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ASSESSMENT OF THE SPINY LOBSTER (*PANULIRUS ARGUS*, LATREILLE, 1804) IN NORTHEASTERN CUBAN WATERS

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ABSTRACT

Spiny lobster (*Panulirus argus*), the most valuable fishery resource in Cuba, is subject to a state property regime and to a limited-access system. Assessment of the population in the northeastern shelf of Cuban waters is the subject of this report. To conduct the analysis required for stock assessment, a matrix of catch at age and length frequency by sex, and effort information from the commercial fleet was used as input data. The possibility of using length frequency from fishery data to analyse different assumptions on growth were evaluated and the suitability of different ADAPT VPA methods tested for the Cuban northeastern lobster to obtain predictions on current stock levels. The effects of different management scenarios including present strategy on the short-term yield of the stock were explored. The aggregated length distributions over each year from the fishing industry are not informative enough to estimate growth parameters for the stock. The exploitation rate has been at high levels since 1998 and over 50% after a decrease in effort in 2001 and 2004 the fisheries induced mortality rate was at 0.4, which is above the $F_{0.1}$. The main age groups in the lobster catch in this zone are of ages 3 to 6. There is a general decreasing trend in recruitment, which can be related to a decrease in spawning stock biomass (SSB). In a projection for 2005 and 2006 it is demonstrated that the $F_{0.1}$ strategy with a fishing mortality rate of 0.3 will most likely result in higher values of SSB in 2005 without a decrease the catch (similar to 2004) and similar applies to yield and SSB in 2006.

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1 INTRODUCTION

Spiny lobster (*Panulirus argus*, Latreille 1804) is a crustacean, which inhabits shallow waters usually no deeper than 50 m and has a wide distribution in the tropical western part of the Atlantic Ocean, from the Bermuda Islands and North Carolina (USA) in the North, down to Rio de Janeiro, (Brazil) in the south. Although it is found around the Yucatan peninsula (Mexico), it does not inhabit the Gulf of Mexico. It is abundant in the Caribbean area from which it draws its common name, Caribbean lobster (Arce and León 2001). Spiny lobsters are widely distributed in all shallow-waters areas around Cuba. They can be found in sea-grass beds, among coralline growth and on sandy or rocky bottom.

The fishery for *Panulirus argus* in the Western Central Atlantic is the largest spiny lobster fishery in the world and the most valuable single-species fishery in Cuba, accounting for 60-65% of the country's gross income from fisheries products. Cuba with an 8,000 t average per year of lobster exported is second only to Australia which exports 11,000 t of a closely a related species *P. cygnus*. More than 60% of the catch is processed as whole cooked lobsters in nine coastal locations and exported, mainly to Japan, Canada, France, Spain and Italy. The rest of the catch is processed as frozen tails, also for export. Although in the last few years, there has been a growing trend in exporting live lobsters (Puga *et al.* 2005). Fishing occurs mostly at depths from 3 to 15 m on the extensive shelves of the south coast and on the less extensive shelves of the north coast.

Spiny lobsters are benthic crustaceans with limited migrations, so there is no adult lobster interchange between areas. Although the phyllosoma larvae are widely distributed in the Caribbean, there are strong currents along the shelf borders that return the larvae to the coastal shelf (Arce and León 2001). Each area is therefore considered a single management unit, although they are administrated nationally.

The Cuban marine shelf is divided in to four regions: southeast, southwest, northwest, and northeast. The main fishing area is the Gulf of Batabanó (southwest), where 60% of the total national catch is harvested. The northeast area represents only 15% of the total national catch with an average catch of 1,567 t between 1974 and 1989, but in the period between 1990 and 2004, catch levels have decreased to 1,394 t.

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

Increases in catch levels since 1978 were due to an increase in fishing effort, in spite of the strict compliance with the regulations on the minimal legal length and increased length of the closed season (León *et al.* 1991 and Puga *et al.* 1992). The total catch of lobster in Cuba was not to exceed 11,800 t in the period 1984 to 1988. Nevertheless the highest catches reached about 12,500 t in these years (Puga *et al.* 1995). In addition to the increase in fishing intensity there has been a decrease in recruitment since 1988 (Puga *et al*. 1991 and Cruz *et al*. 1995), which has further aggravated the situation, and the catch in 1990 was only 7,959 t.

Data collected from the lobster fishery have been used to estimate the age composition of the catch. This has then been used for estimating, recruitment, Stock-Recruitment relationship (S-R), and catchability and selectivity patterns of different fishing gears (Puga *et al.* 1996). In the southwestern zone analytical stock assessments have been used, which are based on size and age composition analysis of the catches (Puga *et al*. 1996), surplus production models (Puga *et al.* 2005) and an age-structured bioeconomic model (Puga *et al.* 2005). The lobster fishery in the northeastern area has not been investigated as much as the southwestern zone, both in terms of the population dynamics and sustainable harvesting.

As the lobster fishery in the northeastern area, though much smaller than in the southeastern area, is important to local communities there is a great need for studying the population dynamics and possible management scenarios for the spiny lobster fishery in that part of the Cuban shelf.

The main objective of the project is to evaluate the possibility of using length frequency from fishery data to analyse different assumptions on growth and to test the suitability of two different ADAPT VPA methods for the Cuban northeastern lobster to obtain predictions on current stock levels. Finally the effects of different management scenarios including present strategy on the short-term yield of the stock will be explored.

2 LITERATURE REVIEW

2.1 Biology of spiny lobster

The spiny lobster has a complex life cycle that includes five phases: egg, larva (phyllosoma), puerulus, juvenile and adult. Gravid females migrate to the edge of the continental shelf to spawn. The number of eggs released in one interval varies from 160 thousand to 2million depending on the size of the female. Spawning takes place throughout the year with a peak in March to May (Arce and León 2001). The wide distribution of the species, its high fecundity and reproductive activity provides a constant supply of larvae that disperse with currents throughout the region.

The smallest size of a berried lobster captured in Cuba is 67 mm CL (Cruz and León 1991) and the estimated sizes at 50% and 100% maturity are 81 mm and 97 mm CL, respectively. A relationship between fecundity and carapace length was estimated (Arce and León 2001):

$$E=0.5911CL^{2.9866}$$

Where E is number of eggs

After mating, females may move several kilometres to the edges of the reefs or coastal shelves to incubate and release larvae (Buesa 1965). The larvae are planktonic in oceanic waters where they are thought to spend 6-10 months, including 11 pelagic larval stages (Baisre 1964). During their long period in the plankton, the larvae become widely distributed throughout the Caribbean Ocean (Alfonso *et al*. 1991). The phyllosoma larvae metamorphose into pueruli, which swim across the continental or insular shelf to arrive at the coast throughout peak in September-December (Briones 1994). The pueruli settle in clumps of *Laurencia sp.* (Herrnkind and Butler 1986) and occasionally in the algal web on submerged mangrove roots (Witham *et al.* 1964). After settlement pueruli moult and become postpuerulus, known as the algae phase (Buttler *et al.* 1997) with a size range of 6-15 mm CL. Post-pueruli become juveniles 10-15 months after settlement (Davis 1978). Post-algal sizes 26-35 mm CL still occupy vegetated habitats, but late juveniles (>35 mm CL) and sub-adults (70-76 mm CL) tend to occupy patches of reef habitats without vegetation (Arce and León 2001). Juveniles leave the settlement (post-algae juveniles) and seek refuge in caves, coral reefs, sponges and soft corals (Arce and León 2001). Older juveniles migrate offshore and are recruited to the fishery at 76 mm CL (Davis 1978). In Florida males attain the size of 76 mm CL in an average of 23 months, whereas females require an average of 30 months (Muller *et al.* 1997). The nursery grounds are spread throughout the whole Cuban shelf, but no fishery takes place there because of the high abundance of small lobsters, under the minimum legal length. Juveniles are rarely found in the same areas as adults, which prefer deeper waters (Arce and León 2001). Studies have shown that environmental conditions such as currents, waves, tides and turbidity are the main factors that influence the lobsters' habitats and survival. Strong disturbance can cause loss of habitat, and subsequently decrease the abundance and density of spiny lobsters. Figure 1 illustrates the average times required to pass from one life history stage to the next, based on data from Cuba.

Several authors have investigated the biology and fishery of spiny lobster in Cuba. An integration of published studies resulted in understanding of the space-time schemes of the spiny lobster's life cycle (Cruz *et al.* 1991a), which together with detailed information collected, provided a basis for further studies on the population dynamics of the species.

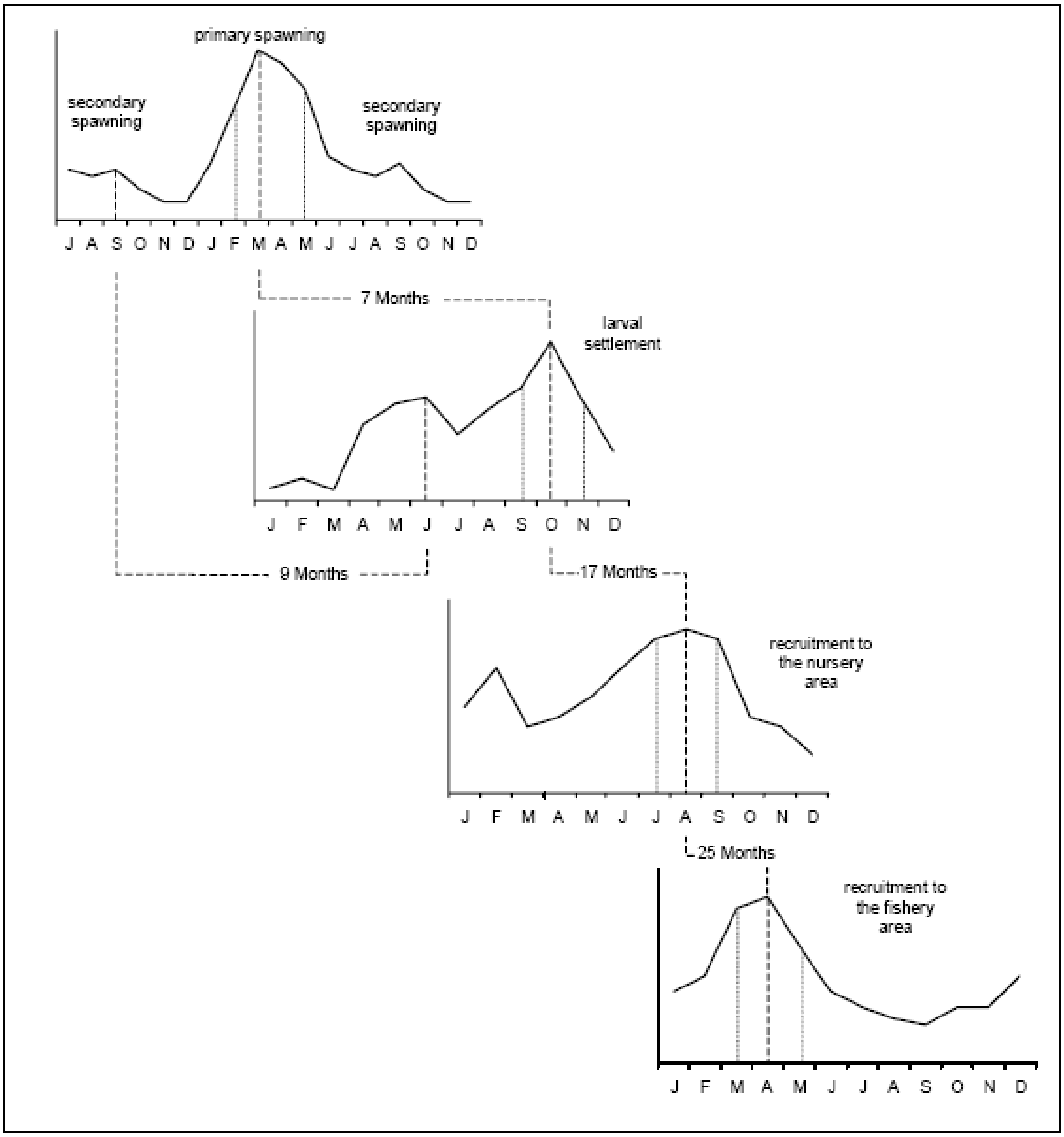

Figure 1: Life periods as suggested by seasonal peaks in indices (Cruz *et al.* 1991a).

Females carry fertilised eggs up to four week prior to spawning (Simmons 1980). These females are referred to as being “berried”. Females migrate to areas populated with males for mating, and then move to deeper reef areas to incubate and release larvae. Adult lobsters spawn offshore in deeper (>20 m) reef habitats affected by oceanic currents; this pattern presumably reduces predation pressure by ensuring larval dispersal away from the adult habitat (Lyons *et al*. 1981).

The reproduction of spiny lobster appears to be consistently higher in the spring and summer months (March-July) although this activity is observed all year round. In Cuba, reproduction occurs throughout the year with the greatest numbers of berried females occurring from March to May and a subsidiary peak in September (Arce and León 2001).

Three major stages of the spiny lobster life cycle are recognised, based upon management and habitat use: larval (open ocean), juvenile (shallow, vegetated coastal areas), and adult (coral reef) (Davis 1978, Cruz *et al.* 1995, Buttler *et al.* 1997).

Different authors have studied growth of spiny lobsters in Cuban waters (Buesa 1972, Cruz *et al.* 1981, Báez *et al.* 1991, 1994, Phillips *et al.* 1992, León *et al.* 1995). León *et al.* (1995) studied growth in the four Cuban fisheries management zones and they did not observe a difference in growth between them. Their results of age at first capture, 3.19 years, corresponded with estimates of CL of first capture of 81 mm as estimated by Puga *et al.* (1994).

2.2 The fishery

2.2.1 Vessels and gathering houses

There are currently 255 boats participating in the Cuban lobster fishery. Although there are still some wood and Ferro-cement vessels, the majority of the fleet consists of plastic boats, which are made of glass-reinforced fibre. The northeastern shelf of Cuba is divided between three provinces and each one has its own fishery zone and vessels. Last year around 55 boats participated in the fishery of the northeastern Cuban shelf.

One particular characteristic of the Cuban lobster boats is the presence of holds in their hulls. They have a lot of holes, which facilitate water circulation and keep the lobsters inside alive and properly oxygenated the whole way from the fishing grounds to the gathering house where they are landed.

The gathering houses (Appendix 9b) are located at sea and surrounded by water. They have big cages submerged in water where the lobsters are kept until they can be transported to the industries inland. This procedure guarantees the freshness of the lobsters and increases the quality of the final product.

2.2.2 Fishing gears

The main fishing gears currently used in the lobster fishery in Cuba are artificial shelters (pesqueros), traps (jaulones), unbaited traps, and old car tires (Cruz and Phillips 1994). Traditional bully nets (*chapingorro*) also still frequently used. The jaulones are rectangular trap-like gear made of chicken wire and have large leader nets (about 50 m long) attached at the two front corners in a V-pattern. They are placed in the sea singularly or several together in a zigzag pattern during the migratory season (15th September to 31st December).

Puga *et al.* (1996) compared the level of catchability and the size of spiny lobsters caught in different gears. They found that the *jaulones* allow more escapes of small-sized lobsters and as a consequence, the length at first capture (L50 % = 25.5 cm TL) is higher than in the *pesqueros* (L50% = 24.2 cm TL). Puga *et al.* (1996) found that *jaulón* catchability was 2.3 times the *pesquero's* catchability. The catchability of pesqueros was higher for the ages 3 and 4 years. But for the *jaulones* the catchability is higher for the age groups 4 and 5 years.

2.2.3 Management system

Because of its economical value, the spiny lobster fishery's 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 the fishermen, who have their own area. There they take care of their fishing gear, they monitor closely the health of the environment, and they are even defenders of the management system, as it has positive affects on their fishing area. The fishery is currently managed with input and biological controls. These include a state property regime, limited entry, territorial rights to fishery enterprises, gear restrictions, and a 110-day closed season from February to May. During the spawning season (March and May) and at the peak of the recruitment the fishing area is closed to protect juveniles and spawners (León *et al.* 2001). There is also a minimum legal size of 69 mm carapace length (CL) and a ban on collecting berried females (Puga *et al.* 2005).

2.3 Stock assessment of spiny lobster

Puga *et al.* (1991) used cohort analysis and surplus yield models to assess the potential yield of lobster populations in each of the four main subfisheries. Maximum sustainable yield has been estimated around 12,300 t and the authors claim that the fishery is fully exploited and point out that a decrease in recruitment has taken place.

Pérez *et al.* (1978) presented the first stock-recruitment relationship (S-R) for the southeastern spiny lobster and estimated S-R curves of the Ricker type for each management unit. Estimates of separate S-R relationships for each fishery zone must be viewed with caution because it is known that larvae of *P. argus* in the Caribbean are distributed throughout the region (Baisre *et al.* 1978). Contrary to this, other studies indicate distinct subpopulations (Menzies 1981) and larval distribution (Alfonso *et al.* 1991) coupled with oceanic circulation (García *et al.* 1991). García *et al.* 1991 pointed out the existence of favourable mechanisms for larval retention along the south cost of Cuba.

According to Cobb and Caddy (1989), the S-R relationship in spiny lobster may be better described by a Beverton-Holt than the Ricker equation. The asymptotic nature of the relationship may explain the stability of the lobster stock as well as its resilience to continued high exploitation rates. This suggests that relatively high levels of fishing mortality might be sustained without a observing a decrease in recruitment. The less exploited part of the lobster population, living in deeper waters (González *et al.* 1991).

Bannister and Addison (1986) have extended the "classical yield per recruit (Y/R) and egg per recruit (EPR) modelling approach for the European lobster (*Homarus gammarus*) by coupling S/R curves to known Y/R and spawning stock biomass per recruit curves to generate total yield and biomass estimates. They used the method of Shepherd (1982) to generate a variety of S/R relationships (the functional form of the S-R relationships for *H. gammarus* is unknown), and then used simulation techniques to investigate the effects of various combinations of F and minimum legal size (MLS) on total yields and biomass.

Puga *et al.* (1996) also assessed the effects of varying the fishing effort in both seasons using Thompson's and Bell model (1934). According to Puga *et al.* (1996) the maximum yield per recruit could be achieved by decreasing the effort in season 1 (June-September) by 20 % of the current level and increasing it by 20-40 % in season 2 (October-February). In spiny lobster (*Panulirus argus*) fisheries annual catches are affected by highly variable recruitment (Cobb and Phillips 1994). Abundance indices for juvenile lobster, derived from post-larvae collectors or from sampling prefishery recruits, have been successfully used in predicting future catches (Caputi and Brown 1986, Phillips *et al.* 1994). Catch and effort data, when size frequency data are available from recruits and prerecruits, have been used to predict the abundance of large lobster from smaller size-classes (Gonzalez-Cano 1991). The juvenile index at a nursery area on the Gulf of Batabanó in Cuba has proven to be a reliable predictor of total catch up to 1 year in advance. Over the last 20 years juveniles have been monitored in concrete-block shelters that permit wider variation in juvenile recruitment and thus a regional and seasonal prediction of catches. Since 1988, puerulus settlement has been measured by means of artificial-seaweed collectors, but the short data series does not allow construction of a predictive model. The full-year model of catch prediction was based on the index of juvenile abundance and its relationships with lobster catches the following year. The seasonal models of catch prediction were based on the seasonal behaviour of the lobster fishery. The catch in the season of the massive migrations or "recalo" (October–February) depends on the intensity of recruitment and the number of fishing days. The catch in "levante season" (June–September) depends on the juvenile index and the catches during the previous 'recalo'. The relationship between observed and predicted catch and management strategies was examined by Cruz and Adriano (2001).

The term virtual population analysis (VPA) was introduced by Fry (1957) to describe the number of fish belonging to a given year class that must have been present in past years by projecting backwards through a time series of catch-at-age to recruitment. Cohort Analysis (CA) (Pope 1972) is a good approximation to VPA and much easier to perform. The difference between these two methods is the way numbers in a cohort decline with time. For VPA the decline in number with age follows an exponential curve, while in CA, the exponential curve within any age group is replaced by a "step function". Thus, Pope's cohort formula can then be derived quite simply by proceeding *backwards* in time from the oldest to the youngest ages. The use of statistical catch-at-age and VPA-based methods for crustacean assessment is limited (Smith and Addison 2003) because of problems with ageing, but age-structured methods have been applied to crustacean stocks, e.g. *Nephrops* (ICES 2001a) and *Pandalus* (ICES 2001b). Age-structured methods can then be applied including VPA (Gulland 1965, Pope 1972, Hilborn and Walters 1992, Darby and Flatman 1994), separable VPA (Pope and Shepherd 1982, Darby and Flatman 1994), extended survivors' analysis (XSA) (Shepherd 1992, Darby and Flatman 1994), the adaptive framework (ADAPT) (Parrick 1985, Gavaris 1988, Conser and Powers 1989, Conser 1993) and integrated catch analysis (ICA) (Patterson and Melvin 1996, Patterson 1999). VPA-based methods, assume catch data are measured without error since length slicing may introduce error and/or reduce contrast between ages and years, age-structured methods are not widely applied to longer living crustacean species. Catch-at-age-based methods can be used to estimate reference points as discussed in the yield, spawner and egg per recruit models section.

3 MATERIALS AND METHODS

3.1 Area of study

Cuba is an archipelago located between 20^{o} and 23^{o} north latitude and 74^{o} and 85^{o} west longitude. As this position suggests, it is a tropical country with high temperatures during most of the year, and the winter season is mainly influenced by short northern fronts.

For management purposes the Cuban shelf is divided into four fishing zones (Figure 2) according to geographical location: northeast, northwest, southeast and southwest. The lobster fishery takes place in these four areas, in shallow waters, where the sea floor is sandy with rocks and coral reefs. This study focuses on the spiny lobster population inhabiting the northeast area of the Cuban shelf or zone D (Figure 2).

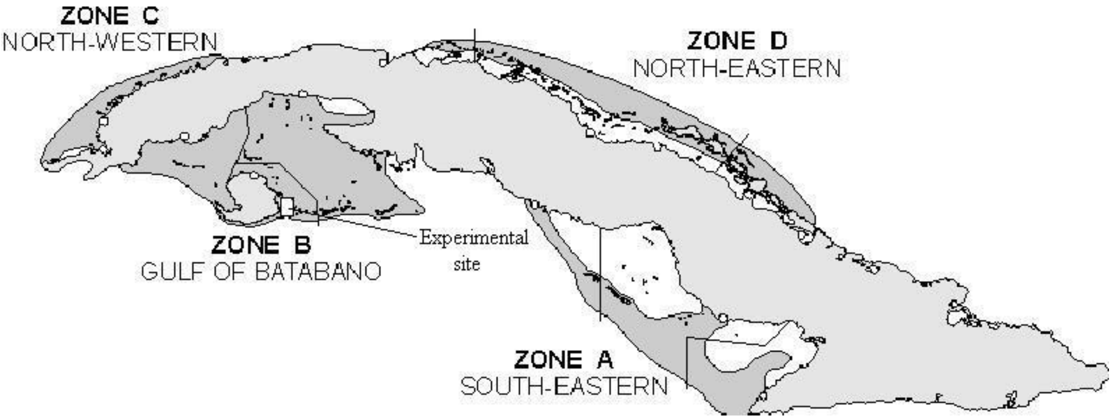

Figure 2: Fishing zones of the Cuban shelf.

3.2 Source of data

The length frequency data were obtained from monthly landings grouped by export size categories from the processing plants. There are 14 commercial size categories. These are: 180-250 g, 250-300 g, 300-350 g, 350-400 g, 400-460 g, 460-520 g, 520-575 g, 575-630 g, 630-690 g, 690-860 g, 860-1200 g, 1200-1500 g, 1500-2000 g and 2000-3000 g. The catch was transformed into length intervals using the SISLAN programme (Alfonso *et al.* 1995), which assumes a normal distribution of length in each category and uses the length-weight relationship in the conversion. The basis of this calculation is to get the length frequency data from the industrial catch. The lobster catch is grouped into different weight ranges and with the average weight of each group the number of lobsters can be estimated by dividing the total catch of lobster in this range with the average weight. Then with the length-weight relationship the composition by length of the catch is obtained. This procedure is described in detail by Cruz (2002).

A matrix of catch at age in numbers per year covering 14 ages (from age 1 to 14, was obtained from the length frequency of landings by a slicing method (Sparre and Venema 1997) with the growth parameters obtained by León *et al.* (1995) which are considered to be the most reliable for the species in Cuba (Arce and León 2001). This method treats the length frequency data sampled each year separately, identifying recruitment variation and changes in fishing mortality. To achieve this, lobster must be referred to age groups of the same time span, usually one year, when there is annual spawning.

When annual samples over a series of years are being sliced, it is important that all individuals of one cohort (year class) go into the same age group. The cohorts are not distributed over two age groups by the slicing.

First for each age group assigned, the mean length is calculated. The corresponding length class for each age group is also determined. Then the fraction in lower groups is calculated. This fraction is the difference between the mean length at age and the minimum length of the length class divided by the length class interval. The total catch by length class is known. The catch at age group is obtained by multiplying the fraction of length classes by the catch (Sparre and Venema 1997).

The natural mortality (Pauly's empirical formula, Pauly 1980) adapted to Cuban lobster by Cruz *et al.* (1981), taking a value of 0.34 for all age classes and the length-weight relationship obtained from survey data ($\mathbf{W=a*L^b}$, with a=0.00243 and b=2.764). Recruitment to the fishery is assumed to occur at age 1.

The data set used in this report is:

Biological data:

- The length frequency distribution in 5 mm class intervals, ranging from 45 mm of carapace length (CL) up to 180 mm CL, from 1974 until 2004.
- The proportion of berried females taken by biological sampling.

Statistical data:

- Catches in metric tonnes for the whole period.
- Effort measured in fishing days per year.
- The catch in number per age from 1974 to 2004.

3.3 Methods used

3.3.1 Analysing different assumptions of growth

The Shepherd's Length Composition Analysis (SLCA, Shepherd 1987), which is implemented in the programme Length Frequency Distribution Analysis LFDA (Kirkwood 2001), was used to find the von Bertalanffy growth parameters by sex for the northeastern Cuban shelf with length frequency data from biological sampling in the fishery area.

The data utilised was the length frequency (1994 to 2004) of the total data obtained from the industrial catch using the SISLAN programme (Alfonso *et al.* 1995) to find the best estimates of K and $L\infty$ that corresponded to a maximum value of the score function in the SLCA procedure.

Initial ranges for K and $L\infty$ were determined from previous estimates of growth of spiny lobster in the fishing area. From this a search grid over the likely parameter space was defined and then the value of the score function was calculated. This was then repeated until the best range of parameters according to the LFDA's built-in automatic maximisation score function was obtained. The SLCA method estimates K, $L\infty$ and t_0 by maximising a goodness-of-fit function from time series analysis of diffraction patterns.

In essence, this maximisation procedure works by starting at a specified point, and then it tries to move away from that point in an "uphill" direction on the score function surface. Once a point is identified for which heading away from it in any direction means going "downhill", this point is taken to be the local maximum. This procedure is repeated from five points within the selected area. The maximum point is then overlaid on two-dimensional contour plot of the score function. It is then up to the user to identify whether maximisation has been successful, and that this maximum represents the $L\infty$ and K combination which fits the data most appropriately.

A goodness-of-fit or score function, S, is then calculated for each sample by summing the over all length classes in the sample:

$$S = \sum T_L * \sqrt{N_L}$$

Where:

T = a test function is calculated for each length class (L)
N = the number in each length class. If there is more than one length-frequency sample, values of S are also summed over samples.

Growth performance index Ø' (Pauly and Munro 1984), which is a way of comparing the growth rate of a species in a particular fishery to the standard growth rate of the species.

$$Ø' = \log(K) + 2\log(L_\infty)$$

3.3.2 *ADAPT VPA*

3.3.2.1 *ADAPT VPA (Method I)*

In this study a Virtual Population Analysis, VPA (Gulland 1965) was conducted, using the Adaptive framework (ADAPT, Stefánsson 2005). The analysis was set up using catches in number at age from 1974 to 2004.

ADAPT-VPA is a well-known method of stock assessment using catches in numbers at age combined with tuning indices to obtain stock size in numbers at age (Stefánsson 1992). In this method, it is assumed that fishing takes place at around the middle of the year and that natural mortality will only affect the stock before and after the fishing season. Natural mortality is assumed to be constant with regard to age and time and is denoted by M.

This method uses fishing mortality rates in the last year as a starting point of the calculation instead of stock size of the last year. The classical virtual population analysis, (Gulland 1965), is based on the assumption that the fishing mortality rates of the last year are known. These coefficients can then be inserted as assumed values.

The virtual population analysis starts with the basic stock (1) and catch (2) equations:

$$\mathbf{N_{a+1,y+1} = e^{-Zay} * N_{ay}} \qquad (1)$$

$$\mathbf{C_{ay} = \frac{F_{ay}}{Z_{ay}} * (1- e^{-Zay}) * N_{ay}} \qquad (2)$$

The stock size in numbers in the last year is calculated through an inversion of the catch equation (2):

$$\mathbf{N_{ay} = \frac{C_{ay}}{(F_{ay}/Z_{ay}) * (1- e^{-Zay})}} \qquad (3)$$

Where:

$\mathbf{N_{a\,y}}$ is the size of the age group a in year **y**
$\mathbf{N_{a+1,\,y+1}}$ is the size of group a in the next year to year **y**
$\mathbf{Z_{a\,y}}$ is the total mortality rate for age group a in year **y**
$\mathbf{F_{a\,y}}$ is the fishing mortality rate for age group a during year **y**
$\mathbf{C_{a\,y}}$ is the total catch in number of age group a in year **y**

It follows that one can deduce knowledge of stock size from the assumption on fishing mortality along with the assumption that the catch is know without error.

For a given age group ***a*** having the size $\mathbf{N_{ay}}$ at the beginning of year ***y***, provided no fishing is taking place in the period of the first six months, the size of the year-class at the middle of the year will be:

$$\mathbf{N_{ay} * e^{-M/2}}$$

If the entire catch is taken at this point of time, the size of the year-class is reduced to:

$$\mathbf{N_{ay} * e^{-M/2} – C_{ay}}$$

and then the year-class decreases due to natural mortality, so the survival of the year-class at the end of the year is:

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

For back calculation of the stock size, this equation can be reversed:

$$\mathbf{N_{ay} = (N_{a+1,\, y+1} * e^{M/2} + C_{ay}) * e^{M/2}} \qquad (4)$$

It is now possible to use exactly the same method to estimate the stock size of the second last year and then continue to back calculate stock size and mortality rate back in time.

This enables calculation of the fishing mortality rates in the youngest age groups using the usual VPA equations:

$$\mathbf{F_{ay} = ln(N_{ay}/N_{a+1,\, y+1}) - M} \qquad (5)$$

The fishing mortality rate of the oldest group is taken as an average of fishing mortality rates for some penultimate younger age groups of the oldest during the same year. Then after computing the fishing mortality and subsequently take the mean across a range of ages within each year, an average fishing mortality for each year was estimated with main ages in the catch in this project.

If the fishing mortality is $\mathbf{F_{ay}}$ with an average fishing mortality for each year, $\mathbf{F_{ay}}$ given as the average of $\mathbf{F_{ay}}$ across some selected age groups, then the annual selection pattern is computed for each age and year through the following formula:

$$\mathbf{S_{ay} = F_{ay} / \overline{F}_{ay}} \qquad (6)$$

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

$\overline{F}_{ay}$,: Average of the fishing mortality rate through the selected age groups

The average selection pattern was estimated from 1996 to 2002, terminal selection pattern (S_{tem}), and for the last year then the fishing mortality rate can be computed as the multiple of the selection pattern terminal by F multiplier:

$$\mathbf{F_y = S_{tem} * \overline{F}} \qquad (7)$$

The fishing mortality rates of the last year are then determined by a tuning method, ADAPT.

In this report the index of abundance used was the catch per unit of effort, based on the equation:

$$CPUE_{ay} = \frac{C_{ay}}{E_y} \qquad (8)$$

Where CPUE$_{ay}$: catch per unit of effort for age a in the year y

If VPA is employed with the correct input, it should provide a sound stock estimate. This estimate could in turn be used to predict indices from survey data and therefore it is feasible to verify whether a given stock estimate is in accordance with a time series of CPUE data.

The tuning part starts with the calculation of the CPUE for the whole matrix following equation 8. Then we calculate the logarithm for this index and stock matrix for each year and age group.

One possible way to conduct such a comparison is through stating that for given terminal fishing mortality coefficient in the last year and a given relationship with indices, the deviation (sum squared errors, SSE) in the forecast concerning indices is given by:

$$\mathbf{SSE = \Sigma_{\mathit{ay}}[lnCPUE_{ay} - (\alpha_a+\beta_a\, lnN_{ay})]^2} \qquad (9)$$

The unknown coefficients in the model are only $\boldsymbol{\alpha_a}$, $\boldsymbol{\beta_a}$. They were obtained from a single linear regression (Stefánsson 2005).

The exploitation rate, E, was computed by dividing fishing mortality (F) by total mortality (Z). The parameter E expresses the proportion of a given cohort/population that ultimately dies due to fishing given existing exploitation pressure (Beverton and Holt 1956). Gulland (1971) suggested that a fish stock is optimally exploited when the fishing mortality is equal to the natural mortality rate or: F_{opt}=M or E_{opt}=0.5

3.3.2.2 ADAPT VPA with methodology used in CUBA (Method II)

The stock at age in number is computed using Pope's approximation from the matrix of catch at age for age groups 1 to 9+. It is similar to the prior method for the last year and oldest two age groups with catch equation (3) and for back calculation of the matrix with the equation (4).

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 (Gavaris 1988). The estimation of the fishing mortality and number of lobsters was implemented in Microsoft Excel (Lassen and Medley 2000). In this methodology an operation patron is added related with age 8. The input parameter for solver is F oldest and the fishing mortality for age 8 the last year. Solver in the tools menu of Microsoft Excel is used to find an optimal value for a formula in one cell "target cell" that in this case is the sum of squares of the matrix of abundance indices residuals and the cells that are related with the target cell is the F oldest and fishing mortality for age 8. The rest of the ages are related to exploitation patron at age 8 and in the computation of the bulk of the fishing mortality rates of the matrix equation (5) is used.

Fishing mortality terminal by age is calculated by age and time as follows:

$$F_{a\ term} = S_{a/8} * F_{8,y} \qquad (10)$$

Where: $S_{a/8}$ is the selectivity pattern by age *a* relative to age 8 years and $F_{8,y}$ is the fishing mortality rate at age 8 at year.

These values of F term by age are like the selection pattern terminal. Also the selection pattern was estimated with equation (6) but this one was calculated with the mean fishing mortality for all age groups and the average selection pattern was estimated from 1996 to 2002, terminal selection pattern (S_{tem}).

The tuning part starts with the calculation of the CPUE for the whole matrix following equation 8. Then through the transformation in logarithm of the equation the relation between abundance indices and the stock size:

$$CPUE_{ay} = q * N_{ay}$$

Where $CPUE_{ay}$: catch per unit of effort for the age a in the year y
N_{ay}: number of lobster in the population
q: coefficient of catchability

Then the logarithm of the catchability coefficient for each year and age group is calculated:

$$\ln q = \ln CPUE_{ay} - \ln N_{ay} \qquad (11)$$

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

$$Residual = \ln q - average(\ln q)$$

Finally the sum of squares of this last matrix is the cell to be minimised by the solver function, varying the F of age 8 in the last year (2004). The fishing mortality for age group 9+ is assumed equal to fishing mortality age 8 while fishing mortality for age group 1-7 in the last year (2004) was estimated with the relation with age 8 for the period 1996-2002.

The proportion of mature females by age was computed through size (age)-specific maturity and fecundity relations from previous studies (Cruz and León 1991). Multiple spawning was modelled by assuming that females larger than 80 mm CL have two broods per year (Lipcius 1985).

The exploitation rate, E, was computed by dividing fishing mortality (F) by total mortality (Z) (Beverton and Holt 1956).

3.3.3 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 and following this procedure:

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

$$Y_a = C_a W_a \qquad (12)$$

Where C_a: catch at age
W_a: 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:

$$SSB_a = N_a W_a M_a$$

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

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

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

Spiny lobster enter the fishery at age two and we assume at the beginning of the first year, the year class size N1 is simply the number of recruits

In order to simplify the calculations the initial stock number is fixed as 1000, and then we will have the yield per 1000 individuals entering to 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 data table option of the Excel is used. The $F_{0.1}$ is defined 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 just a more conservative or risk adverse to departures from the assumptions of the yield–per-recruit analyses (Haddon 2001).

3.3.4 Prediction for the following year

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

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

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 those used before, 2 and 12, respectively.

The problem that arises when projecting the catches is the stock number at the age 1 or the recruitment, which has no data point to be based on. In case of lack of survey indices several ways 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 to do it is applying the stock recruitment relationship, which gives some narrower boundary to the uncertainty that comes in with the predictions.

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

$$R = \alpha SSB \exp\left(-\frac{SSB}{K}\right)$$

Where R is the number of individuals with age 1 and α is the recruits-per-spawner at low stock levels and K represents maximum recruitment in the Ricker model.

The Ricker yield per recruit model was used to generate short-term (equilibrium) predictions of yield per SSB, profit per recruit and spawning per recruit, related with the fishing mortality in the last year (2004) and $F_{0.1.}$ The model was implemented on MS Excel spreadsheets.

4 RESULTS

4.1 Analysing different growth assumptions

Using the converted length frequency data from the spiny lobster fishing industry, growth parameters were estimated using the LFDA5 programme (Kirkwood 2001). A grid search over a parameter space was conducted using previously published estimates for spiny lobster in the fishing area (Table 1.) The search range for L_∞ was from 170 mm to 190 mm for males and 140 mm to 180 mm for females. The range of the K parameter was 0.1 to 0.4 for both sexes at the beginning. Then the value of the score function over a specified grid of values of K and $L\infty$ were calculated. The LFDA's built-in automatic maximisation was used to determine the values of K and $L\infty$ at which the score function was maximised.

Table 1: von Bertalanffy parameters (K and $L\infty$) and index of growth performance Ø' estimated by different authors for *Panulirus argus* (León *et al.* 1995).

Authors	**Sex**	**K**	L_∞	**Ø'**
Dos Santos *et al.*1964(Brazil)	Male	0.34	141	4.11
	Female	0.38	148	
Buesa 1972 (Cuba)		0.16	174	3.68
Munro 1974 (Jam.)		0.22	192	3.89
Olsen and Koblic 1975 (Is. Vig)	Male	0.44	153	3.88
	Female	0.32	133	
Davis 1977(Fla.)		0.34	190	4.09
Clairovin 1980 (Martinique)	Male	0.25	190	3.93
	Female	0.23	188	
Cruz *et al.*1981 (Cuba)	Male	0.22	169	3.79
	Female	0.31	139	
Baéz *et al.* 1991(Cuba)	Male	0.29	250	4.19
	Female	0.31	209	
Arce *et al.* 1991 (México)	Male	0.3	142	3.72
	Female	0.3	122	
Lozano *et al.* 1991 (México)	Male	0.2	257	4.09
	Female	0.25	215	
Phillips *et al.*, 1992 (Cuba)	Male	0.27	250	4.15
	Female	0.39	171	
León *et al.* 1993 (Cuba)	Male	0.31	190	3.95
	Female	0.24	174	
Baéz *et al.* 1994 (Cuba)	Male	0.21	178	3.81
	Female	0.21	171	
León *et al.* 1995 (N-E. Cuba)	Male	0.23	185	3.86
	Female	0.19	154	
León *et al.* 1995 (Cuba)		0.21	184.7	3.88

All the estimated growth parameters (L_∞, K and t_0) are laid down in Table 2. It was estimated with the method Shepherd's Length Composition Analysis (SLCA) in LFDA for both sexes and compared with that found by León *et al.* (1995).

Table 2: von Bertalanffy growth parameters and growth performance index estimates for spiny lobster (*Panulirus argus*) in the northeastern Cuban shelf (1994-2004).

SLCA Method (LFDA)		**L∞**	**K**	**t0**	**Ø'**
Combined	León *et al.* (Cuba shelf)	184.77	0.2	0.43	3.88
	Estimated	185.19	0.3	0.31	4.01
Male	León *et al.*	185	0.23	0.44	3.88
	Estimated	185.01	0.3	0.34	4.01
Female	León *et al.*	153.46	0.192	0.38	3.66
	Estimated	156.88	0.187	0.19	3.66

The growth parameters (K, L∞ and t0) for males, females and for the sexes combined were found using the converted length frequency data from the spiny lobster fishing industry. The values of the growth parameter showed that there aren't significant differences between males and combined sex for the infinite length and K for female with the parameter estimated by León *et al.* (1995).

Figure 3 shows the score grid and the fitted growth curve. The score grid shows that the maximum score was identified at the border of the K range. When the K range was increased the score grid was deformed and the L∞ and K value relationship was distorted. According to the manual of LFDA5, the best fit of L∞ and K are to be found in a banana-shape region going downwards. This was not the case here. Also the VBGF fit by the SLCA method applied show that not all the length frequency distributions were used by the software in the fitting process (Figure 3 B). It is also important to point out that the fitted curve also shows that most of the cohorts just disappear from the catch of the following year.

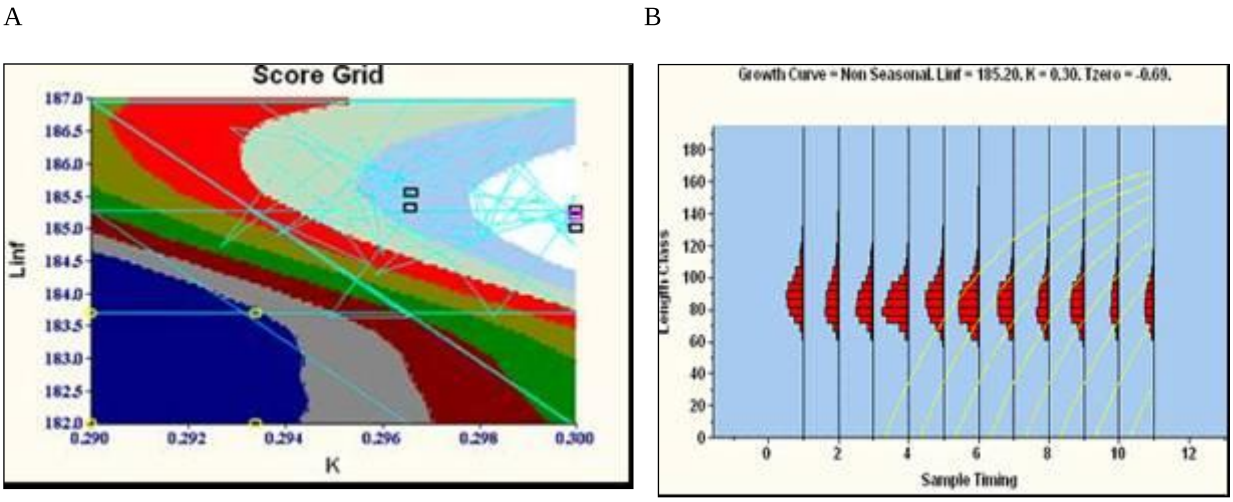

Figure 3: The score function grid (A) showing the best fit of L∞ and K with the maximum score estimated at the edge in the white area and the fitted growth curves using VBGF (B) for length frequency distribution during the period 1994-2004 represented with numbers 1 to 11 as sample timings (LFDA 5, Kirkwood 2001).

4.2 ADAPT VPA

4.2.1 ADAPT VPA (Method I)

Catch per unit of effort was used as an index of abundance in the ADAPT VPA computations to estimate the terminal F and the selection pattern. This method assumes a catch at age matrix known without error.

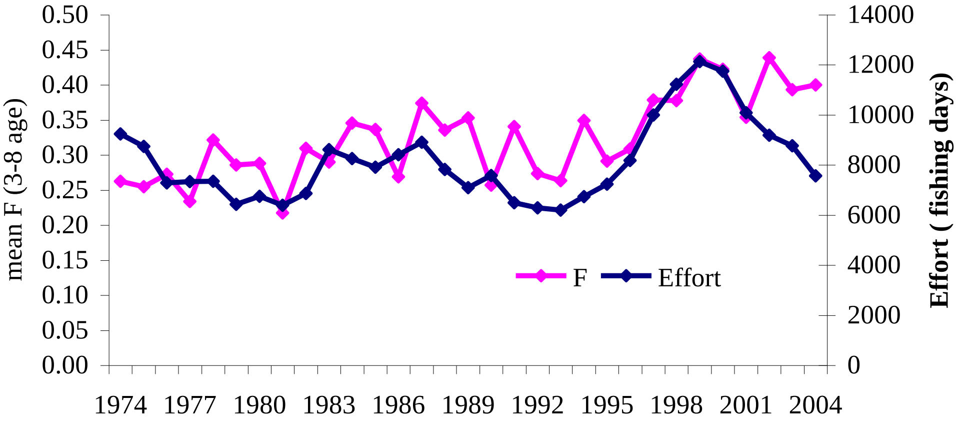

Figure 4: Trend in fishing mortality rates (mean Fper ages 3-8) and effort (fishing days) from 1974 to 2004.

The trends in effort and fishing mortality as estimated from the model are plotted in Figure 4. The average of the fishing mortality for age groups 3 to 8 showed a slight increase between 1980 and 1996 while effort seemed stable or slowly decreasing. Then after 1996 effort increased rapidly and so did F. This peaked in 1999. After 1999 effort has decreased rapidly but not F, which seems to be at its highest levels since 1974.

Figure 5 show exploitation rates after over 50% at 1997 and a high exploitation rate is related with an increase in effort from 1997 to 2000, after this the effort decreased but the exploitation rate remained high.

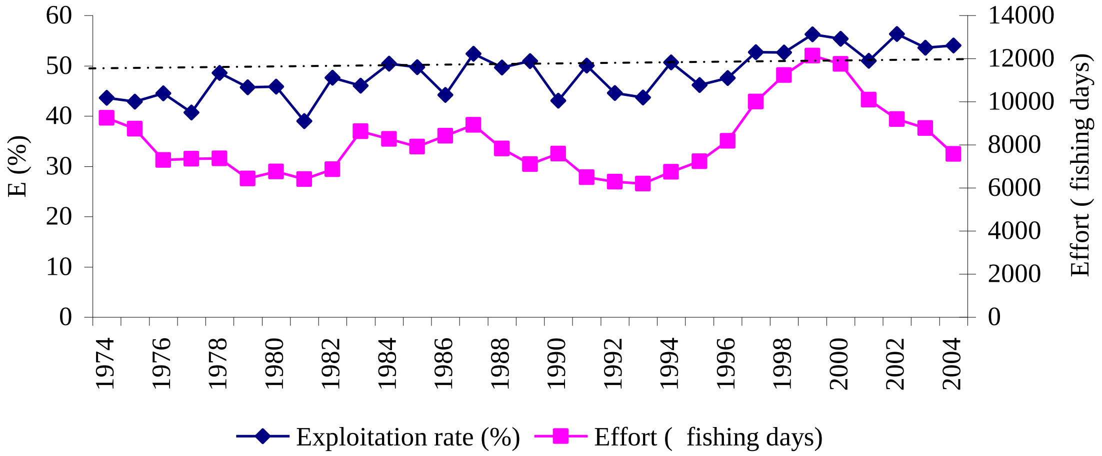

Figure 5: Trends of exploitation rate (F/Z) estimated with fishing mortality per year by ADAPT VPA (Method I) and effort from 1974 to 2004. The dotted line represents 50% of the exploitation rate.

The terminal selection pattern was assumed to be the average of the years from 1996 to 2002 and the terminal F was estimated by minimising the difference between observed and estimated CPUE of age groups 3 to 8. The reference fishing mortality of age groups 3 to 8 years old was estimated to be 0.4.

In Figure 6 the behaviour of the selection pattern is represented. The selection goes up to a value of 0.36 for age 2 and it reaches its highest value at age 4 and later it goes down to 0.6 for age 6. The main age groups in the lobster catch in this zone are ages 2 to 8.

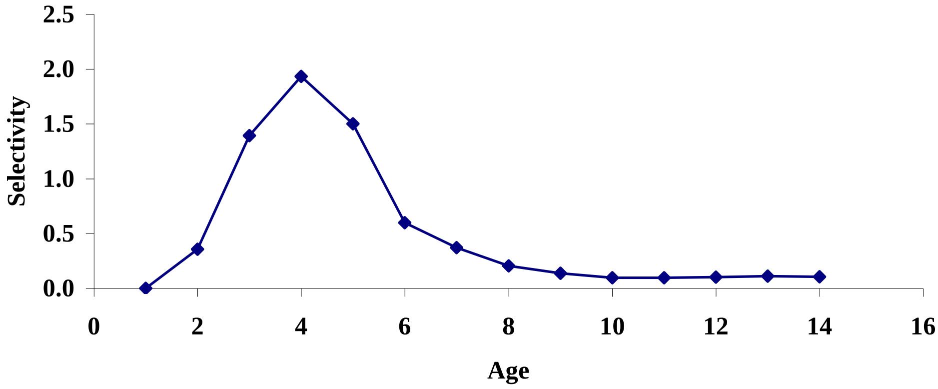

Figure 6: Selectivity (F/Fbar3-8) by age in the northeastern Cuban shelf spiny lobster fishery.

The relationship between CPUE and the stock in number for each age was estimated and is presented in Appendix 9. For ages 3 to 7 the R^2 had values greater or equal to 0.5 ($R^2>0.5$) indicating that the fit for those ages was good and the rest of the age groups had coefficient values less than 0.3.

Figure 7 the logarithmic the indices of abundance CPUE observed for age groups 3 to 8 was related with predicted values of CPUE.

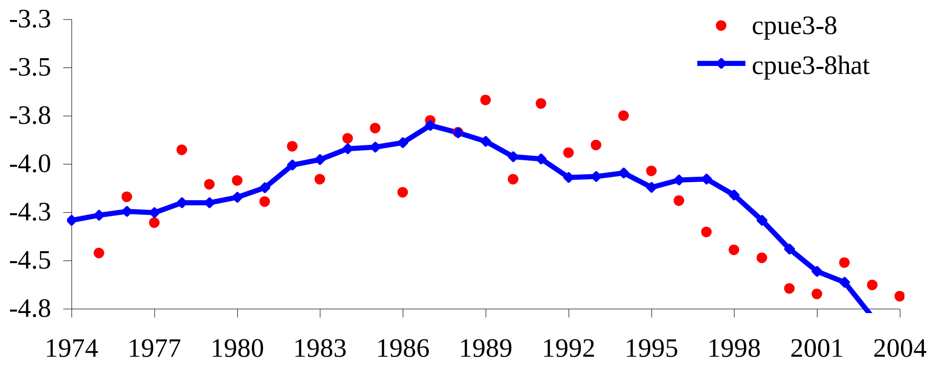

Figure 7: Relationship between the abundance indices of CPUE observed and predicted for age groups 3 to 8 from 19974 to 2004.

The Appendix shows the stock size in number obtained for ADAPT VPA. The values for the recruitment, taken as the stock size in numbers for the age 1 group, are represented in Figure 8. The recruitment patterns show the highest peaks were observed in 1985 and 1995. For 2004 the recruitment has decreased by 729 thousand compared to 2003 and recruitment is at a historically low level.

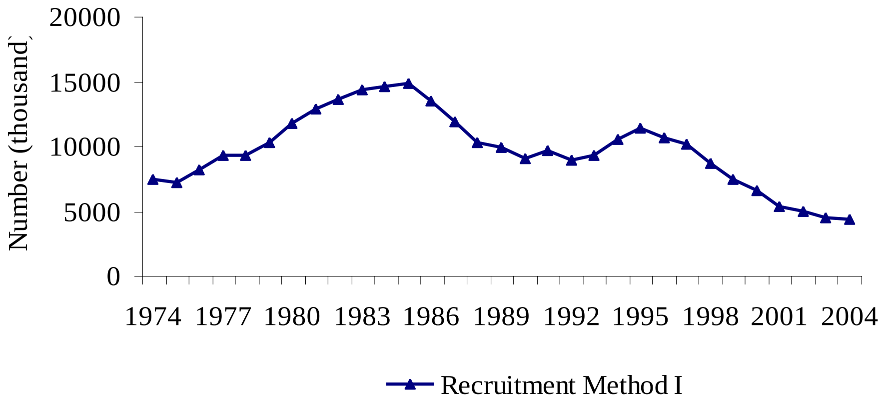

Figure 8: Trend of recruitment of spiny lobster at age 1 estimated from 1974 to 2004 in the northeastern Cuban shelf.

4.2.2 ADAPT VPA methodology used in Cuba (Method II)

The results described above were similar to those, which are currently used in CUBA for the northeast zone. The terminal fishing mortality was 0.4. An index of the "goodness of fit "shows a high coefficient of determination ($r^2=0.66$, $p<0.05$) between fishing mortality rate and effort for the period 1974 to 2004 (Figure 9). The equation describing the relationship between both variables can be represented as: $F = q*f$, where $q = 0.0000549$ per fishing day is the average catchability coefficient.

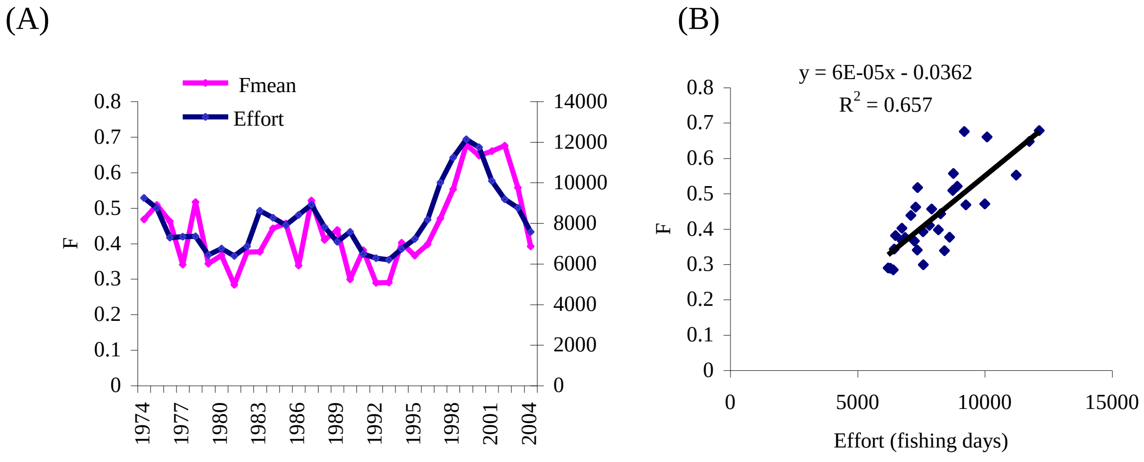

Figure 9: Changes in fishing mortality rate and effort from 1974 to 2004 (A) and the correlation between mean fishing mortality (all age groups) and effort for the same period (B).

Figure 9a shows the highest values of fishing mortality from 1998 to 2002 related with high effort, although the effort after 2001 began to decrease. The fishing mortality from 2003 to 2004 decreased with values in the last year similar to 1994 and 1996, which is a good relationship with the effort for these levels.

The trends of exploitation rates and effort in Figure 10 show that the exploitation rate was maintained for the northeast Cuban shelf with values over or equal to 50%, only from 1990 to 1993, these values were less or near to 50%. After 1997 this rate increased to over 50% until 2003 and then began to decrease. The highest values of exploitation rate are related with an increase in effort from 1997 to 2000, after this the effort decreases but the exploitation rate is still above 50%.

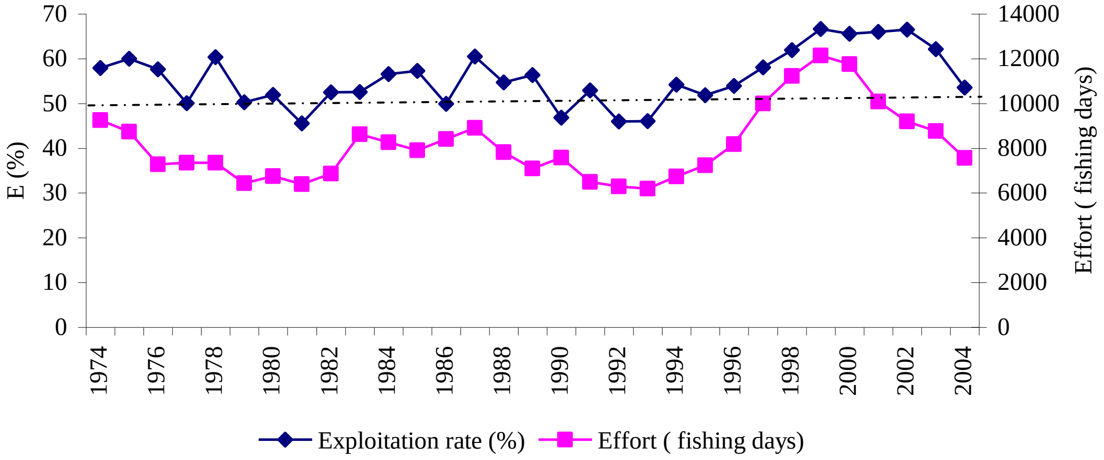

Figure 10: Trends of exploitation rate (F/Z) estimated with fishing mortality per year by ADAPT VPA (Method II) from 1974 to 2004. The dotted line represents 50% of the exploitation rate.

The selection pattern estimated (Figure 11) shows an asymmetric and bell-shaped curve. The main age groups in the catch are 4 and 5.

Figure 11: Selectivity by age in the northeastern Cuban shelf spiny lobster fishery estimated by ADAPT VPA (Method II).

In Appendix 8 the stock size in number obtained for this method is represented. The values for the recruitment, taken as the stock size in numbers for the age 1 group, are represented in Figure 12. The trend of recruitment shows the highest peaks were observed in 1985 and 1995.

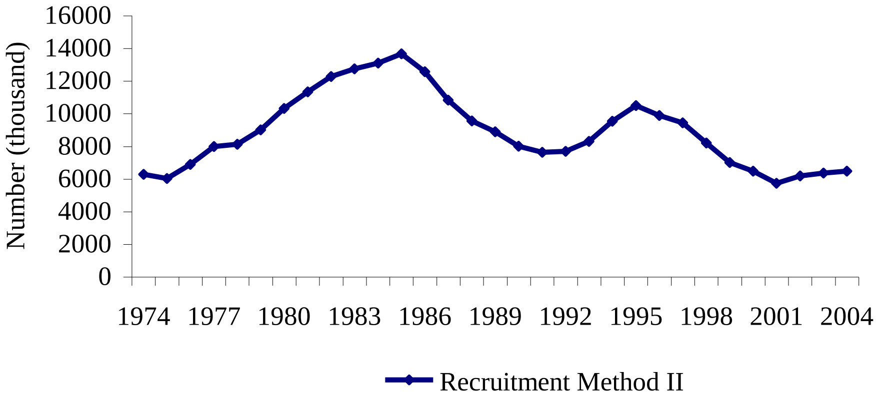

Figure 12: Trend of recruitment of spiny lobster at age 1 estimated from ADAPT VPA (Method II) from 1974 to 2004.

The Spawning Stock Biomass estimated by ADAPT VPA developed in Cuba (Figure 13) shows the highest value in 1987 with 2,373 t and a decreasing trend after that. The lowest values of SSB were estimated from 1999 to 2004 when the fishing mortality was at a historical high.

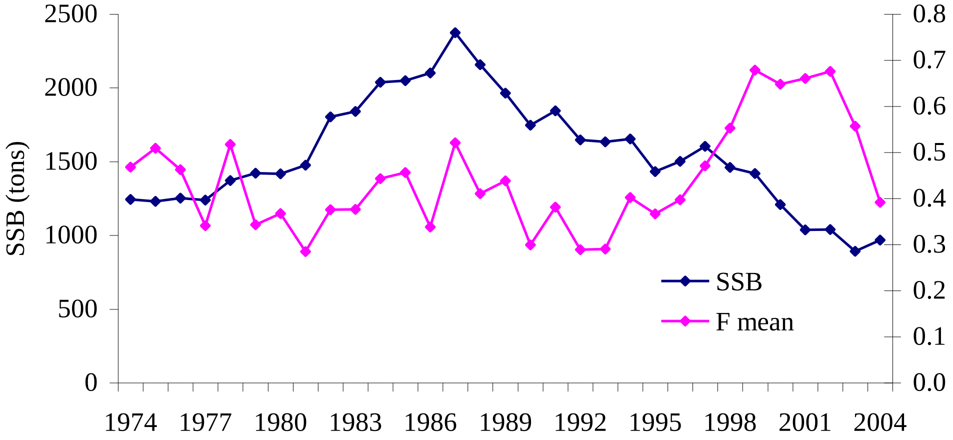

Figure 13: Spawning Stock Biomass (SSB) and mean fishing mortality from ADAPT VPA Method II from 1974 to 2004.

4.3 Yield per recruit and spawning stock biomass per recruit

The yield per recruit and the spawning stock biomass per recruit were calculated; using the assumption made in the catch at age approach for the selection pattern and proportion mature and mean weight at age, respectively.

The values obtained for $F_{0.1}$ and F_{max} and the slope is shown in Appendix 11. 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 (Hilborn and Walter 1992). F_{max} represents the value of the fishing mortality, which corresponds with the maximum yield (Figure 14).

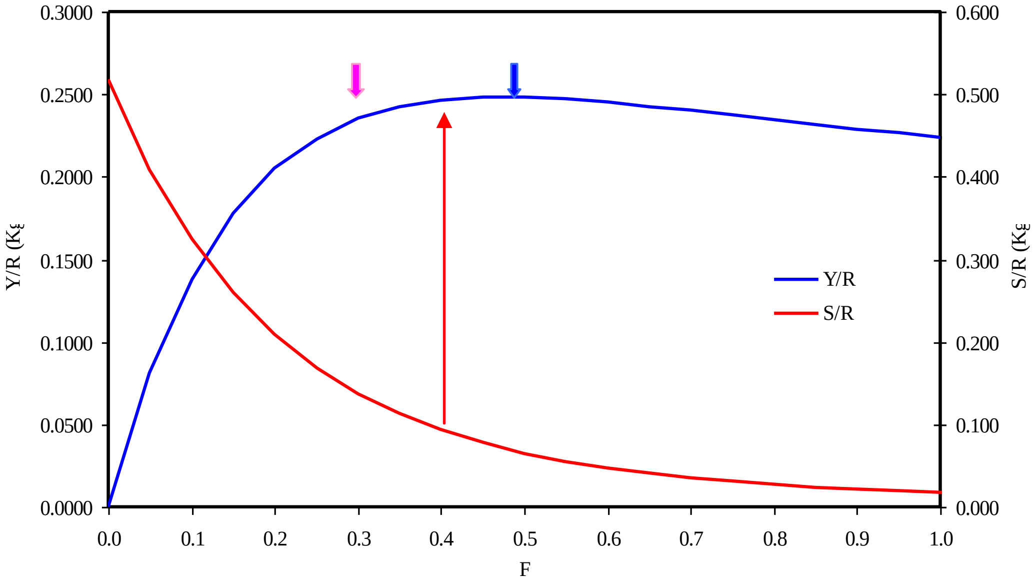

Figure 14: Reference points the fishing mortality in the curve of yield per recruit (Y/R).

The fishing mortality rate, at which we operated in 2004, 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).

4.4 Predictions of yield in the following year

The Ricker stock-recruitment fit (Figure 15) was plotted. The number of recruits ranged from 5,731 lobsters at age 1 in 2001 to a maximum value of 13,674 in 1985. The SSB value was between 348 and 915. The Ricker stock-recruitment fit produces a curve that suggests a density-dependence effect between adults and juveniles. The maximum number of recruits is determined by the total fecundity of the parent.

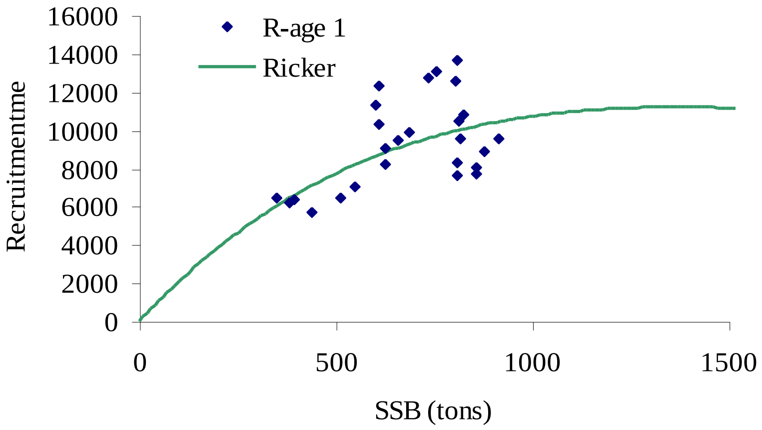

Figure 15: The fit of the Ricker stock-recruitment relationship with Spawning Stock Biomass for *P. argus* in the northeast of the Cuban shelf.

The trend of the fishable biomass from 1974 to 2004 shows a maximum in 1987 at 7870 t (Figure 16). There is a decreasing trend observed since then, when it has decreased to about 3,000 t or by more than 50% in 2004. The Spawning Stock Biomass has also shown fluctuations over the study period from 1974-2004. The maximum value was observed in 1987 at 915 t and the minimum at 348 t in 2003. There is a general decreasing trend observed in SSB over the last 10 years.

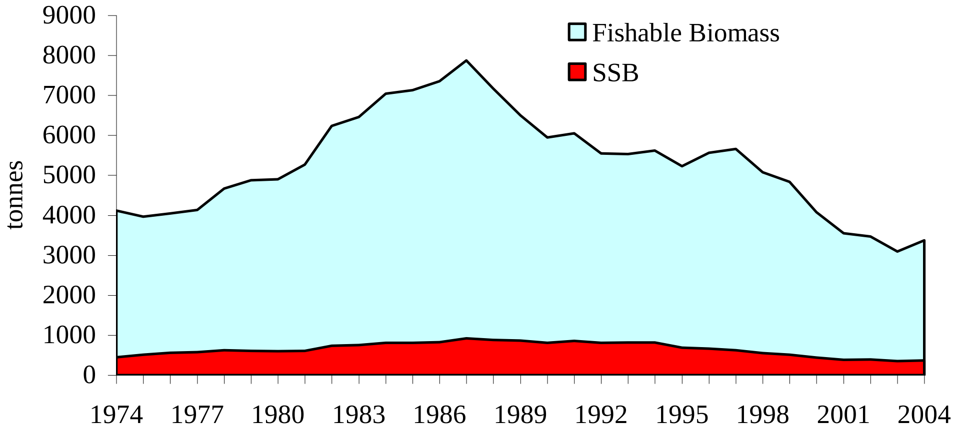

Figure 16: Spawning Stock Biomass and Fishable Biomass for spiny lobster in northeast of Cuban shelf.

The yield curve estimated from the Ricker stock-recruitment relationship (Figure 17) shows the maximum yield at 2,708 t predicted with the fishing mortality at F 0.1. The current fishing mortality (2004) was estimated using ADAPT VPA at 0.4. The $F_{0.1}$ is located further the current fishing mortality and it intercepts the curve at the point to give the maximum yield of 2,570 t.

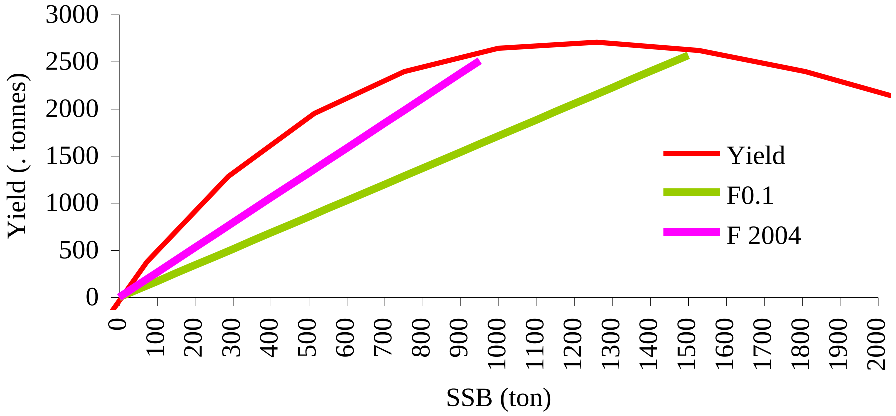

Figure 17: Curve of the yield prediction from the Ricker stock-recruitment relationship for *P. argus* with fishing mortality $F_{0.1}$ and the F_{2004} estimated by ADAPT VPA.

The forward projection was made for the years 2005 and 2006. The yield in tonnes was computed for these years with different scenarios, which were essentially the fishing mortality rates represented as $F_{0.1}$, and F_{max}. Table 3 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 have with each strategy. The prediction for 2006 is assuming the fishing mortality is at 0.3 or 0.4, for 2005.

Table 3: Yield and spawning stock biomass (SSB), corresponding to the prediction for 2005 and 2006 for different fishing mortality rates.

Actual year		**Yield 2004 (t)**	**SSB 2004 (t)**	**2005**			
Fterm	**0.40**	**658.00**	**372.00**	**F=0.3**		**F= 0.4**	
Prediction		**Yield 2005**	**SSB 2005**	**Yield 2006**	**SSB 2006**	**Yield 2006**	**SSB 2006**
	0.00	0	702	0	928	0	856
	0.10	277	644	317	854	297	788
	0.20	491	591	562	786	527	725
F 0.1	**0.30**	**654**	**543**	**748**	**723**	702	667
Fterm	0.40	776	409	888	665	833	614
Fmax	0.50	864	458	988	613	928	565
	0.60	924	421	1058	564	994	521
	0.70	963	387	1102	520	1037	480
	0.80	985	356	1126	479	1060	442
	0.90	993	328	1135	442	1069	408
	1.00	990	301	1131	407	1066	376

When utilising the value of the fishing mortality rate $F_{0.1}$ for the calculation of the yield in the year 2005, considering the recruitment in this year, we obtain a yield with, 654 t, a catch similar to that in 2004 but the spawning stock biomass increases by 171 t. This also represents an increase in the yield and spawning stock biomass for 2006 for the fishing mortality rate from F0.3 to 0.6 without affecting the increase of SSB, maintaining higher values than in 2004.

An increase in the yield is predicted for 2005 if the fishing mortality is maintained at 0.4, but with the cost of reducing the spawning stock biomass by 44 t. This also affects the yield and SSB in 2006 for $F_{0.3}$, is 46 t less and for $F_{0.4}$, 55 t less in the catch compared with $F_{0.3}$ in 2005. On the other hand, if we apply the F_{max} equivalent to 0.5, then a higher yield is obtained but with higher effort and lower spawning biomass.

5 DISCUSSION

5.1 Analysing different assumptions on growth

Estimating growth parameters for spiny lobster (*Panulirus argus*) on the northeastern Cuban shelf did not yield credible results using the length frequency data from the fishing industry with the LFDA5 programme which implements the SLCA method (Shepherd 1987). In the grid search the maximum score was identified at the border of the K range. There was no distinctive banana shape in the L∞ and K parameter space surface as there should be. Furthermore the results from LFDA indicate that most cohorts disappear from the exploitable part of the stock after just one year.

The results obtained by the SLCA method were disappointing mainly because the data used to find if there was considerable cohort/yearly variation in growth parameters for this area was aggregated length distribution over total year. That is, the data was not aggregated into monthly or seasonal intervals. However the results do not differ much from the results obtained by León *et al.* (1995) for females and for L∞ for males with data of length frequency from biological sampling in the fishery area.

The catch at age was estimated for the last two years with the slicing technique of Sparre and Venema utilised in Cuba for lobster. The same values of catch at age were found.

5.2 ADAPT VPA

Two methods of ADAPT VPA use catches in number at age combined with tuning indices to obtain stock size in number at age. The abundance index used was CPUE in both methods. The Adaptive (ADAPT) Framework VPA is based on minimising the sum of squares over any number of abundance indexes to find best fit parameters. The difference between the two methods is that the first method uses the selection pattern terminal average from age groups 3 to 8 in 1996 to 2002 while in the second method that is used in Cuba, the stock at age is computed using Pope's approximation from the matrix of catch at age for age groups 1 to 9+. In this methodology an operation patron related with age 8 is added and the input parameter for solver is F oldest and the fishing mortality for age 8 is the last year.

These two methods assume a well-known catch at age matrix, without errors, and they are tuned with some sort of abundance or effort data. There are differences between the two methods in the trend of fishing mortality mainly from 1998 to 2003. The highest values of fishing mortality were observed in Method II from 1999 to 2002 (Figure 18). In those years there was a decrease in effort, but similar fishing mortality was maintained until the last two years when it decreased. Fishing effort remained at low levels from 1979 to 1982 maybe because since 1979 the closed season was extended to 90 days and the minimum legal landing size (69 mm of length carapace (Lc)) was strictly enforced (Puga *et al.* 2005).

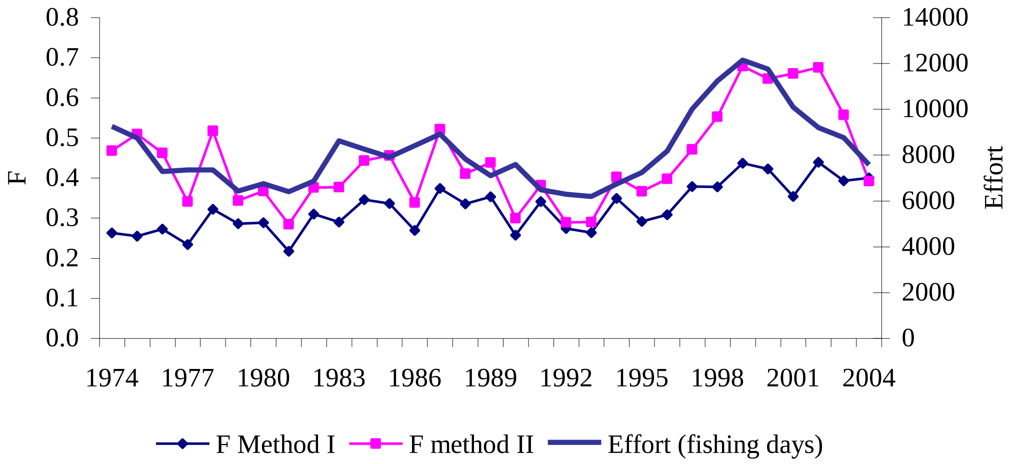

Figure 18: Trends in fishing mortality between 1974 and 2004 using two methods of ADAPT VPA and changes in effort.

The trends in exploitation rate for both methods (Figure 19) were quite similar after 1990. The exploitation rates were maintained over 50% after the decrease in effort in 2001. The trend in exploitation rate in Method II was similar to the estimates obtained by Puga *et al.* (2005) for southwest of the Cuban shelf. It was high and over 50% of the exploitation rate between 1974 and 1978 when the closed season was reduced to 45 days and large quantities of undersized individuals were landed causing a growth in overfishing during this period (Baisre and Cruz 1994) but the trends in effort and exploitation rates are different to those observed by Puga *et al.* (2005) the fishing effort and exploitation rate for the northeast of the Cuban shelf reached high values after 1998. Fishing effort and therefore exploitation rate remain at low levels from 1991 to 1994 because of the high cost of running of the fishing fleet due to bad conditions in the Cuban economy.

The fishing mortality estimated for both methods of ADAPT VPA was 0.4 for the northeast of the Cuban shelf. This fishing mortality is higher than that obtained for the southwest of the Cuban shelf, which was 0.3 (Puga *et al.* 2005). The fishing mortality in the southwest showed a certain stability in the last eight years and in northeastern area an increase was observed in the same period (Puga and León 2002). The higher fishing mortality rates in the northeast may be explained by the predominant use of traps (jaulones) located next to artificial shelters (pesqueros) and when is compared with other zones the jaulones are used in the second fishery season. Also Puga *et al.* (1996) found that *jaulón* catchability was 2.3 times the *pesqueros* catchability.

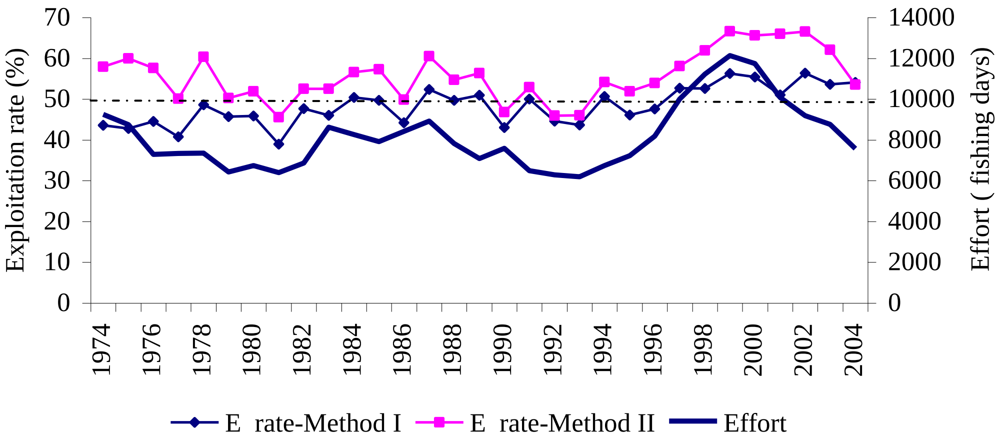

Figure 19: Trends of exploitation rates (F/Z) estimated for both methods and related to effort from 1974 to 2004. The dotted line represents 50% of the exploitation rate.

The selection pattern was not S-shaped, where the last ages are completely recruited to the fishing gear. On the contrary, the selection pattern according to both methods of ADAPT VPA was a bell-shaped curve but the main difference between the methods was that for Method I the selection curve was symmetric but that was not the case for Method II. The main age groups in the lobster catch from the northeast Cuban shelf are mainly ages 3 to 6. The top of the selection curve was around age groups 4 and 5 according to both Methods.

The results from the second method of ADAPT VPA was comparable to the estimates obtained by Puga *et al.* (1996) who described an asymmetric and bell-shaped curve for the selectivity for the same species in southwestern Cuban waters. The authors state that for the bigger lobsters the probabilities of capture decrease 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. It can be explained when considering that the lobster needs at least three times its height for populating a refugee and be vulnerable to the fishing gear, and in most of the aggregating devices, the space between the up and down frames is only 10 cm. In addition, as they growth bigger, the oldest individuals migrate to the end of the shelf and thus they are no longer available to the fishery.

The bell-shaped selectivity curve agrees with the one obtained by Miller (1990) for the gear trap used in the capture of crustaceans. Also the results obtained by Morgan (1979) for *Panulirus cygnus* in west Australia, who reported a twice or three times higher vulnerability for lobsters with a carapace length between 76 mm and 85 mm than for those bigger than 85 mm. FAO/WECFCA (2003) reveals that populations of *P. argus* exploited in the waters south of Saint Lucia comprised a high proportion of small lobsters, 90-110 mm CL size class. This may be a result of selectivity of the gear, however, it may also be due to high exploitation levels; the majority of larger individuals have been removed from the population and the fishery is basically dependent on individuals of these size classes. Puga *et al.* (1996) found a difference between catch composition at age with different gears. They found more lobster in age groups 3 and 4 in the *pesqueros* and age groups 4 and 5 in the *jaulones* in the second fishery season.

The recruitment patterns shown by the two methods investigated show similar trends. The highest recruitments peaks were observed in 1985 and 1995 (Figure 20). However, Method II shows a lower recruitment value as compared to Method I over the period 1974-1996. For the last three years the recruitment for the Method II is higher than Method I.

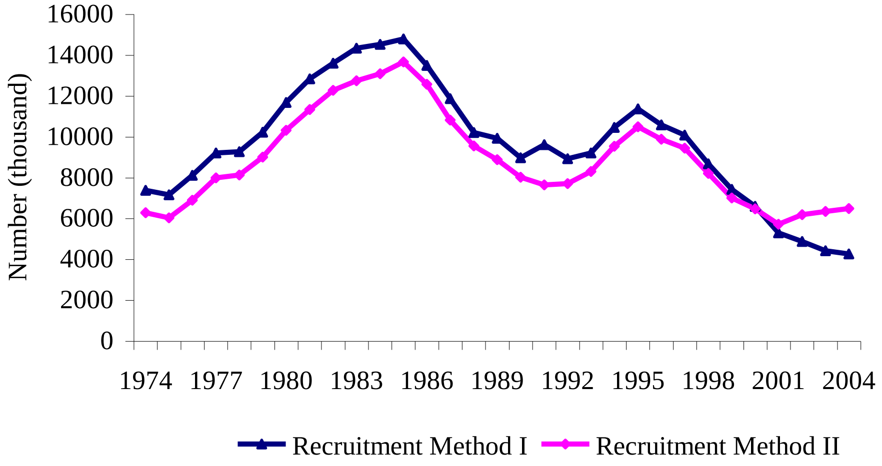

Figure 20: Trends of recruitment of spiny lobster at age 1 estimated for both methods of ADAPT VPA.

Similar trends in recruitment as estimated here for this zone were obtained by Puga and León (2002) in the evaluation of recruitment in the north and south of the Cuban shelf from 1974 to 2001.

The decrease in recruitment began after 1986, which maybe explained by the high catch levels of 1984 and 1985, which was maintained until 1988 with a mean catch from 1984 to 1988 of 2132 t. The general trend since 1986 for recruitment is to decrease. The recruitment has not reached similar levels as the maximum in 1985. The trend of the spawning stock to decrease affects the number of recruits for the next year. The general recruitment trend was affected by high levels of catch in the period 1984 to 1988 and also is related with the decreasing trend of the spawning stock curve from 1988. Fishing along with bad ambient conditions can influence recruitment, normally to decrease it. For example the hurricanes can produce changes in habitat and increases mortality experienced by juveniles (Baisre and Cruz 1994)

There is a good correlation between stock numbers of lobster by age and the abundance indices of CPUE for age groups 3 to 7 in both methods, but as shown in Figure 21, for age groups 5 to 7, the relationship in Method II the R^2 were higher than Method I (Appendix 10).

Figure 21: Relation between the stock numbers of lobster estimated (N) and CPUE abundance indices for age groups 3 to 7 with a good relation for both methodologies of ADAPT VPA (Method I) ADAPT VPA and (Method II).

5.3 Yield per recruit and spawning stock biomass per recruit

Fisheries literature is dotted with different fishing targets or references points. Hilborn and Walter (1992) considered the introduction of the $F_{0.1}$ strategy to be remarkable; regarded as a conservative level of exploitation, which allows for economic viability and a buffer against recruitment overfishing. $F_{0.1}$ policies may be one of the most significant changes in fisheries harvesting practices since the early widespread acceptance of MSY (Haddon 2001).

Yield per recruit analysis is useful in the determination of the $F_{0.1}$ and F_{max}. In this analysis $F_{0.1}$ is lower than the fishing mortality rate currently applied in the fishery, but at the same time lower than F_{max}. In addition the actual fishing mortality is lower than the one corresponding to maximum sustainable 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 sustainable yield is that it is very easy to exceed it, which would result in overfishing. MSY is the largest annual catch that may be taken from a stock continuously without affecting the catch of future years; a constant long-term MSY is not a reality in most fisheries, where stock sizes vary with the strength of year classes moving through the fishery (King 1995).

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.

Another reference point for *Panulirus argus* has been used (Puga *et al.* 2005) in an equilibrium version of the model which estimated a number of bioeconomic reference points, such as the fishing effort. For the maximum sustainable yield per recruit, or the maximum economic yield per recruit. Sissenwine and Shepherd (1987) proposed that F_{med} could be used as a biological reference point for defining recruitment overfishing. More recently, F_{med} has been considered as a limit reference point since at F levels higher than F_{med} stock can be expected to decline (Caddy and Mahon 1995).

5.4 Predictions of the yield in the following year

In terms of predictions of future catch levels it is important to note that spawning stock biomass was estimated with the proportion of berried females, as opposed to mature lobster, in the fishery zone. Furthermore, the stock of large mature lobster, which carries a greater number of eggs, lives outside the fishing area and therefore the size of SSB is almost unknown.

Various mechanisms could in theory lead to different interpretations of the parameters of the Ricker curve (Haddon 2001). Mechanisms have been suggested for generating this form of density-dependence (dependent upon total stock size and not just the cohort size). These include cannibalism of the juveniles by adults (hence stock density is more important than cohort density), damage by spawning adults of each others spawning sites, and finally, there could be density-dependent growth combined with size-dependent predation.

It is a matter of high priority to investigate the role of density-dependent and density-independent effects on the variations of recruitment in Cuban spiny lobster stock. It is necessary to find better a relation of recruitment with SSB because dependence is estimated with the spawning stock in a fishery area without considering the potential of spawning stock outside of shelf line. Density dependence could result from the feeding rate being reduced by the presence of other members of the same population and also from movements due to habitat limiting both in quantity and quality (Rose *et al*. 2001). In Australia, Morgan *et al.* (1982) described a stock–recruitment relationship for *Panulirus cygnus* and believed that after settlement, density dependent relationships dominated. More recent studies (Caputi *et al.* 2001) have shown that environmental conditions could be the factor controlling the level of puerulus settlement. Ehrhardt and Sobreira (2003) reported a density-dependent relationship between recruitment success and parent stock abundance of *P. argus* in northeastern Brazil. They concluded that the significance of environmental signals on recruitment is large, and the overall stock abundance trends are fundamentally governed by recruitment changes.

The Ricker model of stock-recruitment differs from that by Beverton-Holt in that the density-dependent mortality term for eggs and juvenile stages relates to the total stock size and not only to the cohort size. The Ricker equation does not attain an asymptote but instead exhibits a decline in recruitment levels at higher stock levels (Haddon 2001).

The S-R relationship estimated for the northeast in this study and another for *Panulirus argus* in the southeast (Pérez *et al.* 1978) and southwest of the Cuban shelf (Puga *et al.* 2005) have been described better with the Ricker equation than the Beverton-Holt equation. These results were different to those obtained by Cobb and Caddy (1989). They said that the asymptotic nature of the relationship might explain the stability of the lobster stock as well as its resilience to continued high exploitation rates and that relatively high levels of fishing mortality might be sustained without observing a decrease in recruitment

A simple equilibrium yield analysis suggests that the current level of fishing mortality is close to the fishing level that produces maximum sustainable yield (2,708 t), but this strategy could affect the SSB. In contrast fishing in accordance with the $F_{0.1}$ strategy results in relatively high values of yield (2,570 t) are obtained without depleting the SSB.

There is great variation in the SSB-R relationship and it is not likely that these predictions will materialise straight away. As seen in Table 3 the projection considering the $F_{0.1}$ for 2005 gives a lower yield, with values similar to 2004 but higher spawning stock biomass with less effort. The value for the fishing mortality equal to 10% of the slope of the yield per recruit can produce a yield of 654 t in the year 2005 and with a spawning stock biomass of 543 t of individuals. Nevertheless the actual spawning stock biomass is calculated as 372 t with an F equal to 0.4 and yield of 658 t.

The yield that we would obtain with the F_{max} a value of 864 t would arise with a spawning stock biomass of 458 t. Theoretically this yield is sustainable, and we can fish there without over fishing the stock, but then we have to assume a recruitment success, which is not biologically reasonable as it can be variable between years.

Taking into consideration the results given, it is possible to keep fishing the stock of lobster in 2005 at the actual fishing mortality rate of 0.4. This would give some increment in the yield, but a decrease in the spawning stock biomass will be observed, resulting in a decrease in the number of eggs produced. This will lead to a decrease in the number of future recruits (Table 3), as compared to the fishing mortality 0.3 in 2005. Also with the projection for 2006 the yield and SSB are going to be lesser than yield and SSB estimated for 2006 if the fishing mortality rate for 2005 is 0.3.

6 CONCLUSIONS AND RECOMMENDATIONS

This report has been dealing with the assessment of the population of the spiny lobster, which lives in the northeastern shelf of the Cuban waters. The assessment has been made to estimate variation in the growth parameters of this population with data on length frequency from the fishing industry. Similar results were obtained for each of the methods used. The first conclusion obtained was that the converted length frequency data from the fishing industry with aggregated length distribution over total year aren't useful to estimate the von Bertalanffy growth parameters and that for different methods of ADAPT VPA taking different assumptions, and using the same data set for the analysis, the results were almost similar between the methods. The exploitation rate maintained high levels after 1998 and over 50% after the effort decrease in 2001 and the fishing mortality rate was 0.4. The age groups in the lobster catch in this zone are ages 3 to 6 with the highest values for age groups 4 and 5. The general trend of the recruitment is to decrease. The recruitment has not recuperated to the maximum level in 1987. The general recruitment trend is related with the decreasing trend of the Spawning Stock curve. In the projection for 2005 and 2006 is to better use strategy $F_{0.1}$ with a fishing mortality rate of 0.3 to get higher values of SSB in 2005 without decreasing the catch (similar to 2004) and yield and SSB for 2006.

For future works it is necessary to estimate the growth parameters in this zone with biological sampling data and from the convert length frequency of the fishery industry with data by month to compare and to find possible changes in the growth parameters. Is also of great importance to implement biological sampling data in the nursery area to estimate the juvenile abundance index to use together with the recruitment index in the fishery area to support the catch prediction.

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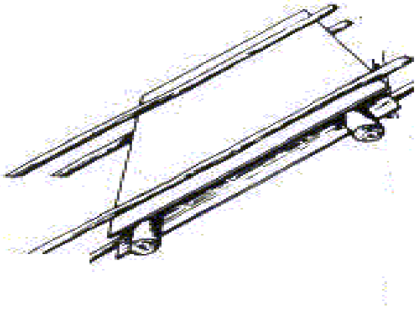
APPENDICES

Appendix 1: Some characteristic of vessel and gathering house in the Cuban's lobster fishery to keep live lobster until to they can be transported to the industries inland

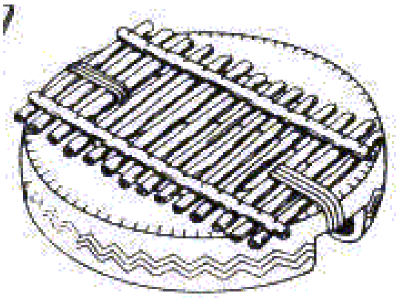
A. Fishpond in the hull of lobster fishing vessel to keep the lobsters inside alive and properly oxygenated the whole way from the fishing grounds until the gathering house.

B. Gathering house with big cages submerged in the water where the lobsters are maintained until they can be transported to the industries inland.

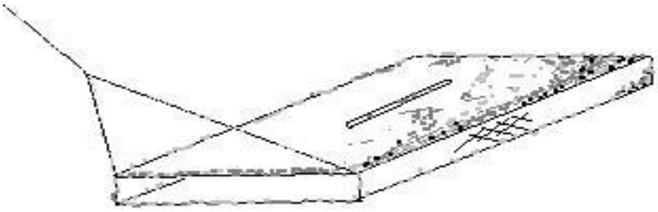
Appendix 2: Fishing gears used in lobster fishery



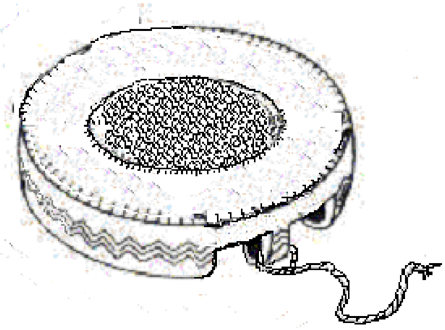
A. Artificial shelters (pesqueros)



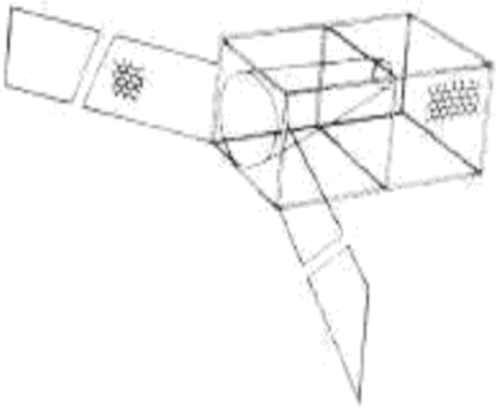
B. Artificial shelters (pesqueros) with used car tires



C. Artificial shelter .” Pesquero levable” levable “ levable”levable.



D. “Pesquero levable” with used car tires



E. Trap joined with net or “jaulón”

Appendix 3: Series of length frequency distribution for male

CL(mm)	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
47.5	32.21	14.01	8.95	8.51	6.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52.5	47.33	18.57	11.82	11.39	9.86	0.76	0.56	0.76	1.23	1.08	1.19	0.83	0.85	0.92	0.99	0.76
57.5	76.84	32.45	22.15	18.26	22.93	4.22	2.60	3.97	6.01	5.26	6.06	5.51	3.92	4.92	5.81	4.52
62.5	113.66	49.92	35.23	26.90	39.57	29.62	17.33	25.95	38.59	33.85	40.60	43.51	25.77	37.61	44.26	33.59
67.5	120.60	52.04	42.90	33.63	44.13	59.49	42.97	52.34	81.83	71.52	85.53	84.89	59.71	89.54	94.47	70.27
72.5	107.38	50.17	47.22	29.06	48.49	109.48	88.70	96.04	149.12	130.62	162.08	170.41	124.51	190.38	188.09	141.12
77.5	112.01	53.96	52.18	30.32	53.35	147.92	132.86	130.33	201.33	175.48	220.83	234.29	189.19	273.16	258.39	190.64
82.5	106.29	57.27	54.83	37.11	60.77	149.60	149.39	127.81	207.48	183.27	234.00	238.64	208.76	292.06	266.82	198.58
87.5	118.55	106.11	105.31	79.77	115.47	144.52	150.26	115.22	202.92	177.21	237.59	231.99	218.94	298.91	263.67	210.65
92.5	109.29	107.56	105.72	81.52	110.55	142.00	138.54	101.00	187.01	163.13	225.97	218.73	218.35	292.30	241.31	211.32
97.5	82.37	88.87	91.54	77.25	92.69	103.14	101.44	71.69	128.93	118.23	160.31	156.06	160.62	209.36	166.46	164.26
102.5	66.30	66.68	76.63	70.18	85.04	83.62	86.17	58.77	96.36	95.18	125.31	117.08	122.09	158.52	119.77	130.60
107.5	52.43	54.38	61.34	59.92	71.63	54.06	56.55	37.12	57.21	63.01	77.58	69.24	65.92	88.90	62.65	71.18
112.5	41.92	37.27	35.50	42.47	46.64	33.67	36.33	29.07	38.22	44.21	51.85	50.72	28.49	59.23	44.78	56.28
117.5	7.39	21.03	24.66	26.15	36.86	16.74	19.07	18.25	21.02	25.15	27.87	29.70	13.97	32.08	26.08	35.07
122.5	3.46	13.61	18.78	14.32	26.82	10.00	12.29	11.36	12.93	15.91	16.52	16.80	10.13	17.42	13.84	18.83
127.5	1.99	10.41	13.35	10.84	20.67	5.56	7.40	7.70	8.29	10.68	10.43	11.64	7.83	11.38	9.92	13.13
132.5	1.06	7.98	9.60	8.37	16.07	3.21	4.74	5.37	5.63	7.60	7.04	8.42	5.79	7.96	7.40	9.68
137.5	0.21	1.70	2.24	2.30	4.73	1.75	2.87	3.49	3.74	5.31	4.73	5.94	3.97	5.50	5.29	6.94
142.5	0.22	1.73	2.27	2.33	4.80	1.05	1.67	2.24	2.46	3.65	3.20	4.04	3.36	3.66	3.44	4.85
147.5	0.22	1.50	2.07	2.12	4.50	0.83	1.35	1.86	2.05	3.13	2.68	3.39	1.58	3.14	2.80	4.16
152.5	0.23	0.58	1.24	1.34	3.49	0.34	0.62	0.83	0.91	1.48	1.26	1.58	0.92	1.49	1.28	1.98
157.5	0.24	0.60	1.30	1.40	3.66	0.18	0.33	0.48	0.53	0.87	0.75	0.92	0.32	0.78	0.72	1.09
162.5	0.00	0.13	0.23	0.26	0.73	0.09	0.08	0.20	0.22	0.30	0.29	0.38	0.11	0.30	0.28	0.47
167.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.11	0.10	0.10	0.10	0.00	0.10	0.09	0.19
172.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
177.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 3: Series of length frequency distribution for male (cont.).

CL(mm)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
47.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.01	0.05	0.00	0.00
52.5	0.43	0.32	0.10	0.05	0.20	0.22	0.30	0.68	1.14	0.66	1.41	0.33	0.76	0.27	0.48
57.5	2.60	2.13	0.82	0.58	1.37	1.97	2.67	4.55	5.47	8.54	7.93	4.64	5.92	2.75	3.31
62.5	20.58	18.86	7.98	6.21	13.24	19.65	25.52	38.21	36.45	74.30	47.90	41.69	43.58	22.46	23.87
67.5	43.29	41.58	20.57	17.86	31.85	45.89	56.31	88.08	75.65	101.36	71.76	59.43	63.45	35.88	39.28
72.5	89.25	90.05	60.06	55.55	83.60	104.53	130.47	203.04	123.00	174.43	130.38	106.47	114.57	68.56	77.50
77.5	121.61	141.36	104.92	96.77	143.06	135.92	176.05	266.79	162.95	209.19	164.28	122.53	137.77	85.91	99.79
82.5	128.47	170.28	127.61	112.91	173.17	137.18	175.78	249.07	194.87	212.73	176.12	114.36	138.11	81.34	95.80
87.5	137.78	189.87	148.38	124.99	194.53	142.09	178.72	239.84	212.03	215.49	193.17	119.20	148.08	82.23	97.23
92.5	139.79	191.29	151.12	130.26	192.48	131.46	155.66	216.08	191.72	201.41	187.09	121.24	146.75	73.89	85.54
97.5	112.61	146.65	113.59	109.52	142.18	95.68	99.13	136.85	120.58	118.69	104.11	73.68	85.15	67.12	75.28
102.5	93.20	119.85	91.50	98.19	120.00	83.73	79.89	69.17	82.12	77.41	61.09	50.48	54.02	49.88	45.29
107.5	51.36	68.35	51.37	56.07	63.84	49.59	46.82	37.90	51.29	48.25	37.91	31.01	33.36	38.32	26.66
112.5	42.36	54.79	41.88	46.79	49.21	42.71	39.55	29.24	36.56	34.41	26.65	22.46	23.83	30.69	18.22
117.5	26.50	33.79	25.71	29.05	30.87	27.36	22.93	17.56	18.41	17.74	17.13	13.24	14.65	18.61	8.60
122.5	13.16	17.73	12.53	13.96	18.60	15.23	8.65	9.84	13.03	13.32	11.09	14.76	13.00	13.25	6.14
127.5	9.89	13.04	9.29	10.90	12.58	11.74	6.95	7.66	8.28	7.92	4.12	11.00	7.95	7.36	3.15
132.5	7.67	9.76	7.00	8.52	8.94	8.21	5.32	4.64	6.12	6.28	3.56	6.09	4.89	5.09	2.51
137.5	5.71	6.77	4.90	6.09	6.12	5.70	4.57	3.16	4.39	4.61	3.11	3.15	3.07	3.09	1.73
142.5	4.02	4.24	3.19	3.78	4.08	3.79	3.79	2.22	3.10	3.23	2.52	1.79	2.07	1.74	1.29
147.5	3.48	3.49	2.65	3.04	3.41	2.63	3.20	1.86	2.39	2.75	2.34	1.42	1.77	1.31	1.45
152.5	1.63	1.56	1.23	1.28	1.63	1.11	1.71	0.96	1.14	1.31	1.21	0.61	0.84	0.62	1.13
157.5	0.90	0.86	0.70	0.72	0.86	0.64	1.04	0.64	0.76	0.75	0.71	0.34	0.47	0.26	1.18
162.5	0.37	0.36	0.31	0.21	0.39	0.22	0.59	0.29	0.45	0.26	0.29	0.12	0.20	0.13	0.68
167.5	0.10	0.09	0.11	0.11	0.10	0.11	0.20	0.19	0.23	0.13	0.15	0.04	0.07	0.00	0.42
172.5	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.12	0.00	0.00	0.00	0.00	0.00	0.29
177.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15

Appendix 4: Series of length frequency distribution for female

Mean CL (mm)	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
47.5	31.08	13.52	8.64	8.21	6.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52.5	59.65	23.41	14.90	14.35	12.43	0.96	0.70	0.96	1.55	1.36	1.50	1.04	1.07	1.16	1.25	0.96
57.5	100.84	42.59	29.07	23.96	30.09	5.54	3.41	5.22	7.89	6.90	7.96	7.23	5.15	6.46	7.63	5.94
62.5	167.66	73.63	51.97	39.68	58.37	43.70	25.57	38.27	56.92	49.93	59.89	64.18	38.01	55.48	65.29	49.54
67.5	204.71	88.33	72.83	57.08	74.91	100.98	72.95	88.84	138.89	121.40	145.19	144.10	101.35	151.99	160.36	119.28
72.5	185.84	86.83	81.73	50.30	83.92	189.48	153.51	166.22	258.08	226.06	280.51	294.93	215.49	329.48	325.53	244.23
77.5	166.41	80.16	77.52	45.04	79.26	219.76	197.38	193.63	299.11	260.70	328.09	348.08	281.07	405.83	383.88	283.23
82.5	142.37	76.71	73.45	49.71	81.41	200.39	200.12	171.21	277.93	245.50	313.46	319.66	279.64	391.22	357.42	266.01
87.5	137.95	123.46	122.53	92.81	134.36	168.16	174.84	134.07	236.12	206.20	276.45	269.94	254.76	347.81	306.81	245.11
92.5	104.39	102.74	100.98	77.87	105.60	135.63	132.33	96.47	178.63	155.82	215.84	208.93	208.57	279.21	230.50	201.85
97.5	64.53	69.62	71.72	60.52	72.62	80.80	79.47	56.17	101.01	92.62	125.59	122.26	125.83	164.02	130.41	128.69
102.5	40.10	40.34	46.35	42.45	51.44	50.58	52.12	35.55	58.29	57.58	75.80	70.82	73.85	95.89	72.45	79.00
107.5	25.95	26.91	30.36	29.66	35.46	26.76	27.99	18.37	28.32	31.19	38.40	34.27	32.63	44.00	31.01	35.23
112.5	19.20	17.07	16.26	19.45	21.36	15.42	16.64	13.32	17.50	20.25	23.75	23.23	13.05	27.12	20.51	25.77
117.5	3.49	9.94	11.66	12.36	17.42	7.91	9.01	8.63	9.94	11.89	13.18	14.04	6.61	15.16	12.33	16.58
122.5	1.47	5.80	8.00	6.10	11.43	4.26	5.24	4.84	5.51	6.78	7.04	7.16	4.32	7.42	5.90	8.02
127.5	0.77	4.04	5.18	4.20	8.01	2.16	2.87	2.98	3.21	4.14	4.04	4.51	3.04	4.41	3.84	5.09
132.5	0.39	2.95	3.55	3.10	5.94	1.19	1.75	1.99	2.08	2.81	2.60	3.12	2.14	2.95	2.74	3.58
137.5	0.08	0.60	0.79	0.81	1.66	0.61	1.01	1.22	1.31	1.87	1.66	2.09	1.40	1.93	1.86	2.44
142.5	0.07	0.58	0.76	0.78	1.60	0.35	0.56	0.75	0.82	1.22	1.07	1.35	1.12	1.22	1.15	1.62
147.5	0.07	0.44	0.61	0.63	1.33	0.24	0.40	0.55	0.61	0.92	0.79	1.00	0.47	0.93	0.83	1.23
152.5	0.06	0.14	0.31	0.33	0.87	0.09	0.15	0.21	0.23	0.37	0.31	0.40	0.23	0.37	0.32	0.50
157.5	0.05	0.12	0.25	0.27	0.70	0.03	0.06	0.09	0.10	0.17	0.14	0.18	0.06	0.15	0.14	0.21
162.5	0.00	0.02	0.03	0.04	0.11	0.01	0.01	0.03	0.03	0.05	0.04	0.06	0.02	0.05	0.04	0.07
167.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.02
172.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
177.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4: Series of length frequency distribution for female (cont.)

CL (mm)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
47.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.01	0.05	0.00	0.00
52.5	0.54	0.40	0.13	0.07	0.25	0.28	0.38	0.86	1.44	0.83	1.78	0.42	0.96	0.35	0.61
57.5	3.41	2.80	1.07	0.77	1.80	2.58	3.50	5.97	7.18	11.20	10.40	6.10	7.77	3.60	4.35
62.5	30.35	27.82	11.78	9.16	19.52	28.98	37.64	56.37	53.77	109.61	70.66	61.50	64.28	33.13	35.21
67.5	73.48	70.58	34.92	30.32	54.07	77.89	95.58	149.52	128.42	172.06	121.81	100.88	107.70	60.90	66.68
72.5	154.47	155.86	103.94	96.13	144.69	180.91	225.81	351.39	212.87	301.89	225.66	184.28	198.28	118.65	134.13
77.5	180.67	210.02	155.88	143.77	212.54	201.94	261.56	396.36	242.10	310.78	244.06	182.03	204.68	127.63	148.25
82.5	172.09	228.09	170.94	151.24	231.96	183.76	235.47	333.64	261.04	284.97	235.92	153.19	185.01	108.96	128.33
87.5	160.31	220.93	172.65	145.43	226.35	165.33	207.96	279.08	246.71	250.74	224.76	138.70	172.30	95.68	113.14
92.5	133.53	182.72	144.35	124.42	183.86	125.57	148.68	206.40	183.13	192.39	178.71	115.80	140.17	70.58	81.70
97.5	88.22	114.89	88.99	85.80	111.39	74.96	77.66	107.21	94.46	92.98	81.56	57.72	66.71	52.58	58.98
102.5	56.38	72.50	55.35	59.39	72.59	50.65	48.33	41.84	49.67	46.83	36.96	30.53	32.68	30.17	27.39
107.5	25.42	33.83	25.43	27.75	31.60	24.55	23.18	18.76	25.39	23.88	18.77	15.35	16.51	18.97	13.20
112.5	19.40	25.09	19.18	21.43	22.54	19.56	18.11	13.39	16.75	15.76	12.20	10.29	10.91	14.06	8.35
117.5	12.53	15.97	12.15	13.73	14.59	12.93	10.84	8.30	8.70	8.39	8.10	6.26	6.93	8.80	4.06
122.5	5.61	7.56	5.34	5.95	7.92	6.49	3.69	4.19	5.55	5.68	4.72	6.29	5.54	5.64	2.61
127.5	3.83	5.05	3.60	4.22	4.88	4.55	2.70	2.97	3.21	3.07	1.60	4.26	3.08	2.85	1.22
132.5	2.84	3.61	2.59	3.15	3.31	3.04	1.97	1.72	2.27	2.32	1.32	2.25	1.81	1.88	0.93
137.5	2.01	2.38	1.72	2.14	2.15	2.00	1.60	1.11	1.54	1.62	1.09	1.11	1.08	1.09	0.61
142.5	1.34	1.41	1.06	1.26	1.36	1.26	1.26	0.74	1.03	1.08	0.84	0.60	0.69	0.58	0.43
147.5	1.03	1.03	0.78	0.90	1.01	0.78	0.95	0.55	0.71	0.81	0.69	0.42	0.52	0.39	0.43
152.5	0.41	0.39	0.31	0.32	0.41	0.28	0.43	0.24	0.28	0.33	0.30	0.15	0.21	0.15	0.28
157.5	0.17	0.16	0.13	0.14	0.16	0.12	0.20	0.12	0.14	0.14	0.13	0.06	0.09	0.05	0.23
162.5	0.06	0.05	0.05	0.03	0.06	0.03	0.09	0.04	0.07	0.04	0.04	0.02	0.03	0.02	0.10
167.5	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.01	0.00	0.05
172.5	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.03
177.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01

Appendix 5: Catch at age for combined sex

Age/Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1974	102.1	1003.8	1230.0	595.8	180.7	57.1	14.1	2.3	0.9	0.3	0.1	0.1	0.1	0.1
1975	41.8	444.8	781.3	489.1	213.6	63.0	23.4	8.8	4.7	2.5	0.7	0.6	0.5	0.3
1976	26.7	353.2	745.4	497.3	231.7	70.1	26.5	12.7	6.2	3.0	0.9	0.8	0.7	0.7
1977	25.4	258.7	557.5	417.6	193.3	70.1	28.9	10.5	5.3	2.7	0.9	0.8	0.7	0.8
1978	21.8	366.0	786.5	568.2	264.3	89.7	41.2	21.2	10.7	5.2	1.8	1.7	1.6	2.0
1979	1.3	511.9	1212.1	735.9	238.9	61.2	18.7	5.8	2.3	1.1	0.6	0.4	0.3	0.2
1980	0.9	419.2	1103.8	744.6	242.5	66.4	21.7	7.4	3.2	1.6	1.0	0.7	0.5	0.3
1981	1.3	450.1	989.9	594.9	180.5	49.8	20.6	7.4	3.5	1.9	1.2	0.9	0.7	0.4
1982	2.0	696.1	1625.5	971.9	302.0	71.3	24.5	8.2	3.8	2.0	1.3	1.0	0.7	0.4
1983	1.7	610.2	1437.9	894.5	287.4	80.3	30.2	10.7	5.0	2.7	1.9	1.4	1.1	0.7
1984	1.9	754.6	1853.4	1154.3	376.1	95.0	32.6	10.6	4.8	2.5	1.7	1.2	0.9	0.6
1985	1.5	786.6	1871.2	1142.2	367.2	91.3	34.7	11.3	5.5	3.0	2.1	1.6	1.2	0.8
1986	1.3	593.4	1610.4	1012.9	356.8	78.5	18.0	6.7	3.5	2.0	1.4	1.2	0.6	0.4
1987	1.5	869.5	2265.6	1431.0	477.8	111.2	37.4	11.4	5.2	2.8	2.0	1.4	1.1	0.7
1988	1.7	860.5	2057.8	1232.6	383.0	84.0	30.2	9.3	4.6	2.6	1.9	1.3	1.0	0.6
1989	1.3	644.0	1668.4	1054.0	384.6	99.2	40.5	13.0	6.3	3.5	2.5	1.9	1.5	0.9
1990	0.7	406.7	1087.3	708.0	265.6	73.6	31.2	9.5	4.8	2.8	2.1	1.5	1.2	0.8
1991	0.6	440.4	1320.5	937.2	349.3	94.3	38.1	11.9	6.1	3.4	2.4	1.7	1.2	0.7
1992	0.2	292.6	967.9	717.3	268.5	70.9	29.0	8.6	4.4	2.5	1.7	1.2	0.9	0.6
1993	0.1	264.8	879.5	667.5	263.3	79.3	32.8	9.6	5.1	3.0	2.1	1.5	1.1	0.6
1994	0.4	410.3	1287.8	933.5	345.1	88.5	35.2	12.3	5.8	3.2	2.2	1.6	1.2	0.8
1995	0.4	444.8	1118.9	721.9	245.3	71.2	30.5	10.1	5.3	2.9	2.0	1.5	0.9	0.5
1996	0.6	564.9	1355.9	846.2	242.8	64.9	27.9	7.1	3.8	2.1	1.8	1.5	1.1	0.9
1997	1.2	857.5	1943.4	1077.5	304.7	51.2	20.1	6.9	3.5	1.8	1.2	0.9	0.7	0.5
1998	1.8	598.3	1483.3	931.0	287.8	66.1	23.3	8.6	4.1	2.3	1.7	1.3	0.8	0.6
1999	1.5	838.8	1768.8	979.6	289.7	63.5	23.1	8.8	3.8	2.3	1.7	1.2	1.0	0.6
2000	2.5	627.5	1429.9	835.3	250.1	48.5	20.1	7.1	2.3	1.4	1.2	0.9	0.8	0.6
2001	0.8	489.0	1043.1	563.5	196.4	42.2	15.7	9.1	4.5	2.0	1.1	0.7	0.5	0.3
2002	1.5	538.0	1186.4	667.4	215.5	44.0	17.3	8.1	3.5	1.7	1.1	0.8	0.6	0.4
2003	0.6	315.3	718.2	445.1	159.2	48.6	20.4	7.9	3.2	1.7	1.1	0.7	0.5	0.3
2004	0.9	356.5	811.9	457.4	153.9	33.6	11.8	5.1	2.4	1.3	0.9	0.7	0.7	0.8

Appendix 6: Data catch and effort.

	Catch (ton)	**Efforts** (fishing day)	**CPUE**
1974	1209	9248	130.70
1975	1009	8743	115.45
1976	1039	7285	142.66
1977	872	7344	118.73
1978	1227	7356	166.84
1979	1321	6432	205.41
1980	1304	6749	193.14
1981	1090	6398	170.34
1982	1738	6865	253.09
1983	1635	8616	189.74
1984	2070	8264	250.44
1985	2069	7912	261.48
1986	1797	8413	213.56
1987	2538	8913	284.75
1988	2189	7819	279.90
1989	1973	7094	278.15
1990	1341	7583	176.84
1991	1705	6490	262.70
1992	1282	6286	203.99
1993	1236	6197	199.50
1994	1670	6738	247.81
1995	1341	7232	185.46
1996	1491	8178	182.32
1997	1897	10000	189.73
1998	1633	11231	145.42
1999	1788	12136	147.33
2000	1479	11749	125.86
2001	1094	10083	108.48
2002	1235	9189	134.45
2003	860	8767	98.06
2004	858	7570	113.38

CPUE = Catch / Effort

Appendix 7: Stock sizes in numbers calculated for ADAPT VPA. Method I

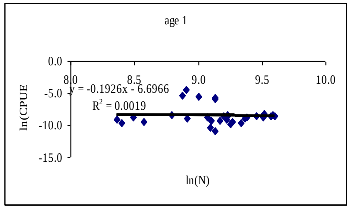
Age/Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1974	7379	5766	3938	1869	773	375	194	106	63	85	66	67	38	77
1975	7166	5166	3257	1765	827	397	219	126	74	44	60	47	48	27
1976	8111	5065	3301	1659	844	409	230	136	82	48	29	42	33	34
1977	9219	5751	3307	1721	762	405	232	141	86	53	32	20	29	23
1978	9280	6541	3875	1884	873	379	229	141	92	57	36	22	14	20
1979	10224	6587	4347	2094	861	398	194	128	82	56	36	24	14	8
1980	11689	7276	4257	2071	870	412	232	122	86	56	39	25	17	10
1981	12838	8319	4825	2098	846	415	237	147	81	59	39	27	17	11
1982	13607	9137	5542	2599	992	450	253	151	98	55	40	27	18	12
1983	14346	9683	5916	2573	1030	451	260	159	101	67	37	28	18	13
1984	14524	10210	6377	2998	1077	491	253	160	105	67	45	25	18	12
1985	14796	10336	6630	2976	1160	449	269	153	105	70	46	31	17	12
1986	13497	10530	6693	3141	1154	516	243	162	99	70	48	31	21	11
1987	11874	9605	6994	3406	1381	521	301	158	110	68	48	33	21	14
1988	10217	8450	6103	3067	1217	580	277	183	103	74	46	33	22	14
1989	9925	7271	5289	2608	1143	543	342	171	122	69	50	31	22	15
1990	8976	7063	4632	2357	967	489	303	209	111	82	46	34	20	14
1991	9617	6389	4684	2380	1080	464	286	189	141	75	56	31	23	14
1992	8928	6845	4176	2220	903	474	251	171	125	95	50	38	21	15
1993	9217	6355	4625	2156	975	416	278	154	115	85	66	34	26	14
1994	10458	6560	4300	2550	971	472	229	170	102	77	58	45	23	17
1995	11378	7443	4323	1974	1027	400	261	134	111	67	52	39	31	16
1996	10593	8098	4923	2133	796	524	225	160	87	74	46	36	27	21
1997	10091	7539	5287	2360	804	362	318	136	108	58	51	31	24	18
1998	8682	7181	4643	2124	771	316	214	210	91	74	40	35	21	17
1999	7430	6178	4607	2053	726	306	169	133	142	62	51	27	24	14
2000	6597	5287	3690	1787	635	273	164	101	87	98	42	35	18	16
2001	5297	4694	3234	1420	567	241	153	100	66	60	68	29	24	12
2002	4883	3769	2928	1422	535	238	136	96	63	43	41	48	20	17
2003	4430	3474	2229	1083	449	199	132	82	61	42	29	28	33	14
2004	4275	3153	2207	981	396	185	101	77	52	41	29	20	20	23

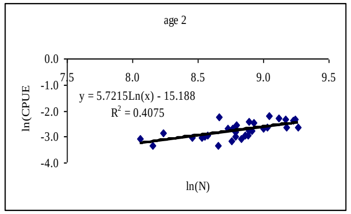
Appendix 8: Stock sizes in numbers calculated for ADAPT VPA. Method II

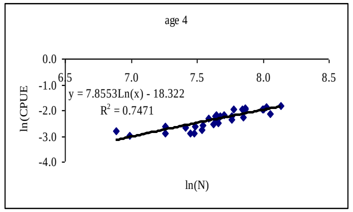
Age /Year	1	2	3	4	5	6	7	8	9+
1974	6281	5150	3515	1488	479	161	40	6	4
1975	6040	4384	2818	1464	556	188	66	17	18
1976	6903	4264	2745	1347	629	216	81	27	27
1977	7998	4891	2737	1325	539	252	94	35	38
1978	8128	5671	3263	1478	591	221	121	43	46
1979	9012	5767	3728	1659	572	198	81	51	43
1980	10330	6413	3673	1631	560	206	89	42	40
1981	11333	7352	4211	1683	532	194	90	45	53
1982	12274	8066	4853	2162	696	227	96	47	53
1983	12753	8735	5154	2083	719	241	101	48	57
1984	13099	9076	5702	2455	728	269	104	47	51
1985	13674	9322	5823	2495	774	201	112	46	57
1986	12577	9732	5971	2566	812	241	66	50	67
1987	10825	8951	6426	2892	972	277	105	32	37
1988	9560	7704	5637	2662	851	289	103	43	56
1989	8891	6803	4757	2276	855	282	135	48	62
1990	8018	6327	4299	1979	731	284	117	62	86
1991	7642	5706	4160	2143	811	296	140	57	75
1992	7704	5439	3690	1847	734	283	131	68	90
1993	8303	5483	3625	1810	710	296	141	69	97
1994	9541	5910	3680	1838	725	283	144	73	87
1995	10498	6791	3860	1533	521	225	127	73	95
1996	9884	7472	4458	1803	482	164	100	64	102
1997	9444	7035	4842	2029	570	138	62	48	60
1998	8214	6721	4284	1807	535	149	55	27	34
1999	7012	5845	4279	1798	500	138	50	20	24
2000	6478	4990	3453	1554	453	112	45	16	16
2001	5731	4609	3022	1251	401	111	39	15	15
2002	6194	4079	2868	1271	415	120	44	14	14

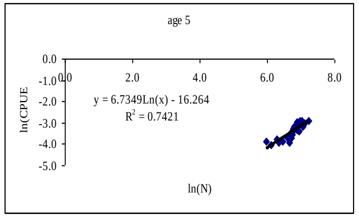
2003	6356	4408	2449	1040	342	114	48	17	16
2004	6485	4524	2871	1137	365	109	40	17	23

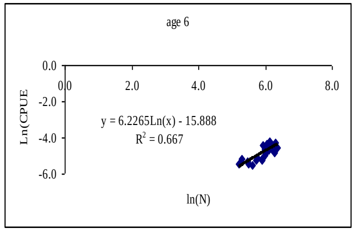
Appendix 9: Relation of abundance index CPUE and the stock in number at age

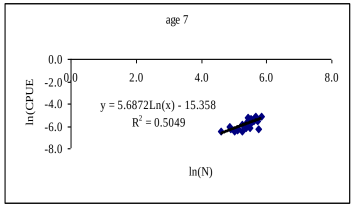


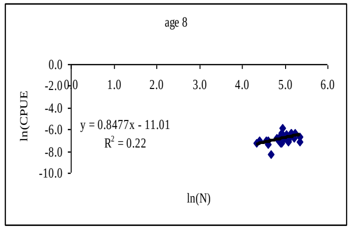


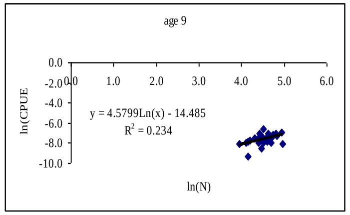


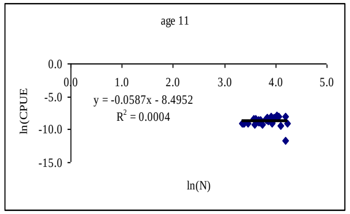


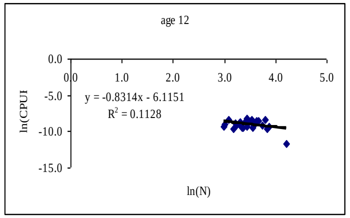


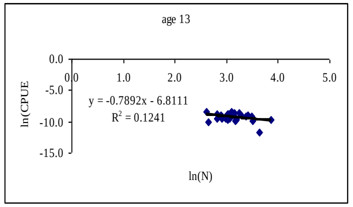


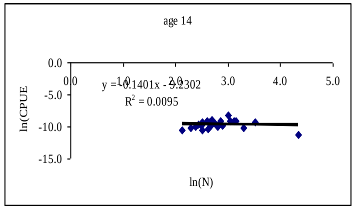




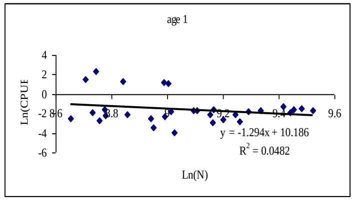








Appendix 10: Relation of abundance index CPUE and the stock in number at age from Method II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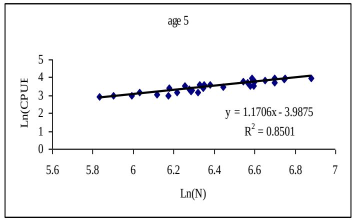
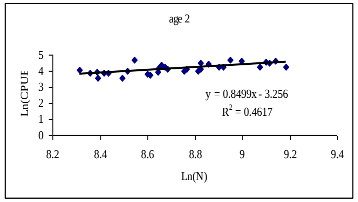

age 5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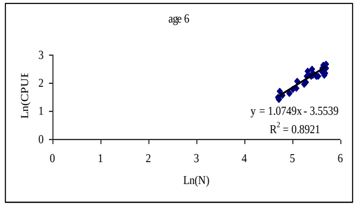
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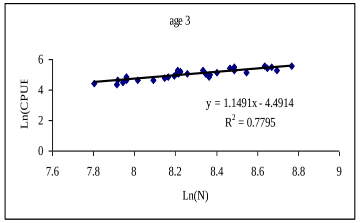
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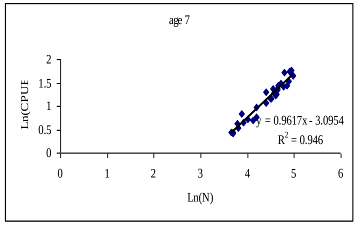
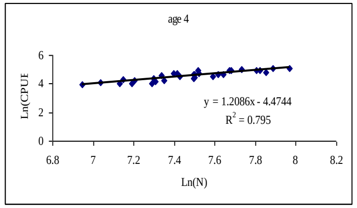
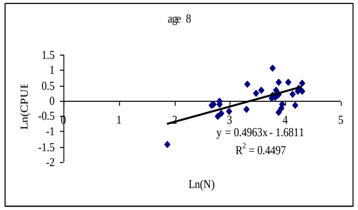

age 7


age 4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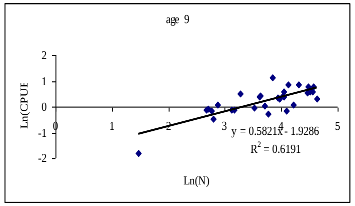
age 9

Appendix 11: 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	0	0.964113	2.031685732
	0.05	0.083793	0.718485	1.42107617
	0.1	0.142108	0.537628	0.984159172
	0.15	0.182209	0.404214	0.672086433
	0.2	0.209316	0.305593	0.449714775
	0.25	0.22718	0.232517	0.291759601
F0.1	**0.3**	**0.238492**	**0.178227**	**0.180029363**
	0.35	0.245183	0.137771	0.101436726
Fterm	**0.4**	**0.248636**	**0.107521**	**0.046567941**
Fmax	**0.45**	**0.24984**	**0.084815**	**0.008653518**
	0.5	0.249501	0.067697	-0.017172549
	0.55	0.248123	0.054728	-0.034405985
	0.6	0.246061	0.044846	-0.045556124
	0.65	0.243567	0.037271	-0.052422321
	0.7	0.240818	0.031424	-0.056293021
	0.75	0.237938	0.026875	-0.058089122
	0.8	0.23501	0.023307	-0.058467245
	0.85	0.232091	0.020482	-0.057894102
	0.9	0.22922	0.018225	-0.056700062
	0.95	0.226421	0.016402	-0.055117719
	1	0.223708	0.014913	-0.053309659