Table of Contents

Go Back

Modelling the management of clam (*Ruditapes decussatus*) exploitation in the Plentzia estuary (Basque Country, Northern Spain)

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Abstract

Some of the estuaries of the Basque Country (Northern Spain) have been areas of exploitation of clam populations, both by professional and illegal fishermen. There is a real possibility of overfishing and, therefore, the Department of Fisheries of the Basque Government needs to: (a) understand the situation relating to these populations; and (b) provide a tool to establish the most adequate management for the exploitation of clams.
In order to simulate different alternatives for the exploitation, based upon scientific data on the population, the best tool available is a system dynamics model. Here the VENSIM® model was employed, utilising data on clam populations: summer stock and biomass in the Plentzia estuary, in 1998, 2000; winter stock in 1999, 2000, and 2001; the area occupied by the species; the length and weight class distribution; the number of fishermen; mean of biomass, captured by the fishermen; natural mortality, by length class; maturation; fertility rate; etc. This study improves previous experiences in modelling clam exploitation in the Plentzia and Mundaka estuaries.
Following validation of the model, after running it for 1 and 10 years, some cases were simulated. This analysis was undertaken in order to establish the effect of modifying the number of fishermen, the aperture-close season of captures, the minimum sustainable biomass, the exploitation area and the minimum legal length for shellfishing. This approach tries to establish the sustainable exploitation of the clam populations in the Basque Country.
Key words: modelling, shellfishing, clams, management model, marine resources, Vensim Software, Basque Country, Spain.

Introduction

Some of the estuaries of the Basque Country (Northern Spain), such as Plentzia and Mundaka (Figure 1), have exploited clam populations (*Ruditapes decussatus*), both by professional and illegal fishermen. There exists a very real possibility of overfishing of this scarce resource. Therefore, the Department of Fisheries of the Basque Government needs to know the real situation regarding these populations, together with a tool to establish the most adequate management for the exploitation of clams.

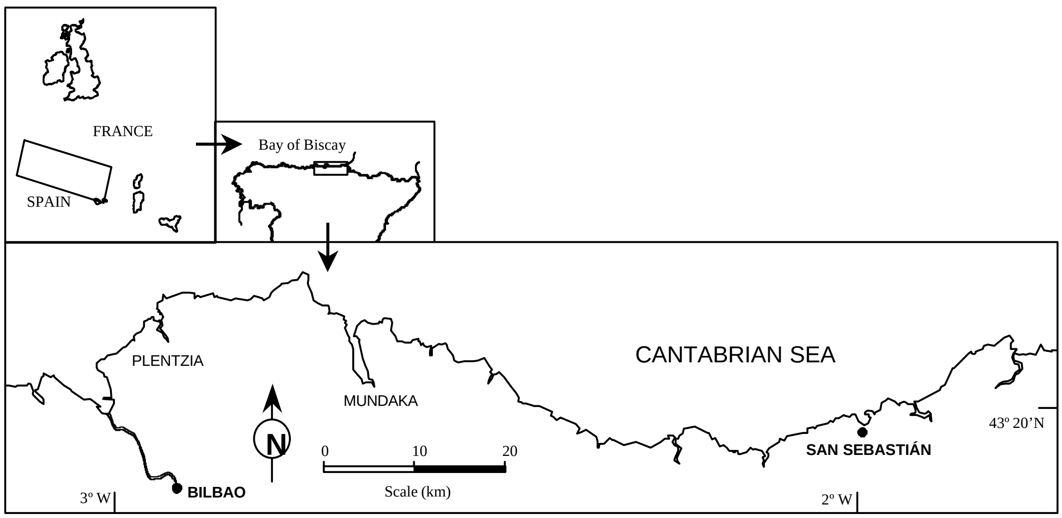

Figure 1. Location of the Basque Country in the Northern Spain, showing the Plentzia and Mundaka estuaries.

In order to simulate different alternatives for the exploitation, based upon scientific data on the population, the best tool available is a model with a clear purpose (Sterman, 1988). From the system dynamics perspective, a model is developed to address a specific set of questions and its purpose helps guide its formulation (Richardson & Pugh, 1981).

In this particular case, the purpose of the model is to answer such questions as, for example: how many fishermen could support this exploitation?; what happens if number of fishermen increase strongly?; is it possible to modify the capture season, or the minimum legal length of capture?; what happens after and during the establishment of a closed-season?; can we modify the establishment of it?; and what are the implications in maintaining a minimum sustainable biomass?.

A model is simply an ordered set of assumptions about a complex system (Meadows *et al.*, 1972). It is an attempt to understand some aspects of the infinitely varied world, by selecting from perceptions and past experience a set of general observations applicable to the problem.

This paper tries to solve this particular problem, by means of a system dynamics model *sensu* (Forrester, 1973); this approach allows for a "whole system" analysis. System dynamics can be employed for non-linear and dynamically complex problems, involving disequilibrium conditions, bottlenecks, delays, stocks and flow relationships, and realistic decision-making (Sterman, 1987). The VENSIM® software has been used previously in urban dynamics, demography, sustainable development, Alfred &

Graham., 1976; Barney *et al.*, 1995) and clam exploitation (Borja & Bald, 2000a, 2000b) and Bald y Borja (2001).

Methodology

The modelling of the exploitation of the clam in the Plentzia estuary is based upon the methodology described in Borja & Bald (2000a, 2000b). The model was constructed graphically; first variables and levels were defined, afterwards the relationships between them. Six levels, corresponding to six length and weight class distribution of clams, were established. These classes were defined from biological data of the species (Perez-Camacho, 1979) (Figure 2). Hence, the class (0-20 mm) includes immature clams and the other five classes are mature individuals. Taking into account that minimum legal length for fishing clams in Spain is 40 mm, these five classes are divided further into two non-exploited mature classes (21-30 mm and 31-40 mm) and three exploited matures classes (41-50 mm, 51-60 mm and >60 mm).

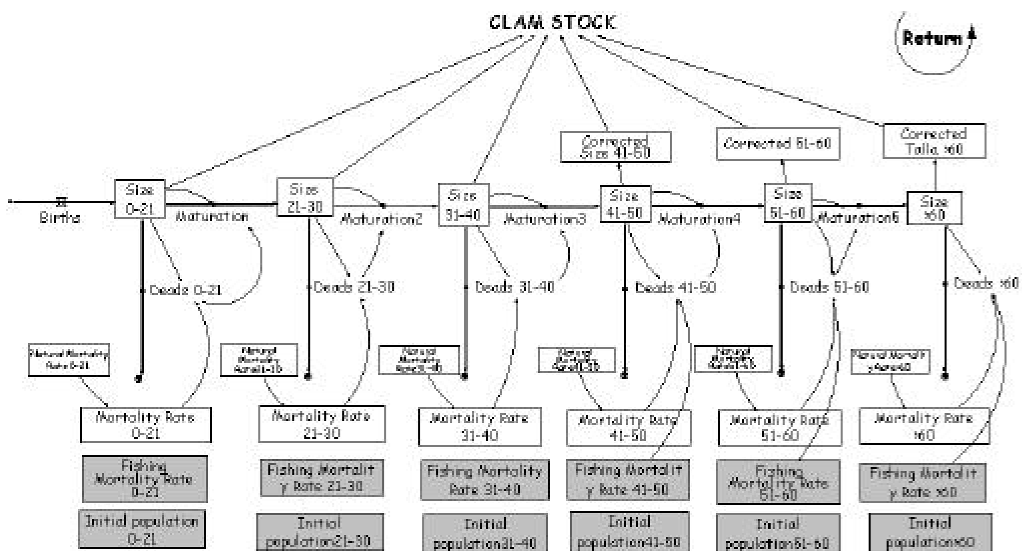

Figure 2. Stock and length class structure of the model.

The weight in kilograms of each level, which contributes to the final stock, is the result of the incorporation of new individuals from a previous class, less those that mature and pass to the next class and those who are dead. The death of clams is due both to natural and fishing mortality. The fishing mortality is equal to zero, in classes under legal length for fishing (Table 1); however it could be modified in order to simulate illegal captures.

On the other hand, the “births” in clam population are the result of the sum of births on each class bias a fertility rate (Table 1). The contribution of each size class to the total weight of births was calculated taking in count the weight of each individual in each size class according to Borja and Bald (2000) and Bald and Borja (2001) (Figure 3).

Table 1. Clam population data inputs to the model, obtained from field experimentation and bibliography.

VARIABLES	LENGTH CLASSES (mm)					
	0-20	**21-30**	**31-40**	**41-50**	**51-60**	**>60**
Initial Population (kg)[(1)]	1504	502,3	333,95	333,95	41,4	0
Natural Mortality Rate[(2)]	0,060	0,044	0,031	0,052	0,071	0,070
Fishing Mortality Rate[(1)]	0	0	0	0,65	0,30	0,05
Fertility Rate[(2)]	0	0,90	0,85	0,80	0,75	0,7

(1) Bald y Borja, 2001.
(2) Pérez-Camacho, 1979.

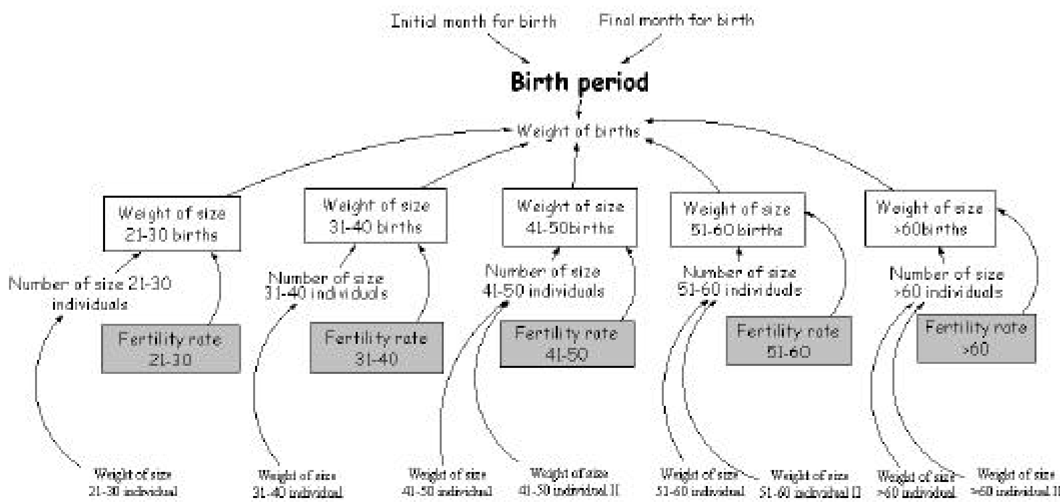

Figure 3. Births structure of the model.

The clam population biomass is calculated on the basis of dividing the total stock, by the shellfishing area (Figure 4). A minimum sustainable biomass is established, in order to calculate the overfishing. Therefore, if real biomass is below established minimum sustainable biomass, there is a deficit that corresponds to an overfishing effort. According to relationships established in the corresponding tables (tables 3 and 3bis), this biomass deficit correspond to a determinate number of fishermen. These Tables of double entry relate biomass with shellfishers number in such a way that increasing the availability of the resource (more biomass) supposes an increasing number of shellfishers. Then, the adequate number of shellfishers is equal to the number of shellfishers without minimum biomass control less the remaining shellfishers according to objectives established by sustainable minimum biomass.

The total captures are the result of shellfishers capture sums. Shellfisher's captures depend upon three factors: biomass of clam population; aperture and close season; and shellfishers capture day rate (Figure 5). The clam biomass modifies captures by mean of different Tables function (Table 1 in Figure 5). These Tables of double entry relate biomass with shellfishers captures, in such a way that increasing the availability of the resource (more biomass) supposes an increasing number of captures.

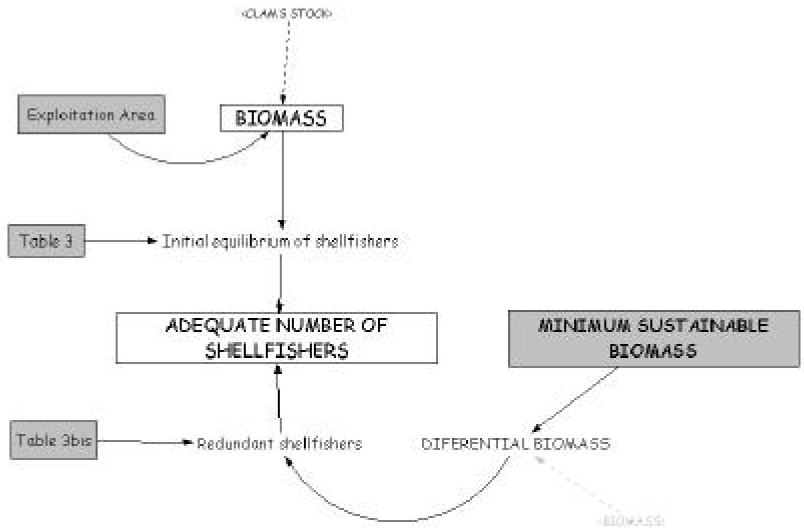

Figure 4. Biomass and number of shellfishers structure in the model.

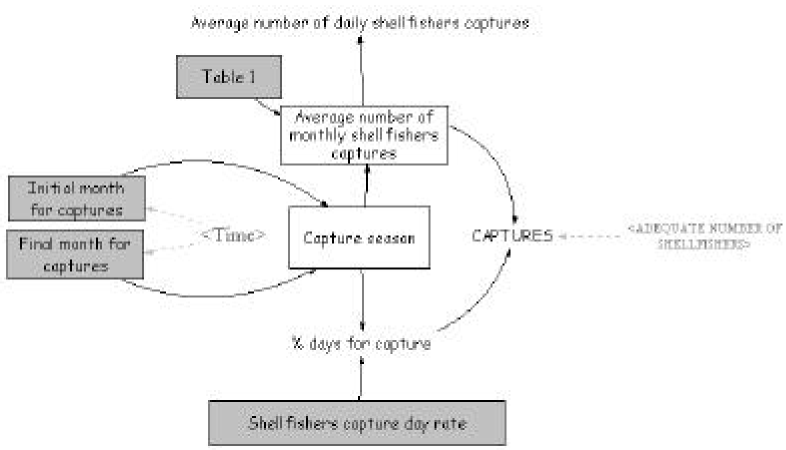

Figure 5. Captures structure in the model.

Furthermore, some improvements described in Bald and Borja (2001) have been incorporated to the model, including:

- new capabilities of modelling and analysis; and
- an easily used approach based upon different "windows", with each one, being capable acceding to a different part of the model.

In order to undertake these objectives, we have used a new version of VENSIM® (version 4.1). Relating to the new capabilities of modelling and analysis, the main improvements, as outlined below, are:

a) The capacity to establish a close season every 2 or 5 years, or the establishment of a closed season only one selected year. This is made by means of two variables (“Periodic close season” and “Within a year close season” variables) that equal to cero, multiplies the adequate number of shellfishers the year or the period selected (every 2 or 5 years) (Figure 6).
b) Beginning within a particular year, the capacity to modify the capture season annually throughout the time of the modelling.
c) Beginning within a particular year, the capacity to increase or decrease the number of fishermen annually throughout the time of the modelling, or in only a selected year. This is made by means of two variables that multiplies the adequate number of fishermen increasing or decreasing in a determinate percentage the number of fishermen. (Figure 7).
d) Beginning in a particular year, the capacity to modify the fishing effort throughout the time of the modelling, by modifying the fish mortality rate for each length class.
e) Beginning in a particular year, the capacity to modify the minimum legal length for capture throughout the time of the modelling, or in only a selected year.
f) The capacity to modify the exploitation area and the minimum sustainable biomass within a particular year.

In order to validate the model, some field samples were collected in the Plentzia estuary for this particular study, using the methodology described in Borja (1989 and 1991)*:* summer stock and biomass, in 1998 and 2000; winter stock and biomass, in 1999, 2000 and 2001 (Table 2); area occupied by the species in 1998 (56.538 m^2) and the length and weight class distribution, in 1998 (see Table 1).
The Fisheries Service of the Basque Government have provided data relating to: shellfishing activities in the estuary, in 1998-1999: capture season dates (October-December); percentage of work days (70%); number of shellfishers (40-50 at the beginning of the capture season) and mean biomass captured by the fishermen (about 3 $kg \cdot day^{-1}$, at the beginning of the season; 1 $kg \cdot day^{-1}$ at the end). Also, bibliographic data on clams were obtained: fertility rate i.e.; natural mortality by length class, maturation, etc, (Perez-Camacho, 1979). Table 1 lists the above mentioned data. The results obtained here are valid only for the management of the stock in the Plentzia estuary.
Any other site application requires specific field data to be obtained, in order to validate the results in that particular area.

Table 2. Clam stock and biomass in the Plentzia estuary between summer 1998 and winter 2001.

VARIABLES	STOCK (kg)	BIOMASS ($g \cdot m^{-2}$)
Summer 1998	2760	47,08
Winter 1999	880	15,56
Winter 2000	840	14,85
Summer 2000	2990	52,88
Winter 2001	1410	24,93

All these new capabilities needs to be easily handled. For this, the model has been structured in different “windows” as mentioned above. These windows allows an easy access to the different parts of the model and the modelization of different cases. Then, the model is divided into three main parts. Each part can be accessed by clicking in the corresponding button of the first view (Figure 6a). The first contains the model structure (Figure 6b), the second permits the query of the results of the key parameters (Figure 6c), after running the model; and the last permits the modelling of different cases (Figure 6d).

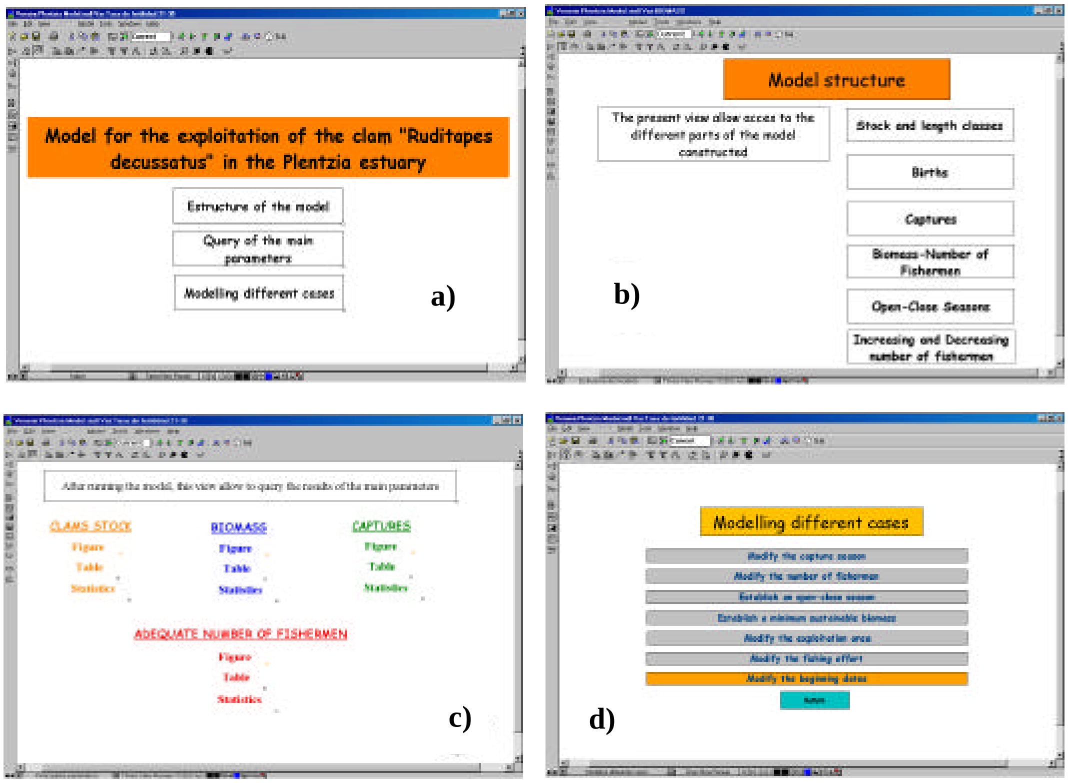

Figure 6. a) Main view of the model for the exploitation of the clam (*Ruditapes decussatus*) in the Plentzia estuary; b) Model structure; c) Query of the main parameters and c) Modelling different cases views.

The view corresponding to “*Model structure*” (Figure 6b) provides access to the different parts of the model that represent the different aspects of the fisheries (captures, open-close seasons, increasing and decreasing of the number of fishermen, etc.) and the natural dynamics of the resource (length and age classes, births, etc). The view corresponding to “*Query of the main parameters*” (Figure 6c) allows investigation of biomass, stock, captures and number of fishermen results, by mean of Figures, Tables and statistics relating to each parameter.
In this paper, some cases are studied. Case 1 validates and fits the model for the first four years (1998-2001), comparing the results with field data. Case 2 runs the validated model over 10 years, starting in September 1998. The model allows then some of the variables to be changed such as: number of shellfishers (Case 3); aperture-close season

(Case 4); the minimum sustainable biomass (Case 5), the exploitation area (Case 6) and the fishing effort (Case 7). The analyses demonstrate the most adequate management policy, according to the management objectives and based upon biological or social requirements.

Results

CASE 1, fitting the model

The inputs to the model were based upon the actual situation of the clam fishery, in 1998-1999. The open capture season was in October, with the close season in December: the shellfishers were auto-regulated by the existing stock each month. Table 3 compares the observed and predicted results. The fit between the data is good (± 10%), excepting for the winter stock and biomass results in 1999 and 2001. However, a 15% of fishing effort in clams below the minimum legal length (31-40 mm) provided a better fit of the model, especially in 1999. The fact is that the "real" fishery in Plentzia fits better to this case, but the lack of information on this particular subject makes us model all the cases, considering only the legal length for capture (40 mm).

Table 3. Comparison between observed and predicted data relating to some variables, showing the deviation percentage.

	VARIABLES	OBSERVED	PREDICTED	DEVIATION %
STOCK (kg)	Summer 1998	2760	2715	-1,63
	Winter 1999	880	1045	+18,75
	Winter 2000	840	902	+7,38
	Summer 2000	2990	2725	-8,86
	Winter 2001	1410	843	-40,21
BIOMASS ($g \cdot m^{-2}$)	Summer 1998	47,08	48	+1,95
	Winter 1999	15,56	18,4	+18,25
	Winter 2000	14,85	15,9	+7,07
	Summer 2000	52,88	48,2	-8,85
	Winter 2001	24,93	14,9	-40,23

Figure 6 shows the annual evolution of the biomass and stock of the population, between 1998 and 2001, together with the predicted values of the model. In autumn-winter (October to March-April), there is a decrease in the population in response to natural mortality. The spring and middle summer (may-august) provide a high increase of the biomass, due to growth and settlement of the larvae and juveniles. Then, commences a new decrease, which accelerates when the capture season opens in October. The captures lie at between 700 to 800 $kg \cdot year^{-1}$ (Figure 7).

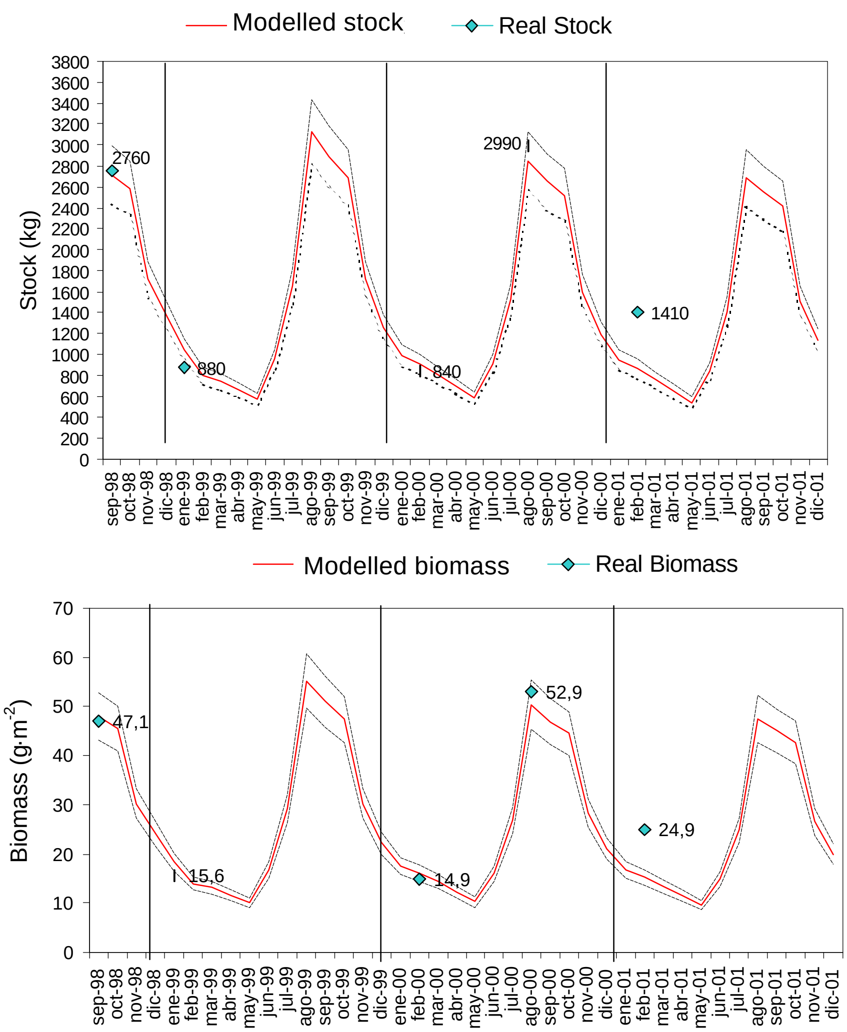

Figure 6. a) Results of the modelled stock in Plentzia, between 1998 and 2001. The hatched lines indicate the maximum deviation accepted (+/- 10%). The vertical lines indicate the transition to each year. b) *Idem*, for the biomass.

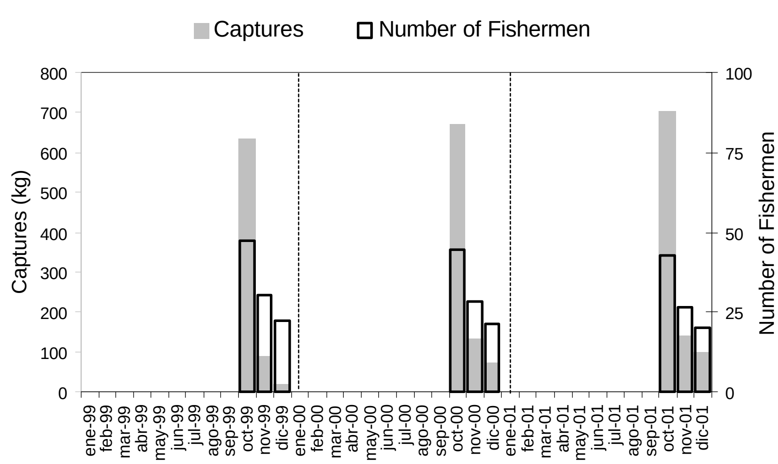

Figure 7. Modelled captures (kg) and number of fishermen in the Plentzia estuary, between 1998 and 2001.

The most important captures are in October, due to the presence of the high biomass and large individuals. Hence, when the season starts there are about 50 fishermen, with a mean number during the season, of 30 shellfishers. The mean capture per day for each shellfisher is about 3 kg during the first month, 2 kg the second one and 1 kg the last one. All these data fit with the information provided by the Department of Fisheries of the Basque Government validating, once again, the developed model.

CASE 2, running the model for 10 years

This case is similar to that of Case 1, but the model runs over a period of approximately 10 years. Over this period, the biomass and clam's stock reach the equilibrium situation with maximum values of about 50 $g \cdot m^{-2}$ and 2500 kg, respectively, in summer and minimum values about 10 $g \cdot m^{-2}$ and 500 kg in winter (Figure 8). Captures are about 1000 kg during each season, whilst the average number of shelfishers is about 30 during each season.

CASE 3, regulating the number of professional fishermen.

In this case we, have increased by 50, 75 and 100% and decreased by 50% the number of fishermen every season, beginning in October 2001 (2001-2002 season). In the first of the cases (50% increase), the number of fishermen increase over 50 in October 2001. Then, the first month of captures they finish with all the legal sized clams stock and biomass decreasing the annual average stock and biomass until 1000 kg and 15 $g \cdot m^{-2}$ respectively (30% less than today). According to relationship established between biomass and number of fishermen and captures in the model (Tables 1, 3 and 3bis), captures decrease to 600 kg per season (15% less than today) but the number of fishermen remain high due to the influence established (50% of increase in the number of shellfishers). Then the expected recovery of stock and biomass is not given and they remain in the above mentioned values (Figure 9).

We find the same behaviour when the number of professional fishermen is increased by 75%. The annual average stock decreases until it is less than 1000 kg with a 12 $g \cdot m^{-2}$ biomass. Captures decrease strongly and only after six years do they reach 60% of the actual captures (Figure 10). When we double the number of fishermen, stock's decrease strongly until 500 kg of annual average with a 10 $g \cdot m^{-2}$ biomass (Figure 11). Captures do not reach 500 kg per season and the number of fishermen decrease slightly at the end of the modelling period. This result shows that the system is not able to support this particular level of fishing effort.

On the other hand, if we reduce the number of fishermen by 50%, we find the contrary behaviour as described above. The decrease of the number of fishermen until an average number of 16 persons in 2001 allows the decrease of the fishing effort and then, stock and biomass increase until 2500 kg and 45 $g \cdot m^{-2}$ of biomass (Figure 12). These increase permit great captures according to relationships established in Tables functions in the model, but the expected parallel increase of the number of fishermen is not given due to the control in the number of fishermen established. These allows the captures increase until 2000 kg during each season and a better performance for fishermen (see discussion).

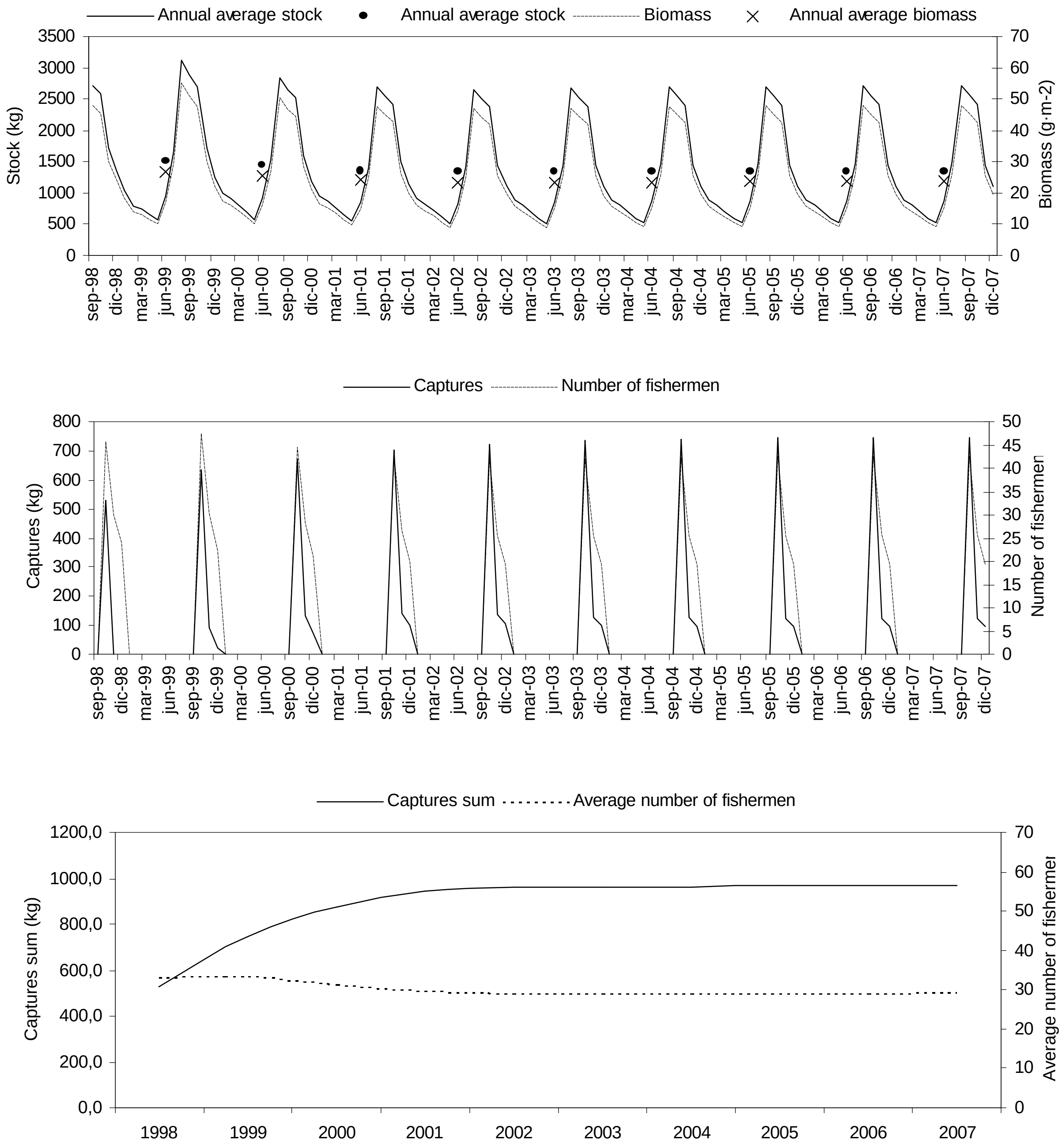

Figure 8. a) Predicted Stock and biomass evolution over ten years in the Plentzia estuary. b) The evolution of captures and number of fishermen. c) Sum of annual captures and the average number of fishermen, showing the evolution.

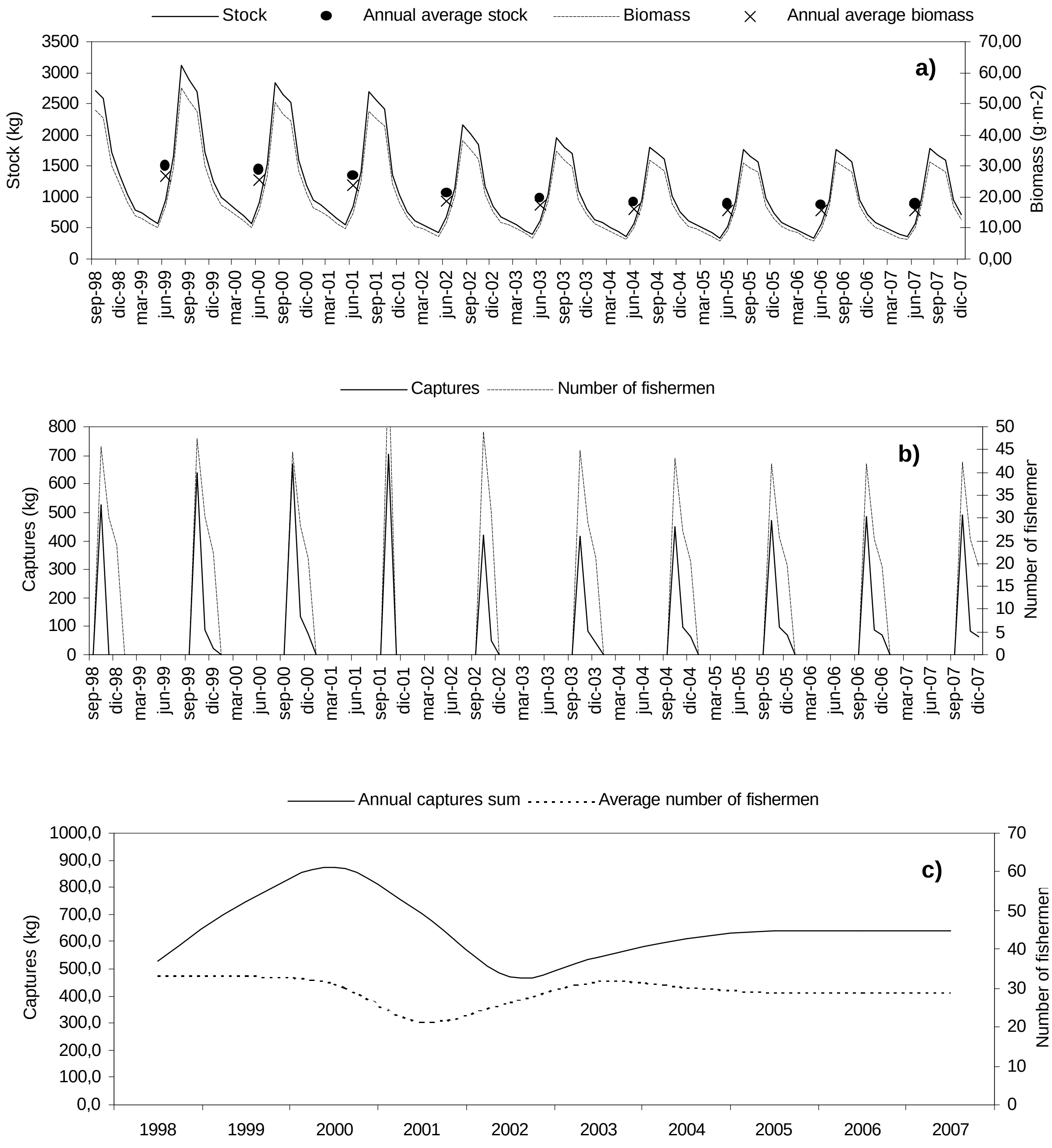

Figure 9. a) Stock and biomass evolution in the Plentzia estuary, increasing by 50 % the number of fishermen. b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

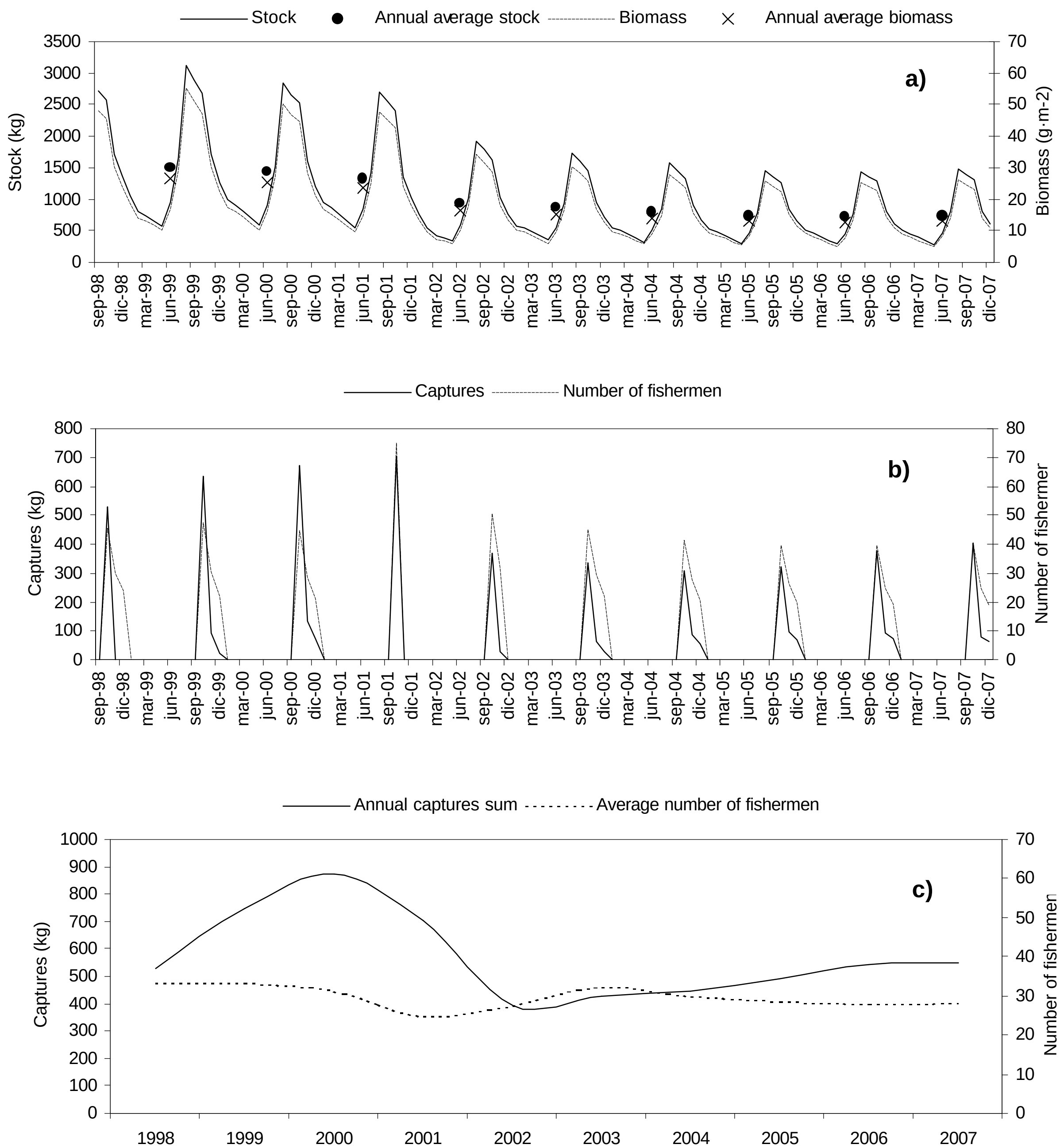

Figure 10. a) Stock and biomass evolution in the Plentzia estuary, increasing by 75 % the number of fishermen. b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

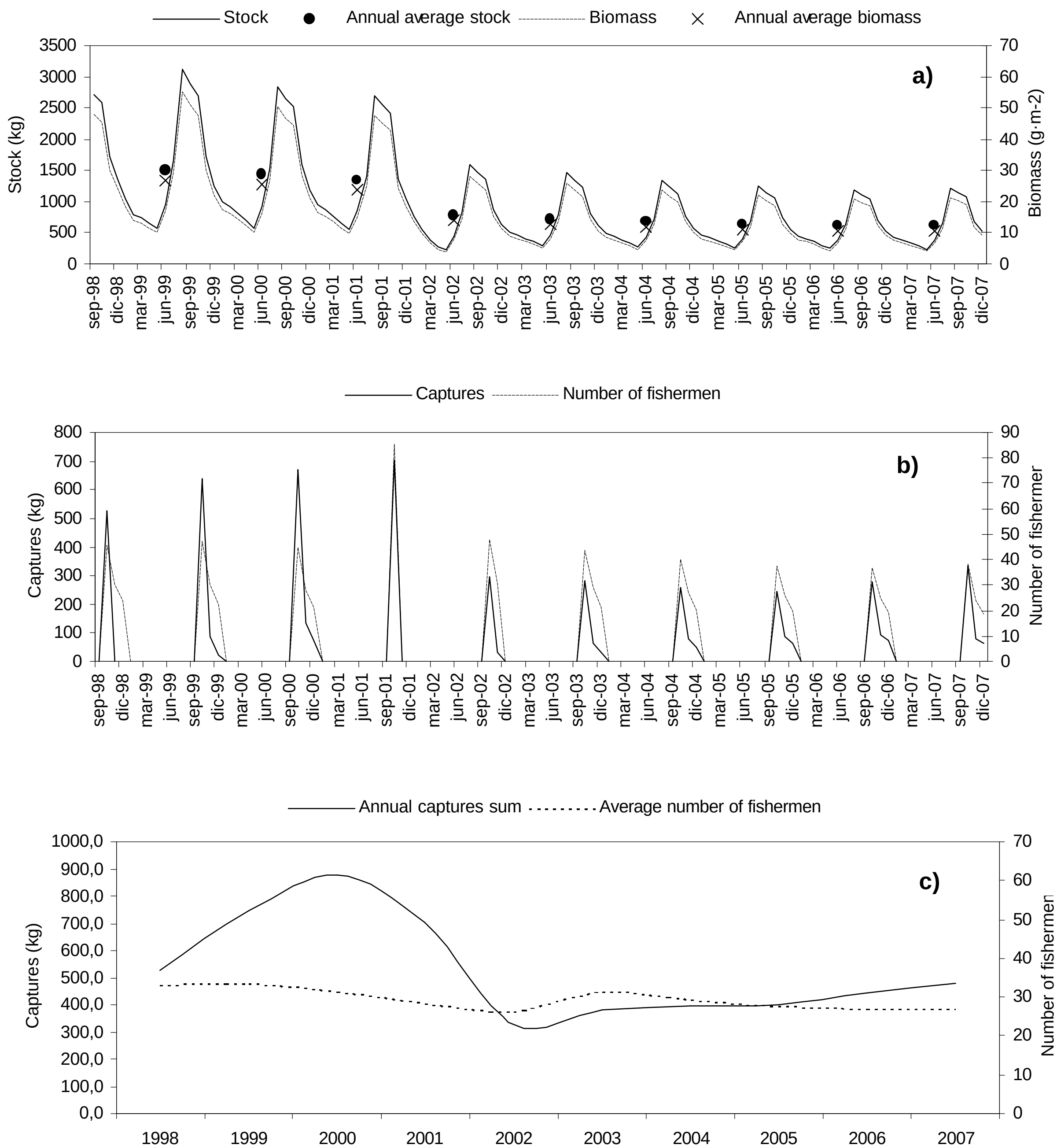

Figure 11. a) Stock and biomass evolution in the Plentzia estuary, doubling the number of fishermen. b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

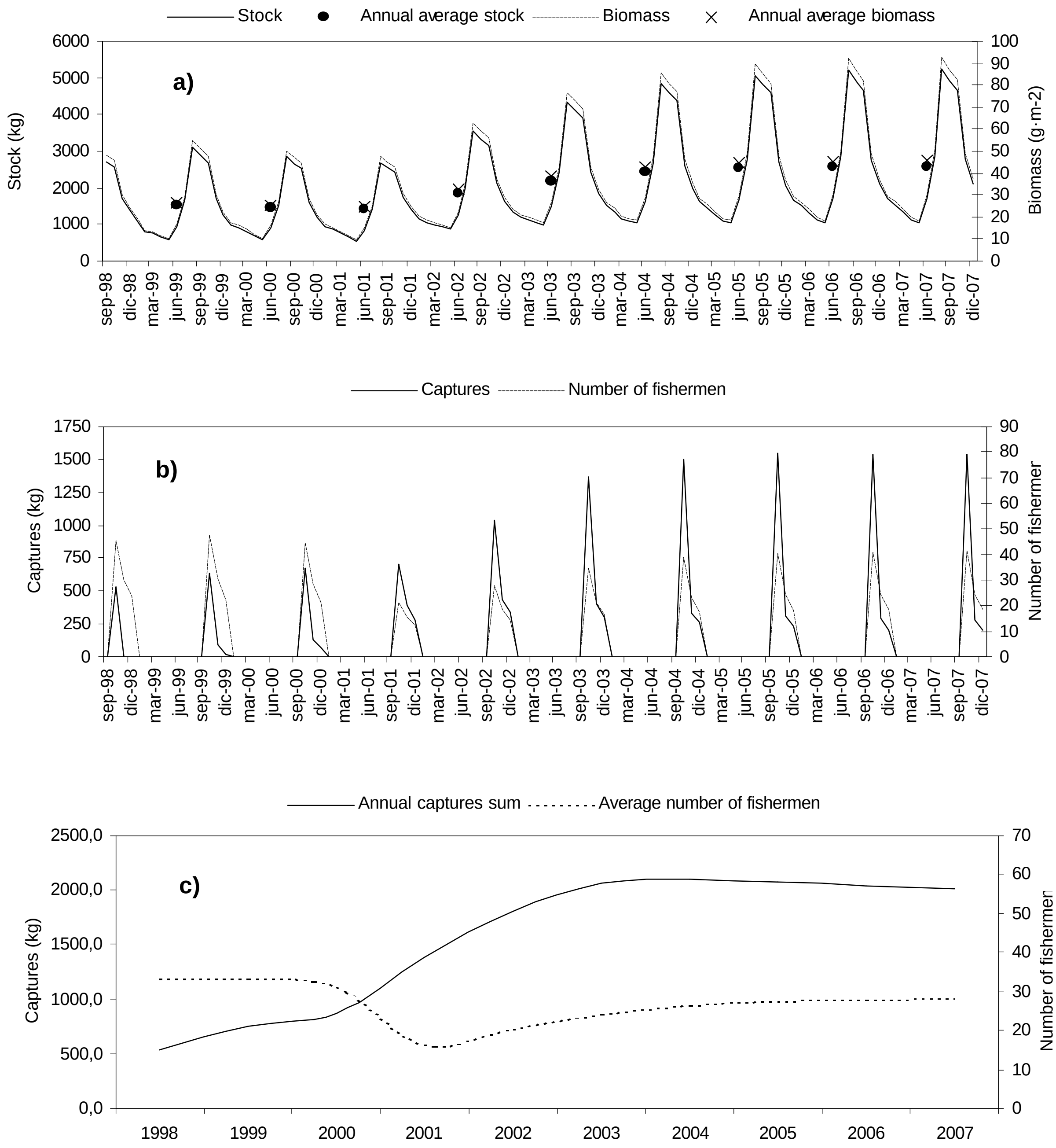

Figure 12. a) Stock and biomass evolution in the Plentzia estuary, decreasing by 50% the number of fishermen. b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

CASE 4, regulating the aperture-close season.

In this case the capture season is reduced, increased and changed in terms of its timing. In the first case, the capture season is reduced to 1 month (October). Due to this modification, the capture season during the first year finish with values of stock and biomass greater than those obtained in the precedent years allowing the recovery of the system until the next year. This recovery is detected every year increasing stock and biomass rapidly until the 3th year were system becomes asymptotic, whilst the summer stock reaches 3 t and biomass 50 $g \cdot m^{-2}$ (Figure 13). According to Tables functions established in the model (Tables 1, 3 and 3bis) the available biomass allows a high number of fishermen, increasing to more than 80 (even if they remain only one month). Captures increase, being asymptotic in 1600 kg each season (60% more than period 1998-2000).

In the second case, the capture season is increased by one month, from October to January (actually it finishes in December and its results have been explained in Cases 1 and 2). This measure allows greater captures and consequently the decrease of the stock and biomass, until an annual average of 1000 kg and 20 $g \cdot m^{-2}$ are reached, respectively (Figure 14). The number of fishermen decrease, and becomes asymptotic, at an annual average of 20, which capture approx. 1100 kg of clams.

The last case modifies the capture season, from May to September during the reproductive period of clams. Consequently, the elimination of reproductive individuals decrease the birth of new generations and the renewal of the system. Therefore, the stock and biomass decrease strongly until an annual average below 1000 kg and 15 $g \cdot m^{-2}$, respectively (Figure 15). The number of fishermen decrease until an annual average of 10 and the captures become asymptotic at 200 kg. This pattern indicates that the establishment of the capture season, during the reproductive period of clams, causes strong damage to this resource.

CASE 5, increasing the minimum sustainable biomass.

On occasions, it may be interesting not only to have a high yield, but also to preserve a part of the stock, in order to feed the wild life (birds, crustaceans, etc.). In this case, a minimum sustainable biomass, proposed as double that of the normal biomass (60 $g \cdot m^{-2}$), was fixed in the model. At the same time, the other inputs, such as capture season (October-December) or auto-regulated number of fishermen depending the existing available biomass are maintained.

The establishment of the minimum sustainable biomass decrease strongly the number of fishermen during 2001-2002 capture season, achieving an average value of below 10 fishermen by mean of the autoregulation described in the methodology and schematised in the Figure 4. This sequence of events entails a parallel reduction of captures in 2001-2002 season, decreasing to below 500 kg, allowing a great recovery of stock and biomass during the following year (2002) until an average value near to 3 t and 50 $g \cdot m^{-2}$ respectively (Figure 16). The above mentioned minimum biomass is reached during that year.

Consequently, the following years, the number of captures and fishermen increase strongly and especially the first month of the capture season, reaching values near 80 fishermen and 1,7 t of captures. However, this situation means a reduction of capture season to only two months (October to November), beginning in 2002, due to the capture of all legal sized individuals during the first two month of each season. Consequently stock and biomass becomes asymptotic at an annual average value near to 3 t and 60 $g \cdot m^{-2}$ respectively. The number of fishermen reach an annual average number near to 40th fishermen.

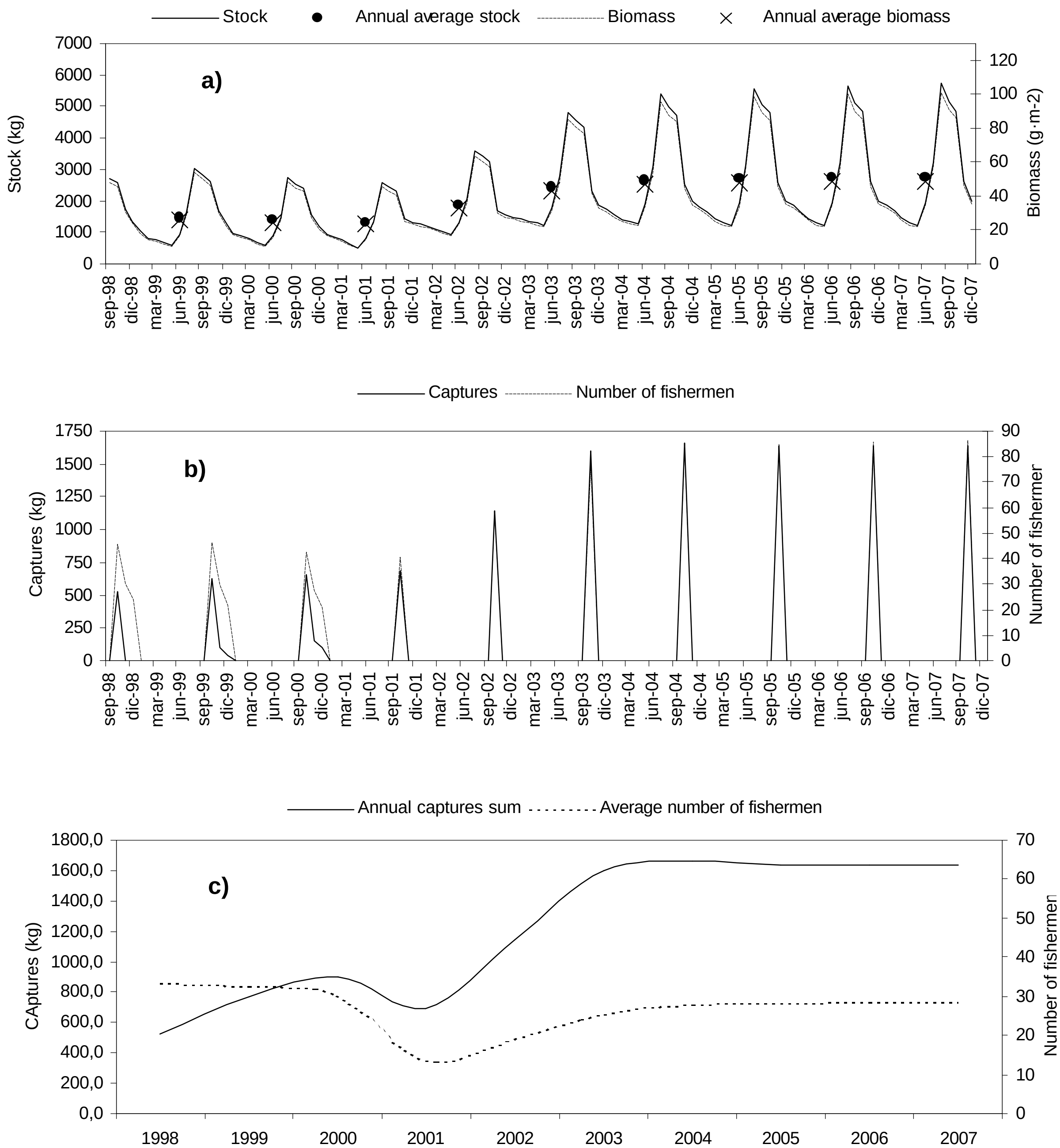

Figure 13. a) Stock and biomass evolution in the Plentzia estuary, reducing the capture season to 1 month (October). b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

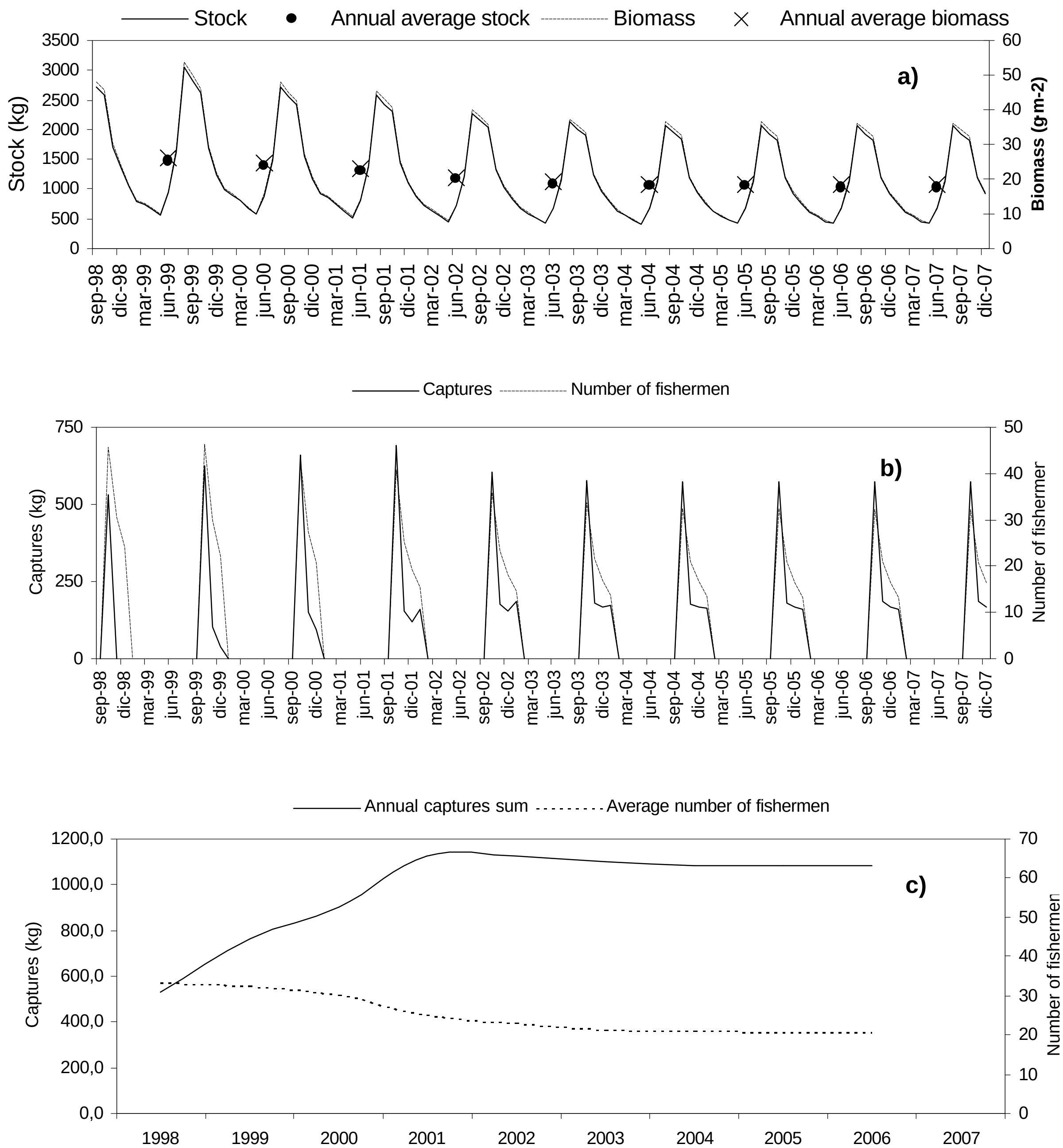

Figure 14. a) Stock and biomass evolution in Plentzia the estuary, increasing the capture season in 1 month (October to January). b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

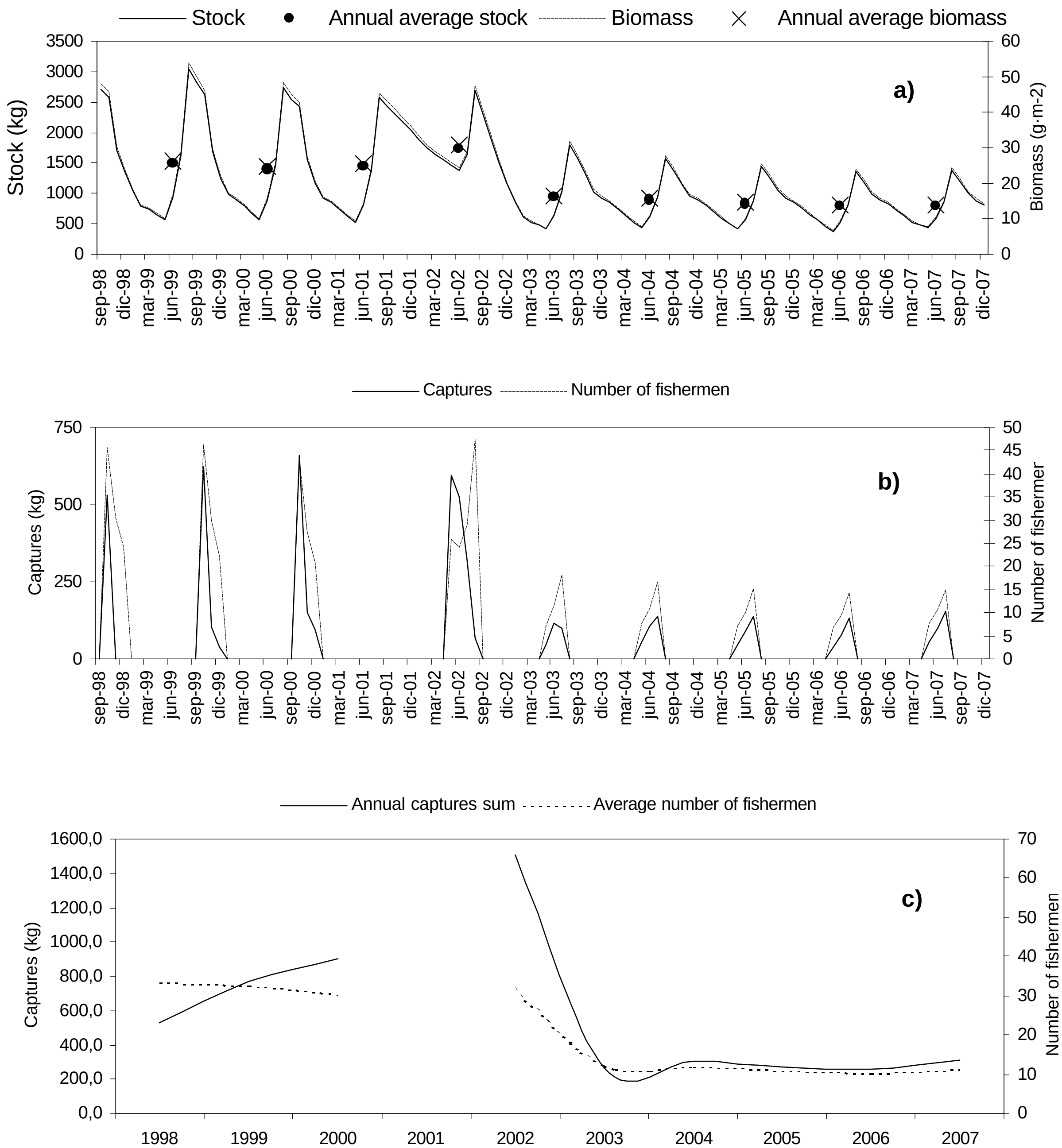

Figure 15. a) Stock and biomass evolution in the Plentzia estuary modifying the capture season from May to September. b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

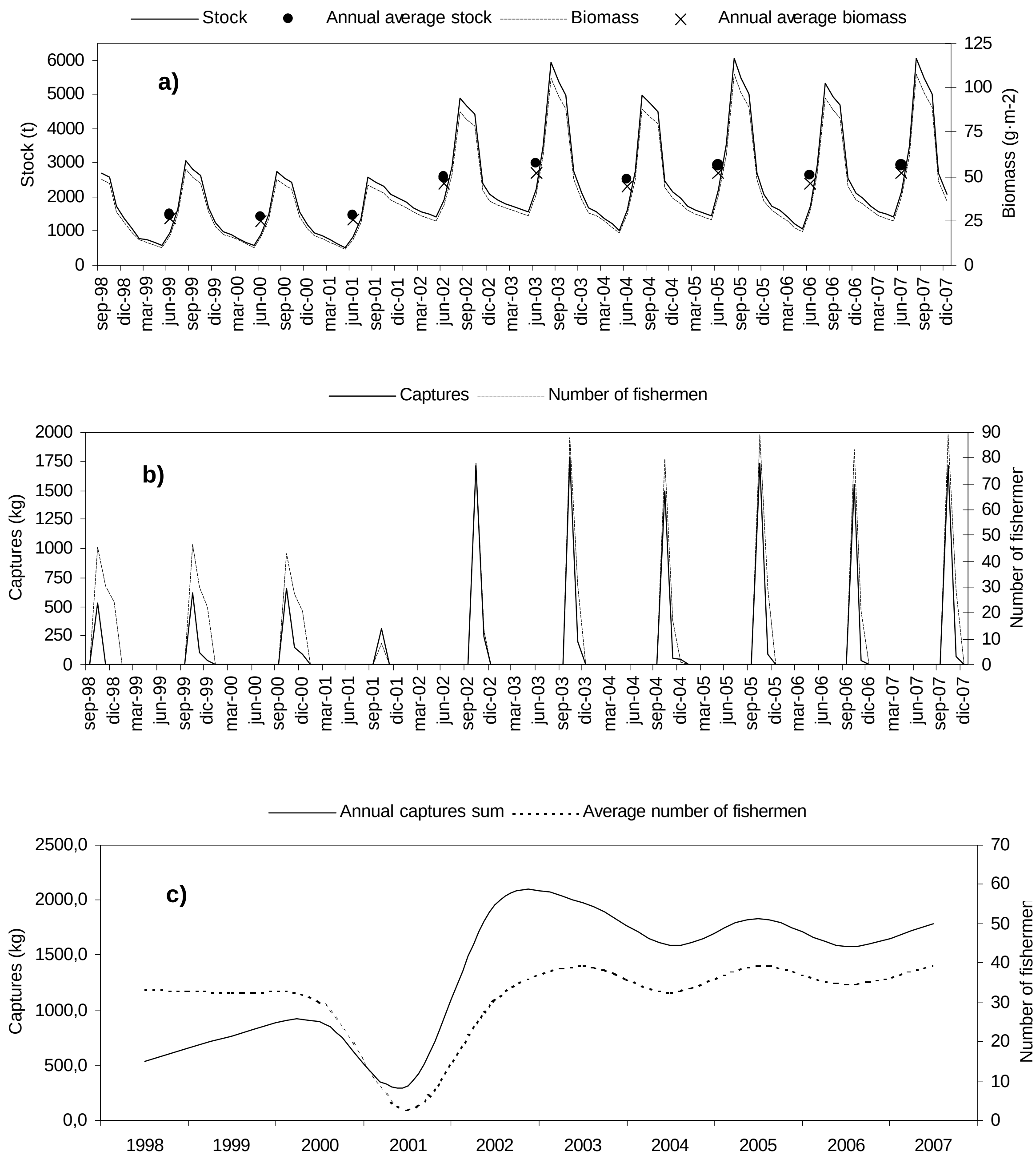

Figure 16. a) Stock and biomass evolution in the Plentzia estuary, increasing the minimum sustainable biomass to 60 g·m^{-2}. b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

CASE 6, increasing the exploitation area

In some cases, it is possible to increase the exploitation area, by seeding the area with small clams in some places. A 10 and a 20% increase in the exploitation area has been simulated. In both cases, there are not significant differences with respect to original situation. Stock and biomass increases slightly to 1500-2000 kg and 25-30 $g \cdot m^{-2}$, respectively. The average number of fishermen is about 27-30 persons, which capture 1200 to 1400 kg of clams each season. This result shows the limited success of this particular measure.

CASE 7, modifying the fishing effort

In this case, a 15% of fishing effort has been applied to the clams below the minimum legal length (specifically, to 21-30 and 31-40 mm size clams). This percentage means, for instance, that 21-30 mm size clams comprise 15% of the total captures. The fishing effort for 41-50 mm size has been reduced in 35%.

These measure increase the fishing effort allowing the capture of one of the most reproductive part of the system (21-30 and 31-40 mm size clams) according to fertility rates established in Table 1. Consequently, the stock and biomass decrease dramatically, to values near 500 kg and 8 $g \cdot m^{-2}$, respectively (Figure 17). Similarly, the number of fishermen and captures decrease, reaching average values of around 10 fishermen and captures of 100 kg each season.

DISCUSSION

In order to determine if a model is valid, system dynamicists attribute many structural changes to a shift in the loop dominance (Forrester, 1987). This pattern is created by endogenous factors in the system; hence, analysts are comfortable in making forecasts about model behaviour into the future and under various assumptions (Krahmer, 1997).

The model presented here has some incorporated important assumptions (Borja & Bald, 2000): (a) the initial values of some variables and levels (natural mortality, area occupied by clams, percentage of days worked by fishers, etc.) do not change, with time; and (b) the possible influence of the environment, on the variability of the population, is included in the natural mortality (which is considered invariable with time), etc.

However, the results obtained for the Plentzia estuary represent very approximately the real fishery (Bald & Borja, 2001). Auto-regulation in the number of shellfishers has been detected, in the field area as well as in the model, when the available biomass is unprofitable. The same behaviour has been detected with the intensive professional clam shellfishing in Galicia (Fernández Cortés *et al*., 1987a, 1987b). This model has detected that the regulation in the shellfishers number and capture season, from October to December, can increase the biomass and yield in the Plentzia estuary, at has been demonstrated for the Mundaka estuary, in response to the control imposed by Fisheries Service, of Basque Government (Bald & Borja, 2001). The model show that the low stock and biomass situation can return, if an increase in the number of fishermen is produced; this reduces, by half, the actual stock and biomass, if the fishing effort is doubled. A similar behaviour has been detected in Galicia, where a 25% decrease in the fishing effort produces a 30% increase in performance, whilst fishing effort increases reduce this performance (Fernández Cortés *et al*., 1987b).

When the results of different cases are compared (Table 4), it can be detected that decreasing by 50% the actual number of fishermen is the best management strategy. Taking in to account the consequent social cost, this measure will produce a 24 $kg \cdot shellfisher^{-1} \cdot month^{-1}$ performance, considerably less than to those produced in Galicia (3,4 $kg \cdot day^{-1}$, according to Fernández Cortés *et al*., 1987a), due to the high productivity of Galician system.

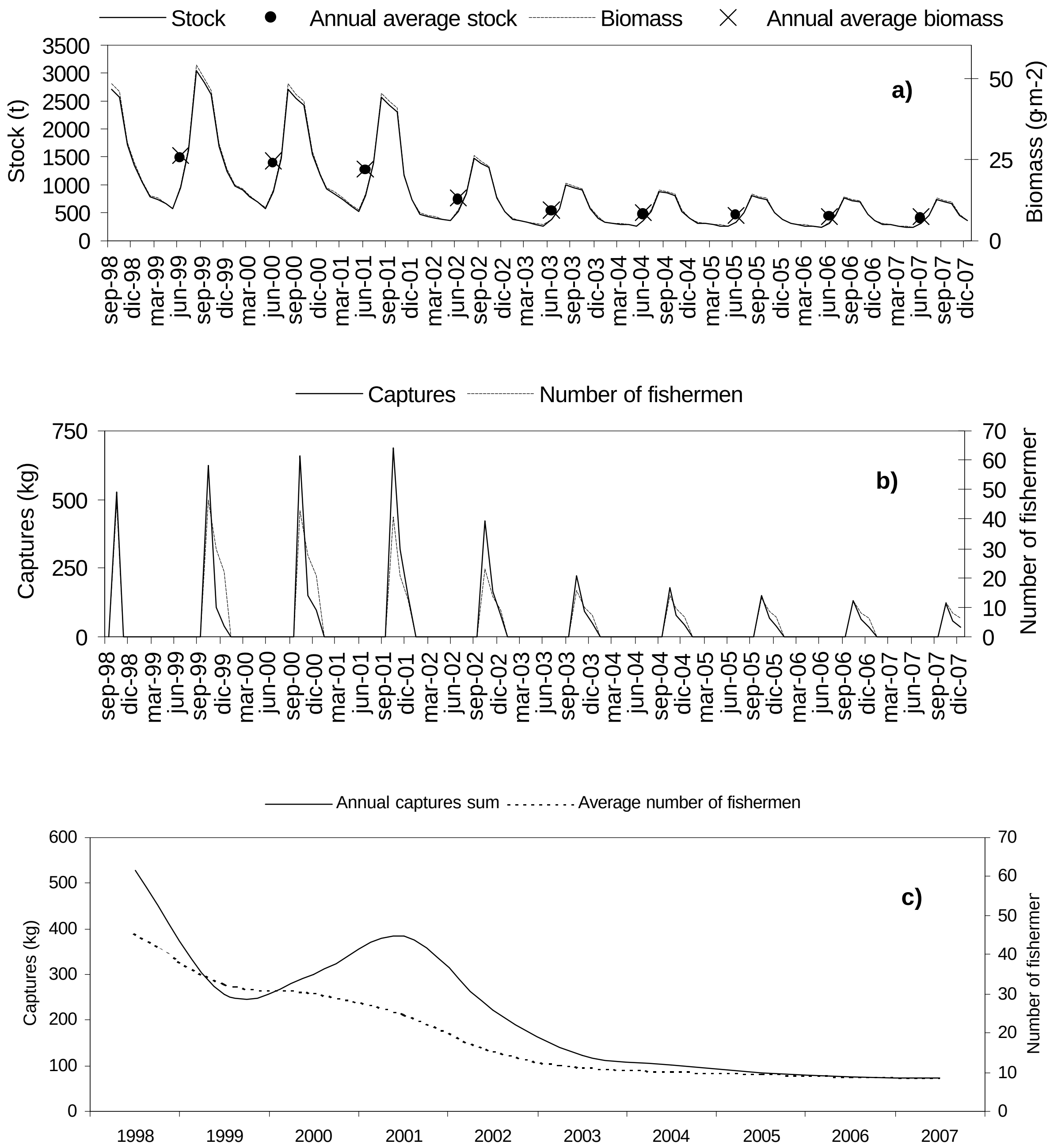

Figure 17. a) Stock and biomass evolution in the Plentzia estuary, applying a 15% of fishing effort to 21-30 and 31-40 mm size clams. b) Captures and number of fishermen evolution. c) Annual captures sum and average number of fishermen evolution.

Table 4. Different modelled management measure results, for clams stock and biomass the in Plentzia estuary. Relate to the time when the system had tended to stabilize we select a period and then the average and total number of shellfishers and the performance is calculated for each management measure, taking in to account the captures of each shellfisher, within the period of the capture season.

		REGULATING							INCREASING				DECREASING
DATA OBTAINED	**ACTUAL**	**NUMBER OF SHELLFISHERS**				**CAPTURE SEASON**			**MINIMUM BIOMASS**		**EXPLOITATION AREA**		**MINIMUM LEGAL LENGTH**
		- 50%	**+ 50%**	**+ 75%**	**+ 100%**	**Oct**	**Oct-Jan**	**May-Sept**	**60 g**	**80 g**	**10%**	**20%**	**> 21 mm**
Stock (t)	2,71	5,2	1,79	1,47	1,21	5,7	2,05	1,37	6,08	7,7	3,1	3,7	0,7
Biomass ($g \cdot m^{-2}$)	47,9	92,9	31,6	26,0	21,4	101,1	36,3	24,2	107,5	135,6	50,5	54,6	13,0
Shellfishers at the beginning (nº)	42,7	41,3	42,2	40,5	38,3	86,1	32,3	7,8	88,8	110,4	45,8	49,4	11,7
Average number of shellfishers in the period (n^{er})	29,3	28,1	29,0	28,1	26,9	86,1	23,1	11,1	58,9	67,8	31,1	33,6	8,6
Total number of shellfishers in the period (n^{er})	87,8	84,4	86,9	84,2	80,8	86,1	69,4	33,4	117,8	135,5	93,3	100,7	25,9
Captures ($kg \cdot year^{-1}$)	966	2010	643	549	477	1636	923	312	1779	233,4	1233	1482	214
Performance ($kg \cdot shellfisher^{-1} \cdot month^{-1}$)	11	23,8	7,4	6,5	5,9	19	13,2	9,3	15,1	17,2	13,2	14,7	8,3

The second best measure is to limit the capture season to one month (October), with a performance of 19 $kg \cdot shellfisher^{-1} \cdot month^{-1}$ and the same social cost as the first measure (actually, the capture season comprise 3 months, October to December).

The third best measure is to establish a minimum sustainable biomass, of 60 $g \cdot m^{-2}$. This measure will produce 15 $kg \cdot shellfisher^{-1} \cdot month^{-1}$ of performance, but it will be necessary to reduce the capture season and the number of shellfishers i.e. only in October the first year and October-November over the remainder of the time (with an average number of shellfishers at below 30).

On the other hand, several measures are contrary to the sustainability of the resource and the continuity of shellfishing activity in the estuary. Such measures are those which modify the present regulations, such as increasing the capture season, the number of shellfishers, and reducing the minimum legal length for capture. Figure 18 shows these alterations.

In all cases, the proposed action takes place in 2001. The system reacts progressively when, for example, the number of shellfishers decrease by 50% (Figure 18c) and the exploitation area increases in response to seed sowing (Figure 18g).

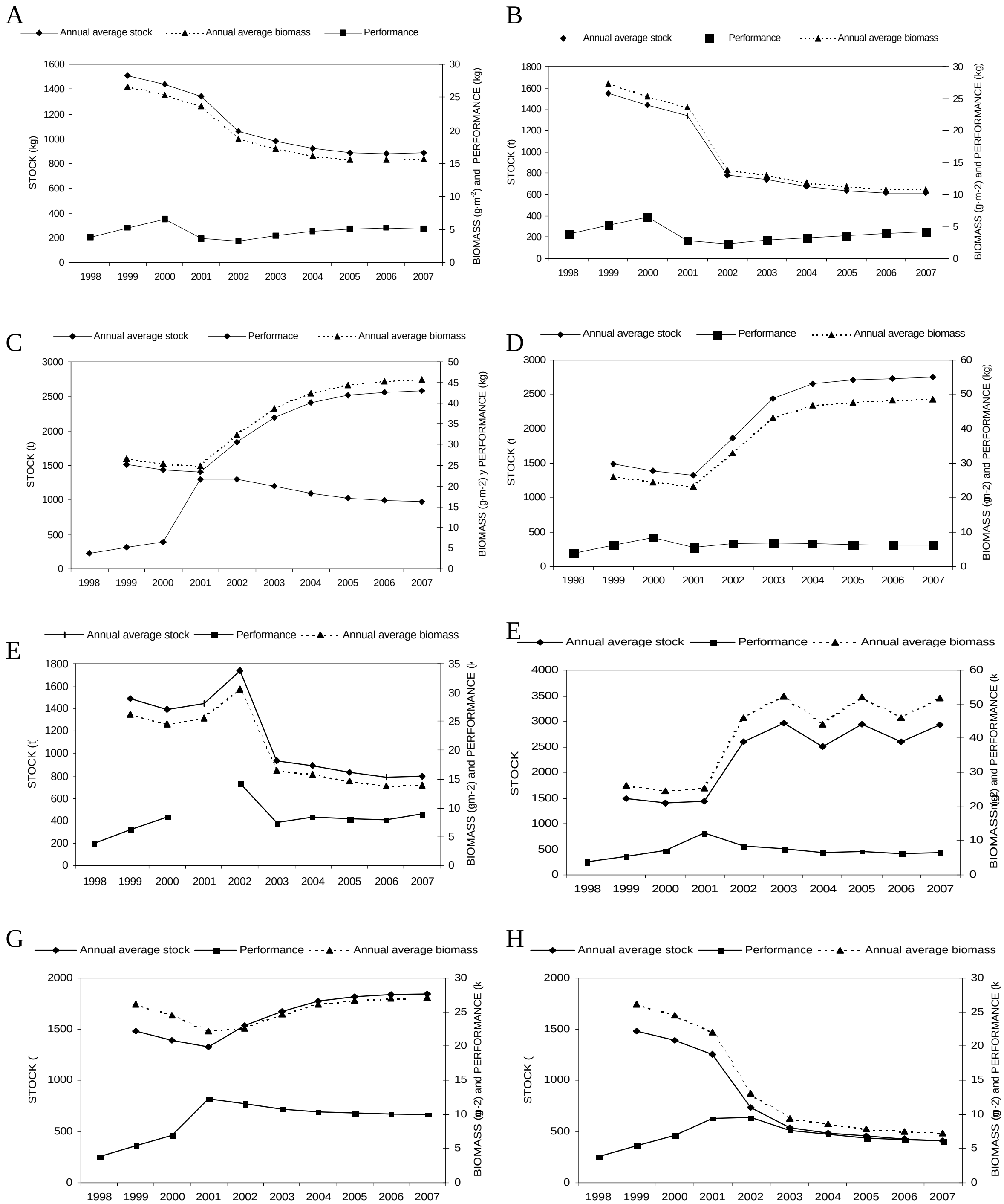

Figure 18. Stock, biomass and performance evolution, depending upon the management measures taken in 2001 for the Plentzia estuary: a) increasing the number of shellfishers by 50%; b) increasing the number of shellfishers by 100%; c) decreasing the number of shellfishers by 50%; d) reducing the capture season to one month (October); e) establishing the capture season May to September; f) establishing a minimum sustainable biomass of 60 $g \cdot m^{-2}$; g) increasing by 20%, the exploitation area; h) reducing the minimum legal length for capture, from 40 to 20 mm size clams.

On the other hand, the system reacts suddenly when, for example, the capture season is established during the reproductive months (Figure 18e), when the minimum legal length for capture is reduced (Figure 18h) and the number of shellfishers is increased (Figures 18a and b). In other cases, even if the stock and biomass recovery is detected, there is not an increase in the capture performance; for example, when captures are reduced to one month (Figure 18d) or a minimum sustainable biomass is established (Figure 18f). It is illustrative to note that for shellfishers, the more small clams that are captured the performance will decrease progressively; for example, when the minimum legal length is reduced (Figure 49h).

This model could be improved in the future, incorporating new items such as: the influence of an increasing vigilance of the fishers; the influence of the environment; and growth effects; etc. However, the results of the model are now reasonably reproducible, by way of validation of a model (Sterman, 1988), however, they have to be interpreted as a guide, rather than as an exact prediction of the future, even if model fitting is within the correct predetermined limits (5-15%).

This analysis provides an interesting approach to the management of a minority fishery, in the Basque Country. Its limited economic importance prevents other scientific approaches, which require large amounts of financial support (from the Administration).

In summary, this second approach to the modelling of clam exploitation and management demonstrates the most adequate policy, according to the management objectives; this is based not only upon biological requirements, but also upon social considerations.

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Back to the Top