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STOCK ASSESSMENT OF THE SPINY LOBSTER (*Panulirus argus*) IN SOUTHEASTERN CUBAN WATERS

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ABSTRACT

An assessment of the population of spiny lobster (*Panulirus argus)* living in the southeastern shelf of the Cuban waters is made in this report. The input data were a matrix of catch at age and effort information from the commercial fleet. Three different methods were applied to the data, the catchability tuning VPA, the ADAPT-VPA and the Excel catch at age model. These methods are in principle the same, the only great difference being how they handle error in the catch at age data. They all showed that there is a discrepancy between the two input data sets, the modelled fishing mortality trends only partially following the trend in the observed effort. The results obtained demonstrate that when analysing the same data set with models that use similar assumptions, the conclusions are more or less the same. The catch at age analysis uses some different assumptions, so more variabilities were observed. For the catchability tuning and the ADAPT VPA the fishing mortality rate in the final year was 0.44, while it was 0.63 for the EXCAM model. The recruitment followed the same pattern for the three methods, declining continuously since 1982. The selection pattern obtained by the catchability tuning and the ADAPT VPA showed a bell shape pattern, but for the catch at age method it has to be assumed to follow a logistic curve, where the last age groups are recruited to the fishing gear with a selectivity of one. Additional information is needed to clear the pattern of selectivity. The yield per recruit analysis indicates that the current fishing mortality rate (0.63) is lower than Fmax (0.8). The predictions were made for different reference points like $F_{0.1}$, $F_{SSB35\%}$ and F_{max}. A 30% reduction in effort is needed to reduce the fishing mortality to $F_{SSB35\%}$. It is possible to keep fishing the stock at the current level, but a consideration in the recruitment has to be taken into account, as a continuous decline has been observed with this parameter.

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1 INTRODUCTION

The spiny lobster (*Panulirus argus*) is a crustacean, which inhabits the shallow waters, usually not deeper than 50 meters, of the tropical and western portion of the Atlantic Ocean. The specie is widely distributed, from the Bermuda Islands and North Carolina in the United States in the north, to Rio de Janeiro, Brazil in the south. Although it is found in the Yucatan peninsula, this specie does not inhabit the Gulf of Mexico. Its abundance in the Caribbean area is why it is commonly called the Caribbean lobster.

This lobster is one of the most economically important species in the Caribbean. About 26 countries are involved in the fishery and the commercialisation, with a total ex-vessel value of about US$350 million in 1995. Cuba, the Bahamas and Brazil, are the biggest producers with more than 60% of the total catch in the region followed by United States, Honduras and Nicaragua (Ehrhardt 2001).

In Cuba the spiny lobster is the most important marine resource. The profits of the fishery are around US$ 80 million per year and there are thousands of people in the coastal communities dedicated to extractive and industrial activities related to the fishery (Baisre 2000). Spiny lobster is caught by 258 small boats, of about 14 to 18 m in length, all of them with engines.

Because of the economical value of the spiny lobster there is a management system for the fishery, which includes a closed season of three months (from March to May) when higher spawning activity occurs. This closure also coincides with the peak in the recruitment to the fishing area (Arce and León 2001). This measure protects both the spawning and the recruitment. In addition, a regulation on the minimal legal length exists which states that landing size should not be less than 69 mm of carapace length.

Four periods have been identified in the fishery history of the spiny lobster (Puga *et al.* 2001). The period between 1928 and 1956 has been classified as the predevelopment phase, which was characterised by a null rate of capture increment. Later on, the growth or developmental phase was reached in the 1970's. Investments in new fishing vessels, capture and processing technologies grew rapidly. In the 1980's the fishery reached the maturity phase. At the end of this decade, some evidence suggests that fishing intensity exceeded the sustainable level. As a result, management measures were intensified.

The increase in capture since 1978 was due to increased fishing effort, but also as a result of the strict compliance with the regulations on the minimal legal length and the closed season (León *et al.* 1991 and Puga *et al.* 1992). This situation provoked an increase in the fishing mortality and the highest catches of about 12 500 mt in the five year period from 1984 to 1988. Nevertheless the potential catch estimated for that period was 11 800 mt (Puga *et al.* 1995). In addition, a failure in recruitment since 1988 (Puga *et al.* 1991 and Cruz *et al.* 1995) aggravated the situation, and the catche in 1990 was only 7 959 mt.

Baisre and Cruz (1994) made the suggestion that the Gilbert hurricane in 1988, which passed through the south coast of Cuba, affected the marine floor in the nursery ground of the spiny lobster. This led to a decrease in the abundance of the youngest individuals. The high catch levels made the situation worse (Puga *et al*. 1995).

The biology and fishery of spiny lobster in Cuba have been investigated by several authors. An analysis of the results of these studies made it possible to update the space-time schemes of the life cycle (Cruz *et al*. 1991a), which together with the detailed information collected, provide a solid basis for further studies on the population dynamics of the specie.

The use of methods based on the length composition of the catch (Cruz, *et al*. 1991b and Puga *et al*. 1992) and methods related to the age composition, allow research on the structure of the stock, the stock-recruitment relationship and the relationship between landings and year class strength (Puga *et al*. 1991 and Leon *et al*., 1991).

Later on the catchability and the selection pattern of the fishing gears used in the lobster fishery in the southwestern zone were studied throughout the application of analytical stock assessment methods based on size and age composition analysis of the catches (Puga *et al*. 1996). The lobster fishery in the southeastern area has not been as widely investigated as the southwestern zone, in terms of assessment approach, which implies a need for increased knowledge on the population dynamics in this part of the Cuban shelf.

The main objective of this project is to evaluate the suitability of different stock assessment methods for the Cuban southeastern lobster.In addition, it is valuable to obtain some predictions or forecasts for the future with different fisheries situations for the stock.

2 LITERATURE REVIEW

2.1 Biology of the spiny lobster

Crustaceans, as arthropods, have several features, which distinguish them from other living creatures. The most remarkable is their way of growing. As they have an external skeleton, they need to shed it to grow. This is done throughout the moulting process. When they are moulting they become defenceless against their predators. This process can take several hours and, in addition, various days pass before the new exoskeleton becomes hard. The Cuban spiny lobster is a crustacean (Appendix 1) so it has an external skeleton. Therefore, it has been stated that the density and abundance of the lobsters depends on the quantity of available shelters, as well as the rate of production and renovation of alimentary resources.

The lobsters usually inhabit the concavities of rocks and coral reefs during the day, where they have a good refuge. At night they go out to get food, which is essentially small snails, bivalves, sea worms, sea urchins, and other echinoderms that live in the thalassia seaweed surrounding the rocks. The main predators of the spiny lobsters are big fish, dolphins and especially sharks and octopuses.

A short description of the life cycle of this crustacean can be described as: after mating females incubate their eggs. Their larvae are released at the edge of the shelf which mainly happens between February and May (Cruz and León 1991). The larvae are oceanic and planktonic, drifting for a period of 6 to 8 months (Alfonso *et al*. 1991 and García *et al*. 1991). After moulting the larvae turn into pueruli, which swim across the insular shelf to arrive at the coast. This takes place every month of the year, but there is a main peak between September and December (Cruz *et al*. 1995). When they arrive at the coast they settle in clumps of algae or any other structure suitable for hiding and moult again into juveniles (Cruz *et al*. 1995). The juveniles go to the nursery grounds where they live hidden in caves, coral reefs, sponges, etc, usually around themonths of July and August, usually 10-15 months after settlement. Later on, between March and May, the juveniles enter the fishery ground. This happens approximately two and a half years after the eggs have hatched (León *et al*. 1991 and Cruz *et al*. 1991a).

The lobsters that survive in the fishery of the shallow waters, continue growing and move to the edge of the shelf. Once they reach the deeper waters where the coral reef is more abundant, they stay there and probably never return to the shallow waters (González *et al*. 1991).

2.2 The Fishery

The lobster fisheries in Cuba take place in all the shallow waters around the Cuban shelf with 20 fishing ports, nine in the north and 11 in the south. The lobster is processed in nine industries spread all over the country, where the main products are lobster tales and whole cooked lobster, which are exported mainly to Japan, Europe and Canada. Recently the commercialisation of living lobster is gaining importance in the international market. This is a new strategy that is currently being developed.

2.2.1 Vessels and gathering houses

There are currently 258 engine boats in the country dedicated to the lobster fishery. Although there are still some wood and Ferro-cement vessels, the majority of the fleet is made up of plastic boats, which are made out of glass-reinforced fibre. The southeastern shelf of Cuba, which we will focus on, has coastal boundaries with five provinces, but only three of them have a lobster fishery. Each one has its own fishery zone, and its own vessels. In the last decade an average of 45 boats have fished in the area.

One particular characteristic of the Cuban lobster boats is the presence of fishponds in their hulls. They have a lot of holes, which facilitate water circulation and keep the lobsters inside alive and properly oxygenated until they reach the gathering house where they are landed.

Gathering houses are located at sea and surrounded by water. They have big cages submerged in water where the lobsters are maintained until they can be transported to the industries inland. This guarantees the freshness of the lobsters, increasing the quality of the final product.

2.2.2 Fishing gears

Two periods per year can be described in the lobster fishery: one after the closed season, in June, and another one at the end of the year, when the north fronts appear, in October, November or December, depending on the area. In the southeastern zone of the shelf the second period takes place in December.

During the first months of the open season the most used fishing gears are aggregating devices (Appendix 2). They are made of a rectangular frame of wood with a roof of cement, giving an artificial shelter for the lobsters. They can be considered aggregating devices since they don't catch the lobsters, but they act as a refuge for them.

During the second part of the fishery, when the mass migration occurs, the most commonly used fishing gears are traps joined by nets of 40 m long (usually there are 10 trap units in each long rope) (Appendix 2). This period ends in February, when the closed season begins (Puga *et al*. 1996).

2.2.3 Management system

The state of any marine resource highly depends on its management. Because of the economical value of the spiny lobster, its management has been a priority and numerous measures have been taken to preserve the resource and avoid over fishing. In Cuba, the allocation of territorial fishing rights to the different companies was introduced in 1970. This system facilitates the distribution of the fishing grounds between the companies, and even between fishermen, who have their own area. There they take care of the fishing gears, monitor the health of the environment, and are defenders of the management system, as it positively affects their fishing area.

Another protection measure is the closed season from March to May, which has been extended recently to include February. The closed season protects both the spawning and the recruitment to the fishing area, as those are the peak months for these processes (Arce and León 2001). In addition, there is a regulation on the minimal legal length of caught lobsters (69 mm of carapace length).

3 MATERIALS AND METHODS

This report assesses the population of spiny lobster, living in the waters off the southeastern shelf of Cuba, during a period of 28 years (from 1974 to 2001). Using length frequency distribution data as a starting point, the population dynamics of the spiny lobster was studied using three different methods to become familiarised with the various approaches used in the catch at age analysis. Two methods based on sequential or virtual population analysis (VPA) were applied to the data. A third method of assessment was used, which is based on different assumptions. It has been named the Statistical Catch at Age model. In addition, predictions of the yield and the spawning stock biomass were obtained for the next year, using different scenarios of fishing mortality rates. Preferential advice was given based on reference points from calculations of the yield per recruit and the spawning stock biomass per recruit.

3.1 Taxonomic situation of the specie

Phyllum Artropoda
  Subphyllum Crustacea
    Class Malacostraca
      Order Decapoda
        Family Palinuridae
          Genera *Panulirus*
            Specie *argus*

Scientific name: *Panulirus argus* (Latreille 1804)
Common name: Spiny lobster, Caribbean lobster, or common lobster (Cruz *et al.* 1990)

3.2 Area of study

This report studies the spiny lobster population inhabiting the southeast area of the Cuban marine platform. Cuba is an archipelago located between the 20° and 23° north latitude and the 74° and 85° west longitude. As this position suggest, it is a tropical country with high temperatures almost throughout the year, and winters seasons mainly influenced by short northern fronts. The temperature of the water is relatively constant throughout the year; although in the insular shelf there can be high variations due to the low depth of the water, which is no more than 25 m in this particular area.

For management purposes the Cuban shelf is divided into four fishing zones according to geographical location: northeast, northwest, southeast, and southwest. The lobster fishery takes place in those four zones, in shallow waters, where the sea floor is sandy with rocks, coral reef, and seaweed that provide food for the lobsters.

Figure 1: Fishing zones of the Cuban shelf.

Figure 1 shows the four fishing zones of the Cuban shelf. The southeastern zone is the one of interest in this report. This area is second in lobster catch level compared to the other zones of the country and in general has a high production of marine resources because of its characteristics. Compared with the other zones, the waters in the southeastern zone are deeper, about 20 to 25 meters, although the depth varies especially near the keys and small islands at the edge of the shelf.

There are high levels of nutrients close to the coastline due to large estuaries, but at the same time there are clear waters offshore suitable for coral reef formations. In this area of the Cuban shelf, the ecological succession of ecosystems is clearly visible. There we find mangroves, thalassia seaweed, and coral reefs. All these ecosystems support the fisheries developed there (Claro and Reshetnikov 1994), which are not only the lobster fishery, but also shrimps, different species of fishes, and some other invertebrates such as dog-whelks and sea cucumbers.

3.3 Source of data

The data was obtained from the industry where the lobsters are received and sorted into size groups for industrial treatment. A method has been developed to obtain the length frequency composition of the catches in 5 mm carapace length (CL) intervals from the industry weight categories data. The method assumes that inside each industrial category the carapace lengths are normally distributed. This is performed using the SISLAN package of programs (Sotomayor and Cruz 1990).

The available data sets that were used in this report are:

Biological data:

- The length frequency distribution in 5 mm class intervals, ranging from 45 mm of carapace length (CL) to 180 mm CL, from 1974 to 2001 (Appendix 3).
- The length-weight relationship obtained from survey data (Appendix 4).
- The growth parameters for males and females estimated using the Shepherd’s Length Composition Analysis (SLCA routine), which is contained in the LFDA package (Length Frequency Distribution Analysis), based on the Shepherd method (Shepherd 1987) for estimating the growth parameters from the length composition data. (Appendix 4).
- The sexual proportion for each class interval in the sample (Appendix 4).
- The maturity of males and females taken from Arce and León (2001) (Appendix 4).
- The age-length key with the proportion of each length class interval by age.
- The assumed natural mortality of 0.34, estimated from an approximation of Pauly’s empirical equation for the natural mortality proposed by Cruz *et al.* (1981).

Statistical data:

- Catches in metric tons (mt) for the whole period taken from statistical books from the Ministry of Fishery Industry (Appendix 5).
- Effort measured in fishing days (fd) from 1983 to 2001, taken from the same source (Appendix 5).

3.4 Methods used

3.4.1 Preparation of the data sheet

To apply the assessment methods based on virtual population analysis, it is necessary to have the data age-structured. In general these types of methods are preferable when age-structured data are available (Lassen and Medley 2000). In the particular case of crustaceans, age-structured data have to be obtained from length frequency analysis methods, which identify the modal progression in length composition throughout time (Gulland and Rosenberg 1992).

In this report, the catch at age matrix in numbers was obtained for both sexes having the proportion of each sex in the sample and the proportion of each length in the ages. The length weight relationship was used to obtain the frequency data in weight, and then a raising factor was calculated for further computation of the catch in numbers for each sex. The procedure can be described in the following steps:

a) Obtaining the mean weight at length using the length weight relationship (**$W=a*L^b$**).
b) Multiplying the length frequency data by the mean weight at length to get the weight frequency matrix.
c) Obtaining the raising factor using the formula:

$$RF = \frac{Cy}{\sum W_L y}$$

where		
	RF:	Raising factor
	Cy:	Catches observed for year y
	W_Ly:	Weight for each length interval and each year

d) Splitting the original frequency data into male and female frequency data using the raising factor and the proportion of sexes at each length.
e) Determining the catch at age matrix using the proportion of length at age.

3.4.2 Catchability tuning VPA

This method, as its name implies, is a virtual population analysis (VPA) tuned with the effort data using the formula for the catchability coefficient:

$$F_{ay} = q * E_y \qquad (1)$$

where		
	F_{ay}:	Fishing mortality for age a in year y
	E_y:	Effort in year y
	q:	Catchability coefficient

This is one of the "tuning methods" which began to be developed in ICES during the 1980s (Mohn and Cook 1993) and utilises effort data in the most appropriate way, and assuming that they are a good source of external information.

For performing the catchability tuning VPA, a spreadsheet was settled for the males and another one for the females, where the input data was the catch at age matrix in numbers. This was also done for the mixed sexes using the joined catch at age matrix.

Considering the statement made by Haddon (2001) that the MacCall equation for the stock size in number behaves better at higher values of natural mortality than Pope's equation, this approximation was used for the calculations. As noted by the author, the MacCall formula is less sensitive to the assumption that all the catch is taken halfway through the fishing year and it works better when the natural mortality rate is higher than 0.3, giving values slightly smaller than the Pope's equation.

The stock size in numbers is computed differently for the last year and age group than for the rest of the matrix. First we use the MacCall approximation for the stock equation, where the fishing mortality is not included:

$$N_{ay} = N_{a+1,y+1} * e^{M} + C_{ay} * (\frac{M}{1-e^{-M}}) \qquad (2)$$

where N_{ay}: Size of the stock of age a in year y
$N_{a+1,\, y+1}$: Size of the stock in the next year after year y
M: Natural mortality
C_{ay}: Catches in number for age a in year y

For the edges of the matrix (last year and oldest age) the inverted catch equation is used:

$$N_{ay} = \frac{C_{ay}}{\left(1-e^{-(M+F_{ay})}\right)} \frac{M+F_{ay}}{F_{ay}} \qquad (3)$$

As described in Mohn and Cook (1993), this method assumes some initial values of fishing mortality rates in the oldest year. This makes it possible to calculate the fishing mortality rates in the youngest age groups using the usual VPA equations:

$$F_{ay} = \ln(\frac{N_{ay}}{N_{a+1,y+1}}) - M \qquad (4)$$

For the last age group the fishing mortality rate is calculated as the average of the fishing mortality rates of the previous age groups in the same year.

Now we use tuning for computing the fishing mortality rate. Equation (1) is used to calculate the catchability coefficient, except for the last year where we use an average of the q in those years in which we know that the fishery effort has not changed. Then the fishing mortality rate for the last year is calculated with the same equation, knowing the effort and the catchability coefficient. The iteration option in Excel is useful and needs to be activated in this analysis.

3.4.3 ADAPT-VPA

The Adaptive (ADAPT) Framework VPA is based on minimising the sum of squares over any numbers of indices of abundance to find best-fit parameters (Lassen and Medley 2000). In this report the indices of abundance used were the catch per unit of efforts, based on the following equation:

$$CPUE = \frac{C_{ay}}{E_{y}} \qquad (5)$$

where $CPUE_{ay}$: Catch per unit of effort for age a in year y

at the same time the following equation is used:

$$CPUE = q * N_{ay} \qquad (6)$$

This method assumes that the catch data is well known, so the catch at age matrix is calculated without error. The stock size in numbers for the matrix is calculated with the MacCall approximation for the stock equation (equation 2), just like the previous method, and the inverted catch equation is used for the edges of the matrix (equation 3).

Similar to the previous method, this one also uses the fishing mortality of the last age group as an average of the fishing mortality of the penultimate younger ages, and for the last year it is determined by tuning. When computing the bulk of the fishing mortality rates of the matrix, equation 4 is used.

The selection pattern is computed for each age and year using the following equation:

$$S_{ay} = \frac{F_{ay}}{\overline{F_y}} \qquad (7)$$

where S_{ay}: Selection pattern for age a in year y

$\overline{F_y}$: Average of the fishing mortality rate through the age groups

For the last year the fishing mortality rate can be computed as the multiple of the selection pattern in the last year by some F multiplier, which in this case is taken as the maximum of the fishing mortality rates in its last year ($F_y$max):

$$F_y = S_{ay} * F_y \max \qquad (8)$$

The tuning part starts with the calculation of the CPUE for the whole matrix following equation 5. Then through the transformation in logarithm of equation 6, we calculate the logarithm of the catchability coefficient for each year and age group, except for the last age group:

$$\ln q = \ln CPUE_{ay} - \ln N_{ay} \qquad (9)$$

Next the average of the ln q for those years in which there has not been a considerable change in effort is calculated. The following step is to compute the residuals of the ln q matrix defined as ln q minus the average of the ln q:

$$\mathrm{Re}\,siduals = \ln q - average(\ln q)$$

Finally the sum of squares of this last matrix is the cell to be minimised by the solver function, varying the F terminal or F multiplier previously calculated.

3.4.4 *Excel catch at age model (EXCAM)*

The catch at age model is considered an integrated analysis, which, unlike VPA, estimates fewer parameters than the available number of data points (Haddon 2001). For catch at age to produce accurate estimates, some type of auxiliary information must be collected (Quinn and Deriso 1999), either catch rates, effort, or independent population estimates, to tie the model to the stock size. The EXCAM uses an objective function, in this case the least squares, through the minimisation routine of the Excel solver function, to fit the model to the data.

Quinn and Deriso (1999), state that in this model the catch is not necessarily from a survey with minimal impact on the population, but rather can be from any source like commercial, survey, sport, or other data, and can be of any magnitude of removal from the population.

The input data for the model were the catch at age matrix for the males and the females and the effort. The setting of the model started with the assumption that selectivity is constant throughout the years. This can be estimated either directly for each age or by assuming a logistic equation, which considers the selectivity curve symmetrical about age where 50% of the selectivity occurs (Einar Hjörleifsson, personal communication). The equation for this assumption is:

$$s_a = \frac{1}{1+e^{-Ln(19)\frac{(a-a_{50})}{(a_{95}-a_{50})}}} \qquad (10)$$

where Sa: Selectivity of age a
a_{50}: Age at which selectivity is 50%
a_{95}: Age at which selectivity is 95%

The fully selected fishing mortality rate in year y, F_y is one of the foundations of the analysis and values for each year are treated as parameters in the fitting process. In this way, the fishing mortality rate for each age a in each year y ($F_{a,y)}$ is computed according to:

$$F_{ay} = S_a F_y \qquad (11)$$

where F_y: The fitted fishing mortality rate of the oldest age in year y

The next step is to calculate the survivorship for each age and year (Say), and the stock size in numbers using the stock equation:

$$N_{a+1,y+1} = N_{ay} e^{-(M+F_{ay})} \qquad (12)$$

and

$$S_{ay} = e^{-(M+F_{ay})} \qquad (13)$$

where S_{ay} is the survivorship of age a in year y, so:

$$N_{a+1,y+1} = N_{ay}S_{ay} \qquad (14)$$

Now, using the estimation of the numbers at age we generate a matrix of predicted catch at age according to:

$$\hat{C}_{ay} = \frac{F_{ay}}{M + F_{ay}} N_{ay}\left(1 - e^{-(M+F_{ay})}\right) = \frac{F_{ay}}{M + F_{ay}} N_{ay}(1 - S_{ay}) \qquad (15)$$

Up to here we have an observed and predicted catch at age matrix but now we need to use the solver tool to minimise the sum of the squared difference between the two matrixes following the formula:

$$SSR_C = \sum_a \sum_y \left[\ln(C_{ay}) - \ln(\hat{C}_{ay})\right]^2 \qquad (16)$$

But, we also need some other data to tie the model, in this case the effort data. Having the fishing days per year we calculate the predicted fishing mortality by year using the formula:

$$\hat{F}_y = qE_y$$

where E_y: Effort observed in year y
$\hat{F}_y$: Predicted fishing mortality

and then we also minimise the squared difference between the observed and predicted fishing mortality.

$$SSR_E = \sum_y \left[\ln(F_y) - \ln(\hat{F}_y)\right]^2$$

An additional penalty factor can be placed to force the model to fit the observed data. Thus we add a penalty factor for the yield and for the fishing mortality rate calculated:

$$SSR_Y = \sum_y \left[Y_y - \hat{Y}_y\right]^2$$

where Y_y: Observed yield for the year y
$\hat{Y}_y$: Predicted yield for the year y

and

$$SSR_F = \sum_y \left[\ln(F_{y+1}) - \ln(F_y)\right]^2$$

Each sum of squares has a weight in the total sum of squares. Therefore we have a weight of 1 for those, which we want to emphasise when the minimisation routine runs, and a weight closer to 0 for the ones where we do not want to influence the result as much.

So the final sum of squares, which is going to be minimised by the solver function, is:

$$SSR_T = SSR_C * 0.05 + SSR_E * 0.95 + SSR_Y * 100 + SSR_F * 0$$

The minimisation is run by changing the initial parameters, which are the starting point for the setting of the equations, they are:

- The logarithm of the initial stock number for the first age class (N_{1y})
- The logarithm of the initial numbers for all ages in the first year (N_{a1})
- The logarithm of the fishing mortality rates used in equation 11
- The logarithm of the a_{50} and a_{95} if a logistic equation is assumed
- The logarithm of the catchability coefficient

Two columns are used for these computations, one with the equivalent for the logarithm of the parameters and the other one with the values obtained by the exponential of the previous column. In the setting of the equations the values are used, and in the solver function the logarithms are changed.

It is possible to do some other calculations when establishing the catch at age model. In this case the spreadsheet was set up for the estimation of the biomass, the fishable biomass and the spawning stock biomass using the matrix of weight at age obtained from the length weight relationship, and the maturity proportion at age.

3.4.5 Yield per recruit and spawning stock biomass per recruit

For the computation of the yield per recruit and the spawning stock biomass per recruit we only need the weight at age, an estimation of the selectivity curve, an assumption for the natural mortality and for the fishing mortality. The equations used are the same as described previously:

1) Calculating the stock number N_a using equation 13
2) Calculating the catch for each age using equation 14
3) Calculating the yield for each age (Y_a) by multiplying the catch by the weight at age:

$$Y_a = C_a W_a \qquad (17)$$

where Ca: Catch at age
Wa: Mean weight at age

4) Computing the yield per recruit, Y/R, as:

$$Y / R = \frac{\sum Y_a}{R}$$

where R: Recruitment, which is the starting number of the population

5) Calculating the spawning stock biomass at each age a, SSB_a, using:

$$SSB_a = N_a W_a Mp_a$$

where Mp_a: maturity proportion by age
W_a: mean weight at age

6) Calculating the spawning stock biomass per recruit, SSB/R, by:

$$SSB/R = \frac{\sum SSB_a}{R}$$

In order to simplify the calculations the initial stock number is fixed as 1, then we will have the yield per one individual entering the fishery. At this point we need to run the computations for different fishing rates, to find the different values of the yield in relation to them. For this purpose the Excel data table option is used.

The $F_{0.1}$ has been described as the value of F at which the slope for the Y/R curve is 10% of the slope at the origin (Hilborn and Walters 1992). The $F_{0.1}$ will give us a more conservative or risk adverse fishing mortality rate from the assumptions made in the yield per recruit analyses (Haddon 2001).

3.4.6 Prediction for the following year

Having the stock size at the beginning of the last year for which data is available, the prediction for the following year uses the same equations that have been previously described. The first step to follow is to re-estimate the numbers at age for the particular year being analysed using the catch equation formula:

$$N_{ay} = N_{a-1,y-1} e^{-(Z_{a-1,y-1})}$$

where the terminal F is assumed to be: $F_{ay} = F_{a,y-1}$.

The equations for the catch at age and the yield per age are the same as those described before (equations 15 and 17 respectively).

The problems that arise when projecting the catches is the stock number at age 1 or the recruitment, which has no data point to be based on. In the case of the lack of survey indices several steps can be taken. One of them could be to consider recruitment as the average of the previous recent years to the one being predicted. The other way is to apply the stock recruitment relationship, which gives a somewhat narrower boundary to the uncertainty that comes in with the predictions.

In this report the stock recruitment relationship was used as an indicator of the numbers of individuals in the first class group. Here the model of Beverton and Holt is used. The equation for this model is:

$$R = \frac{\alpha SSB}{1 + \frac{SSB}{K}}$$

Where α (alpha) and K are coefficients from the stock recruit models each with a specific meaning. In the Beverton and Holt model, K is the size of the spawning stock that produces half of the recruitment, and α is a multiplier for the prospective recruitment.

For calculating α and K any initial values are used as a starting point to compute a forecast for the recruitment which will be called $\hat{R}_y$. Then this is compared with the spawning stock in year y, which now becomes [R_y- $\hat{R}_y$]. Next we minimise the squared differences between both by giving different values for the alpha and K throughout the solver function.

4 RESULTS

4.1 Preparation of the data set

The frequency data were sliced into 13 age groups for males and females (Appendix 6, a and b), the resulting matrixes of catch at age in numbers were summed, resulting in a unique matrix for the joined sexes (Appendix 6c). This was the input data for all the analyses.

It is important to clarify that the ages are being used as relative ages, and not biological ages, since the lobsters do not enter the fishery, until at least, two years after the eggs have been hatched. This means that when they enter the fishery the individuals are already two years old, but for practical reasons it is better to start with the age 1.

The ages with higher proportions in the catches are 2, 3, 4 and 5 (12%, 28.2%, 27.8% and17% respectively). Age 6 has a lower proportion (8% of the total).

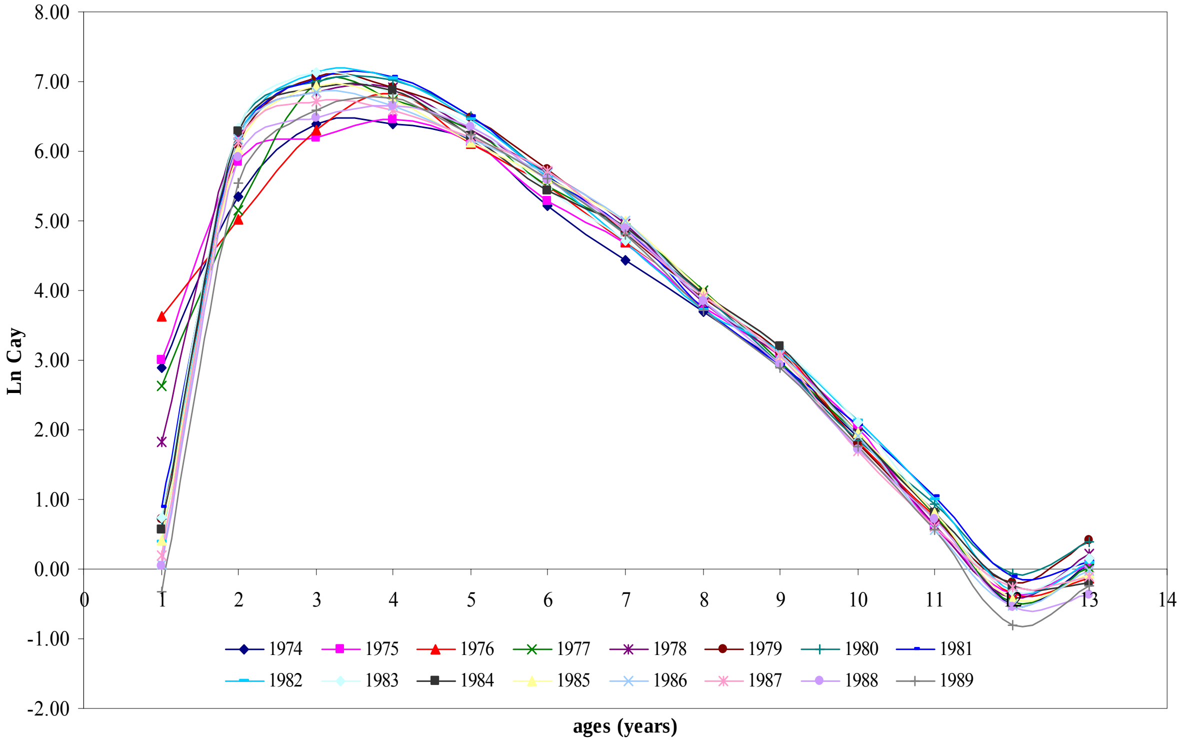

Figure 2: Plotting of the natural logarithm of the catches at age in numbers for each cohort.

In Figure 2 the plotting of the natural logarithm of the catches for the different cohorts in each year is shown. It appears that the lobsters become fully recruited into the fishery when they reach 3 or 4 years. It can also be seen that by age 5 there is a downward trend in the catch curve, except for age 13, which is a plus group with a few individuals represented there.

4.2 Catchability tuning virtual population analysis

When applying this method internal loops are created in calculating the fishing mortality rate (F_{ay}) for the last year based on the catchability coefficient (q) and the effort, and at the same time the q is based on the equation $F_{ay} = qE_y$. Those loops are the basis for the necessary iterations that give a best fitting of the fishing mortality rate to the effort data provided.

The F terminal in this model is taken as the average of the final F for each year, which is, at the same time, the average of the F of those ages that have a higher contribution to the fishery (from the age 2 to 8 years old). The resultant terminal F was 0.44.

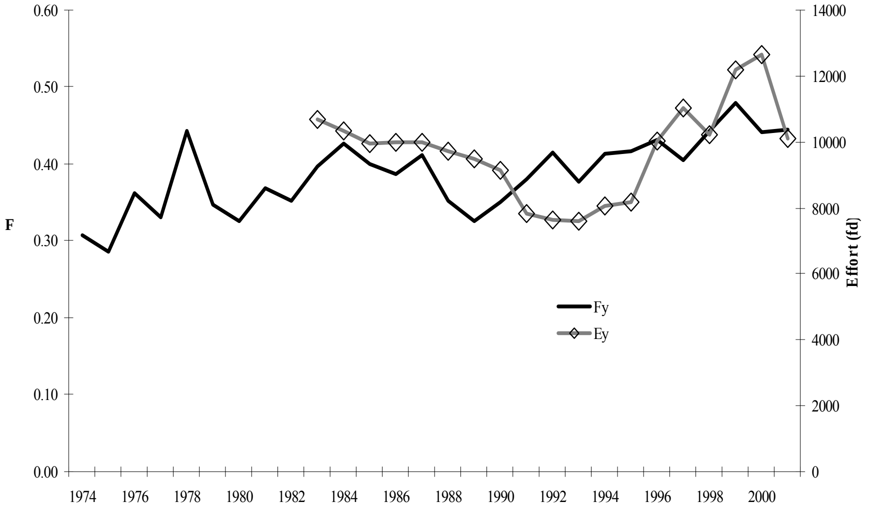

Figure 3: Relation between the fishing mortality rate calculated by the model and the effort observed.

Figure 3 represents the plotting of the fishing mortality rate calculated with the model and the effort data. It can be seen that the curve for the mortality rate does not have the same pattern as the effort from 1990 to 1998. Although the pattern is not the same in the whole series, the increase in effort observed in the last years is also accompanied by an increase in fishing mortality.

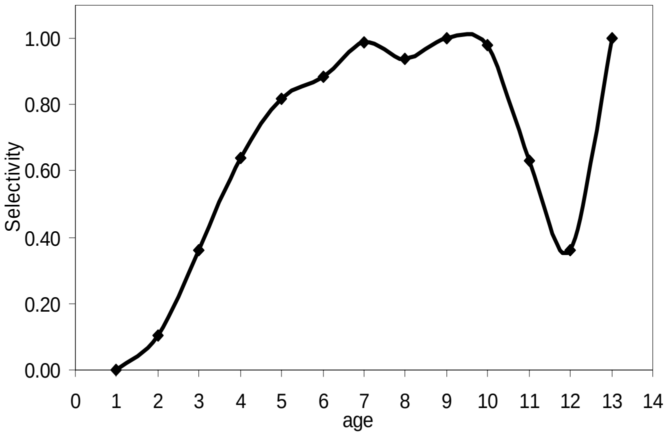

Figure 4: Selectivity curve obtained for the catchability method analysis.

The selection pattern curve obtained does not reach a plateau in the older age groups. Instead the selectivity first increases with age and then declines again. Figure 4 represents the pattern for them, and it can be seen that by age 9 the maximum selectivity is obtained with a value of 1. Previous to that year a slight plateau is observed with values higher than 0.9 for the 7 and 8 age groups, then, after age 9, the selectivity has a negative slope, indicating a low number of lobsters selected by the gear.

Figure 5 shows the stock size in numbers obtained for age group 1 from the running of this method, which represents recruitment to the fishery. After the higher values obtained in the years 1980, 1981, and 1982, a permanent downward trend is observed in the recruitment. The lowest values were obtained in the years 1999 and 2000, with 6848 and 6425 thousand respectively. The last year does not represent an increase in the recruitment, but is the result of averaging the previous six years.

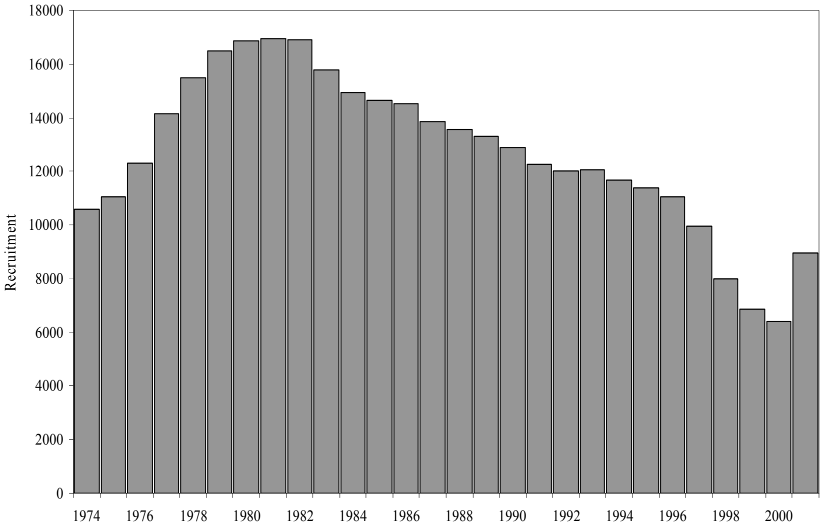

Figure 5: Recruitment represented as number of individuals of age group 1.

The stock size in numbers calculated for this method is listed in Appendix 7.

4.3 ADAPT-virtual population analysis

Similar to the catchability tuning virtual population analysis, this method also uses effort data to tune the model, as an external index of abundance. Therefore the catch per unit of effort is used in the computations to find an estimation of the terminal F and the selection pattern. Like the previous method, this one also assumes a catch at age matrix calculated without error.

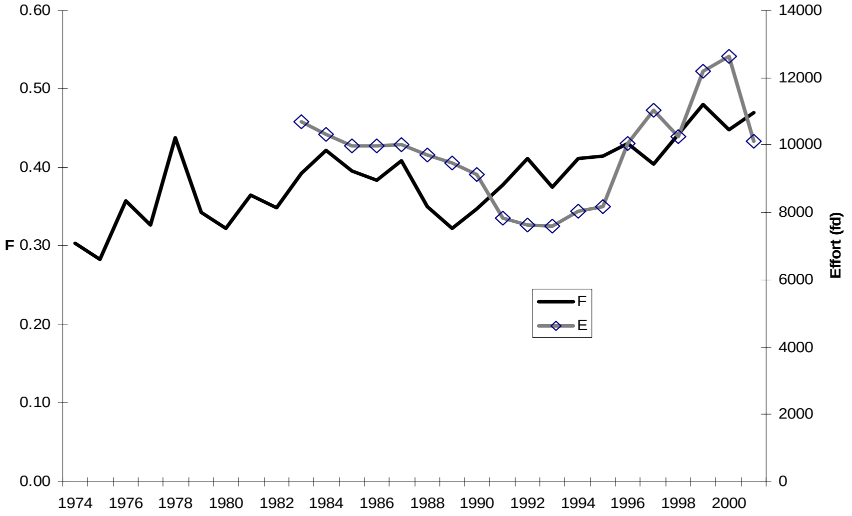

Figure 6: Plotting of fishing mortality rates (F) and effort (E) for the ADAPT.

The behaviour between the effort and the fishing mortality values obtained from the model is plotted in Figure 6. As in the previous method, the fishing mortality doesn't follow the same behaviour as the effort between certain years, especially from 1990 to 1998. The terminal selectivity was assumed to be the average of the previous 6 years and the terminal F was estimated by the minimising the difference between observed and estimated CPUE of individual age groups. The reference fishing mortality of age groups 2 to 8 years old was estimated to be 0.44.

In Figure 7 the behaviour of the selection pattern is represented, showing a similar pattern to the one obtained in the previous method. Here the selection goes up to a value of 0.87 for the age 5, from there on the pattern approaches a plateau shape, increase a little to 0.98 for age group 7 and 0.99 for age group 9, and later it goes down to 0.27 for age group 12. The higher value obtained for the last age group is most likely the result of it being a plus group.

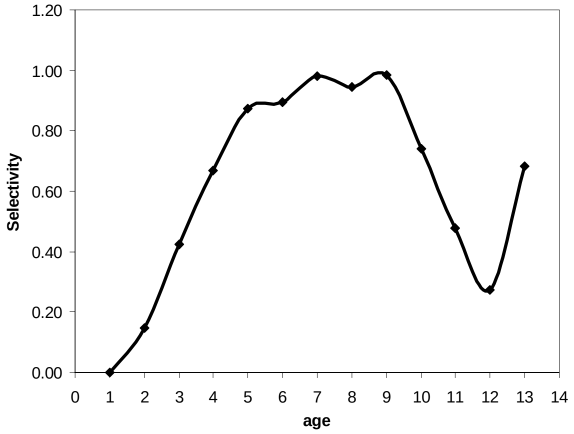

Figure 7: Selectivity curve obtained for the ADAPT-VPA method.

The correlation coefficient for the catches per unit of effort and the stock in number for each age was calculated and is represented in Appendix 8. For ages 1, 11 and 12, the correlation coefficient had values under 0.5 (R^2<0.5), which were 0.13, 0.49, and 0.44, respectively. The rest of the age groups had coefficient values higher than 0.5, indicating that the fit for those ages was relatively good.

In Appendix 9 the stock size in number obtained for this method is represented. The values for the recruitment, taken as the stock size in numbers for age group1 are represented in Figure 8.

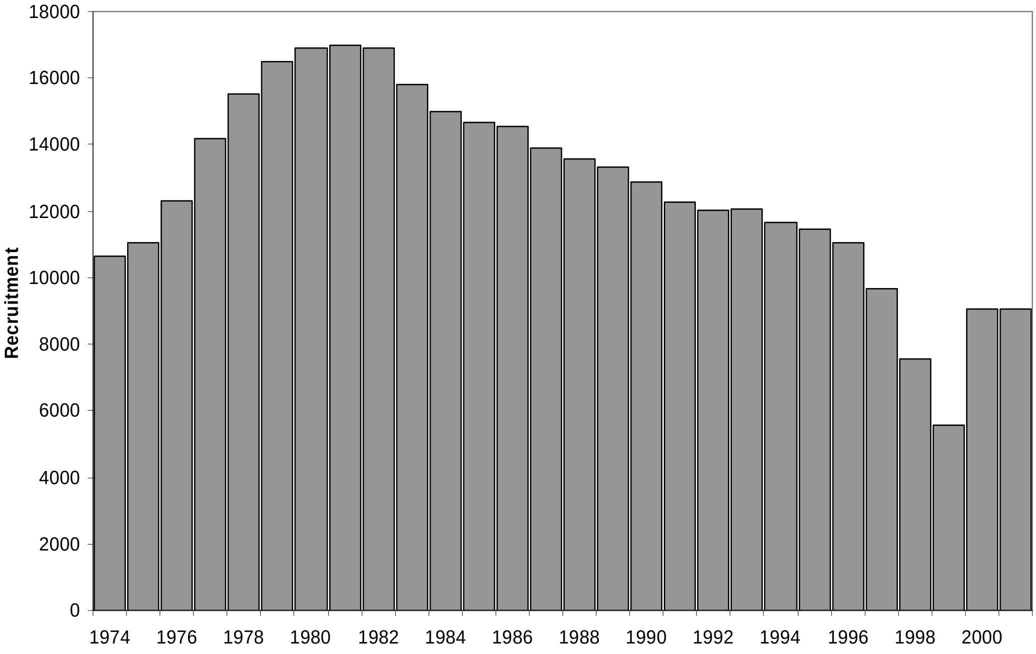

Figure 8: Recruitment calculated by the ADAPT-VPA method.

Similar to the previous catchability tuning method, this one also shows a continuous decrease in recruitment. From 1981, the recruitment decreases persistently. Again the lower value for recruitment was obtained in 1999 with 5578 thousand individuals. In this method the recruitment for the years 2000 and 2001 are the average of the previous five years.

4.4 Statistical catch at age model

The Excel catch at age model uses the numbers of fish by age that enter the fisheries, the fishing mortality and the catchability are estimated and the catch at age is modelled by assuming a separable model, using a logistic function for the selectivity. The computation of predicted catch at age and effort are obtained and compared with the observed catch at age. The model is solved by minimising the difference between the observed and the predicted catch at age using Excel solver.

By applying this model we aim to have the residuals from the squared differences between the observed and predicted matrixes of catch at age distributed randomly around 0. Several runnings of the solver have to be made before tying to the final predicted matrix, numbers in the first year and age and fishing mortality rate in the last year. In a first running the residuals for the ages previous to the years 1979 were too high, so two periods were considered in the fishery related to the selectivity: pre 1979 and post 1979. By doing this, the data fitted the model better through lower and more randomly distributed residuals throughout the time series.

The logistic function, initially assumed for the selectivity was not found to fit to the data very well, because it gave systematically high predicted catch at age numbers of individuals in the first year and age, and very low values for the fishing mortality rates. Therefore, the selection curve was calculated individually for the ages 1 to 5, letting the solver find it, and for the rest of the age groups the curve was fixed as 1 (Figure 9), assuming that these ages are completely recruited to the fishery and to the fishing gear. This was made for the two periods, pre 1979 and post 1979, obtaining similarly shaped selectivity curves.

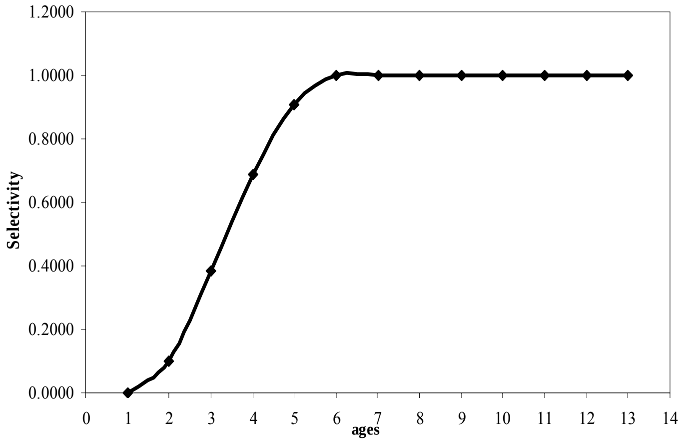

Figure 9: Selectivity used in the computation of the catch at age model.

Appendix 10 lists the values for the residuals from the differences between the observed and the predicted matrixes of catch at age. It is clear that ages 2 to 8 have a random distribution of residuals around 0, although groups 7 and 8 have few negative values, which means that the model is predicting a lower catch than the observed ones. Age groups 9 and 13 have few negative points, thus making the observed catches higher than the predicted ones. Finally the model estimates higher catches for ages 10 to 12 than the observed making the residuals almost entirely negative.

As we weighted the penalty factor for the yield a 100, we forced the model to fit the observed yield. The influence of this forcing was considered minimal to the population estimators.

The effort in fishing days of the recent 19 years is again the external data used in the tuning for this study. Figure 10 represents the relationship between the series of fishing mortality calculated by the model and the one that is observed based on the effort data. In general, the curves follow the same trend, except for the years 1991 and 1992, where the fishing mortality rates go up while the effort goes down. There are differences in the values from 1989 to 1998, which have the greatest residuals. After running the model a terminal F of 0.63 was obtained.

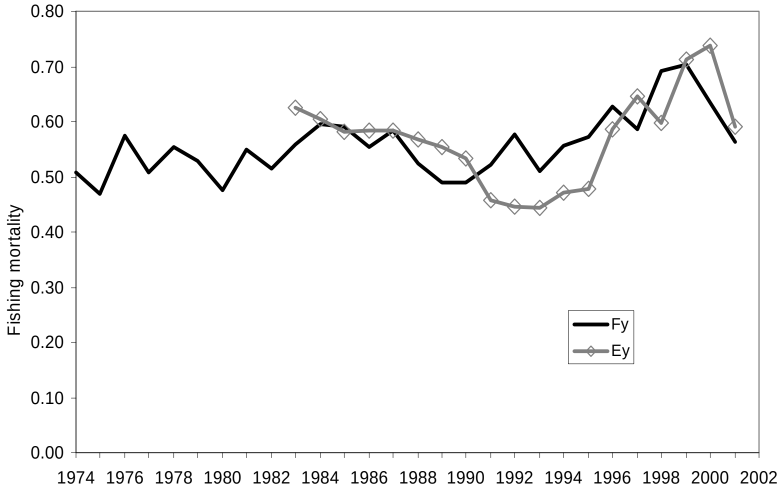

Figure 10: Plotting of the fishing mortality rates observed (effort) and calculated (F).

The stock size in numbers of individuals calculated by the model drop a matrix, which is shown in Appendix 11. The recruitment in 2000 and 2001 was calculated as the average of the previous five years (from 1995 to 1999). This was done because there is only limited catch at age information from the fishery for the most recent year classes.

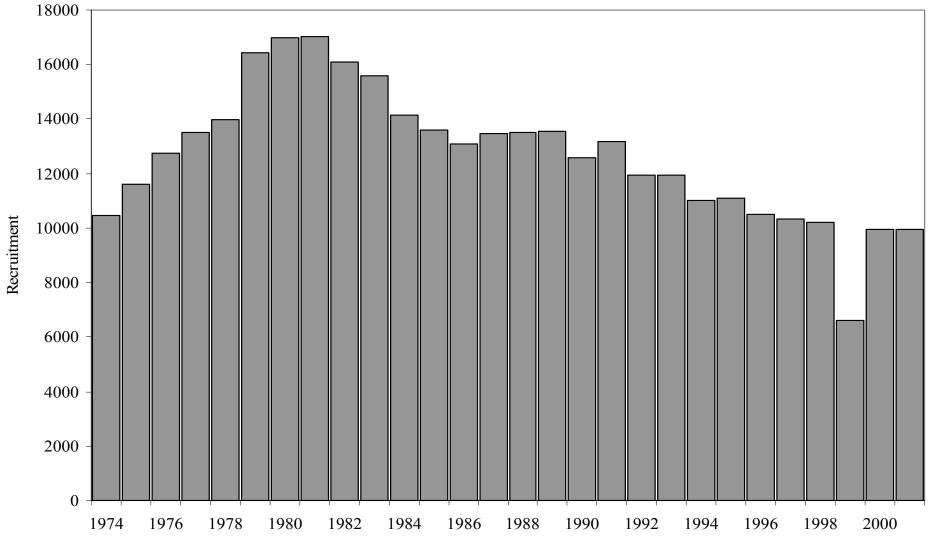

Figure 11: Recruitment obtained in the catch at age approach.

The recruitment, represented by the stock size in year 1, is plotted in Figure 11. After an increment of the stock size in the first age class up to the maximum in 1981 with 17010 thousand lobsters, the numbers decreased to a minimum value in 1999, where only 6610 thousand individuals were estimated to live in the water. The increase in the value of the recruitment in the last two years was because they are an average of the previous five years. The year1999 had a lower value of recruitment, and in general a diminishing trend was observed in recruitment for these five years.

4.5 Yield per recruit and spawning stock biomass per recruit

The yield per recruit and the spawning stock biomass per recruit are analysis that can be done without any assessment. Nevertheless, it is better to improve the analysis with some information about the selectivity and the terminal fishing mortality rate. In this report the yield per recruit and the spawning stock biomass per recruit was calculated, using the assumption made in the catch at age approach for the selection pattern. In Table 1 it is compared with the value for the terminal F (0.63). Table 1 represents the results obtained for those parameters with different fishing mortality rates.

Table 1: Yield per recruit (Y/R) and spawning stock biomass per recruit (SSB/R).

	F values	Y/R	SSB/R	Slope of the Y/R curve
	0.00	0.0000	1.4177	1.064802
	0.05	0.0532	1.1713	0.719418
	0.10	0.0892	0.9896	0.499766
	0.15	0.1142	0.8513	0.354655
	0.20	0.1319	0.7432	0.255779
	0.25	0.1447	0.6570	0.186659
	0.30	0.1541	0.5869	0.137286
$F_{0.1}$	**0.35**	**0.1609**	**0.5291**	**0.101366**
$F_{SSB35\%}$	**0.40**	**0.1660**	**0.4807**	**0.074818**
	0.45	0.1697	0.4398	0.054929
	0.50	0.1725	0.4049	0.039854
	0.55	0.1745	0.3747	0.028312
Fterm	**0.60**	**0.1759**	**0.3484**	**0.019398**
	0.65	0.1769	0.3254	0.012463
	0.70	0.1775	0.3051	0.007035
	0.75	0.1778	0.2871	0.002765
Fmax	**0.80**	**0.1780**	**0.2710**	**-0.000608**
	0.85	0.1779	0.2566	-0.003278
	0.90	0.1778	0.2436	-0.005396
	0.95	0.1775	0.2318	-0.007077
	1.00	0.1771	0.2211	-0.008408

This table also lists the values obtained for $F_{0.1}$, $F_{SSB35\%}$, and F_{max}. The term $F_{0.1}$ is interpreted as the fishing mortality corresponding to 10% of the slope calculated for the curve of yield per recruit in relation to different values of fishing mortality. F_{max} represents the value of fishing mortality, which corresponds with the maximum yield. On the other hand, the term $F_{SSB35\%}$ has been used lately to point out the fishing mortality rate that results in a spawning stock biomass per recruit that is 35% of that with no fishing (Quinn and Deriso 1999).

The first characteristic that arises when Table 1 is analysed, is that the fishing mortality rate at which we are operating is less than the F_{max}, so it means theoretically that we are able to increase the effort and the yield will increase without over fishing the stock. This strategy has not been considered a conservative policy, as we can frequently exceed sustainable harvest rates by fishing at F_{max} (Quinn and Deriso 1999). At this point an improvement of F_{max} is $F_{0.1}$. For this study the value of the fishing mortality represented by $F_{0.1}$ (0.35) is almost half of the F existing (0.60), so if the strategy of fishing at $F_{0.1}$ is going to be applied, the effort has to be reduced by almost half.

4.6 Predictions of the yield in following year

The forward projection was made only for the year after the last one we have data for, 2002. Thus the yield in tons was computed for this year with different scenarios, which were essentially the fishing mortality rates represented as $F_{0.1}$, $F_{SSB35\%}$ and F_{max}. Table 2 shows the different values for the yield that can be reached if the fishing mortality is decreased or increased, and the spawning stock biomass that we are having with each strategy. The fishable biomasses corresponding to the year 2003 are also represented related to the different fishing mortality rates.

Table 2: Values for the yield and the spawning stock biomass (SSB), corresponding to the prediction for 2002, and fishable biomass (FSB) for 2003 for different fishing mortality rates.

Actual year	F oldest	Yield 2001 (tons)	SSB 2001 (tons)	FSB 2003 (tons)
F term	**0.60**	**1514**	**3201**	**3849**
Prediction	F oldest	Yield 2002 (tons)	SSB 2002 (tons)	FSB 2003 (tons)
	0.00	0	4588	5532
	0.05	223	4437	5365
	0.10	425	4291	5204
	0.15	608	4151	5049
	0.20	772	4017	4900
	0.25	921	3888	4756
	0.30	1055	3764	4618
$F_{0.1}$	**0.35**	**1176**	**3645**	**4485**
$F_{SSB35\%}$	**0.40**	**1284**	**3531**	**4357**
	0.45	1381	3421	4234
	0.50	1469	3315	4115
	0.55	1547	3214	4001
Fterm	**0.60**	**1616**	**3116**	**3891**
	0.65	1678	3022	3785
	0.70	1733	2932	3683
	0.75	1782	2845	3584
Fmax	**0.80**	**1825**	**2761**	**3490**
	0.85	1863	2681	3398
	0.90	1896	2603	3310
	0.95	1924	2529	3225
	1.00	1949	2457	3143

When utilising the value of the fishing mortality rate for $F_{0.1}$ in the calculation of the yield in 2002, considering the recruitment in this year, we obtain a yield of 1177 tons. This represents 338 tons less in 2002 than the 1514 tons obtained in 2001, but also with half of the effort and with a spawning stock biomass of 4485 tons, higher than the actual amount. An increase in the yield is predicted for 2002 if the fishing mortality is maintained at 0.60, but with the cost of reducing the spawning stock biomass. On the other hand, if we apply the F_{max} equivalent to 0.8, then a higher yield is obtained but with higher effort and lower spawning biomass. In addition, the fishable spawning stock biomass for the year 2003 falls to 3490 tons from the actual value of 3849 tons (Table 2).

5 DISCUSSION

5.1 Previous analysis of the data

Analysing the matrix of catch at age in numbers obtained (Appendix 6c), we can see that age groups 3 and 4 contribute more than the 55% of the total catch. Then come ages 2, 5 and 6 with almost 40%. Thus 90% of the lobster fishery is based on individuals ranging from 2 to 6 years old, so only a few lobsters of others ages contribute to the catches.

If the separated matrixes were analysed (Appendix 6 a and b) we would obtain a high contribution to the catches of males from ages 2 to 4 (about 80%) and 3 to 5 for the females (about 78%). A similar situation is observed in the southwestern zone of the Cuban shelf, where ages 2 and 3 contribute to 82% of the total catch of males, while 70% of the females are composed of age groups 3 to 4 (Puga *et al.* 1996). Although some studies exist which state that the lobsters in the southeastern platform grow bigger, and older, these results cannot support them.

The low contribution of age group 1 to the catches is in part due to the management measure of the minimal legal carapace length of 69 mm, which forces fishermen to select the animals bigger than this size. In this age group the lobsters still have a mean length of 21.6 mm for males and 18.9 mm for females, even in year 2 the females have still not reached the minimal legal length, with a mean of 45.9 mm. It has also been said that the lobsters compete for habitat, so the smaller individuals are much more affected when finding a cave to live in, especially if the bigger ones already have them occupied.

When observing Figure 2, where the natural logarithms of the catches are plotted through the ages, a trend line is distinguished since age group 5. This gives us an indication that from this particular age the mortality rates are stable. The behaviour of the curve after age 12 is due to the low contribution of the last age group to the catches.

5.2 Catchability tuning and ADAPT virtual population analyses

These two models assume a well-known catch at age matrix, without errors, and they are tuned with the effort data. In order to fit them, the fishing mortality calculated is plotted with the effort data (Figures 3 and 6). In both plots, it is observed that the period from 1990 to 1998 has the biggest differences between these two series. In those years a decrease in effort took place, but no decrease in the fishing mortality was observed.

After 1984, where the highest catches were obtained, a successive decrease took place. As a result additional regulatory measures were implemented in 1990, like the closed season, and the strict enforcement on the minimal legal length. These measures stopped the decrease in catches through a decrease in effort, but did not decrease the fishing mortality. As they didn't catch the individuals in the closed season, they could possibly catch them in the open season.

The pattern of selectivities in the two models was not a monotone increase to a plateau. Instead the selectivity for the oldest years went down. In the catchability tuning it went down to a low value after age 10, and in ADAPT after age 9. With both methods the pattern for the selectivity was the same.

This result was also found by Puga *et al.* (1996) who described an asymmetric and bell-shaped curve for the selectivity in the same specie in southwestern Cuban waters. The author states that in the bigger lobsters the probability of capture decreases because of a combination of two factors: the size of the gear compared with the animal, and the availability of the oldest lobster in the fishing ground. This can be explained when considering that the lobster needs at least three times its height for populating a refugee and is vulnerable to the fishing gear. In most of the aggregating devices, the space between the upper and lower frames is only 10 cm. In addition, as they grow bigger, the oldest individuals migrate to the end of the shelf and thus they are not as available in the fishery ground.

The bell-shaped selectivity curves agree with the one obtained by Miller (1990) for the gear trap-like used in the capture of crustaceans. Also, the results obtained by Morgan (1979) on *Panulirus cygnus* in West Australia, revealed a two or three times higher vulnerability rate for the lobsters with carapace length between 76 mm and 85 mm than for those larger than 85 mm.

5.3 Statistical catch at age model

The assumption of a well known matrix of catch at age is no longer assumed in this method, which calculates a predicted catch at age matrix and depending on the weight of each sum of squares, it minimise them by varying the initial parameters. Quinn and Deriso (1999), describing this model, state that the catch is not necessarily from a survey, but rather can be from any source like a commercial, survey, sport, or other data.

The assumption of a fixed selectivity of 1 for the older age groups was used because when bell shaped selectivity was obtained by the solver, there were very low fishing mortality rates. It also produced high stock numbers in the beginning, especially in age group 1 throughout the years, although low residuals in the predicted and observed catches were observed for all the ages, except for the first one. Since the information provided with the input data is not enough to clear and solve all the problems, the selectivity for the first five years was calculated by the solver function, and for the oldest ages was fixed as 1.

Figure 12 represents the plotting of the squared differences between the observed and predicted catches for ages 2 to 8. The rest of the ages were not considered because of their low contribution to the catches. It can be seen that the most distant values from 0 for the residuals does not go further than ±0.6, the bulk of them is between ±0.2. This gives us a good fitting of the model to the data.

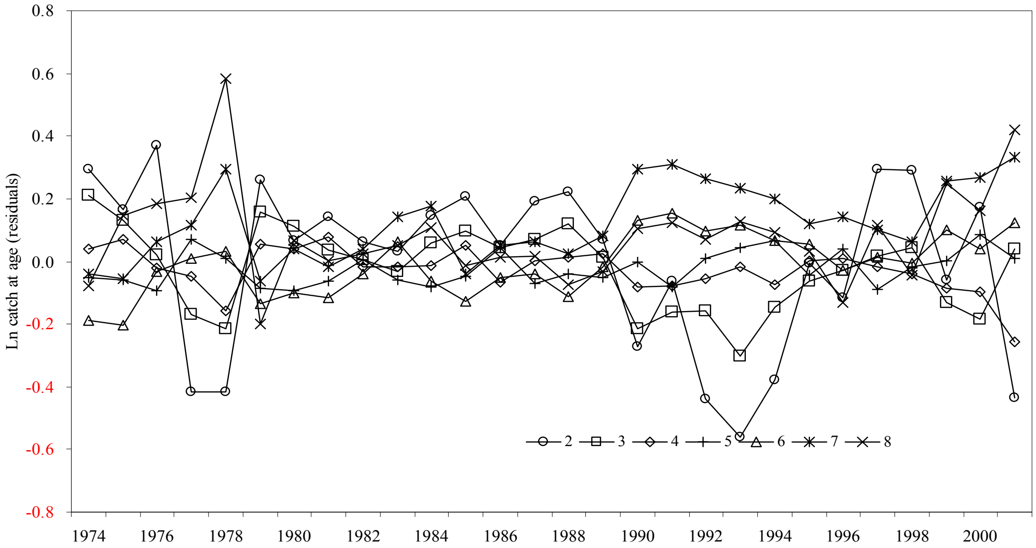

Figure 12: Plotting of the residuals from the difference between the natural logarithms of the observed and predicted matrixes of catch at age.

Compared with the catchability tuning and the ADAPT-VPA, this model includes the same period for the differences between the fishing mortality rate and the effort data, as it is represented in Figure 10. This can be either a problem with the estimation of the catch at age matrix, or a problem with the information on the effort for those years. The data does not explain those differences, so further information is necessary.

5.4 Comparison of the assessment methods

In this report all models have similar assumptions. Firstly, the assumptions on the accurately estimated catch at age matrix is for both sexes. This matrix is obtained by slicing the length into ages, using the proportions of each age at length. Those proportions are, at the same time, obtained from a length frequency analysis, which works searching the modes present in the length distribution of the population that corresponds to the ages. Secondly, the assumption on the accurate measurement of effort, which is taken in fishing days and reported from the fishing companies each day. Then comes the assumption on the constant natural mortality of 0.34, determined using an empirical equation proposed by Cruz *et al.* (1981) as an adaptation of Pauly´s formula for the natural mortality. Finally the catchability was assumed to be constant throughout the period.

The difference between the methods is the method of calculation. The catchability tuning and the ADAPT-VPA use backwards calculation, while the catch at age is based on a forward calculation. In the backward calculations the catch at age is assumed to be determined precisely, without errors, so it is used to calculate the numbers of individuals living in the sea. The EXCAM method accepts that the matrix of catch at age can have some errors, so it is modelled and compared with the given one. In addition, the selectivity is estimated and is assumed to be constant throughout the period.

In this report minor differences arose from the assessment methods applied. For example the selection pattern was different in each method and although we have the reference of a bell-shaped curve, the data was not enough to model it in the catch at age method, which needs additional information. However, despite the use of different selectivity curves the results of stock trends and fishing mortality are very similar in all models, indicating that they are not sensitive to the assumption made about the shape of the selection pattern. This is understandable since the estimated decline in selectivity occurs only in the oldest age groups, which are very poorly represented in the fisheries.

The estimation obtained for the terminal fishing mortality rate was different in the absolute values for the catchability tuning and the ADAPT-VPA in respect to the statistical catch at age (Figure 13), but in general they coincide in pattern and the values are very close. Even for the two first methods the fishing mortality rates throughout the years were almost the same.

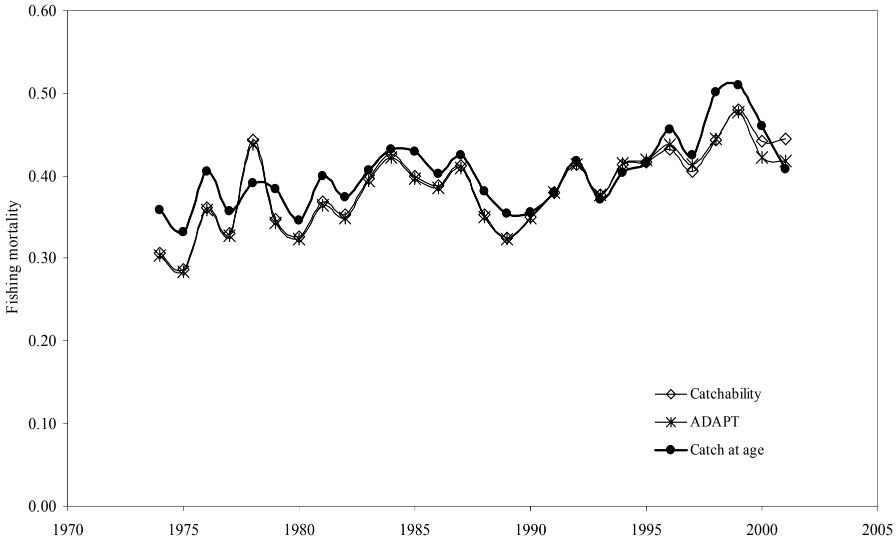

Figure 13: Pattern for the fishing mortality rate obtained from the different methods applied.

The estimation of the stock in number and the recruitment was slightly different between methods, and this could cause some problems when making predictions. A particular problem is that recruitment has to be assumed for the prognosis. If overestimated, the estimation on the biomass will be higher and so the spawning stock biomass, which will lead to an overestimation of the fishing mortality. Even though this was not the case as Figure 14 shows, where the recruitment calculated for the three methods was not so different. The values that were obtained for the catch at age model were the most different from the other lines for the recruitment, but these differences were small. The biggest differences were obtained in the last years, especially the last two years, for which there is limited information from the year classes, and so an average of the recruitment from the previous years was assumed.

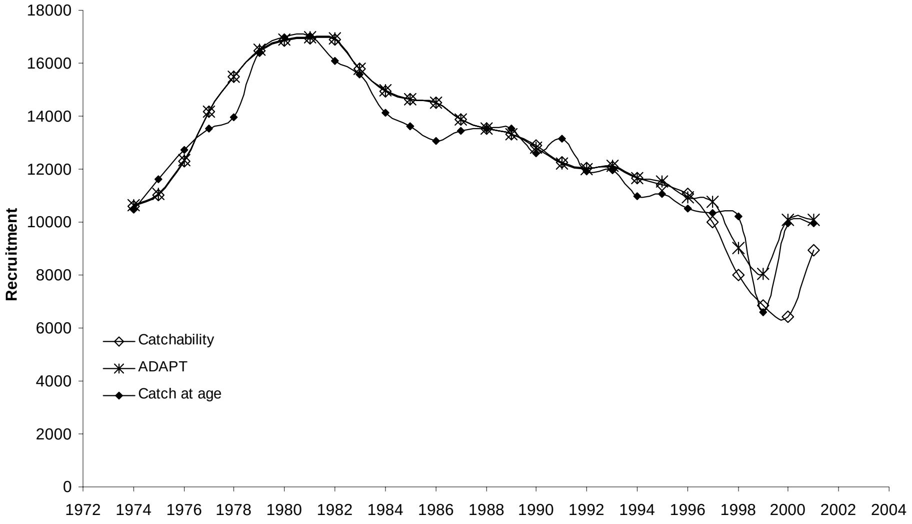

Figure 14: Recruitment obtained from the three methods applied.

When analysing the fishable biomass computed for each method applied, it is evident that for the catchability tuning and the ADAPT-VPA the fishable biomass are very similar, and they follow the same pattern. The catch at age method is not like this, although it follows the similar pattern of increasing until the highest values from 1980 to 1985 and then decreases continuously until the most recent year.

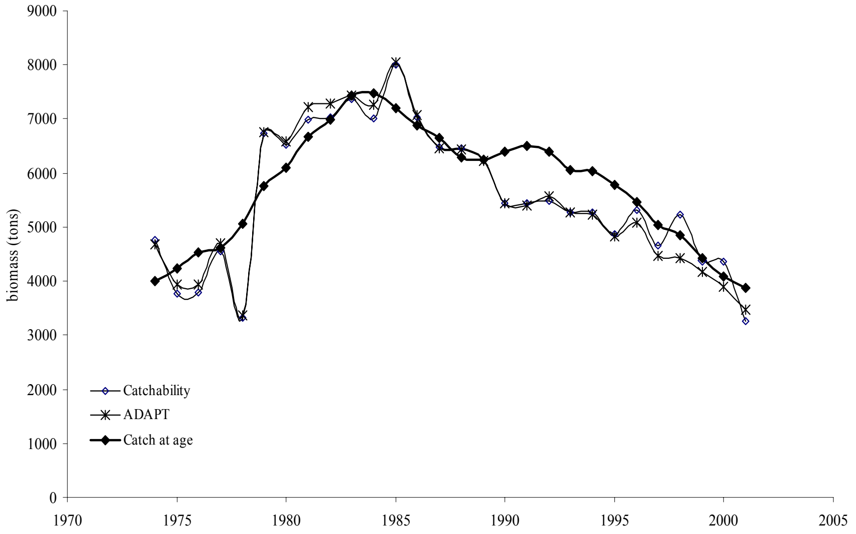

Figure 15: Values for the fishable biomass obtained from the three methods.

The previous results indicated that for the same input data of catch at age matrix, very similar results were obtained for the catchability tuning and the ADAPT-VPA. This is possible because both of them take into consideration the same assumptions. The catch at age method is different, because here the matrix is no longer assumed to be precisely determined, so a new matrix is calculated and compared with the one given. In general the results do not show a different pattern.

All models show a continuous increase in fishing mortality and a continuous decline in spawning stock biomass and recruitment. These patterns indicate that there might be a serious risk of recruitment over fishing in this stock and that current fishing efforts might not be sustainable.

5.5 Yield per recruit and spawning stock biomass per recruit

The yield per recruit is similar in each method because this is a relative estimation, which is dependent on the catch at age and the weight at age for each year, being constant. As the values for them are the same between the models, the resulting estimations were very close.

The yield per recruit is useful in the determination of $F_{0.1}$ and F_{max}. In this calculation $F_{0.1}$ was lower than the fishing mortality rate at which the fishery is developing, but at the same time is lower than F_{max} (Table 1). In addition, the actual fishing mortality is lower than the one corresponding to the maximum yield, which means that we could in theory, increase the effort and higher catches would result. The problem with increasing the fishing mortality rate up to the maximum yield however, is that the resultant decreasing in the spawning stock biomass may be not enough to sustain the population and thereafter it will be continuously lower. Quinn and Deriso (1999) state that it is possible to exceed the sustainable level by harvesting at F_{max}, so an approach of $F_{0.1}$ was taken, but neither of these policies consider the effects on spawning populations and the amount of eggs produced, which can be substantial.

The same authors presented an analysis of the different strategies for biological reference points. They state that rather than a value based on the yield per recruit, such as F_{max} and $F_{0.1}$, where the effects on the spawning population are essentially ignored, it is best to accept the view of the spawning stock or egg production as a means to preserve the reproductive potential of the population. This is calculated as a reference fishing mortality $F_{x\%}$, which represents a spawning stock biomass per recruit that is x% of that with no fishing, so a prudent level to recommend for a biological reference point based on spawning biomass is around 35-50%.

In this report the fishing mortality, which occurs at a spawning stock biomass of 35% of the original, was calculated. It was seen that this value of the fishing mortality rate (0.40) is very near from the one represented as $F_{0.1}$ (0.35), although it is slightly higher. In relation to the value of the actual fishing mortality, it is lower, and also lower than F_{max}. In this kind of analysis it is better to look at the spawning stock biomass that is left in the water than to the yield that is possible to obtain if fishing pressure is increased.

5.6 Predictions

As seen in Table 2 the prediction considering $F_{0.1}$ gives a lower yield, but higher spawning stock biomass with half of the effort. This is reasonable considering that when we diminish the effort fewer individuals will be caught and lower catches will result, but at the same time we are leaving more fishes in the water to spawn and produce eggs. The value for the fishing mortality equal to 10% of the slope of the yield per recruit can produce a yield of 1176 tons in 2002 and a spawning stock biomass of 3645 tons of individuals. Nevertheless, the actual spawning stock biomass is calculated as 3201 tons with an F equal to 0.63 and yield of 1514 tons. In addition when analysing the fishable biomass calculated for 2003, it is clear that the higher value is obtained when applying the strategy of $F_{0.1}$.

If we calculate the yield that we would obtain with the F_{max} a value of 1989 tons would arise with a spawning stock biomass of 2838 tons. Theoretically this yield is sustainable, but then we have to assume that there are no failures in recruitment, which is not a biologically reasonable thought as this can be so variable across the years. Otherwise when analysing the reference of $F_{SSB35\%}$, it gives results between $F_{0.1}$ and F_{max}, but this particular strategy considers more the spawning stock biomass. So in this case with a fishing mortality rate about 30% lower than the actual one, we can predict a yield for 2002 of 1284 tons, only 230 tons less, and an increment of 508 tons are obtained in the spawning stock biomass.

Taking into consideration the results given, it is possible to keep fishing the stock of lobster at the actual fishing mortality rate of 0.63. This would give some increment in the yield for the next year, but a decrease in the spawning stock biomass, which could lead to a decreasing in the number of eggs produced, and consequently in the number of future recruits. As this may happen, it is convenient to have a better estimation of the recruitment, to be able to model their behaviour and their influence on the estimation of the future of the fishery. In the interim period a reduction in fishing mortality is advised to decrease the likelihood of recruitment over fishing.

6 CONCLUSIONS AND RECOMMENDATIONS

This report has been dealing with the assessment of the population of the spiny lobster, which lives in the southeastern shelf of the Cuban waters. The assessment has been made through different methods and similar results were obtained. The first conclusion obtained was that for the same assumptions taken, and using the same data set for the analysis, the results were highly similar between the methods. This was obtained with the catchability tuning VPA, and the ADAPT-VPA, which basically work with the same formulas, the same backward calculation and the same assumptions. This was not the situation for the Excel catch at age model, which does not assume an accurately estimated catch at age. Nevertheless, the results were not that different.

Of the three methods applied the EXCAM is the most accurate, because of the initial condition that there can be errors in the estimation of the catch at age matrix. This statement will be elucidated when running the model, and through an estimation of a new predicted catch at age, that will be compared with the observed one. This model needs some external information to adjust it to the data, and the fitting will depend on the quality of this information. The conclusion is that the data provided are not enough to explain the behaviour of the fishing mortality in relation to the effort. There is also a problem in the estimation of the selectivity, which is fixed as 1 for the oldest ages, but references have proven that this is not accurate. No external information exists that can elucidate this problem.

In the future a function describing the selectivity at age is necessary for introducing it in the catch at age model for a best fitting to the real data and the behaviour of the lobster in nature. Later an assessment of each sex can be done separately, taking into account that they have different growth parameters and even the achievement of the assessment for the two fishing periods occurring: after the open season, and in the mass migration by the end of the year. The implementation of surveys to collect biological data is also of great importance, independent from the catches, which can give information about the recruitment and other parameters. This would lead to a better understanding of the biology of the lobster and therefore the population dynamics.

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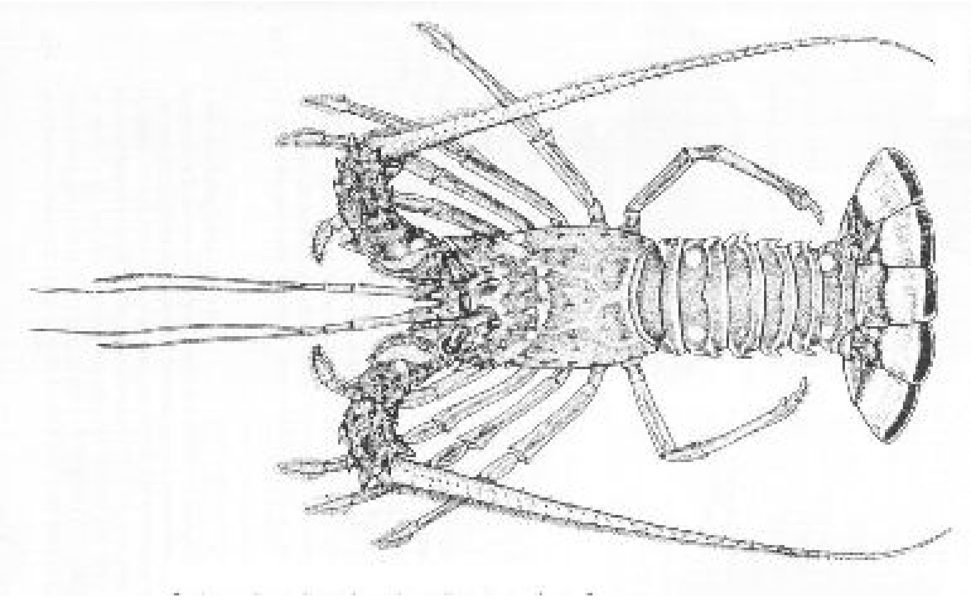
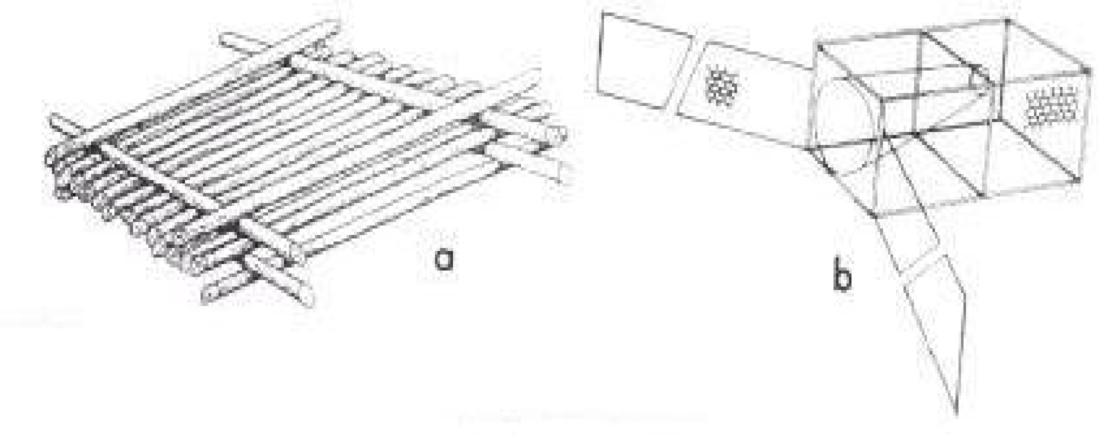
9 APPENDICES

Appendix 1: The spiny lobster



Appendix 2: Fishing gears used in the lobster fishery

a. Aggregating devices, artificial shelter or "pesqueros".
b. Traps joined with nets or "jaulón"



Appendix 3: Series of length frequency distribution

CL (mm)	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
48	11	12	24	10	3	0	0	0	0	0	0	0	0	0
53	15	19	36	15	6	3	3	4	2	3	3	2	2	2
58	31	34	51	23	17	12	14	16	11	13	14	11	10	11
63	55	58	73	36	35	67	71	87	69	67	93	78	72	89
68	68	22	89	48	58	158	169	208	165	140	184	159	136	168
73	70	70	125	62	73	259	261	334	306	269	347	308	247	294
78	70	81	132	64	75	326	319	401	388	345	420	381	291	334
83	87	96	112	88	93	330	329	391	396	366	423	387	295	320
88	273	252	219	286	269	311	318	368	390	371	422	395	299	319
93	261	237	215	274	256	294	307	354	373	373	415	406	352	330
98	191	179	185	230	206	224	241	286	292	312	339	330	347	294
103	124	125	155	179	153	190	212	255	255	280	312	292	297	278
108	107	109	157	156	132	134	161	187	186	212	234	202	198	205
113	72	77	135	118	102	105	132	156	158	186	207	177	174	188
118	51	54	79	96	91	69	90	108	112	132	149	125	126	139
123	33	41	64	68	78	49	68	78	83	95	111	87	93	102
128	22	32	47	49	63	32	47	56	62	67	80	63	69	74
133	15	25	37	36	53	22	33	41	48	49	60	46	53	55
138	4	8	15	13	19	14	21	28	34	31	39	29	36	37
143	4	8	15	13	19	8	13	17	22	19	23	16	22	22
148	4	7	13	12	18	6	10	13	17	15	18	12	17	17
153	1	3	6	8	15	3	4	6	8	6	8	5	7	7
158	1	3	6	8	15	1	2	3	4	3	4	3	4	4
163	0	1	1	2	3	1	1	1	2	1	1	1	1	1
168	0	0	0	0	0	0	0	0	1	0	1	0	0	1
173	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0

CL (mm)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
48	0	0	0	0	0	0	0	0	0	0	1	0	0	0
53	1	1	1	1	1	1	1	1	2	4	9	1	2	2
58	12	7	5	7	3	3	3	8	10	20	37	9	11	7
63	98	57	41	47	26	20	24	53	61	108	140	75	56	26
68	161	112	77	90	59	44	59	87	88	138	176	94	80	33
73	273	215	144	167	129	97	136	172	171	218	218	139	135	50
78	304	258	182	200	185	148	189	209	220	238	243	156	165	62
83	294	251	190	197	211	184	210	219	242	228	266	166	185	72
88	293	253	206	202	239	222	239	237	273	227	288	180	213	88
93	299	255	228	214	268	257	265	251	294	221	272	198	264	113
98	251	216	212	199	253	247	250	227	270	196	242	188	237	107
103	226	193	203	194	242	244	245	216	251	176	218	147	169	82
108	164	149	172	171	183	182	183	158	191	146	171	124	132	67
113	154	145	174	173	177	171	175	150	181	134	141	114	120	64
118	115	107	129	125	128	125	130	111	124	102	95	88	87	46
123	83	72	87	80	84	87	93	79	76	77	78	66	63	37
128	63	57	71	66	68	67	69	62	60	56	52	45	45	27
133	48	46	57	55	55	52	53	46	37	40	41	33	33	21
138	32	32	40	41	40	36	35	32	24	28	30	23	22	15
143	19	20	24	26	26	22	21	20	15	19	20	14	14	9
148	14	15	19	21	21	17	17	15	11	14	13	11	11	7
153	6	7	8	9	9	8	7	7	5	6	6	5	5	3
158	3	4	4	5	5	4	4	4	3	3	4	3	3	2
163	1	1	1	2	2	1	1	2	1	1	2	1	1	1
168	0	0	1	1	1	1	0	1	1	1	1	0	0	0
173	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4: Biological parameters for the lobster

1) Growth parameters and length- weight relationship for males and females.

	Equation	**Parameters**	**Males**	**Females**
Von Bertalanffy growth parameters	$Lt = L\infty (1 - \exp^{-K(t-t0)})$	L∞ (CL)	185.6 mm	156.2 mm
		K	0.221	0.219
		t_0	0.44	0.41
Length-weight relationship	$W = a L^{b}$	a	0.00243	
		b	2.764	

2) Proportion of mature individuals per age.

Ages	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Prop. mature	0.00	0.12	0.25	0.50	0.75	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00

3) Sexual proportion by class length interval.

CL (mm)	**Males**	**Females**
17	0.3	0.8
22	0.9	0.1
27	0.6	0.4
32	0.6	0.4
37	0.7	0.3
42	0.6	0.4
47	0.60	0.40
52	0.42	0.58
57	0.49	0.51
62	0.44	0.56
67	0.45	0.55
72	0.39	0.61
77	0.39	0.61
82	0.37	0.63
87	0.36	0.64
92	0.36	0.64
97	0.40	0.60
102	0.44	0.56

CL (mm)	**Males**	**Females**
107	0.49	0.51
112	0.54	0.46
117	0.57	0.43
122	0.64	0.36
127	0.68	0.32
132	0.85	0.15
137	0.92	0.08
142	0.92	0.08
147	0.95	0.05
152	0.98	0.02
157	0.99	0.01
162	0.95	0.05
167	1.00	0.00
172	1.00	0.00
177	1.00	0.00
182	0.75	0.25
187	0.0	0.0
192	1.0	0.0

Appendix 5: Data of catches and effort for the series

Year	**Catches (Metric Tones)**	**Effort (fishing days)**
1974	1447.4	
1975	1431.2	
1976	1808.5	
1977	1666.2	
1978	1962.9	
1979	2150.4	
1980	2083.7	
1981	2578.4	
1982	2553.5	
1983	2902.3	10697
1984	3064.6	10331
1985	2938.9	9964
1986	2652.5	9986
1987	2682.6	10008
1988	2322.2	9704
1989	2176.7	9477
1990	2233.4	9126
1991	2390.8	7840
1992	2546.5	7646
1993	2193.0	7595
1994	2331.4	8056
1995	2287.7	8187
1996	2335.0	10041
1997	2034.1	11040
1998	2236.8	10237
1999	2072.3	12193
2000	1768.2	12636
2001	1514.0	10123

Appendix 6a: Catch at age in numbers for the males

Age/ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL
1974	18	177	418	185	60	16	6	2	0	0	0	0	0	882
1975	20	151	370	180	77	27	13	5	2	0	0	0	0	845
1976	37	252	353	263	113	43	22	9	3	0	0	0	0	1094
1977	14	116	380	238	105	35	19	11	3	0	0	0	0	922
1978	6	145	402	238	149	58	34	25	7	1	0	0	0	1064
1979	2	476	542	243	84	33	12	3	1	0	0	0	0	1395
1980	2	410	481	253	102	42	15	4	1	0	0	0	0	1311
1981	2	526	582	308	124	56	21	6	2	1	0	0	0	1629
1982	1	458	577	298	132	65	26	8	2	1	0	0	0	1568
1983	2	453	641	381	159	68	25	7	2	1	0	0	0	1739
1984	2	521	658	389	173	77	28	8	2	1	0	0	0	1860
1985	2	506	683	368	148	62	21	6	1	0	0	0	0	1798
1986	1	383	570	345	153	72	27	8	2	1	0	0	0	1561
1987	1	444	538	355	162	73	27	8	2	1	0	0	0	1611
1988	1	421	479	291	136	64	23	6	2	0	0	0	0	1423
1989	1	344	435	281	130	67	26	7	2	1	0	0	0	1294
1990	1	240	388	328	159	84	32	9	2	1	0	0	0	1244
1991	1	291	404	347	161	92	38	11	3	1	0	0	0	1350
1992	0	237	488	368	164	90	37	11	3	1	0	0	0	1400
1993	0	170	423	330	149	74	29	8	2	1	0	0	0	1186
1994	0	223	450	342	159	75	28	8	2	1	0	0	0	1288
1995	1	297	451	312	147	71	27	8	3	1	0	0	0	1318
1996	1	295	496	348	131	52	19	6	2	1	0	0	0	1351
1997	3	374	386	263	128	60	24	7	2	1	0	0	0	1247
1998	6	420	468	282	123	62	23	7	2	1	0	0	0	1395
1999	1	310	410	280	133	59	23	7	2	1	0	0	0	1226
2000	2	233	394	231	102	46	18	5	1	0	0	0	0	1033
2001	2	161	296	206	106	52	20	6	2	0	0	0	0	852

Appendix 6b: Catch at age in numbers for the females

Age/ Year	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL
1974	58	169	424	319	118	47	17	7	2	0	0	0	1162
1975	60	136	381	283	114	47	20	10	3	1	0	1	1055
1976	91	250	355	287	163	73	30	14	5	1	0	1	1271
1977	37	112	358	312	143	69	29	13	4	1	0	1	1078
1978	28	148	394	320	139	73	38	19	7	1	1	1	1170
1979	33	528	678	378	152	63	24	10	3	1	0	0	1870
1980	30	454	584	346	155	69	28	12	4	1	0	1	1685
1981	37	588	708	422	187	85	34	15	5	2	1	1	2085
1982	27	510	702	413	180	84	35	17	6	2	1	1	1977
1983	31	498	738	486	228	109	44	19	6	2	1	1	2163
1984	36	580	773	490	231	113	47	21	7	2	1	1	2303
1985	33	562	789	516	221	104	40	18	6	2	1	1	2292
1986	28	425	582	482	206	98	41	19	6	2	1	1	1891
1987	34	497	600	424	208	105	44	20	6	2	1	1	1943
1988	36	468	553	365	169	87	36	17	6	2	1	1	1740
1989	23	385	501	331	162	86	34	17	6	2	1	1	1548
1990	17	265	402	324	186	104	41	21	7	2	1	1	1370
1991	21	325	432	329	199	109	41	21	7	3	1	2	1489
1992	11	258	491	412	214	111	42	21	7	3	1	1	1573
1993	9	181	406	368	192	99	39	19	6	2	1	1	1323
1994	10	245	453	381	198	104	42	20	7	2	1	1	1464
1995	23	326	481	366	182	94	39	19	6	2	1	1	1540
1996	26	318	517	408	206	102	35	17	5	1	1	1	1635
1997	48	404	445	294	152	80	35	16	5	2	1	1	1484
1998	70	435	529	357	173	78	34	15	5	2	1	1	1699
1999	37	333	434	333	161	87	37	16	5	2	1	1	1446
2000	25	248	403	326	137	68	28	13	4	1	0	1	1254
2001	23	167	284	256	120	63	28	13	4	1	1	1	962

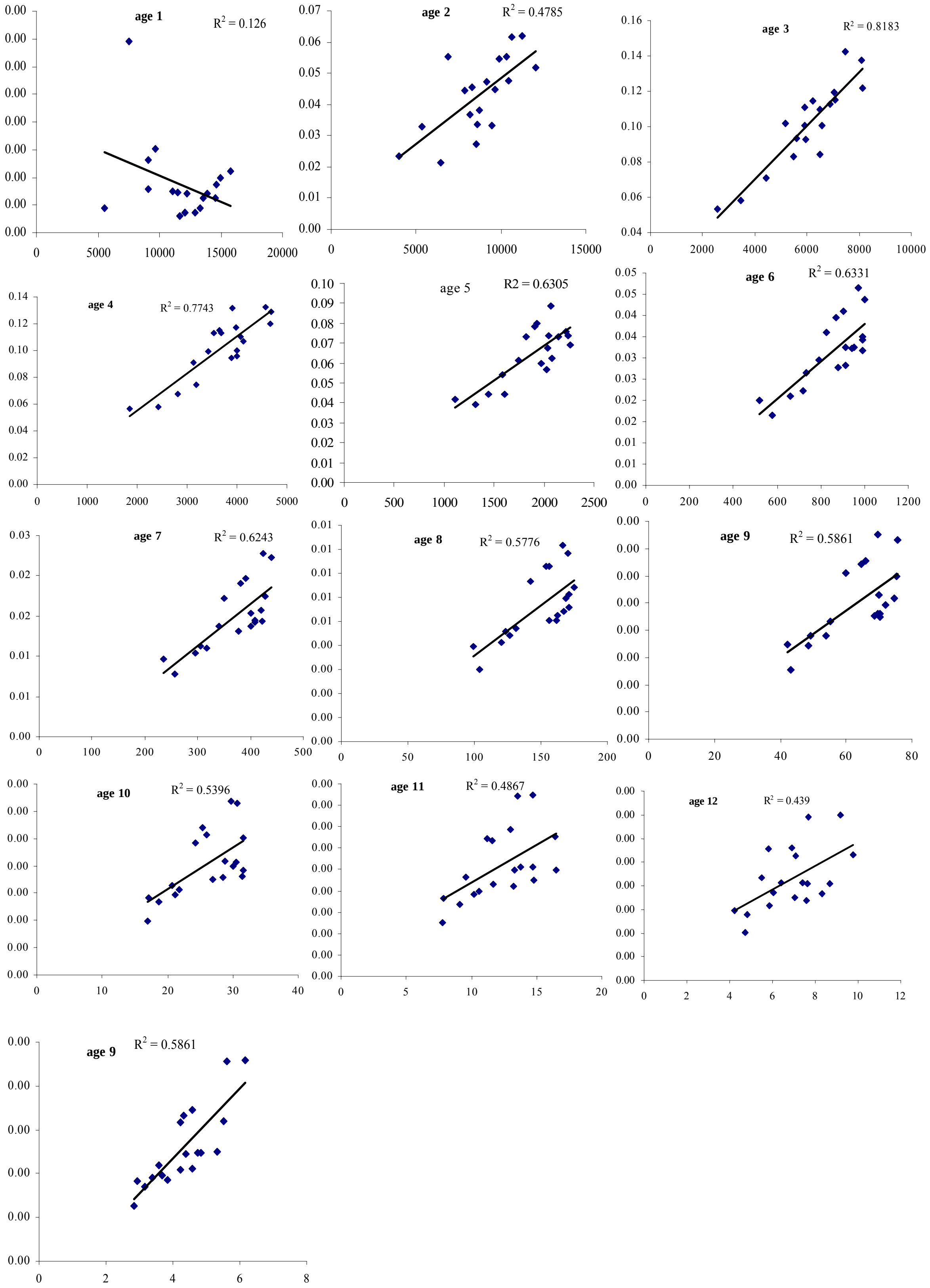
Appendix 6c: Catch at age in numbers for the joined sexes

Age/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1974	20	263	656	681	424	149	60	21	8	2	0	0	0
1975	23	241	576	640	410	161	69	29	13	4	1	0	1
1976	43	399	700	718	465	240	109	45	20	6	1	0	1
1977	16	177	569	688	482	206	101	46	19	5	1	0	1
1978	7	205	650	747	555	233	126	74	32	9	1	1	2
1979	2	571	1203	1035	519	208	84	30	12	4	1	0	1
1980	2	500	1062	951	509	224	96	37	15	5	1	0	1
1981	3	643	1336	1159	623	278	121	46	19	6	2	1	1
1982	2	557	1247	1147	625	281	126	49	22	7	2	1	1
1983	2	555	1306	1282	739	339	154	58	25	8	2	1	1
1984	2	641	1423	1336	763	354	162	63	27	9	3	1	1
1985	2	614	1419	1318	756	323	142	52	22	7	2	1	1
1986	1	474	1149	1070	733	321	144	56	25	8	2	1	1
1987	1	553	1197	1105	678	326	154	60	26	8	3	1	1
1988	1	528	1093	973	578	269	127	49	22	7	2	1	1
1989	1	426	953	909	536	267	130	48	22	7	2	1	1
1990	1	303	771	860	569	318	160	58	27	9	3	1	1
1991	1	370	861	921	580	343	174	61	29	10	3	1	2
1992	1	291	875	1008	676	356	174	62	29	10	3	1	2
1993	1	208	706	861	606	311	149	55	25	8	3	1	1
1994	0	271	812	929	630	319	154	59	26	8	3	1	1
1995	1	373	906	925	597	294	141	55	25	8	3	1	1
1996	1	369	935	994	618	296	138	47	22	6	2	1	1
1997	3	491	918	823	491	247	121	49	21	7	2	1	1
1998	7	565	1039	934	553	270	116	47	20	7	2	1	1
1999	1	402	862	827	541	256	127	50	21	7	2	1	1
2000	2	297	739	730	493	210	99	38	16	5	2	1	1
2001	3	216	541	574	424	201	97	40	17	6	2	1	1

Appendix 7: Stock size in numbers calculated for the catchability tuning

Age/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1974	10607	7067	4760	2953	1427	546	212	77	38	15	8	4	2
1975	11037	7533	4810	2838	1530	660	264	100	38	20	9	5	3
1976	12299	7837	5160	2940	1483	745	335	130	47	16	11	6	3
1977	14155	8718	5243	3085	1489	665	329	146	55	17	7	7	4
1978	15478	10061	6057	3254	1618	655	300	149	66	23	8	4	5
1979	16481	11011	6990	3765	1689	686	270	108	44	20	9	4	2
1980	16866	11729	7357	3965	1811	766	314	122	52	21	11	6	3
1981	16944	12003	7929	4345	2024	861	357	143	56	24	11	7	4
1982	16903	12058	8004	4522	2119	917	380	153	63	24	12	6	4
1983	15780	12030	8115	4650	2256	983	417	164	67	27	11	6	4
1984	14957	11230	8097	4680	2233	985	416	168	68	27	13	6	4
1985	14642	10644	7455	4568	2209	949	404	160	67	26	12	7	3
1986	14527	10420	7061	4115	2145	937	404	168	70	28	12	7	4
1987	13876	10339	7019	4061	2030	911	398	167	73	29	14	7	4
1988	13553	9876	6895	3991	1963	876	375	154	68	30	14	8	4
1989	13329	9646	6586	3989	2023	912	398	160	69	30	16	8	5
1990	12883	9487	6508	3887	2076	990	425	174	74	31	16	9	5
1991	12253	9169	6498	3985	2044	1000	437	168	74	30	14	9	6
1992	12035	8721	6216	3902	2063	968	423	165	68	29	13	7	5
1993	12076	8565	5963	3690	1931	901	390	155	65	25	12	6	4
1994	11663	8595	5922	3651	1903	866	379	152	64	25	11	7	4
1995	11392	8301	5890	3533	1819	825	349	141	59	24	11	5	4
1996	11050	8108	5595	3431	1739	793	341	130	54	21	10	6	3
1997	9983	7864	5461	3198	1608	718	316	126	53	21	10	6	3
1998	7987	7103	5185	3116	1585	732	304	123	49	20	9	5	3
1999	6848	5679	4581	2818	1433	664	294	119	48	19	9	5	3
2000	6425	4874	3704	2537	1311	566	258	103	43	17	8	4	3
2001	8947	4572	3220	2016	1193	520	227	100	41	17	8	4	3

Appendix 8: Correlation between the capture per unit of effort (cpue) and the numbers of individuals (n) for each age group



Appendix 9: Stock size in numbers for the adapt-vpa method

Age/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1974	10501	7006	4716	2921	1399	530	201	71	32	10	5	2	1
1975	10939	7458	4767	2806	1508	640	252	93	33	15	5	3	1
1976	12195	7766	5106	2909	1460	729	321	122	42	13	8	3	2
1977	14031	8643	5193	3046	1468	649	317	136	49	13	4	5	2
1978	15364	9973	6004	3219	1591	640	289	141	59	19	5	2	3
1979	16363	10930	6927	3727	1664	666	259	100	38	15	6	3	1
1980	16762	11645	7300	3920	1784	748	300	114	46	17	8	3	2
1981	16852	11929	7868	4304	1992	842	344	133	50	20	8	4	2
1982	16823	11993	7951	4479	2090	895	366	144	56	20	9	4	3
1983	15698	11973	8069	4612	2225	963	401	154	61	22	8	4	2
1984	14892	11171	8056	4646	2206	964	401	156	61	23	9	4	2
1985	14568	10598	7413	4539	2186	930	388	149	58	21	9	4	2
1986	14453	10367	7028	4085	2124	921	391	157	62	23	9	5	3
1987	13814	10286	6981	4037	2009	896	386	157	65	24	9	4	3
1988	13487	9831	6857	3964	1946	861	365	146	62	25	10	5	2
1989	13281	9598	6554	3963	2004	900	387	153	63	26	12	5	3
1990	12770	9452	6475	3865	2057	976	417	166	69	26	12	6	3
1991	12162	9089	6474	3961	2028	987	427	162	69	26	11	6	4
1992	11894	8656	6159	3885	2046	957	414	158	64	25	10	5	3
1993	11933	8465	5917	3649	1919	888	382	148	60	21	10	5	3
1994	11487	8493	5850	3618	1874	857	371	147	59	22	8	5	3
1995	11199	8175	5817	3482	1795	805	343	135	55	20	9	4	3
1996	10604	7970	5506	3380	1702	776	326	126	50	18	8	4	2
1997	9021	7546	5363	3134	1571	693	304	116	50	17	8	4	2
1998	6766	6418	4959	3046	1540	706	286	115	42	18	7	4	2
1999	5281	4810	4094	2657	1384	631	276	106	42	13	7	3	2
2000	8574	3758	3086	2191	1197	531	235	90	33	13	4	3	2
2001	8574	18694	2426	1576	946	438	202	84	32	10	5	2	2

Appendix 10: Residuals obtained from the difference between the observed and predicted matrix of catch at age

Age/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1974	0.26	0.29	0.21	0.04	-0.05	-0.19	-0.04	-0.08	-0.16	-0.30	-1.13	-1.16	-0.00
1975	0.37	0.17	0.13	0.07	-0.06	-0.20	-0.05	0.15	0.36	-0.04	-0.72	-0.44	1.16
1976	0.71	0.37	0.02	-0.02	-0.09	-0.03	0.06	0.18	0.41	0.17	-0.68	-0.34	1.56
1977	-0.21	-0.41	-0.17	-0.05	0.07	0.01	0.11	0.20	0.31	0.04	-0.74	-0.74	1.35
1978	-1.13	-0.42	-0.21	-0.16	0.01	0.03	0.29	0.58	0.62	0.31	-0.46	-0.26	1.60
1979	0.23	0.26	0.16	0.06	-0.09	-0.13	-0.06	-0.20	-0.28	-0.60	-0.81	-0.90	0.49
1980	0.30	0.07	0.11	0.04	-0.09	-0.10	0.04	0.07	0.07	-0.30	-0.62	-0.74	0.69
1981	0.33	0.14	0.04	0.08	-0.06	-0.12	-0.02	0.00	0.13	-0.14	-0.48	-0.73	0.70
1982	-0.04	0.06	0.00	-0.02	0.01	-0.04	0.04	0.02	0.19	0.06	-0.19	-0.49	0.87
1983	0.25	0.03	-0.03	-0.02	-0.06	0.06	0.14	0.05	0.13	-0.05	-0.27	-0.52	0.70
1984	0.13	0.15	0.06	-0.01	-0.08	-0.06	0.18	0.11	0.15	-0.07	-0.26	-0.41	0.86
1985	0.01	0.21	0.10	0.05	-0.05	-0.13	-0.04	-0.01	0.01	-0.27	-0.54	-0.69	0.60
1986	-0.22	0.05	0.04	-0.07	0.04	-0.05	0.05	0.01	0.22	-0.05	-0.33	-0.51	0.89
1987	-0.17	0.19	0.07	0.00	-0.07	-0.04	0.06	0.02	0.09	-0.03	-0.33	-0.58	0.76
1988	-0.22	0.22	0.12	0.01	-0.04	-0.11	0.03	-0.07	0.02	-0.20	-0.35	-0.59	0.65
1989	-0.53	0.07	0.01	0.02	-0.05	-0.02	0.08	-0.03	0.04	-0.15	-0.37	-0.47	0.83
1990	-0.69	-0.27	-0.21	-0.08	-0.00	0.13	0.30	0.11	0.23	0.00	-0.22	-0.43	1.00
1991	-0.27	-0.06	-0.16	-0.08	-0.08	0.15	0.31	0.12	0.18	-0.00	-0.23	-0.44	0.96
1992	-0.99	-0.44	-0.16	-0.06	0.01	0.10	0.26	0.07	0.15	-0.12	-0.33	-0.59	0.81
1993	-0.88	-0.56	-0.30	-0.02	0.04	0.12	0.23	0.13	0.16	-0.10	-0.42	-0.66	0.64
1994	-0.98	-0.38	-0.15	-0.08	0.07	0.07	0.20	0.09	0.15	-0.15	-0.46	-0.76	0.54
1995	-0.13	-0.01	-0.06	0.00	-0.04	0.05	0.12	0.03	0.10	-0.16	-0.44	-0.64	0.58
1996	0.06	-0.12	-0.03	0.01	0.04	-0.03	0.14	-0.13	-0.04	-0.44	-0.69	-0.84	0.25
1997	0.96	0.29	0.02	-0.02	-0.09	0.01	0.10	0.12	0.08	-0.23	-0.50	-0.73	0.55
1998	1.55	0.29	0.04	-0.04	-0.02	-0.01	0.06	-0.04	0.01	-0.26	-0.43	-0.56	0.55
1999	0.09	-0.06	-0.13	-0.09	0.00	0.10	0.26	0.25	0.16	-0.07	-0.42	-0.67	0.62
2000	0.39	0.17	-0.18	-0.10	0.08	0.04	0.27	0.16	0.23	-0.14	-0.37	-0.69	0.62
2001	0.81	-0.43	0.04	-0.26	0.01	0.12	0.33	0.42	0.45	0.26	-0.09	-0.28	0.96

Appendix 11: Stock size in numbers obtained for the catch at age method

Age/ Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1974	10457	6608	4428	2774	1380	525	182	65	29	9	3	1	1
1975	11610	7430	4539	2708	1432	612	225	78	28	12	4	1	1
1976	12730	8250	5118	2809	1432	658	272	100	35	12	5	2	1
1977	13527	9043	5641	3069	1390	597	264	109	40	14	5	2	1
1978	13970	9612	6212	3452	1585	617	256	113	47	17	6	2	1
1979	16425	9924	6581	3748	1730	674	252	105	46	19	7	2	1
1980	16973	11690	6695	3825	1855	762	283	106	44	19	8	3	1
1981	17010	12080	7928	3970	1962	857	337	125	47	19	9	4	1
1982	16089	12106	8130	4568	1934	847	352	138	51	19	8	4	1
1983	15592	11450	8177	4750	2281	862	360	150	59	22	8	3	1
1984	14147	11096	7699	4696	2299	976	351	147	61	24	9	3	1
1985	13600	10068	7434	4361	2218	953	383	138	58	24	9	3	1
1986	13071	9678	6748	4217	2065	922	375	151	54	23	9	4	1
1987	13453	9302	6512	3884	2050	889	377	154	62	22	9	4	2
1988	13530	9574	6239	3703	1848	857	352	150	61	24	9	4	2
1989	13536	9629	6460	3631	1836	816	361	148	63	26	10	4	2
1990	12588	9634	6521	3812	1846	838	356	158	65	28	11	5	2
1991	13160	8959	6523	3845	1935	841	365	155	69	28	12	5	2
1992	11929	9366	6047	3800	1910	857	355	154	66	29	12	5	2
1993	11960	8490	6287	3451	1819	805	343	142	62	26	12	5	2
1994	11000	8512	5737	3678	1727	814	344	146	61	26	11	5	2
1995	11078	7828	5726	3300	1786	742	332	140	60	25	11	5	2
1996	10493	7884	5257	3272	1583	756	298	133	56	24	10	4	2
1997	10320	7468	5264	2940	1511	637	287	113	51	21	9	4	2
1998	10225	7344	5008	2993	1398	631	252	114	45	20	8	4	1
1999	6610	7277	4873	2734	1324	531	225	90	41	16	7	3	1
2000	9954	4704	4822	2649	1200	497	187	79	32	14	6	3	1
2001	9954	7084	3139	2691	1218	480	188	71	30	12	5	2	1