Immediate maximum economic yield; a realistic fisheries economic reference point

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Unregulated or poorly managed fisheries tend towards overexploitation, but fisheries rent does not completely dissipate when immediate rent maximization is sought. The principle of immediate economic rent maximization is the basis of the derivation of a classic model and has led to the definition of a relationship in a catch-and-effort diagram termed the dynamic immediate maximum economic yield (DIMEY) curve. For any initial biomass, if the economic rent in the immediate fishing season is maximized, then the fishing effort and catch strategy that follows will be located on the DIMEY curve. The DIMEY curve is not only used for dynamic simulation but also used to identify a new reference point, the immediate maximum economic yield (IMEY), which is proposed as more realistic than the classic open-access solution for unregulated fisheries. IMEY is proposed as an asymptotic outcome for unregulated or poorly managed fisheries when short-term economic objectives drive fleet activities. IMEY properties are described and compared with traditional fisheries reference points in the yield-and-effort diagram. Theoretical conclusions are compared with empirical evidence provided by the red shrimp fishery off Blanes, Spain (NW Mediterranean). Observed catch-and-effort records are plotted and were positively correlated with the DIMEY curve and IMEY.

Keywords: fisheries bioeconomics, overexploitation, short-term economic maximization, unregulation.

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Introduction

The novelty of this work is the use of the rationale of immediate maximization of the economic rent as a cause of fisheries overexploitation without further consideration of the long-term sustainability objectives (Pauly *et al.*, 2002), to find a stable equilibrium point, which we suggest better describes unregulated or poorly managed fisheries. Fisheries bioeconomic models are used effectively to couple fish population dynamics with the economic balance of the earnings and costs of fishing. The Gordon–Schaefer model (Gordon, 1954; Schaefer, 1954) describes biomass growth following a logistic curve and a harvest rate. A set of economic parameters allows an economic analysis of the efficiency of the activity. Imposing steady-state conditions allows the identification of three well-known reference points: maximum sustainable yield (MSY) and maximum economic yield (MEY) as management targets and bioeconomic equilibrium (BE) as a limit to be avoided (Seijo *et al.*, 1998). Although the principles of the Gordon–Schaefer model remain in use, successive fisheries modelling derivations have been proposed for the accurate resolution of the harvest functions to avoid equilibrium solutions and to incorporate a time component for the evaluation of fish resources. Fish stocks are far from equilibrium even without being exploited (Hilborn and Walters, 1992); as a consequence, management objectives and optimal management strategies need to include a set of initial conditions and temporarily limited evaluation functions (Clark, 1976).

In management strategy evaluations, exploiters' economic behaviour is usually ignored and is assumed to follow optimization recommendations. However, half the world's fish stocks are fully exploited near their MSY, but not their MEY, and a quarter of the stocks are overexploited (Grafton *et al.*, 2007; FAO, 2008). The causes of overexploitation may be diverse (Finlayson, 1994; Pauly *et al.*, 2002; Merino *et al.*, 2007a, b), but multiple ownership and maximizing the short-term rent are the traditional explanations (Hardin, 1968; Pauly *et al.*, 2002).

Fleet dynamics, or direct exploiters' perception, was first included in the dynamics of natural resources and the rationale for their exploitation by Smith (1969). In a non-regulated or open-access (OA) fishery, the fishery will attract exploiters until their capacity exceeds ecosystem productivity with respect to the stock's productivity, and will continue exploitation until fishing costs exceed revenues and exploiters discontinue the activity. When the latter transpires, the stocks recover and exploiters return to the fishery until the rent is completely dissipated. Fisheries rent dissipation as a rational outcome of fleet dynamics can also be explained in terms of game theory. The economic rent of a fishery tends to dissipate as the number of non-cooperative agents that strive to maximize their own profits increases (Nash, 1951; Mesterton-Gibbons, 1993; Grønbæk, 2000; Merino, 2007). Currently, under the scope of the global attempts to regulate marine resources, including ecological and economic regulations known as the Ecosystem Approach to

Fisheries or EAF (FAO, 1995a, b; Garcia *et al.*, 2003), exploiters continue to make their own decisions based on their technical characteristics and economic interest (Merino *et al.*, 2007a, b).

It is unlikely that the economic rent of a fishery could be optimized or dissipated without adequate external management. Here, we combine equilibrium conditions with the immediate economic maximization objective. Our hypothesis states that most poorly regulated fisheries are exploited at a rate beyond MSY, but not reaching BE (Grafton *et al.*, 2007), and that this point not only satisfies the immediate maximization condition, but is obtainable and stable.

We define an alternative reference point to describe unregulated or OA fisheries and propose that an equilibrium point in the catch-and-effort diagram can be determined for which the immediate economic rent is maximized. This point is the immediate maximum economic yield (IMEY). Moreover, the effort that will maximize the immediate rent and associated dynamic yield for any initial exploitable biomass will rely on a curve termed the dynamic immediate maximum economic yield (DIMEY). The properties of these new terms are explained in Methodology below.

Theoretical considerations are compared with empirical evidence provided by a case study. Red shrimp (*Aristeus antennatus*) is likely the most profitable species taken by Mediterranean bottom trawlers. The fleet based in Blanes (Spain) is one of the fleets exploiting this species most heavily in the northwestern Mediterranean, and the fishery has been assessed in recent decades (Demestre and Lleonart, 1993; Demestre and Martin, 1993; Lleonart and Maynou, 2003; Sardá *et al.*, 2003). The red shrimp fishery is a multispecies fishery regulated with input measures (effort and selectivity control), which aim to achieve biological and economic sustainability.

The validity of DIMEY and IMEY and the management and scientific implications are discussed in the sections below.

Methodology

Following Schaefer (1954), exploited population dynamics follow the mathematical expression shown in Equation (1). Stock biomass (B) growth over time (t) is described by a logistic curve and a harvest term (Y; Hilborn and Walters, 1992). It is assumed that the yield is proportional to the biomass and the fishing mortality (F). Fishing mortality is usually split into two terms: the catchability parameter (q) and the fishing effort (E); see Equation (2). Logistic stock dynamics with a harvest term are therefore expressed as follows (intrinsic growth rate r, carrying capacity K, and yield Y, expressed as a rate):

$$\frac{\mathrm{d}B}{\mathrm{d}t} = rB\left(1 - \frac{B}{K}\right) - Y, \tag{1}$$

$$Y = FB = qEB. \tag{2}$$

Yield turns into economic gain and fishing effort becomes fishing cost through linear revenue and cost equations (p is the price of a landed unit, and c the cost per unit of fishing effort). Note that no opportunity costs of the capital are considered here. The economic rent from the activity (π) is therefore

$$\pi = pY - cE. \tag{3}$$

The steady-state condition in the population dynamics ($\mathrm{d}B/\mathrm{d}t = 0$) and setting the yield and economic rent maximization conditions leads to the description of the well-known MSY and MEY, whereas imposing the rent dissipation, or $\pi = 0$, condition leads to the definition of the BE or the OA solution.

Dynamic conditions affect the yield during the fishing period $[h, h+\delta]$ from any initial biomass B_h and fishing effort applied homogeneously. Integration of Equation (2) with respect to time allows biomass and yield to be modelled through time. When $\alpha_h = r - qE_h$ and $\beta = r/K$, modelling the yield during the fishing period involves the integration shown in Equation (4) (Pella, 1967; Schnute, 1977; Prager, 1994):

$$Y_h = \int_{t=h}^{h+\delta} qE_hB_t\,\mathrm{d}t = \frac{qE_h}{\beta}\ln\left[1 - \frac{\beta B_h(1 - \mathrm{e}^{\alpha_h\delta})}{\alpha_h}\right]. \tag{4}$$

For the period beginning at $t = h$ and ending at $t = h + \delta$, during which the instantaneous fishing mortality rate is F_h, the biomass estimated at $t = h + \delta$ is

$$B_{h+\delta} = \frac{\alpha_h B_h \mathrm{e}^{\alpha_h\delta}}{\alpha_h + \beta B_h(\mathrm{e}^{\alpha_h\delta} - 1)}. \tag{5}$$

Economic rent over a period $[h, h+\delta]$ is therefore calculated as

$$\pi_h = pY_h - cE_h. \tag{6}$$

Note that we follow the notation proposed by Prager (1994) in Equations (4) and (6), where $Y[h, h+\delta]$ is shortened to Y_h. In the same way, the effort and economic rent during the time interval $[h, h+\delta]$ is shortened to E_h and π_h in Equation (6).

The strategy that is proposed here to mimic exploiters' behaviour is E_h^*, i.e. the effort strategy that will maximize their rent in period h, which satisfies the following condition:

$$\left.\frac{\partial\pi_h}{\partial E_h}\right|_{E_h^*} = 0. \tag{7}$$

This equation means that the effort level E_h^* leads to the highest economic rent during the fishing period h. Because the model is too intricate to be solved analytically, we are restricted to numerical solutions. The yield produced by E_h^* during the period $[h, h+\delta]$ is Y_h^*[Equation (4)] when $E_h = E_h^*$. Note that no economic discount is included because no future evaluation of exploitation is considered.

DIMEY is the curve defined by (Y_h^*, E_h^*) for any possible initial biomass B_t between 0 and the carrying capacity K because DIMEY has no meaning for biomass beyond these limits (Figure 1). The point where the DIMEY curve meets the economic equilibrium yield curve is defined here as the IMEY, a steady state ($\mathrm{d}B/\mathrm{d}t = 0$) that also satisfies the short-term (immediate) economic rent maximization condition.

The design of an effort strategy that satisfies the short-term economic maximization condition depending on the initial stock abundance requires an $E^*(B_t)$ effort with a harvest of $Y_h^* = f(E_h^*(B_t))$. This point is on the DIMEY curve, and it will converge to the IMEY if successive effort strategies are chosen as the stocks also evolve in time. Stock level, yield, and effort will converge to the IMEY conditions. In other words, after E_h^* is applied to a stock initially at B_t, biomass will evolve following Equation (5) to $B_{t+1}(E_h^*)$, and E_{t+1}^* is calculated with the rent maximization condition [Equation (7)] using Equations (4) and (6).

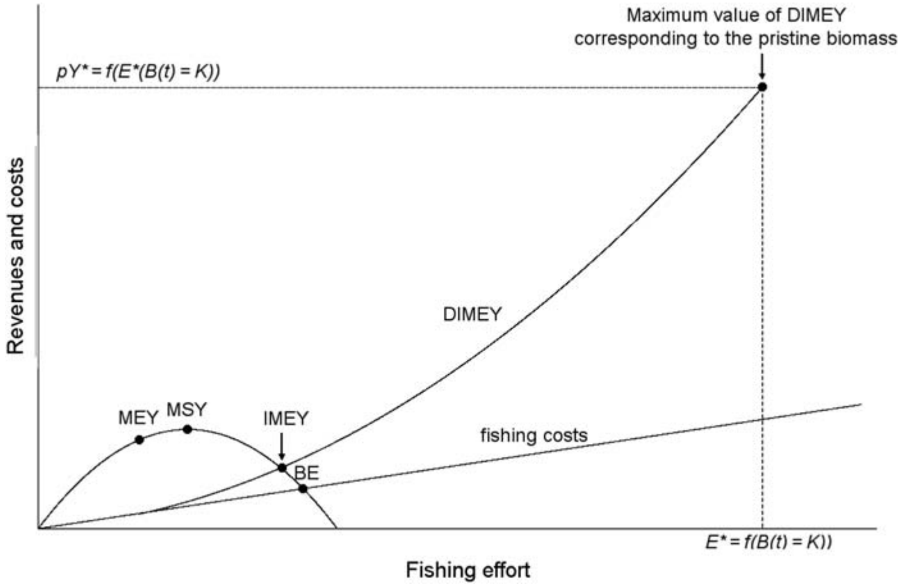

Figure 1. The Gordon–Schaefer equilibrium curve, traditional reference points (maximum economic yield, MEY; maximum sustainable yield, MSY; and bioeconomic equilibrium, BE), and fishing costs, as well as the proposed immediate maximum economic yield (IMEY) and the non-equilibrium short-term economic yield curve (DIMEY).

For successive periods, the short-term rent maximizing effort E^* will asymptotically converge to the IMEY effort (E_{IMEY}), and the three bioeconomic indicators will lead towards the IMEY equilibrium conditions, B_{IMEY}, Y_{IMEY} (or IMEY), and π_{IMEY}. Once the IMEY equilibrium conditions are reached, no change in the fishing strategy will take place if the short-term rent maximization condition remains satisfied.

The trajectory followed by a fishery since the onset of exploitation is shown in Figure 2. The initial condition $t = 1$ is an unexploited stock. For the first time interval $[h = 1, h + \delta = 2]$, the immediate revenue $(pY(h))$ curve is plotted from Equation (4) and the price of fish is set as 1 (Figure 2). The point where the difference between this curve and fishing costs is maximum is where the immediate economic rent is at its maximum, i.e. the point in the DIMEY curve for unexploited stocks. Note the significant difference between the MSY on the equilibrium curve and the maximum short-term yield.

In the subsequent time-intervals (Figure 2b–d), the point that maximizes rent at t will converge to IMEY (Figure 2d). Contrary to what happens with traditional reference points, IMEY is proposed here to be asymptotic when the maximizing short-term economic rent condition is satisfied and no other long-term management criteria are imposed.

The Blanes red shrimp fishery

Red shrimp are fished in canyons at depths of 400–800 m. The fishing grounds are far from the coast, so are costly to reach. Fishers target the high-priced red shrimp when they are aware of its abundance. Moreover, they operate on the red shrimp grounds when they anticipate sufficient economic rent from their exploitation. Initially, fisheries regulated under input management criteria appear to be the most suitable for testing our hypothesis. Once the mechanisms directing fishing effort and mortality are understood, the effects of management measures can be predicted. The Blanes (NW Mediterranean) fishery for red shrimp has been assessed by different studies and was diagnosed at near its maximum capacity in the early 1990s, then approached a moderate overexploitation level in the late 1990s and early 2000s (Demestre and Lleonart, 1993; Demestre and Martin, 1993; Sardá *et al.*, 2003, 2004). Annual catch-and-effort data from 1997 to 2004 are plotted in the yield–effort equilibrium curve built with the parameters obtained in the most recent study (Merino, 2007) and compared with the DIMEY curve and the IMEY equilibrium conditions.

Results

The relative position of IMEY is always between MEY and BE and depends on economic parameters (price and fishing costs). With increasing costs, MEY, BE, and IMEY move towards lower effort levels. In contrast, if costs decrease in relation to the price of fish, both BE and IMEY points will move towards higher levels of effort and, hence, overexploitation. One of the most interesting aspects of the reference point described here is that it is an attractor for any fishery where the condition of the exploiters' short-term maximization objective is satisfied. For any initial biomass, exploiters will converge to the IMEY along the trajectory of the DIMEY curve.

The effort that will maximize the rent from a pristine biomass $[E^* = f(B = K)]$ is very intense, and its associated yield $Y^* = f[E^*(B = K)]$ is also very high (unsustainable) compared with the potential MSY (Figure 1). Unregulated or poorly managed fisheries are not driven towards rent dissipation or towards global economic rent or production maximization management objectives.

The Gordon–Schaefer equilibrium curve and observed fisheries data, as well as estimated biomass, are shown in Figure 3. The data follow similar patterns to those described earlier (Demestre and Lleonart, 1993; Sardá *et al.*, 2003). All annual effort observations are beyond the MEY and MSY effort levels. The Blanes fishery for red shrimp has recently been reported to be subject to naturally driven environmental fluctuations (Company *et al.*, 2008; Maynou, 2008). The trajectory starting in

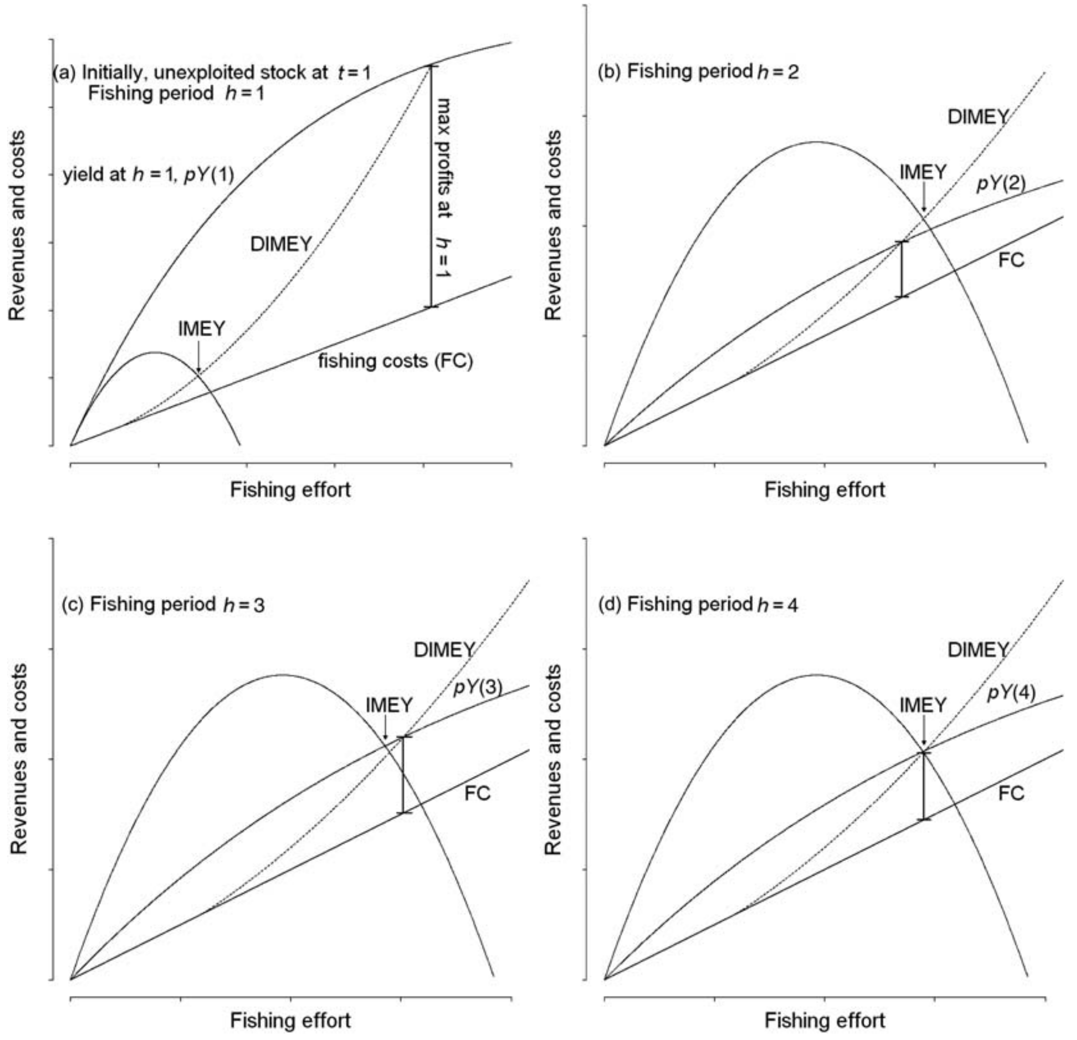

Figure 2. The Gordon–Schaefer equilibrium curve, short-term economic yield, fishing costs, and maximum short-term rent evolution since an unexploited stock has been exploited. Unexploited stock at the beginning of the year (a) $t = 1$, (b) $t = 2$, (c) $t = 3$, and (d) $t = 4$, where the fishery converges to IMEY.

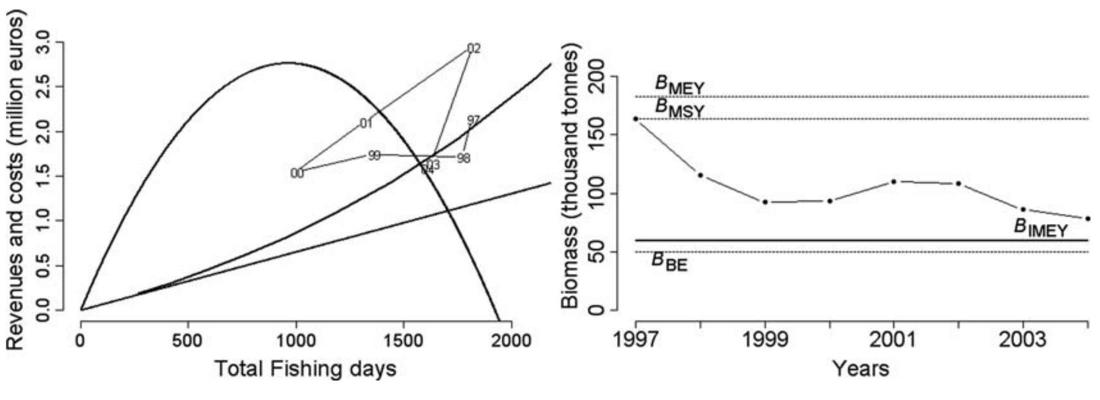

Figure 3. (Left) The Gordon–Schaefer equilibrium curve, fishing costs, observations (1997–2004), DIMEY curve, and IMEY for the Blanes fishery for red shrimp [$r = 0.9626$; $K = 327.700$ t; $q = 4.1 \times 10^{-4}$; $p = €35\ \mathrm{kg}^{-1}$; $c = €651\ \mathrm{vessel}^{-1}\ \mathrm{d}^{-1}$ (Merino, 2007)]. (Right) Estimated biomass of red shrimp in Blanes and the associated biomass at traditional reference points (MSY, MEY, and BE) and IMEY.

1997 has moved towards lower effort levels (a scarcity period) and increased effort in 2001 and 2002 (a period of abundance), then again to lower levels (close to IMEY). High levels of fishing effort in the years 2002 and 1997 were associated with great stock abundance as trawler activity has historically been linked to the abundance of the species (Bas *et al.*, 2003).

Recent records suggest that short-term economic maximization is taking place and, although the observations are not stable, exploiters seemingly respond to positive environmental causes that modulate (increase) their effort on the DIMEY trajectory. Exploiters respond to favourable or unfavourable environmental conditions (Company *et al*., 2008; Maynou, 2008) in an effort to maximize their immediate rent.

Discussion

A derivation of the Gordon–Schaefer model is proposed here with the main objective of coupling steady-state equilibrium with economic maximization conditions. Equilibrium solutions are generally used to identify three main management reference points that are intended to mimic alternative management scenarios. First, maximizing the sustainable total rent of the fishery (MEY) jointly achieves economic and conservation objectives, yielding the highest rent from a non-endangered stock. MSY means matching fishing strategies to the species' ecological productivity. In contrast, BE is obtained by imposing the rent-dissipation condition to describe the state of unregulated fisheries.

The FAO reports that 75% of the world's fisheries are fully exploited or overexploited (FAO, 2008). The rationale of rent dissipation and unsettled economic maximization is complex. Resource-ownership conflicts (Hardin, 1968) and short-term economic objectives are among the causes of economic waste (Pauly *et al*., 2003). However, our mathematical results agree with previous studies that indicate continued fishing profits despite the lack of common and appropriate management (Grafton *et al*., 2007).

IMEY is proposed as a realistic reference point that satisfies both the steady-state condition and the immediate economic maximization assumption. Moreover, the DIMEY curve satisfies the immediate economic maximum as a function of the abundance of the stock at the beginning of the fishing period. Given any initial exploitation level of a fishery (including MEY and MSY), this level will approach the IMEY equilibrium (including biomass, catch, and rent) following a trajectory on the DIMEY curve if the short-term rent maximization condition is satisfied. This model suggests that a poorly managed or unregulated fishery that is conditioned to short-term economic maximization will tend to overexploitation, but will avoid the complete dissipation of economic rent. Although no discount rate was taken into account in our analysis, a short-term economic maximization strategy formulation involves very high discount rates for the exploiters' economic strategies. In summary, short-term rent objectives and non-regulation are explicitly modelled here, and they indicate that exploited stocks are somewhere in between their associated MSY and BE levels (Grafton *et al*., 2007).

Red shrimp constitute one of the most sought-after species for Mediterranean trawling fleets (Farrugio *et al*., 1993; Lleonart and Maynou, 2003). The activity of European Mediterranean trawlers is regulated by effort control or selectivity measures that aim to provide biological and economic sustainability. However, most target species exploited by Mediterranean fleets have been overexploited for decades (Lleonart and Maynou, 2003; Lleonart *et al*., 2003; Maynou *et al*., 2006). Under the current input regulation of Mediterranean fisheries, exploiters seek to design their own effort strategies with economic objectives. Predictions of the future behaviour of the Blanes fishery for red shrimp, based on stock and market externalities among exploiters and a mid-term rent maximization strategy, led to an overall estimate of fishing effort comparable with IMEY (Merino *et al*., 2007a, b), although environmentally driven stock fluctuations were not accounted for (Company *et al*., 2008; Maynou, 2008). Activities of the Blanes trawler fleet are closely related to the availability of red shrimp, i.e. red shrimp are intensively targeted by fishers when abundant because it is the most valuable species in the area, whereas alternative species are targeted when the abundance of red shrimp was low. Moreover, environmentally driven stock fluctuations and fishing-activity modulation should be managed cautiously (Company *et al*., 2008).

An alternative theoretical approach to poorly or unregulated fisheries has been explained here. The main conclusion from our analysis is that unregulated or poorly managed fisheries tend to overexploitation, but at a level insufficient to dissipate exploitation rent entirely. The mathematical formulation described here is based on the explanatory principle of short-term economic maximization as one of the causes of the overexploitation of the world's fisheries (Pauly *et al*., 2003).

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