



## Interdecadal variability of anchoveta abundance and overcapacity of the fishery in Peru

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### ARTICLE INFO

#### Article history:

Accepted 14 October 2008

Available online 21 October 2008

#### Keywords:

Fishery management  
Pelagic fisheries  
Fishing effort  
Overcapacity  
Overexploitation  
Temporal variations  
Humboldt current  
Peru

### ABSTRACT

Paleontological and historical stock abundance estimates indicate that pelagic fish populations inhabiting upwelling ecosystems undergo large interdecadal variations in abundance with amplitudes equal to, if not larger than, the interannual variability. The interdecadal variability is characterized by periods of high and low abundance, termed “pseudo-cycles”, because of their irregular periodicity. Fisheries targeting small pelagic fish suffer from overall overcapitalization, like many other fisheries, but also from an additional overcapitalization problem: a phase displacement between rapid fish population decreases and a slower disinvestment which follows. This lag produces economic hardship.

Here we document the fish:fishery relationship for the Peruvian anchoveta. Anchoveta pseudo-cycles of 20 to >100 years are observed, with the present stock abundance most likely located near upper part of the cycle. Fleet overcapacity expressed as the proportion of unused present capacity is estimated at 72% and processing overcapacity at 89%. A simple bio-economic model demonstrates the risks associated with the pseudo-periodicity in fish stock abundance in conjunction with fishery investment, open access, and overcapacity: a timing bomb for the fishing sector. The lag between disinvestment and decrease in fish abundance is quantified. A reduction of the fishing and processing capacity and measures to decrease the investment lag are recommended to limit the social, economical and political tensions that will result from the expected decrease in stock abundance. Finally, some management options to reduce these risks are discussed.

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### 1. Introduction

Despite a century of research effort, the major challenge for fishery biologists remains to forecast the abundance of exploited fish stocks. Recently, fisheries have been managed within an ecosystem-based framework (García et al., 2003) but still face the same challenge. Historically, the scientific focus was placed on environmental-forcing or exploitation-forcing (review in Fréon et al., 2005), but until recently, only the interannual scale was taken into account. Historical data on catches and conventional stock abundance estimates show that several fish populations, and especially small pelagic fish inhabiting upwelling ecosystems, undergo large interdecadal variations in abundance with amplitudes equal, if not larger than, the interannual variability (e.g. Bakun, 1996; Spencer and Collie, 1997; Schwartzlose et al., 1999). Paleontological records of scale deposition in anaerobic sediments indicate that this interdecadal variability existed long before fishery exploitation (Baumgartner et al., 1992; Holmgren-Urba and Baumgartner, 1993). The variability alternates between periods of high and low

abundance, qualified as “quasiperiodic” (Turchin and Taylor, 1992) or termed “pseudo-cycles” (Fréon et al., 2005) because of their irregularity in periodicity (pseudo-periodic) an shape (often pseudo-sinusoidal or pseudo-U-shaped). Such pseudo-cycles also exist in other environments and systems (Menu et al., 2002). The mean period of the pseudo-cycles in the marine realm varies widely between 10 and 80 years depending on the species and region, but within a system the coefficient of variation of the period is approximately 30% and 50% according to historical and paleontological records, respectively. Because much investment within the fishery industry (and also in small-scale fisheries, see Fréon and Weber, 1983) also occurs on decadal rather than annual or interannual scales, analyses of decade-scale fish:fisheries relations are appropriate.

Fisheries suffer from overcapitalization (Glantz and Tompson, 1981) resulting in the first place from the tragedy of the commons: communal resources suffer from an inexorable process of degradation due to selfishness of “free riders” who use or destroy more than their fair share of common property. In open access fisheries (unlimited number of fishing license), a “race for fishing” is observed where the interest of any individual fisher of fishing company is to invest as much as possible in order to catch the

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biggest part possible of the annual quota before it is filled. Furthermore two additional factors aggravate fishing overcapacity: the positive feedback between overexploitation and overcapitalization, and misguided subsidies including buy-back programs of old vessels that end up in re-investment of less but much more powerful modern ones (Ludwig et al., 1993; Gréboval, 1999). The fisheries targeting small pelagic fish suffer from an additional overcapitalization problem – the phase displacement between highly variable fish abundance and investment. Investors typically do not anticipate changes in fish abundance, yet there is a long lag between investment and realization of profit (decision-making, factory or boat building delay, accumulation of benefits). Invested capital often peaks and remains committed as stocks enter the declining phase of their interdecadal pseudo-cycle. As stocks decline, the heavy investment has not been recovered and must be reformed, lost, or maintained in hope of a turnaround. Disinvestment in fisheries is slower than investment (Ludwig et al., 1993), which increases losses, i.e. rent dissipation. These powerful economic and political interests that drive fisheries to overcapitalization and overexploit despite scientific evidence that stocks are declining were called the “Ludwig’s ratchet” by Hennessey and Healey (2000).

The Peruvian anchoveta fishery is at present the largest single-species fishery in the world, with average landings of *Engraulis ringens* (an anchovy species known as “anchoveta”) over 5 million tons annually during the last decade (Ñiquen and Fréon, 2006). The fleet of over 1200 purse-seiners operates from several fishing harbors along the Peruvian coast and performs daily trips of about 20 h. From 1976 to 1999, sardine *Sardinops sagax* was a major secondary target for this fleet with a maximum landing of 3 million tons in 1985. But since then, catches declined, and since 2000, the fleet has been catching around 95% of anchoveta. For this reason the present paper concentrates on anchoveta. More than 99% of the landings of the fleet are processed into fish meal and fish oil, although recently, anchoveta processing for human consumption has started to take place. There was initially a single type of fishing vessel, all with steel hull but of different sizes ranging from 30 to 900 tons of holding capacity (HC), mostly owned by large fishing companies (the ‘industrial’ fleet). Since 1999 a semi-artisanal fleet of purse-seiners developed using wooden hulls and ranging from 30 to 110 tons HC (denominated the ‘artisanal’ fleet here, despite the local use of ‘industrial wooden fleet’). This fleet is more labor-intensive than the industrial fleet, both for the construction of boat and capture of fish per fisher. Most of the owners have a single boat or share it with co-owners in familial or neighborhood social structures. There are at present about equal numbers of industrial and artisanal boats (~600 in total), but the industrial fleet lands over 85% of the catch.

Despite some official regulation of fishing effort, from a practical point of view the fishery is free access. Anchoveta fishery management is based on seasonal fishing quotas. IMARPE recommendations to the Peruvian Ministry of Fisheries are based on biological years starting on the 1st of October and ending on 30th of the following September. Usually there are two fishing seasons, each with its own quota: a summer season from October to March, and a winter season from April to September. The seasonal quotas are mainly based on acoustic and ichthyoplankton surveys performed at the beginning of every season estimating spawning biomass, recruitment and the age-structure of the stock. Many additional components of the ecosystem are also assessed in an attempt to apply ecosystem-based management: other pelagic species, major predators like birds, sea lions, seals and other fishes. Presently, the immediate goal of management is to maintain spawning biomass above about 5 million tons at the onset of each spawning period (August and February).

In this paper we examine the stock’s pseudo-periodicity and relations between Peruvian anchoveta abundance and two main

components of the fishery overcapacity: fleet overcapacity and processing overcapacity. We first document the decade-scale variability via literature review and with new data. Then we present a simple bio-economic model demonstrating the risks associated with the pseudo-periodicity of fish stock abundance in conjunction with the open access, the usual patterns of investment, and overcapacity. Finally, management options to reduce these risks are briefly discussed.

## 2. Material and methods

The study area is the Peruvian continental shelf and margin. It spreads from Tumbes (03°24’S) to (18°21’S), extending offshore up to 90 nautical miles (Fig. 1). Major emphasis is given to the north-central area, from 04°S to 14°S because the bulk of catches comes from the sub-stock located in this area (Pauly and Tsukama, 1987). The catch from the southern area of Peru (from 14°00’S to 18°21’S) are commonly taken to be from a different sub-stock shared by Peru and Chili (Serra, 1983). The issue of stock identity is still debated because individuals from the two sub-stocks sometimes mix (Alheit and Ñiquen, 2004).

Annual time series of catches and effort result from the compilation by IMARPE<sup>1</sup> of daily records of landing by individual purse-seiners, and are associated with sub-sampling of the catch composition as in Bouchon et al. (1997). By combining the information on daily individual landings with the official files on the industrial fleet (characteristics of the vessels), IMARPE produced annual series of holding capacity (HC) and GRT<sup>2</sup>. Because there is a linear relationship between HC and GRT (Tsukayama, 1969), only the first value is used here. The number of fishing days between 1959 and 1996 was obtained by subtracting days of official (“Vedas”) and strike closure of the fishery in legal records from 365.

The general definition of overcapacity in fisheries retained here is the “harvesting capacity in excess of the minimum amount required to harvest the desired quantity of fish at the least cost” (OECD, 1996). A conventional expression of excess capacity is the capacity utilisation coefficient (CU) derived from the economy of firms. Applied to fisheries this is

$$CU = Y/Y' \quad (1)$$

where  $Y$  is the fleet harvest desired by the resource managers (e.g. total allowable catch or TAC), and  $Y'$  is the potential harvest of the fleet, given the existing stock size. Thus, in a typical situation of overcapacity,  $Y' > Y$ , hence, we would have  $CU < 1$  (review in Gréboval, 1999). Following Gréboval (1999), we define excess fleet overcapacity as the proportion of the unused present capacity, that is

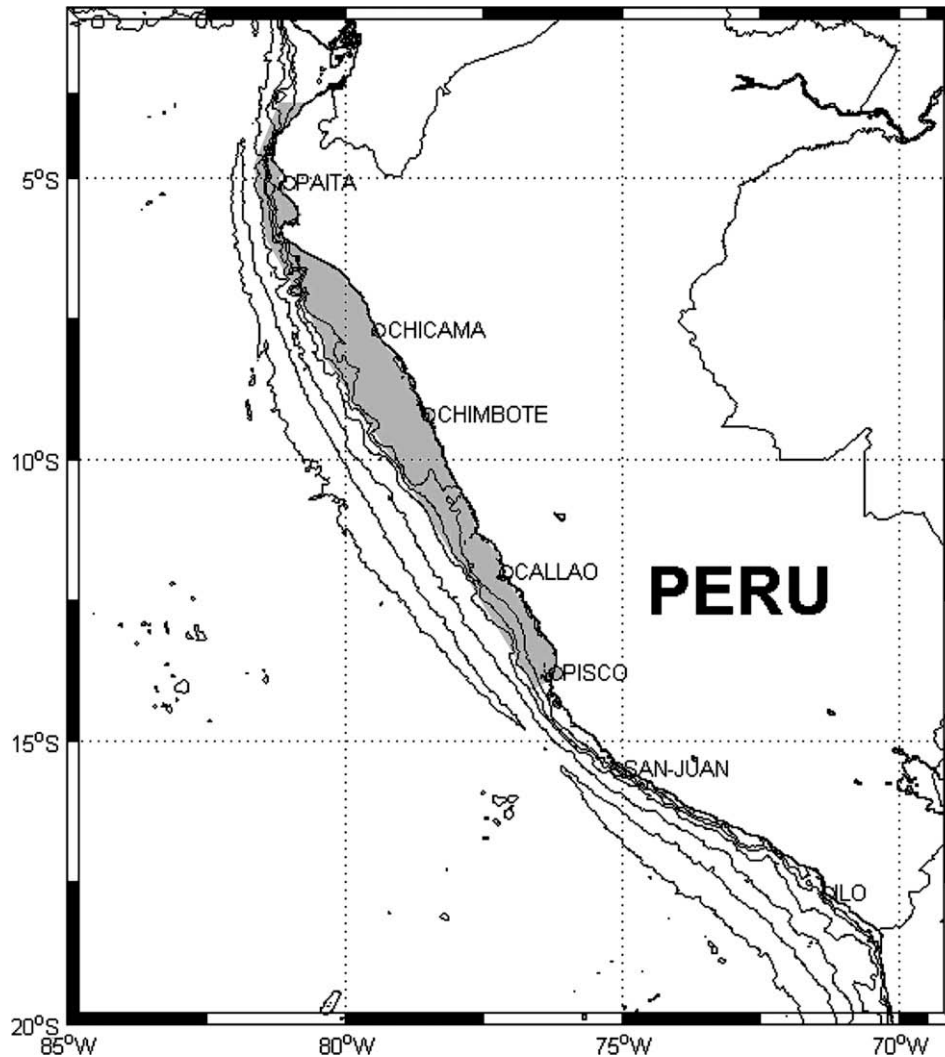
$$\text{Overcapacity (\%)} = 100 * (1 - CU) \quad (2)$$

$Y$  and  $Y'$  being strictly proportional to fishing effort in case of constant catch per unit of effort, Eqs. (1) and (2) can also apply to effort as in literature examples below. The same equation can apply to processing overcapacity,  $Y'$  being here the potential processing capacity.

Stock abundance is estimated by three different methods: the daily egg production method, hydroacoustic surveys, and virtual population analyses (VPA). Only VPA is used here because it covers a longer time period, but acoustic data were used to calibrate VPA estimates. Three VPAs were applied to the north-central stock of anchoveta: one by Pauly and Palomares (1989) for 1953–1985,

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<sup>2</sup> Gross register tonnage, that is the total internal volume of a vessel, with some exemptions for non-productive spaces such as crew quarters.



**Fig. 1.** Studied area. The northern-central stock of anchoveta is mainly located from 4°S to 14°S, within the 200 m isobath (grey area). The Peruvian component of the southern stock (not shown), less abundant and less exploited, is located from 14°S to the southern border around 18°21'S. Source: bathymetry: ETOPO02/coastline: GSHHS/boundary: DCW (produced by Dominique Dagorne, IRD US191).

one by Csirke et al. (1996) for 1960–1994 and one from Ñiquen et al. (2000) for 1961–1999 but updated here up to 2004.

Total fish consumption in Peru from 1999 to 2005 was estimated by multiplying the consumption per capita provided by PRODUCE (2007) by an estimation of the Peruvian population during the same period, assuming that INEI computed its value without using any age threshold. The Peruvian population was estimated by linear interpolation of the INEI census performed in 1993 and 2005.

Five theoretical bio-economic models of increasing complexity are used. All of them are simple implementations of a classical bio-economic model by Smith (Smith, 1968; see also Clark, 2006). In model-I, the carrying capacity of the ecosystem regarding anchoveta (mainly dependent on environmental conditions) is constant and investment and disinvestment patterns symmetrical. In model-II, a time-varying carrying capacity is used to simulate the cyclic character of pelagic stock abundance and investment patterns remain symmetrical. In model-III, the carrying capacity is constant as in model-I, but the investment and disinvestment patterns are dissymmetrical, investment being faster than disinvestment. Model-IV combines the cyclic pattern of abundance in model-II with the asymmetrical investment patterns of model-III (Table 1). Model-V adds total allowable catch (TAC) to model-III.

In models-I and -III, the biological compartment is based on the logistic equation:

$$X'_t = rX_t(1 - X_t/K) - qX_tE_t, \tag{3}$$

where  $X$  is the fish stock abundance (and  $X'$  its variation),  $r$  the natural renewal rate of the population,  $K$  the ecosystem carrying capacity,  $q$  the coefficient of catchability and  $E$  the fishing capacity.

In models-I and -II, we make the assumption that variations of effective fishing capacity ( $E'_t$ ) are strictly proportional to benefits, such that investment or disinvestment does not lag benefits:

$$E'_t = k(pqX_tE_t - cE_t), \tag{4}$$

where  $k$  is the proportion of gains invested or the proportion of losses disinvested,  $p$  is a price coefficient and  $c$  a cost coefficient. In the second member of Eq. (4), the first part represents sales, proportional to catches ( $qX_tE_t$ ), whereas the second part represents costs proportional to fishing capacity. One may consider ( $E'_t$ ) and ( $X'_t$ ) as annual changes of fishing capacity and fish stock abundance respectively.

In models-II and -IV, a periodic function is associated with the biological compartment:

$$X'_t = rX_t(1 - X_t/K_t) - qX_tE_t, \tag{5}$$

**Table 1**  
Characteristics of the four bio-economic models.

Compartment	Model-I	Model-II	Model-III	Model-IV	Model-V
Biological (variation in $K$ )	Constant (Eq. (3))	Cyclic (Eqs. (5) and (6))	Constant (Eq. (3))	Cyclic (Eqs. (5) and (6))	Constant, then cyclic (Eqs. (5) and (6))
Economical (investment/disinvestment patterns)	Symmetrical (Eq. (4))	Symmetrical (Eq. (4))	Asymmetrical (Eq. (7))	Asymmetrical (Eq. (7))	Symmetrical (Eq. (9))
Catch regulation	No	No	No	No	TAC (Eq. (8))

where

$$K_t = K_0(1 + a\sin(\omega t)) \quad (6)$$

In models-III and -IV, the economic compartment is modified in order to obtain faster investment compared to disinvestment:

$$E_t' = S(pqX_tE_t - cE_t), \quad (7)$$

where  $S$  is a function defined such as  $S(P) = aP$  for  $P < 0$ , and  $S(P) = bP$  for  $P > 0$ , with  $a < b$ , expressing that investment is faster than disinvestment. Indeed we made the strong assumption that capacity is changing proportionate to profits, and being slower to respond where profits are negative. Although we could have used a less drastic asymmetry between investment and disinvestments ( $S$ , a nonlinear smooth curve), we have chosen Eq. (7) to keep the model simple, avoid overparameterization, and amplify the differences between dynamics.

In model-V, the catch is regulated by a constant TAC, and the fishing effort is free to increase until the TAC is reached (which does not always occur because of other constraints in the model):

$$X_t' = rX_t(1 - X_t/K_t) - \text{Min}(\text{Tac}, qX_tE_t) \quad (8)$$

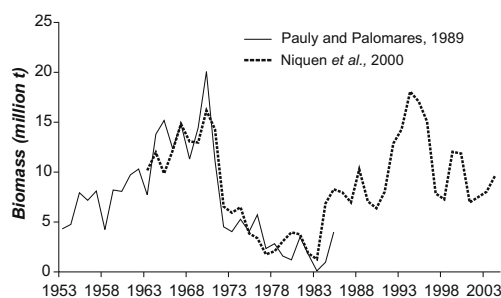
and

$$E_t' = k(p\text{Min}(\text{Tac}, qX_tE_t) - cE_t) \quad (9)$$

The bibliographical reviews on pseudo-cycle in abundance and history of the fishery were performed using Internet and direct access to libraries in Peru.

### 3. Results

Evidence of pseudo-cyclic variation in the Peruvian anchoveta stocks can be found among VPA data (Fig. 2) and paleontological records. VPAs of the north-central Peruvian stock suggest the existence of one full cycle followed by half a cycle since the 1950s. If we consider this series as pseudo-sinusoidal and arbitrarily assume that the starting point of a cycle is its lowest value, then the first cycle was likely to begin around 1948 and to end around 1983. The second cycle follows immediately and continues. The analysis of anoxic sediment cores from the continental shelf off Callao

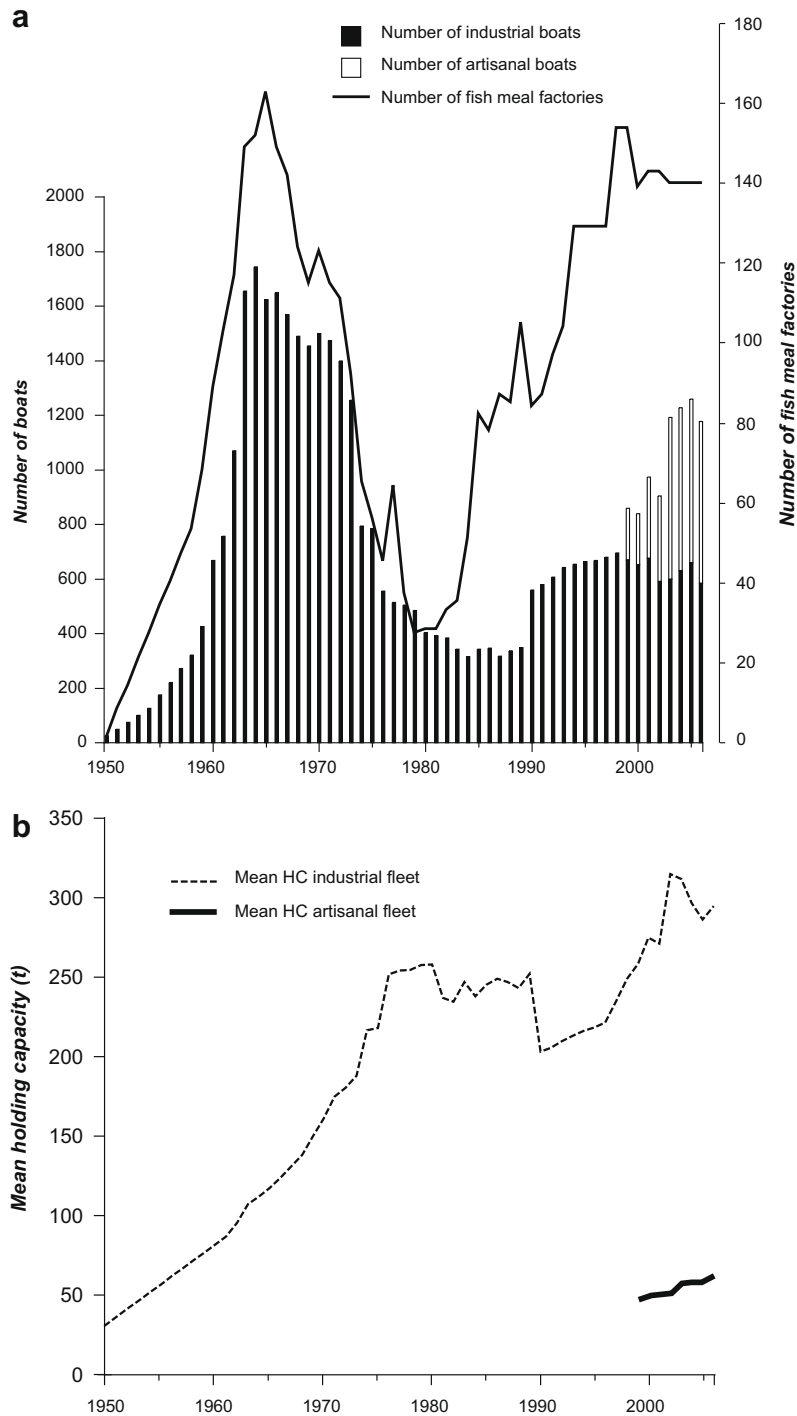


**Fig. 2.** Anchoveta biomass estimates from two VPA studies. Note the presence of nearly two pseudo-cycles. Sources: Pauly and Palomares (1989) and Niquen et al. (2000).

( $00^{\circ}\text{S}$ ,  $72^{\circ}42'\text{S}$ , 184 m depth) and in the upper slope off Pisco ( $14^{\circ}07'\text{S}$ ,  $76^{\circ}30'\text{S}$ , 299 m) by Gutiérrez et al. (2008) confirm the turning point of the 1980s, but only a local minimum in the early 1940s. Earlier decadal-scale turning points are obvious in the Gutiérrez et al. (2008) data sets of Callo and Pisco that start at the beginning of the 14th Century. The data suggest pseudo-cycles from 20 up to 120 years long, even though the number of turning points could be underestimated due to the low temporal resolution of the data.

IMARPE (1974) stressed the overcapacity of the pelagic fleet at the beginning of the 1970s, indicating that the fleet could catch a third of the biomass in 1 month (which exceeded by far the turnover rate of the population). Assuming that a commercial fishing vessel can operate 240 days per year, Agüero (1987) estimated that only 364 purse-seiners were necessary to catch the TAC instead of 580 in activity in 1982, resulting in a 37% fishing overcapacity according to Eq. (2). He found a similar value for the processing overcapacity. At that time the total abundance of pelagic stocks was low and the computation was based on sustained catches of 3.5 million tons per year, that is half the production of the 2000–2006 period. More recently, Hatzioilos and de Haan (2006) estimated that in 2005 the industrial fleet used only 31% of its fishing capacity and the artisanal fleet 25%, i.e. 69% and 75% of overcapacity respectively; they also estimated the potential catch of the new larger vessels was 95% greater than the old ones (no methodological details provided). A major proof of overcapacity during the following decades appears when comparing trends in fishing capacity and length of fishing seasons between 1987 and 2006. During this period, dominated by anchoveta abundance and landings (Fig. 2), both the number of fishing boats and their mean holding capacity increased dramatically (Fig. 3). As a result, the total fishing capacity of the fleet doubled from about 87,000 to 210,000 tons of holding capacity (Fig. 4). Similarly, the number of processing plants increased from 87 to 140 (Fig. 3a). In the mean time, although the annual quota recommended by IMARPE increased from 1.5 in 1987 to around 6 million tons in 1994, the fishing season decreased from 336 to 49 days because every year the quota was reached earlier due to increased capacity. As a result, the annual number of trips per fishing vessel is now extremely low. Most vessels made less than 50 trips per year in 2006, and a third of the fleet made fewer than 35 trips (Fig. 5). During November 2005, the total catch of anchoveta landings reached a record 2.6 million tons in the north-central area due to increased effort and capacity – there was no evidence of increased anchoveta abundance or availability (Niquen and Fréon, 2006). This record demonstrates that the potential catch and processing capacity amount, if the fishery was continually open and fish available, to at least to 31 million tons a year or, more realistically if one take into account the 4 months of fishing closure, 20.8 million tons in 240 days. The processing capacity itself is actually even higher, as total factory capacity is  $8\,976\text{ ton h}^{-1}$ , which over 240 working days per year amounts to 51.7 million tons processed annually. This processing capacity is about six times more than the average biomass of the stock during the last 5 years.

The recent increase in the number and size of vessels (and to their technical improvements, not discussed here), reflects the



**Fig. 3.** Dynamics of the Peruvian pelagic industry from 1950 to 2006: (a) number of purse-seiners and number of factories; (b) mean holding capacity (HC) according to type of boat. Note the level off in the number of industrial boats and their mean HC from the mid 70 s. Nonetheless the total fishing power did not decrease due to technological improvements (not shown). Note also the lower mean HC of the artisanal fleet.

response of the fishery to the recovery of the anchoveta stock from 1986 onwards, with rapid and massive investments in more and larger boats (Figs. 3 and 6). In contrast, as shown in Fig. 6, the disinvestment that took place after the collapse of the anchoveta stock in the early 1970s was lagged and less intense than the fish population decrease, and the lag would certainly have been longer without the nationalization of the fishery (into Pesca Perú in 1973; Flores, 1976; Aguilar Ibarra et al., 2000). At that time, part of the fleet was sold to Chile and other countries,

and some boats targeted the slow-growing sardine resource, other underexploited species like mackerel and horse mackerel, and the remains of the anchoveta stock. But many boats were idle until the mid 1980s (IMARPE, 1974a,b; Martinez et al., 1990). Pesca Perú was dissolved in 1978 and fishing and processing privatized (Hammergren, 1981). The misbalance between investment and fish abundance increased during the late 1990s and 2000s as stock abundance declined while investment and capacity increased.

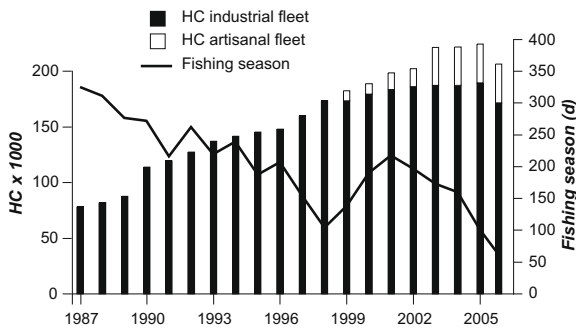


Fig. 4. Dynamics of the Peruvian pelagic fleet compared with the length of the fishing season. Note the opposite trends between the holding capacity (HC) of the fleet and the length of the fishing season.

The bio-economic model shows that, after the realization of a few pseudo-cycles and under stable biological and economical conditions, a stable equilibrium state for all variables develops, which is an attractor of the model dynamics (model-I; Fig. 7). When adding a periodicity to the ecosystem carrying capacity of the previous model (Fig. 8a), the stock, fishing capacity and yield responses are synchronous and stable oscillations (model-II; Fig. 8b–d). When modifying model-I by the incorporation of asymmetry in the investment/disinvestment pattern, the bio-economic system again develops a stable equilibrium on the long term (model-III; Fig. 9). The more dissymmetry in the patterns the larger the oscillations and the longer the damping takes. When increasing the investment rate and decreasing the disinvestment rate, the stock average biomass decreases and its standard deviation increases (Table 2). An instable system, with frequent economic losses and collapses, is obtained by combining a periodic variation of ecosystem carrying capacity and an asymmetry in the investment/disinvestment pattern (model-IV; Fig. 10). Finally, adding a constant total allowable catch to model-III results in a relatively stable system where ecosystem carrying capacity is constant (model-V; Fig. 11), but when oscillations of the carrying capacity are added, the system quickly becomes unstable (model-V; Fig. 12). Model-V is extremely sensitive to the amplitude of variations in carrying capacity (not shown).

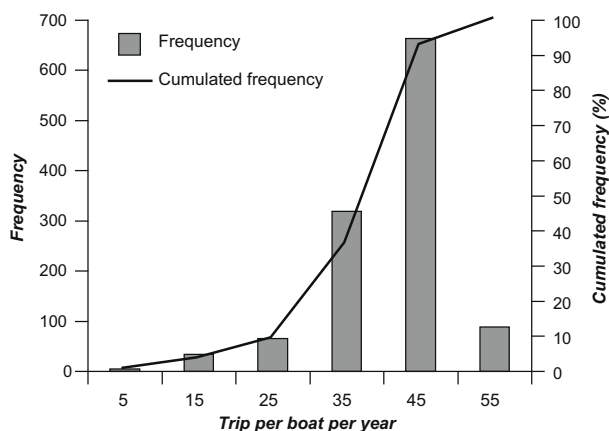


Fig. 5. Frequency distribution histogram of the number of fishing trips per boat in the north-central area in 2006 (the class interval is 10 and the central value of the class is displayed on the x axis). 93% of the vessels made less than 50 trips per year, and 36% made fewer than 35 trips

## 4. Discussion and conclusion

### 4.1. Is there a need to decrease fishing and processing capacity?

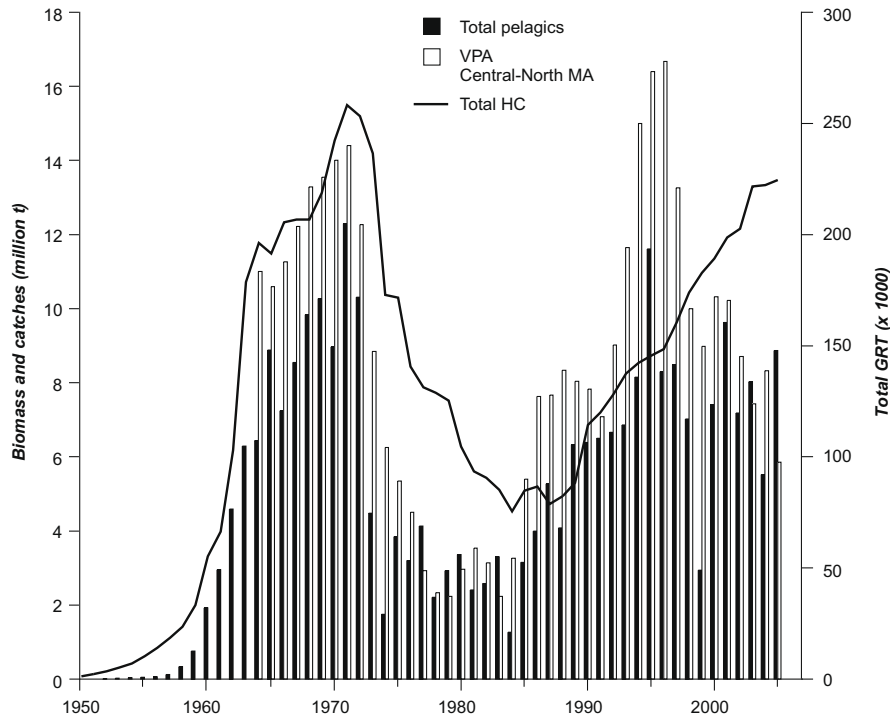
Paleontological and historical data about conventional stock abundance estimates during the last decades indicate that populations of small pelagic fish inhabiting upwelling ecosystems undergo large interdecadal variations in abundance equal, if not larger, than interannual variations. The anchoveta stock of north-central Peru illustrates such a pseudo-cyclic pattern, which for anchoveta is associated with chronic overcapitalization of its fishery. The situation is aggravated by a phase displacement between fish abundance and investment, characterized by slow disinvestment after declines in fish stocks. It is difficult to predict the length of pseudo-cycles and the cycle-to-cycle variability in stock abundance because (1) few realizations of the pseudo-cycles are available, (2) the process(es) responsible for the pattern of variability are largely unknown, (3) the recent global warming might have an impact on anchoveta.

The reduction in fishing days since 1987 days during a period of relatively stable anchoveta abundance demonstrates the overcapacity of the fishery (Fig. 4). Based on a capture capacity of over 20.8 million ton year<sup>-1</sup> when average annual quotas was 5.8 million tons since 1987, fleet overcapacity is about 72% according to Eq. (2). Processing overcapacity is even higher ( $100 * ((51.7 - 5.8)/51.7) = 89\%$ ), although only 35% of this capacity can be used to produce first quality fish meal (high protein content) from fresh fish (Hatzioles and de Haan, 2006). The fishery overcapacity problem is not new. Gordon (1954) reported the case of the Pacific halibut fishery and its competitive race for fish: “In 1933 the fishing season was more than 6 month-long. In 1952 it took just 26 days to catch the legal limit in the area from Willapa Harbor to Cape Spence, and 60 days in the Alaska region”. The continuation of this story is provided by Munro (2001). After the 1950s the race for halibut continued until the fishing season decreased to 6 days in 1990, when individual vessel quotas were established. Ten years later the number of active halibut boats had declined by over 50%. As a result, the number of fishing days per annum increased from 6 to 245 (Munro, 2001).

Obviously a fishing fleet must benefit from a certain level of overcapacity to adjust to high abundance periods and/or low availability of the resource. But the present fishing capacity of the Peruvian pelagic fleet is at least three times higher than the average TAC, which does not seem justified. There is now growing evidence that the catchability of pelagic species increases while abundance decreases (review in Fréon et al., 2005), resulting, especially if the quota is not enforced, in a high risk of population collapse. In agreement, Csirke (1989) found a strong negative relationship between the monthly anchoveta biomass estimated by VPA by Pauly et al. (1987) and the coefficient of catchability  $q$  resulting from the use of GRT trip<sup>-1</sup> as a unit of fishing effort.

Since the end of the 1980s, anchoveta off Peru are, despite substantial fishing pressure and interannual variability due to El Niño events, abundant. Decreased abundance must be expected during the next decade(s), and a Peruvian crisis with high social, economical and political tensions will follow. This crisis will occur, even if IMARPE and the Peruvian Ministry of Fishery succeed in preventing a collapse of the resource by unpopular reduced quotas.

This kind of warning and recommendation is not new (review in Glantz and Tompson, 1981). In 1969 a panel of scientific experts recommended decreases to the fleet and processing facilities, 2 years before the stock started to collapse (Bermejo, 2006). At that time the fishing sector was heavily invested and in debt (Bermejo, 2006), illustrating the difficulty of fighting “Ludwig’s ratchet” in an open access fishery (Hennessey and Healey, 2000). Gordon (1954)

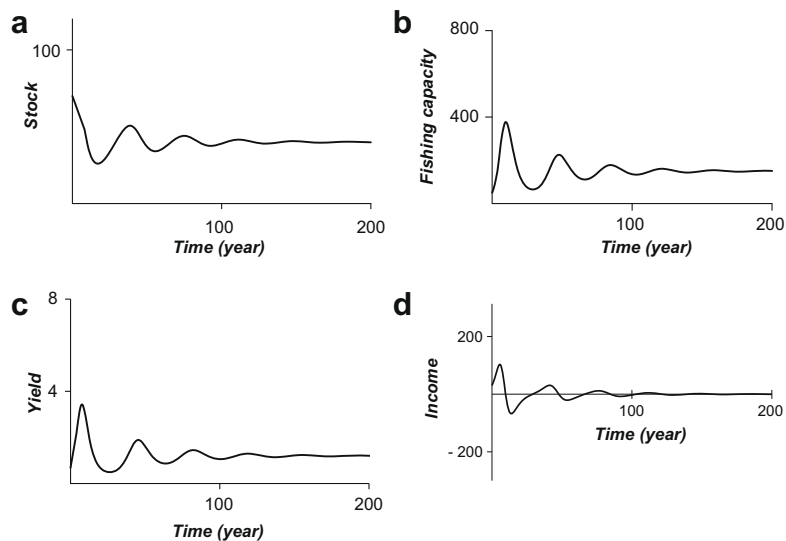


**Fig. 6.** Comparison of the dynamics of the Peruvian pelagic fleet (expressed in total holding capacity (HC)) with the dynamics of the major exploited resource (3-year moving average of the biomass of the north-central stock of anchoveta estimated by VPA) and the total pelagic catches of the fleet. Note the absence of lag between increasing resource (VPA) and investment (HC) and the positive lag between decreasing resource and disinvestment.

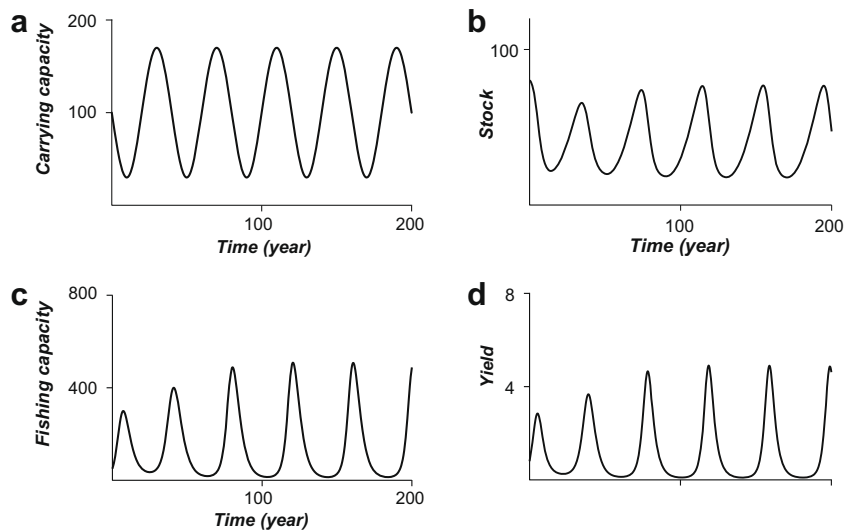
demonstrated that the competition among fishers culminates in the rent dissipation in an open access fishery. The equilibrium condition of uncontrolled exploitation is such that total costs must match total income; hence the net profit is zero, at least in the long run (Scott, 1955, 1993). This was also the base of our bio-economic models. In model-IV we added pseudo-periodicity in the stock abundance and an asymmetrical pattern of investment/disinvestment. It showed that in fisheries, the “conventional capital” *sensu* Munro (i.e. the non-human capital) is essentially “non-malleable” (McKelvey, 1985; Munro, 1999), that is here with some inertia in investment pattern.

4.2. Technical versus economic overcapacity and food security

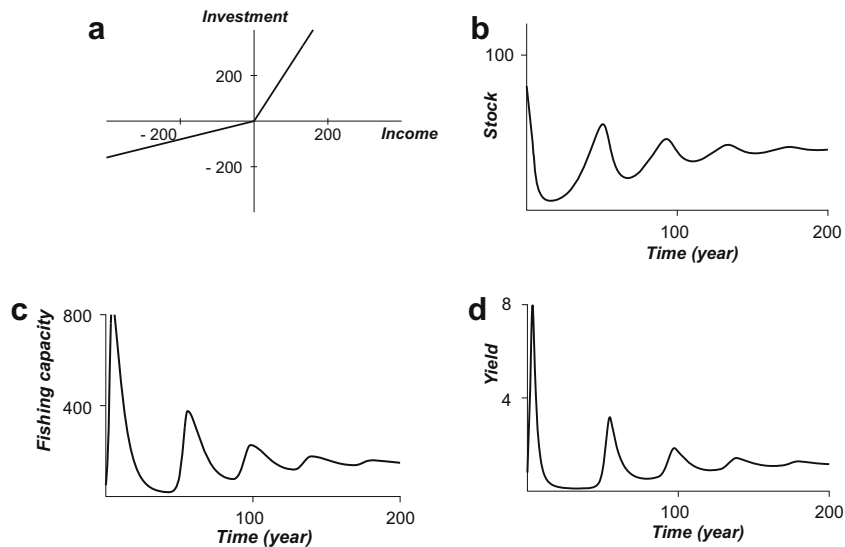
Even if models-IV and -V demonstrated the risks associated with fishery overcapacity, the usual pattern of investment and pseudo-periodicity in fish stock abundance, they did not treat economic overcapacity – in particular price variability ( $p$  is a constant in Eq. (4)). The Peruvian pelagic fishery dominates the global fish meal and oil markets, as Peruvian products constitute ~40% of the world exportations (Tacon, 2003). As a result, price responds to Peruvian rates of production (Aguero, 1987). This production is now limited by fishing quotas and is relatively sta-



**Fig. 7.** Theoretical model-I (constant ecosystem carrying capacity; symmetrical investment/disinvestment patterns): (a) time series of stock abundance, (b) fishing capacity, (c) yield and (d) income. Note the long term equilibrium reached after a few oscillations on all time series.



**Fig. 8.** Theoretical model-II (periodic ecosystem carrying capacity; symmetrical investment/disinvestment patterns): (a) time series of ecosystem carrying capacity, (b) stock abundance, (c) fishing capacity and (d) yield. Note the absence of attenuation of the oscillation generated by the periodic ecosystem carrying capacity.



**Fig. 9.** Theoretical model-III (constant ecosystem carrying capacity; asymmetrical investment/disinvestment patterns): (a) investment/disinvestment behavior according to income, (b) time series of stock abundance, (c) fishing capacity and (d) yield. Note the long term equilibrium reached after a few oscillations on all time series.

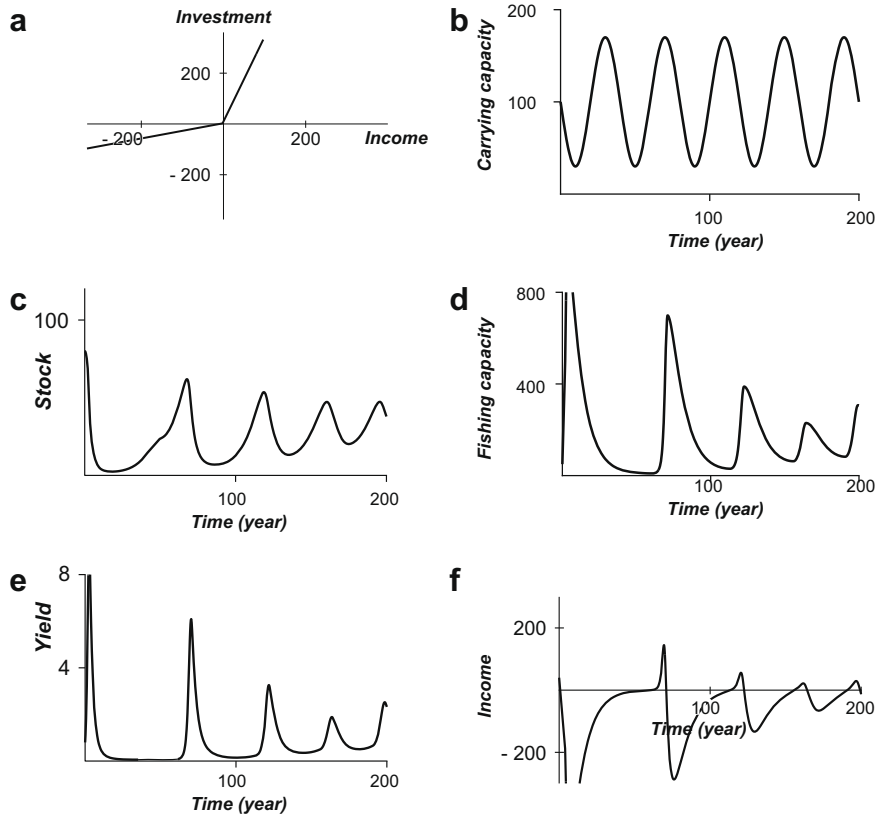
**Table 2**

Simulation of the effect of changing investment and disinvestment rates on the average and standard deviation of the stock biomass.

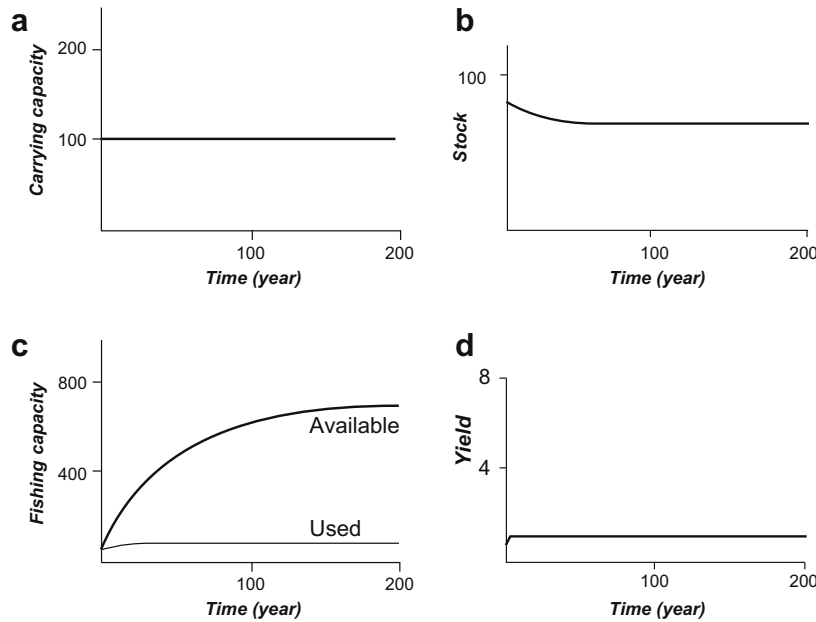
Investment rate ( $\times 100$ )	Disinvestment rate ( $\times 100$ )	Average of the stock biomass	Standard deviation of the stock biomass
20	20	40	7
22	18	40	8
25	16	39	8
28	14	38	8
33	12	37	9
40	10	36	10
50	7	33	12
66	5	28	15
100	3	16	16

ble except during El Niño events. But the demand for both meal and oil has grown during the last 25 years due to the increase of aquaculture, especially for freshwater species in China, and farming of poultry and swine (Tacon, 2003; Asche and Tveterås, 2004). Thus if prices increase, overcapacity might be economi-

cally sustainable in Peru providing that fishing quotas are still adequate and enforced to prevent stock collapse. Still, the economic drawbacks of overcapacity in the Peruvian pelagic fishery ought to be better documented, as economic forces can produce a loss of control of the nominal effort or inappropriate



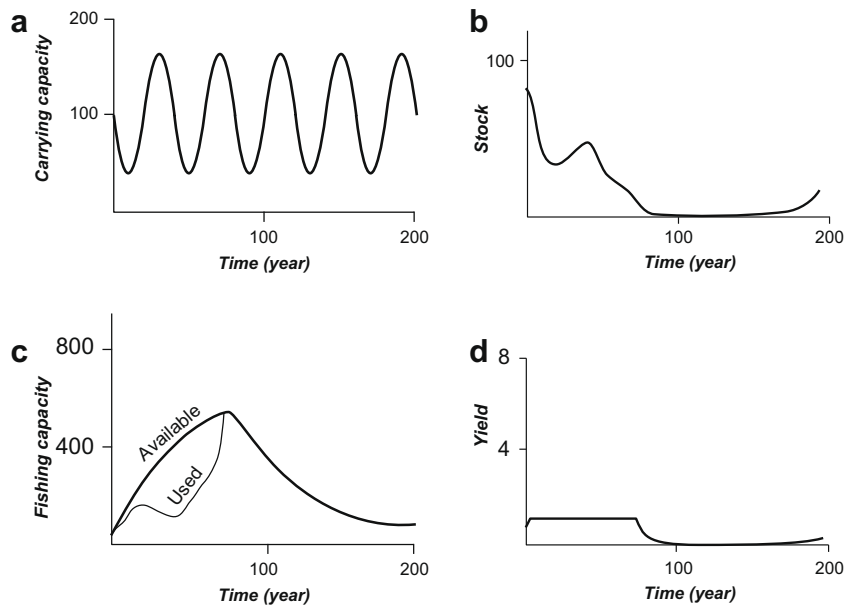
**Fig. 10.** Theoretical model-IV (periodic ecosystem carrying capacity; asymmetrical investment/disinvestment patterns): (a) investment/disinvestment behavior, (b), time series of ecosystem carrying capacity, (c) stock abundance, (d) fishing capacity, (e) yield and (f) income. Note the instability of the system, with frequent economic losses and collapses.



**Fig. 11.** Theoretical model-V (constant ecosystem carrying capacity; catch controlled by quota): (a) time series of ecosystem carrying capacity, (b) stock abundance, (c) available (bold curve) or used (thin curve) fishing capacity and (e) yield. This is an idealistic situation where, despite a strong overcapacity, the system is stable.

setting of the annual quotas. Sustainable high prices motivate catch under-reporting and poaching, which occur in this fishery as in many others (Castillo and Mendo, 1987; Hatzioles and de Haan, 2006).

Beyond the operational and economic aspects of overcapacity lies the issue of food security, especially in developing countries with high poverty rates such as Peru. Since most Peruvian pelagic catches are processed into fish meal and oil, Peru is a special case.



**Fig. 12.** Theoretical model-V (periodic ecosystem carrying capacity; catch controlled by quota): (a) time series of ecosystem carrying capacity, (b) stock abundance, (c) available (bold curve) or used (thin curve) fishing capacity and (d) yield. The system quickly becomes unstable.

First, within Peru fish meal is largely used to feed poultry and swine which constitute a source of protein. [Storz et al. \(2005\)](#) estimated that Peruvians consume 24 kg of poultry per year. Second, the Peruvian Government has recently encouraged the use of anchoveta products for human consumption, resulting in effective landing of 27,000 ton of fish used for fresh consumption, canning or production of fish pasta in 2005. In both cases the impact of fleet and processing overcapacity on food security is economic. Abundance of pelagic and demersal fish resources off Peru is so high, compared to Peruvian demand, that resource scarcity is not likely to occur within Peru. Only a few percent of the present fishing capacity suffice to secure food: from 1999 to 2005 we estimated that 6% of the total Peruvian production ([Table 3](#)), mainly demersal fish, were used for direct human consumption in Peru. But because overcapacity results in higher price of production, it can limit the access of the main source of proteins for the poorest segment of the Peruvian population.

All these negative aspects of fishing overcapacity need be balanced against positive aspects like employment and profits in the fishing sector in the broad sense of the word (construction or importation of fishing gear, boats and plants, etc.). How such positive and negative aspects interact and how profits flow into the overall economy are important economic and political issues that deserve further investigations.

#### 4.3. How to reduce capacity in Peru?

Open access leads to fishery overcapacity and neo-liberalism implemented in Peru from the beginning of the 1990s favored overcapacity ([Aguilar Ibarra et al., 2000](#)). Alternative models in-

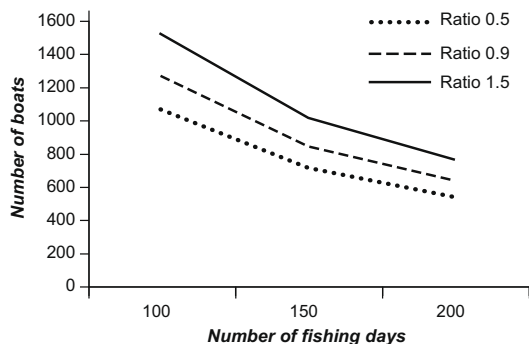
clude (1) establishment of individual quotas (IQ), transferable (ITQ) or not, (2) allocation of specific fishing rights to communities, (3) involving local communities in co-management. These options encourage conservation by fishers ([McCay et al., 1998](#); [Clark, 2006](#)). Despite their strong theoretical background, experience to date with these alternative models has been mixed, even to fight the Ludwig's ratchet (review in [Hennessey and Healey \(2000\)](#)). But as pointed out by [Troadec and Boncoeur \(2003\)](#), alternative models to free access are more likely to succeed when national fleets exploit mostly resident stocks. Because the bulk of the resource (north-central anchoveta stock) is mostly a national resource this is presently the case of the Peruvian pelagic fishery.

Important questions remain. Are IQ feasible in Peru, are IQT adapted to a species with a short lifespan such as anchoveta? From an economic point of view, one may suggest that fishery capacity should be strongly reduced. Nonetheless, such a decision must also consider that fishing companies will need to refit older vessels, convert others to alternative users, and hopefully find ways to redeploy personnel. Now that the industrial and artisanal fleets are characterized by a wide range of HC, there are several options regarding the reduction of fishing capacity ([Fig. 13](#)). Because the artisanal fleet is more labor-intensive, both at sea and on land, reductions will more strongly affect manpower, whereas reductions to the industrial fleet will decrease invested capital.

All these ecological, economical and management considerations show that if fishery overcapacity must be reduced, solutions are complicated (e.g. effect of continuous technological improvements) and difficult. Nevertheless, a first and urgent measure is to remove the economic incentives that result in ever-increasing investment and fishery overcapacity. Such incentives will surely

**Table 3**  
Estimation of the total annual consumption of fish by the Peruvian population based on the consumption per capita ([PRODUCE, 2007](#)) and interpolation of the 1993 and 2005 population census.

Year	1999	2000	2001	2002	2003	2004	2005
Consumption per capita (kg)	18.7	21.3	22.5	19.1	20.7	20.4	19.0
Peruvian population (million)	24.9	25.3	25.7	26.1	26.5	26.8	27.2
Estimated consumption (ton)	466,179	539,124	578,085	498,019	547,638	547,487	517,166



**Fig. 13.** Simulation of the increase in the number of fishing days and corresponding reduction in the number of boats according to the ratio between the number of artisanal boats and the number of industrial boats (present ratio is 0.9). This simulation is based on year 2005. Note the sensitivity of the total number of boats to the composition of the fleet.

produce economic and political hardship when the Peruvian anchoveta stock, inevitably, begins its next decline.

#### 4.4. How to adjust changes in capacity to abundance fluctuations?

Beyond the need of reducing the overall overcapacity is the need to adjust capacity to the fluctuation of stock abundance. Fréon et al. (2005) proposed a two-level strategy to cope with interannual and interdecadal variations. The first level is the conventional adaptive management approach which incorporates new ecosystem-based thresholds or limit reference points as much as possible. The second level attempts to cope with inter-decadal variations in abundance. Once the turning point in abundance has been documented, uncertainty decreases and management could limit long-term investment in fishing units and related infrastructures and also take into account the entire range of social, economic and political implications. To quantify the associated risks will largely depend on our knowledge of the pseudo-cycle, which remains limited. While better understanding of the interrelated ecological, social, economic, political and governance issues are needed, reduction of the fishing overcapacity is an obvious and immediate need because it represents a timing bomb for the fishing sector.

#### Acknowledgements

We are grateful to Olivier Thebaud who provided us with references and guidance on the issue of economic overcapacity and to Pierre Lopez who produced the art drawings. This is a contribution to the European network of excellence EUR-OCEANS (EC Contract No. 511106-2) and to the research unit R097 ECO-UP of IRD.

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