing effort (Quignard, 1984; Bailey, 1988).

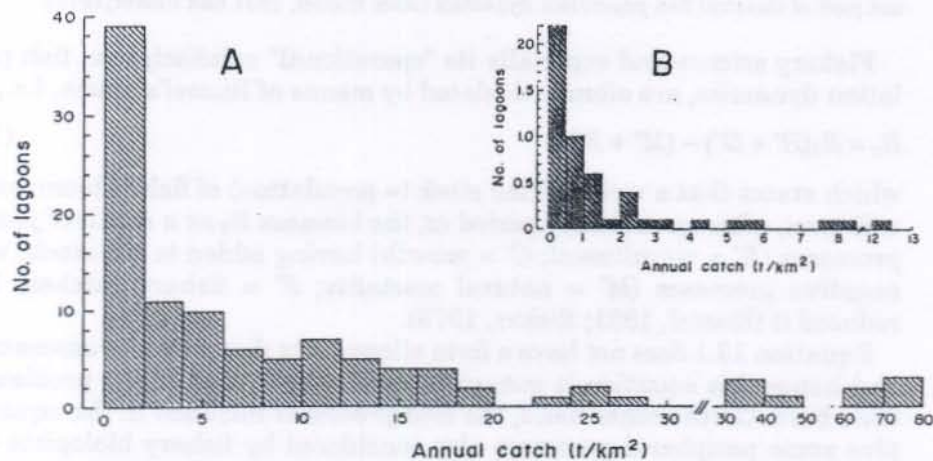


Fig. 13.1. Frequency distribution of fishery catches from coastal lagoons (after Kapetsky, 1984). (A) Finfish,  $n = 106$ . (B) Penaeid shrimp,  $n = 51$ .

The few extremely productive lagoons in Fig. 13.1 may benefit, on the other hand, from a number of factors:

- a coastal habitat supplying a large recruitment;
- fertilization via agricultural runoff, or human sewage and through water exchanges with the sea;
- a management regime which makes the best of the incoming recruitment.

### Fish Population Dynamics and Its Four Factors

#### *Russel's Axiom*

The definition of 'fisheries' in the introduction implies the need for management: common-property, open-access natural resources systems, given competing users, cannot produce high, sustained yields if left to themselves (Hardin, 1968).

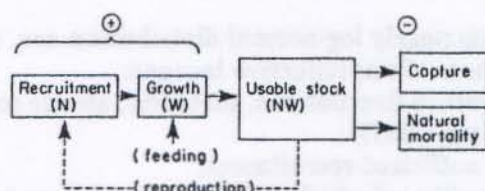


Fig. 13.2. Schematic representation of the four key factors determining the future biomass of and catches from a stock: recruitment where  $N$  = number of fish added to the stock, individual growth in weight ( $W$ ) of the recruited fish, natural mortality and capture or fishing mortality. Feeding and reproduction, although necessary for stock build-up and maintenance, are usually not part of classical fish population dynamics (after Russel, 1931 and Ricker, 1975).

Fishery science and especially its "operational" subdiscipline, fish population dynamics, are often articulated by means of Russel's axiom, i.e.,

$$B_2 = B_1(R' + G') - (M' + F') \quad (13.1)$$

which states that a well-defined stock (= population) of fish of biomass ( $B_1$ ) will have, after an arbitrary period  $\Delta t$ , the biomass  $B_2$  as a result of positive processes ( $R'$  = recruitment;  $G'$  = growth) having added to the stock, while negative processes ( $M'$  = natural mortality;  $F'$  = fishery catches) have reduced it (Russel, 1931; Ricker, 1975).

Equation 13.1 does not have a form allowing its direct use for assessment, and hence this equation is generally used only for defining a problem, as done here. On the other hand, the four processes included in the equation, plus some peripheral processes also considered by fishery biologists (Fig. 13.2) have been put in a mathematically tractable form (see Schaefer, 1957; Beverton and Holt, 1957; Ricker, 1975; Gulland, 1983; Pauly, 1984). Here, we shall present a few of the models that have resulted from these efforts, specifically those which have been used in dealing with coastal lagoons.

The four factors shall be examined in the sequence: growth, natural mortality, fishing mortality and related factors (mainly catch/effort), with recruitment being last, because it is the most complex factor to investigate, to model and to predict.

#### *Growth of Fishes in Coastal Lagoons*

Lagoon environments are highly seasonal, more so than the open marine environment to which they are connected. Thus, the food types (cf. Aguirre-Leon and Yáñez-Arancibia, 1986; Chavance *et al.*, 1984, and Fig. 13.3) and food consumption, and hence, the growth of lagoon fishes are bound to oscillate seasonally, whether the fish in question undertake seasonal migrations in and out of coastal lagoons or not. Various authors have modified the von Bertalanffy equation (von Bertalanffy, 1938), commonly used to express growth of fish, to accommodate seasonal growth oscillations (Longhurst and

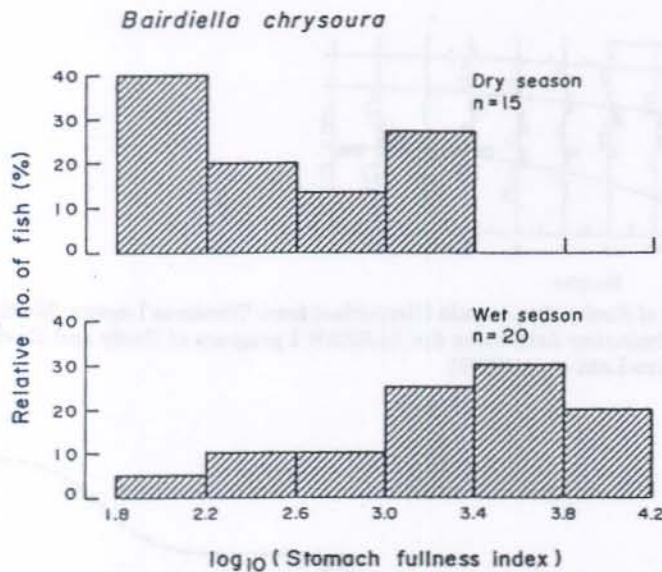


Fig. 13.3. An example of seasonal changes in the stomach contents and hence, presumably the food consumption of a lagoon fish: *Bairdiella chrysoura*, Términos Lagoon, Mexico (computed from Chavance *et al.*, 1984).

Pauly, 1987; Hoenig and Chaudhury Hanumara, 1982; Somers, 1988; Soriano and Jarre, 1988).

Figure 13.4 presents an application example pertaining to a lagoon fish, *Eucinostomus gula* (Gerreidae) from Términos Lagoon, Mexico (Aguirre-León *et al.*, 1989).

The growth models presented by these authors cannot accommodate long periods of zero growth. Therefore, we present here a new model, which can accommodate a (winter) period of growth stagnation called no-growth time (NGT). To fit the curve, the time axis is divided into one growth and one no-growth time over each period of one year. Then, during growth time, we have

$$L_t = L_{\infty} [1 - \exp(-w)] \quad (13.2)$$

in which  $L_t$  is the length at age  $t$ , and where

$$w = K(t' - t_0) + \frac{K}{(1 - NGT)} \left[ \sin \frac{2\pi}{1 - NGT} (t' - t_s) - \sin \frac{2\pi}{1 - NGT} (t_0 - t_s) \right] \quad (13.3)$$

where  $t'$  is obtained by subtracting from the age  $t$  the total amount of NGT the fish experienced, since  $t = 0$ .

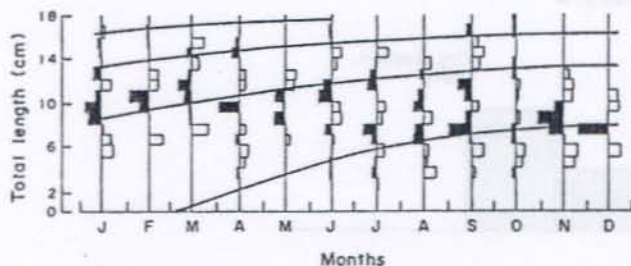


Fig. 13.4. Seasonal growth of *Eucinostomus gula* (Gerreidae) from Términos Lagoon, Mexico as estimated from length-frequency data using the ELEFAN I program of Pauly and David (1981). Adapted from Aguirre-León *et al.* (1989).

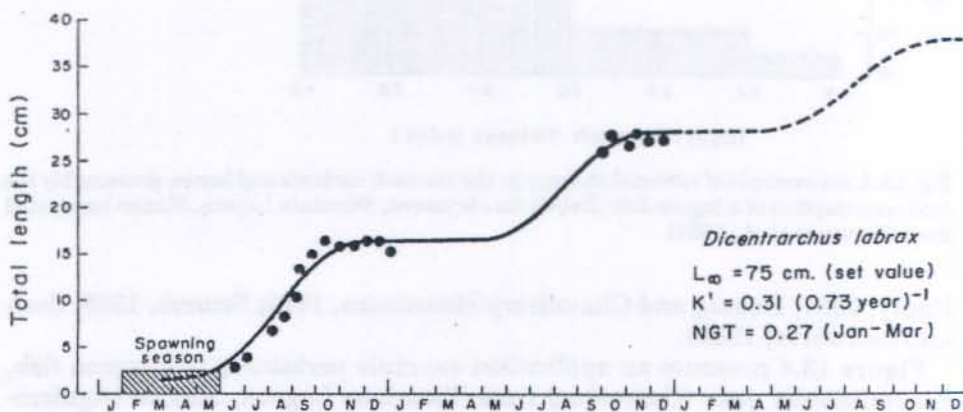


Fig. 13.5. Seasonally oscillating growth of a major fish species in Mediterranean lagoon catches (Monthly size data from Quignard, 1984; maximum size ( $\approx L_{\infty}$ ) and spawning season from Beauchot, 1987).

The other parameters are  $L_{\infty}$  the asymptotic length, i.e., the average length the fish would attain if they lived indefinitely;  $K'$  a parameter expressing how fast  $L_{\infty}$  is approached,  $t_0$  the theoretical 'age' at length zero if the fish always grew according to the equation; and  $t_s$  is a parameter adjusting a seasonal cycle to start at  $t = 0$ . Note that the seasonal growth itself (outside of  $NGT$ ) is described by a sine wave curve with period  $1 - NGT$ , and that the unit of  $K'$  is  $(\text{year} - NGT)^{-1}$  instead of  $\text{year}^{-1}$ .

An application example for this model is given in Fig. 13.5. As might be seen, the model predicts a no-growth time of about 3 months (January to March) for *Dicentrarchus labrax* in l'Étang d'Or, France, a feature which earlier growth models could not have picked up.

When growth is not seasonal, i.e., when one deals with data points that are one year apart or when working with otolith microstructures of fish not

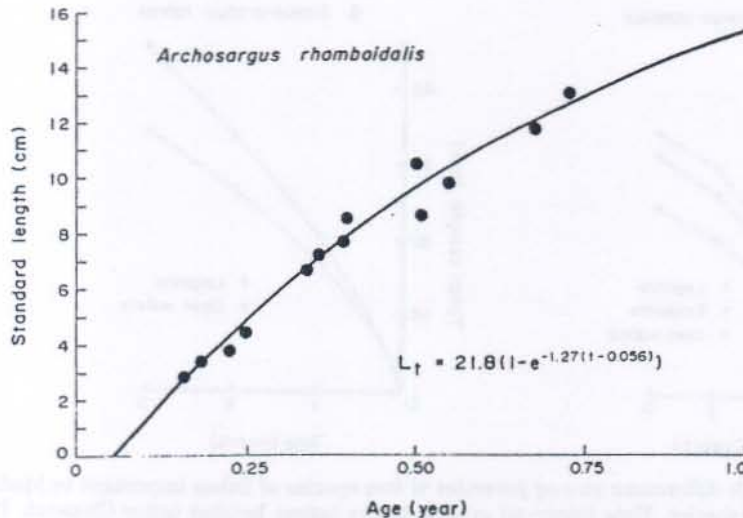


Fig. 13.6. Growth of *Archosargus rhomboidalis* (Sparidae) in Términos Lagoon, Mexico as inferred from counts of otolith microstructures (recomputed from Chavance *et al.*, 1986). The new parameter estimates derived here differ from those originally presented because a non-linear routine was used to fit the data; the new estimate of  $L_{\infty} = 22$  cm is closer to the maximum length in Términos Lagoon (23 cm) than the original estimate of  $L_{\infty} = 20$  cm (cf. Chavance *et al.*, 1986).

belonging to a given cohort, the standard von Bertalanffy curve can be used. It has the form:

$$L_t = L_{\infty}(1 - e^{K(t-t_0)}) \quad (13.4)$$

where  $L_{\infty}$  and  $t_0$  have the same definitions as in Eqs. 13.2 and 13.3, where  $K$  has the dimension of  $\text{time}^{-1}$  (e.g.,  $\text{year}^{-1}$ ). An application example is presented in Fig. 13.6.

The growth of fishes within coastal lagoons relative to that of conspecifics growing in other habitat appears to be a function of (a) the type of lagoon and/or of habitats being compared, (b) the species of fish, and (c) the life stage of the fish species.

Thus, Chauvet (1988) suggests that shallow, eutrophic lagoons lead to improved growth compared with deep lagoons, strongly influenced by the marine regime. He also noted, with regard to Mediterranean species such as *Sparus auratus* (Fam. Sparidae) and *Dicentrarchus labrax* (Fam. Moronidae) that the lagoon habitat appears to lead to higher growth rates among the juveniles and young adults (Fig. 13.7), while among the older specimens of these two species, growth within lagoons is at best equivalent to, and generally less than, that in the marine environment (Chauvet, 1988).

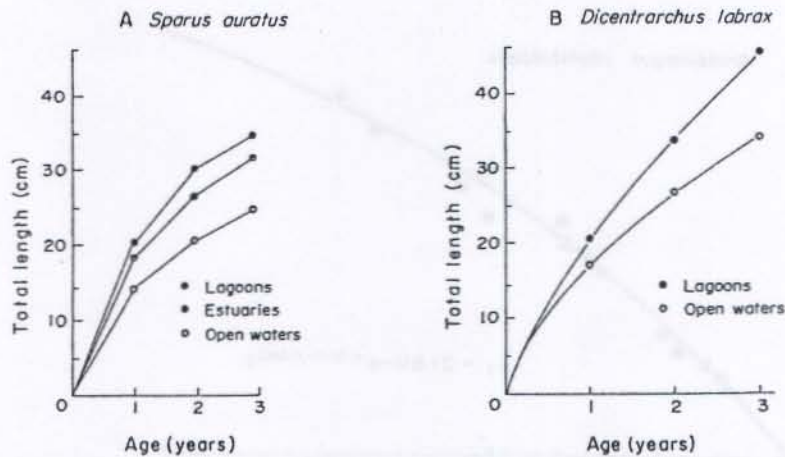


Fig. 13.7. Growth differences among juveniles of two species of fishes important to Mediterranean lagoon fisheries. Note improved growth in the lagoon habitat (after Chauvet, 1984, 1988).

The West African coast offers further and clearer indications of at least small coastal lagoons being habitats leading, independently of fishing effects, to reduced final (maximum) sizes among resident fishes: (a) the maximum observed size of *Sarotherodon melanothron* (Cichlidae) in the small poikilohaline Sakumo lagoon was 19.5 cm (Pauly, 1976) vs. 25 cm in the much larger, estuarine Lagos lagoon (Fagade, 1974), and (b) two forms of the *Ethmalosa fimbriata* (Clupeidae) appear to occur in West Africa, one occurring along the coast, and in estuaries and large 'open' coastal lagoons, and reaching sizes up to 30 cm, the other limited to length of about 15 cm and occurring and reproducing only within closed lagoons (Longhurst and Pauly, 1987).

Improved growth of juveniles combined with limited maximum sizes of adults are not necessarily contradictory. Indeed, rapid juvenile growth due to availability of abundant food and high habitat temperatures generally implies a reduction of maximum adult sizes. Longhurst and Pauly (1987) give reasons why this should be so.

#### Natural Mortality of Fishes in Coastal Lagoons

The natural mortality of a fish population is straightforward and can be modelled using:

$$N_2 = N_1 e^{-M\Delta t} \quad (13.5)$$

where  $N_1$  and  $N_2$  are the numbers of fish at the beginning and end, respectively, and  $M$  is the instantaneous rate of natural mortality during a period  $\Delta t$ . Instantaneous rates such as in Eq. 13.5 e.g., natural ( $M$ ) and



fishing ( $F$ ) mortality can be added to yield total mortality ( $Z$ ) and the latter used in equations analogous to Eq. 13.5.

Beverton and Holt (1959) were the first to demonstrate rigorously that the growth performance of fishes is strongly correlated with their natural mortality, i.e., that the growth parameter  $K$  of fishes with similar  $L_{\infty}$  values (Eq. 13.4) generally represents a constant proportion of  $M$ . Their findings were generalized by Pauly (1980) based on data from 175 fish stocks to yield the empirical equation:

$$M = (K^{0.65}) \frac{T^{0.46}}{L_{\infty}^{0.28}} \quad (13.6)$$

where  $L_{\infty}$  = asymptotic length (total length, in cm),  $K$  = year<sup>-1</sup> and  $T$  = temperature in °C.

Hence, lagoon fishes, which tend to have higher  $K$  and lower  $L_{\infty}$  values than their conspecifics in open waters, can be expected to have generally higher natural mortalities than their open-water counterparts. This explains the observation of Chauvet (1988), who noted that "strangely, it is in the lagoon habitats that are most favorable for growth that the mortality rates are highest ...".

It is important, however, to distinguish between the relatively low natural mortality rates affecting late juveniles and adults, which are fairly constant and somehow predictable, from those affecting larval and early juveniles, which are high and largely unpredictable.

Moreover, an important distinction with regard to lagoons is that between natural mortality rates as discussed above and catastrophic mortalities, as caused e.g., by dystrophic crises (Chauvet, 1988). The former may be seen, at least as far as stocks rather than individuals are concerned, as a gradual process. Thus, natural mortality, as influenced or determined by predation, will be more or less continuous over a certain period, and can be compensated for by population growth, leading to the observed narrow range of  $M/K$  values, otherwise, stock could not maintain themselves in evolutionary times.

Catastrophic mortalities, on the other hand, which are quite frequent in lagoons, are episodic events, usually connected with sudden changes of water characteristics such as dissolved  $O_2$ ,  $H_2S$  content, temperature, which can induce large-scale death among resident stocks and sometimes their total annihilation.

Many natural or anthropogenic factors may cause catastrophic mortalities in coastal lagoons, including:

- eutrophication, leading to nighttime depletion of oxygen and/or benthic production of  $H_2S$  which can be released into the water column by storms;
- cold or hot spells, particularly effective in shallow lagoons (Gunter, 1952; 1957; 1967);
- terrigenous pollution e.g., from agricultural pesticides.

Catastrophic mortalities are difficult to incorporate into standard population dynamics model and have indeed not generally been considered explicitly in fisheries management. Their probability of occurrence and their prevention are, however, important aspects of management schemes involving bordigues and aquaculture in coastal lagoons.

#### *Fishing Mortality and Related Statistics*

Fishing mortality defined above as  $F = Z - M$  can also be defined as:

$$F = \frac{C}{B} \quad (13.7)$$

where  $C$  is the fisheries catch (in weight) during a given period and  $B$  is the mean biomass during that same period. Equation 13.6 provides the rationale for attempts to estimate the biomass of fishes in coastal lagoons using e.g., tagging (see Lam Hoai and Lasserre, 1984). Another important definition involving  $F$  is

$$C = q \cdot f \cdot F \quad (13.8)$$

and hence,  $C/f = q \cdot F$ , where  $C$  is as defined above,  $f$  represents the fishing effort and  $q$  is the catchability coefficient of the gear represented by  $f$ . These definitions imply that  $C/f$  (the catch per unit of effort or CPUE of earlier authors) is, given a constant  $q$ , proportional to biomass and hence can be used to monitor the status of a stock whose absolute biomass may be unknown (Fig. 13.8A).

Lam Hoai and Lasserre (1984) reviewed the applicability of these and derived models, notably yield per recruit ( $Y/R$ ) and cohort analysis, to lagoon fisheries, and the methods, e.g., surveys or tagging studies, were used to estimate their parameters. They concluded that:

- the assumption of equilibrium implicit in most standard models for analyzing the population dynamics of fish (notably  $Y/R$  analysis) render these models questionable when applied to data from lagoon fisheries;
- the scattered and small-scale nature of fisheries operation in coastal lagoons generally makes the routine collection of  $C/f$  data too costly. Hence, such data are lacking for most lagoons (Kapetsky, 1984) or are largely unreliable (Bailey, 1988);
- the methods that may be most appropriate for lagoon fisheries, i.e. virtual population analysis or cohort analysis (Gulland, 1965; Pope, 1972), which have the advantage of not requiring estimates of fishing effort, do require catch-at-age data, which can be obtained in a cost-effective fashion only for the most important species in major lagoon fisheries;

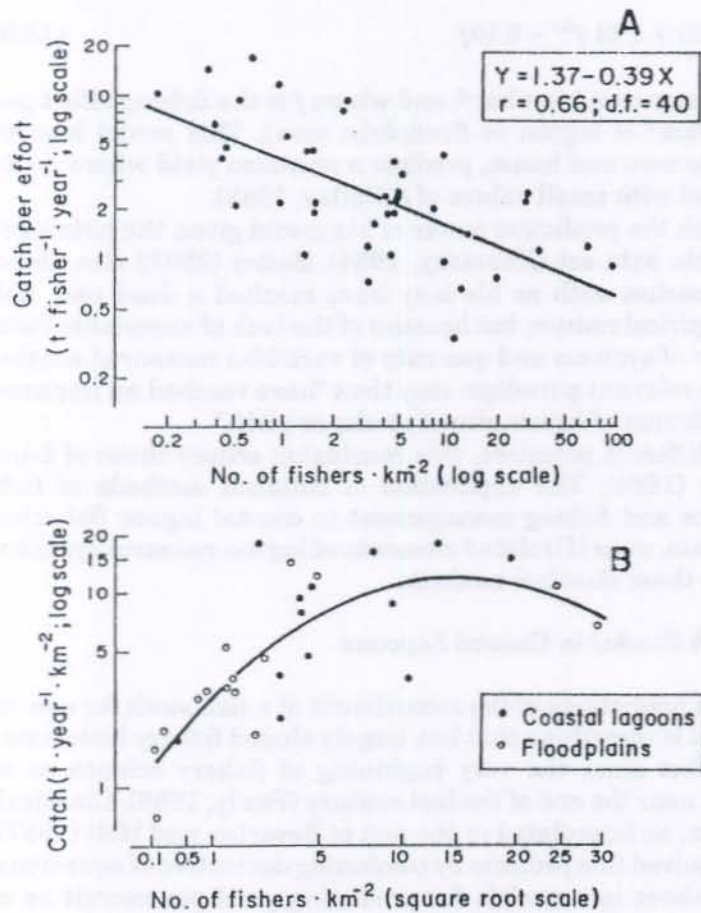


Fig. 13.8. Examples of the relationships between fishing effort per area, i.e. fishing intensity, and dependent variables. (A) Relationship between  $C/f$  and fishing intensity in 42 coastal lagoons (Kapetsky, 1984). (B) Relationship between yield,  $C$ , and fishing intensity in 13 coastal lagoons (plus 15 river floodplains, which appear to have similar yields) (Bailey, 1988).

– it may be most appropriate to manage lagoon fisheries as a black-box system, using a form of adaptive management in which the catches resulting from initial interventions are monitored and used to refine a next set of interventions.

Bailey (1988), working on various tropical small-scale fisheries data sets, including coastal lagoons, noted that the inclusion of fishing effort considerably added to the precision of empirical, i.e., black-box models in predicting yields in such systems. He derived, for lagoons ( $n = 13$ ) and floodplains ( $n = 15$ ), the joint model (Fig. 13.8B):

$$\log_e(\text{yield} + 1) = -0.19 + 1.44 f^{0.5} - 0.19f \quad (13.9)$$

for an annual yield expressed in t km<sup>-2</sup>, and where  $f$  is the fishing effort per area (here, fishers/km<sup>2</sup> of lagoon or floodplain area). This model has an intercept unequal to zero and hence, predicts a non-zero yield where  $f = 0$ . It should not be used with small values of  $f$  (Bailey, 1988).

While pleased with the predictive power of his model given the heterogeneity of the available data set (Kapetsky, 1984), Bailey (1988) also noted that external approaches such as his may have reached a dead end, not because of their empirical nature, but because of the lack of acceptable data "in terms of number of systems and quantity of variables measured consistently" and that the relevant paradigm may thus "have reached an impasse with respect to prediction of future size of stocks or yield."

While based on different premises, this conclusion echoes those of Lam Hoai and Lasserre (1984). The application of classical methods of fish population dynamics and fishing management to coastal lagoon fisheries appears inappropriate, even if isolated elements of lagoon resource systems can be described by these classical methods.

#### *Recruitment to (Fish Stocks) in Coastal Lagoons*

Providing reliable predictions of the recruitment of a fish stock for use in fishery management is something that has largely eluded fishery biologists, despite massive effort since the very beginning of fishery science as a discipline of its own near the end of the last century (Pauly, 1986). Classical population dynamics, as formulated in the text of Beverton and Holt (1957) or Ricker (1958), resolved this problem by combining derivative of equations such as presented above into models for predicting yield per recruit as a function of control variable such as  $F$  and age at first capture ( $t_c$ ). An example of such model is:

$$\frac{Y}{R} = F \cdot e^{MR_2W_{..}} \left[ \frac{1}{Z} - \frac{3e^{-Kr_1}}{Z+K} + \frac{3e^{-2Kr_1}}{Z+2K} + \frac{e^{-3Kr_1}}{Z+3K} \right] \quad (13.10)$$

where  $r_1 = t_c - t_0$  and  $r_2 = t_c - t_r$ ,  $Z$  and  $K$  are as defined above,  $W_{..}$  is the weight corresponding to  $L_{..}$ , and recruits of age  $t_r$  are defined as fully metamorphosed young fish whose growth is described adequately by an equation also describing the growth of the adults, whose instantaneous rate of natural mortality is similar to that of the adults, and who occur in or swim into some fishing ground (Pauly, 1984).

Following Ricker (1954), numerous fishery biologists have attempted to develop models linking parent stock and subsequent recruitment. The various curves are not reviewed here. Their lack of usefulness has been sufficiently demonstrated (Sharp and Csirke, 1983).

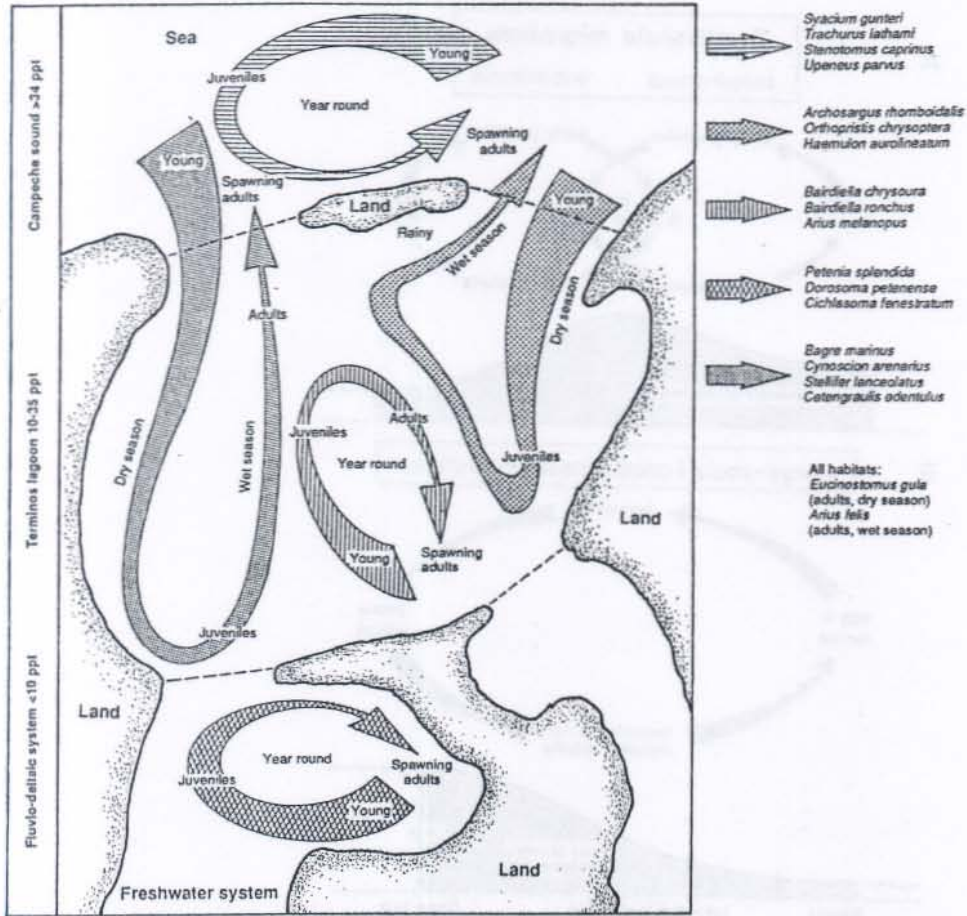


Fig. 13.9. Examples of fishes with characteristic migration patterns within, outside of, and into and out of Términos Lagoon, Southern Gulf of Mexico (redrawn from Yáñez-Arancibia *et al.*, 1988).

Three groups of fishes occur in coastal lagoons: (i) sedentary species: those which spend their entire life cycles within coastal lagoons; (ii) seasonal migrants: those which enter the lagoon during a more or less well-defined season from either the marine or the freshwater side and leave it during another season (Fig. 13.9); and (iii) occasional visitors: those which enter and leave lagoon without a clear pattern within and among years.

Group (i) is usually very limited, especially when species with planktonic stages are considered. Most lagoon fishes spawn outside lagoons. The tilapia *Sarotherodon melanotheron*, a male mouthbrooder, is an exception and its special ability to withstand large variations of temperature and salinity has enabled it to dominate completely the fauna of small closed

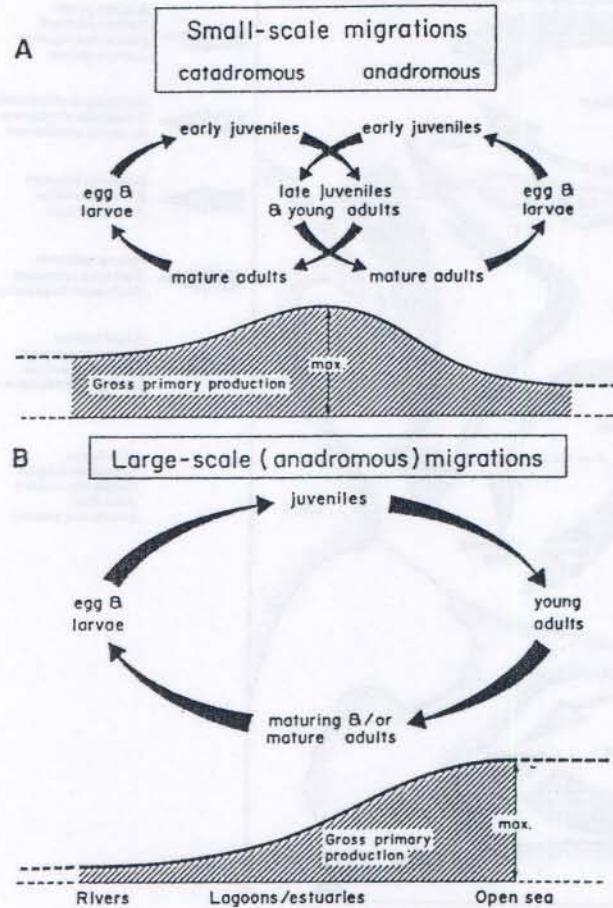


Fig. 13.10. Schematic representation of (A) small-scale migrations involving shelf, lagoon/estuary and freshwater habitats and allowing certain tropical fish stocks to maintain higher abundances than if they utilized only one type of habitat, and (B) large-scale migrations. Note the marked difference of the scheme in A to the cold/temperate situation, characterized by large-scale anadromic migrations (after Yáñez-Arancibia and Sanchez-Gil, 1988).

lagoons along the West African coast (Pauly, 1976).

Generally, however, it is members of Group (ii) which dominate the fauna of coastal lagoons, e.g. by contributing near 100% of the ichthyofauna of many Mediterranean lagoons (Quignard, 1984). Group (iii) is represented in the Mediterranean by species such as *Belone belone* or *Scomber scombrus* (J.P. Quignard, pers. com.), by species such as *Lutjanus* spp or *Caranx hippo* in West African lagoons (Pauly, 1975), or species such as *Bagre marinus*, *Cetengraulis edentulus*, *Archosargus rhomboidalis* or *Haemulon aurolineatum* in lagoons of the southern Gulf of Mexico (Fig. 13.9).

Different opinions exist with regard to the mechanisms of recruitment into lagoons of Group (ii) fishes. Quignard (1984) and Chauvet (1988), representing the Eastern Atlantic school, stress that the recruitment of Group (ii) fishes into coastal lagoons is not necessarily due to migrations (Harden-Jones, 1968). Rather, fishes of this group are either flushed into lagoons while still in the planktonic stage, or swim as early juveniles into lagoons against the outgoing current, either due to their effort to stay close inshore or due to coastal wanderings (*errances* in French texts) in search of food.

The other school, which may be called Western Atlantic, stresses the important role that lagoons play in the life cycles of many coastal fishes. Here, lagoons are viewed as major elements of small-scale migrations, which, by involving lagoon/estuarine habitats, allow a high standing stock to be maintained (Fig. 13.10).

In either case, the relative level of recruitment into coastal lagoons will be determined between lagoons by the ease with which fish can penetrate into these, and between years by the overall number of potential recruits along the coast. This former point implies, as also emphasized by Chauvet (1988), that recruitment to coastal lagoons can be artificially increased by keeping the mouth of lagoons open during periods when juveniles of preferred species occur along the coast, or by deepening the sill of lagoons with very shallow mouths.

Coping with between-year variability of recruitment to lagoons is more difficult, and one of the few practical approaches for dealing with this problem is management through *bordigues*, the gear and management tool to which the Food and Agriculture Organization of the United Nations (FAO) devoted its first manual on lagoon management (Chauvet, 1984).

## Management of Coastal Lagoon Fisheries

### *Conventional Fisheries Management*

As alluded to in the introduction, fisheries, at least in modern times, tend to quickly become overfished unless they are managed, the result of an overwhelming harvesting capability applied to finite resources that belong to no one before they are caught (common property) and which everyone has the right to exploit (open access). Fisheries management, therefore, generally involves putting restrictions on either (a) access to the resources, (b) number of gears, (c) type of gear deployed, (d) timing of effort deployment, or (e) some combination of these (Kapetsky, 1981). The models used to derive the numbers needed for such management are commonly (i) analytical models (Beverton and Holt, 1957), or (ii) surplus-production model (Schaefer, 1957; Munro, 1979), with either of these possibly containing some economic component, i.e. consideration of fishing costs and of gross returns.

One commonly-used analytic model, structured around the four factors discussed above, is the yield-per-recruit model (Eq. 13.9), which can be used to assess the optimum size/age at first capture. The optimum mesh size in a given fishery with known fishing mortality identify the optimum fishing mortality, given a certain unique range of size/age at which the fish of a given stock should be caught. Such computations can be made a bit more realistic by adding a size-value relation into the model, which leads to optimum monetary or non-monetary return per recruit being evaluated (Willman and Garcia, 1985; Die *et al.*, 1988).

Surplus-production models, on the other hand, can either be time- or space-structured. In the former, a time series of catch data from a given fishery is related to the corresponding time series of effort data such that the optimum level of effort, yielding the largest (hopefully) sustained catch (MSY) is identified (Schaefer, 1957; Ricker, 1975). The other class of surplus production model is based on the assumption that a number of units compared such as lakes, lagoons, and coastal stretches, had similar potential production before onset of a fishery, and that catch differences between them are due to different levels of effort (Munro, 1979). This leads to models such as Eq. 13.8, which allow rough estimation of potential or optimum yields for given levels of effort. This allows the assessment of whether a lagoon is under- or over-fished. Unfortunately, long time series of catch and effort data, needed for fitting time-structured surplus models, are generally lacking.

Yield-per-recruit models, on the other hand, when thoughtlessly used to assess fishes or shrimp stocks within lagoons, tend to lead to the same results: wherever they are applied, they suggest that it is better to let the generally small fish and shrimp that occur inside lagoons escape, and be caught later by some offshore fishery.

This reflects the fact that, until recently, fishery research viewed lagoons as one side of an antagonistic relationship, in which often poor, small-scale fishers catch large numbers of undersized fish and shrimp, which if they had escaped from the lagoons, would have contributed yields to more rational industrial fisheries outside the lagoons (Garcia and Le Reste, 1981). There exists, however, an approach by which the conflict between lagoon and coastal fisheries can be resolved, and this involves turning coastal lagoons from marginal sites for harvesting of undersized fish into production units making most of the natural recruitment they receive, just as any well-managed coastal fishery is supposed to do.

#### *Using 'Bordigues' as a Tool for Fisheries Management*

The French word *bordigues* (from the Provençal *bourdigo*) refers to a fishing gear widespread around the Mediterranean and representing the culmination of an evolution spanning over two millennia (Chauvet, 1988; McCann, 1988). It is essentially a trap. Its basic principle is simple: all young fish wanting to



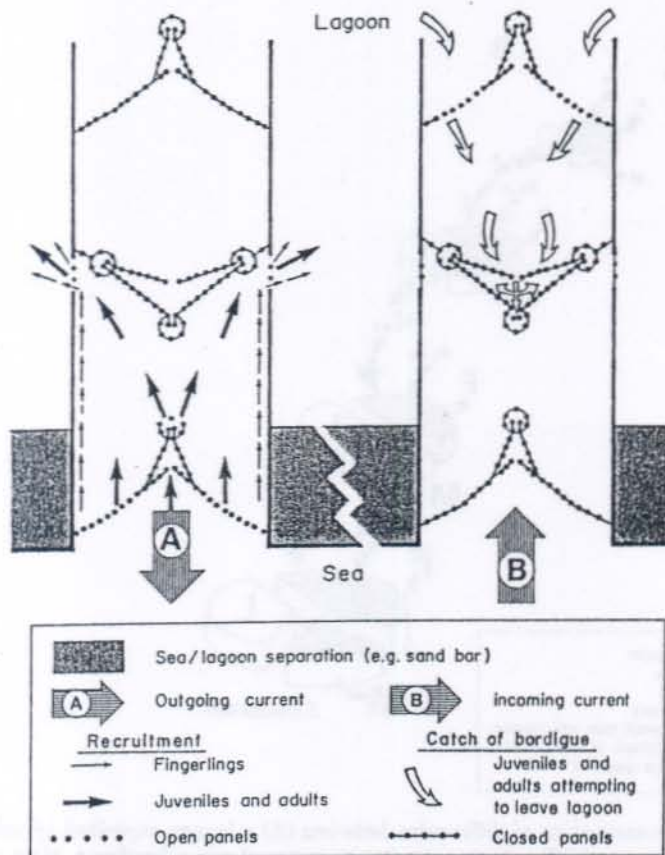


Fig. 13.11. Schematic representation of a (Tunisian) bordigue, showing (A) how recruits are let through to the lagoon when the water flows out of the lagoon, and (B) how fish attempting to leave when the water flows into the lagoon are caught to be either marketed or returned to the lagoon for another growth cycle (after Chauvet, 1988).

get into the lagoon through a bordigue can; none of those who try to leave the lagoon can do so (Fig. 13.11). Bordigues, which are usually placed along the channel connecting a lagoon and the sea, thus differ in principle from gears such as traps, fish corrals, and gill nets that are deployed, often in great numbers, within the lagoon but which do not totally block the outlet, and hence let a fraction of the fish leave the lagoon to the sea.

Here, the question might arise: how can a gear which retains all the fish attempting to leave a lagoon be useful to management? The point is that the bordigues are so constructed that the fish they retain are not killed, but rather graded according to size, and diverted into holding areas through adjustable panels of different mesh sizes. Only fish that have reached

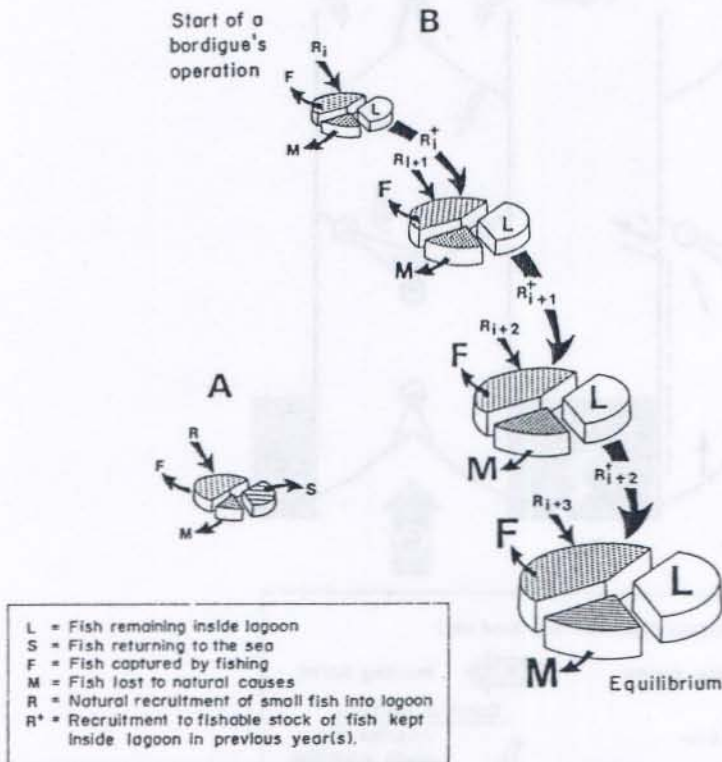


Fig. 13.12. Schematic representation of differences between (A) a lagoon exploited by gears deployed within the lagoon, and (B) a lagoon exploited/managed via a bordigue. Note the build-up of fish biomass in case (B) within the lagoon, due to retention of undersized fishes, which would have left the lagoon in case (A) (after Chauvet, 1988).

market size are harvested. Others are recycled, i.e., returned to the lagoon to grow until the next harvest season along with fresh recruits that have just entered the lagoon. Figure 13.12 contrasts the operation of a bordigue over a period of several years after set up with the traditional exploitation scheme of a lagoon, as repeated every year.

As might be seen in Fig. 13.12a, the harvest of a conventionally managed lagoon will be based only on the single recruitment preceding that harvest, there being no fish left in the lagoon from previous recruitment. Thus, catches will vary between years in proportion to recruitment levels, given consistent effort, and the fish caught will generally be undersized.

Bordigues, on the other hand, lead to a harvest level that is a function of the average level of recruitment over several years, besides harvesting fishes that are always of optimum size.

Thus, bordigues allow the kind of resource exploitation that is optimal in

terms of yield-per-recruit analysis, just as in a well-managed trawl fishery. Fish that have not grown to sufficient size escape through the mesh, grow some more, and then may be caught, or again escape through the mesh of the trawl's cod end, depending on whether they have grown to some size deemed as optimal in terms of weight or price.

As in a trawl fishery, the size at harvest in a bordigue will thus depend on the ratio between growth and natural mortality. Therefore, it would make little sense for the small fish retained by a bordigue to be returned to a lagoon in which natural mortalities are such that they offset any gain in individual weight of the released fish. Thus, managing a lagoon by means of a bordigue also implies removing as many sources of natural mortality as possible, e.g., by filling in deep pools in which large predators can accumulate, as well as reducing the likelihood of catastrophic mortalities by preventing inflows of pollutants. *Acadja*-type structures within lagoon, which enhance the survival and the growth of young fish may be considered in this context.

The technical aspects of the construction of bordigues are discussed in Chauvet (1988). It is worth mentioning that construction of bordigues requires sophisticated engineering and large investments. However daunting, the technical and financial aspects of the construction of bordigues, social factors are the key factors regarding their implementation. The use of bordigues as a fishing gear and management tool requires from those with access to or fishing rights in a lagoon an extremely high degree of cooperation and well-honed management skills. Bordigues must be staffed permanently to prevent them from becoming clogged with drifting seagrass, to change the retaining panels of different mesh size depending on which species are in the process of swimming to different retention chambers. Also, fishing within the lagoon must be restrained, as it could otherwise offset the gains obtained by returning to the lagoon undersized fish retained by the bordigue. Fishing in lagoons equipped with bordigues (Table 13.2) is not fitting for individualistic fishers. Bourquard and Quignard (1984) document the case of a bordigue which failed because of their non-cooperation.

## Discussion

We did not present the bordigues as a management tool for lagoon fisheries because we believe that this method of harvesting/managing is likely to become widely adopted outside its area of origin. We realize that, although it is technically applicable in principle in virtually any place in the world, the potential for its adoption outside the Western Mediterranean is rather unlikely because of the high degree of cooperation between fishermen that it required, and because of the high level of prerequisite management skills.

Rather, we presented the bordigue as an important element in the continuum of lagoon fisheries, which range from totally unmanaged to partially

TABLE 13.2

Comparative fishery yields of lagoons with and without systems to improve survival and/or growth of recruits (Chauvet, 1988).

Location/System	Annual mean yield (t km <sup>-2</sup> )	Standard error (t km <sup>-2</sup> )	n
<b>Africa</b>			
Fishing only	0.10	0.52	10
<i>Acadja</i> <sup>a</sup> and fishing	7.75	2.57	3
<b>Mediterranean</b>			
Without bordigues <sup>b</sup>	0.83	—	52
Non-permanent bordigues	0.82	0.64	10
Permanent bordigues	1.85	0.18	2
Permanent bordigues plus artificial stocking <sup>c</sup>	3.77	2.96	4

<sup>a</sup>See Kapetsky (1981) for a description of *acadja*-based fisheries.

<sup>b</sup>Computed by subtracting bordigues yields from grand mean for Mediterranean.

<sup>c</sup>This is a form of aquaculture (Ardizzone *et al.*, 1988).

and well-managed fisheries and beyond, to extensive, semi-intensive and intensive aquaculture operations. Indeed, the bordigue, although it is not an aquaculture operation is a key element of one of the most sophisticated capture fisheries regime one can imagine. It requires a level of cooperation and of management skill probably higher than that involved in extensive aquaculture, whose yield the bordigue can approximate (Table 13.2).

Other worthwhile management regimes for lagoon fisheries do exist and have been discussed by Kapetsky and Lasserre (1984).

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