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RESEARCH ARTICLE

Differences in the exploited oyster (*Crassostrea virginica* (Gmelin, 1791)) populations from different coastal lagoons of the Gulf of Mexico.

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Abstract

1 - Oyster fishery is one of the most important coastal fisheries of Mexico. Production from the Gulf of Mexico coast makes up 93.4% of national production; during 2000-2002 it reached over 49,000 mT, with value of 9.2 to 15.5 million USD. Production is based on enhanced beds management. It is an activity of social importance, as many coastal communities find their income and work opportunities in it. In the state of Tabasco there are 1,371 oyster fishers in 14 cooperative societies, and 3,000 shuckers. There is an extensive bed management activity with seeding of collected spat and shell laying. Although a minimum legal size of 80 mm is required, it is not observed.

2 - We identified the growth equation parameters for size structure data for five beds from three lagoons. Maximum height varied between 118 and 140 mm with means between 58 and 63 mm. The von Bertalanffy growth equation parameters were L8 between 124 and 154 mm, with K between 0.71 and 1.21. In most cases a significant influence of seasonality was detected, mostly during winter, but at some localities it was during summer. Total mortality Z varies from 1.64 to 2.39. As no data on natural mortality M were available we applied 25, 50 and 75% of Z to M, which allowed us to model the behaviour of the populations under different rates of fishing mortality F and the impact of different M in yields.

3 - We conclude that the populations are over exploited in size and this is affecting yields. Besides, the populations are at risk of collapse if natural mortality increases awing to any environmental impact. It is recommended to increase mean size to 90 mm which means a minimum catch size of over 70 mm, as required by the official norm, this would increase yields in weight 100% and there would be a significant number of organisms to buffer any increase on natural mortality.

Keywords: *Crassostrea virginica*, fisheries biology, Bertalanffy growth equation, Gulf of Mexico

Introduction

Oyster culture started in the Gulf coast of Mexico around 1960, with the improvement of natural beds and later with the catch and transplantation of seed between areas (Ramirez and Sevilla, 1965). After a peak of 59,600 tons in 1989, production declined to 25,800 tons in 1993. At present it has risen to 56,000 tons. Gulf of Mexico has led with 88 to 92 % of National production, but has not exceeded 65% of the value. This difference in value is the result of the poor quality in size and sanitary aspects of the Gulf production.

Within the Gulf of Mexico, the state leading production has changed with time. Up to the 1970s it was the state of Campeche that led with production from Terminos Lagoon; from the middle of the 1970s to 1996 the state of Veracruz took over awing to the support of the Federal authorities for the development of extensive aquaculture. When subsidies were transferred to Tabasco, this state took the lead. The production registered in the different Gulf States is below the potential. The State of

Tamaulipas with 274,736 Ha has 40% of coastal lagoon area of the Mexican Gulf coast, but only 2% of oyster production; Veracruz with 193,300 Ha has 28% of the area, and 49% of production; Tabasco with 27,400 Ha has 4% of the area and 45% of production, and Campeche with 198,500 Ha has 29% of the area with only 3% of production. These figures give an idea of the potential production of the Gulf of Mexico coast, which in theory could increase to 500,000 tons.

A decrease in yields and sizes of oyster catches despite the constant support of Tabasco State authorities demands a bed management strategy. This study evaluates population parameters of oyster populations from the principal beds in the lagoon system of Tabasco to evaluate the impact of seeding and fishing on the dynamics of oyster beds.

Methods

Sampling sites

The coastal lagoons of Tabasco form part of the Grijalva - Usumasinta rivers delta system. Prevailing environmental conditions are presented on table 1, adapted from Santoyo and Signoret (1981), and Contreras (1993).

Mecoacan lagoon is the third largest in area in the state of Tabasco, with 5,168 ha. It is located between 18°16' - 18° 26' N and 93° 04' - 93° 14' W (Fig. 1a). The rivers Escarbado, Gonzalez, Cuscuchapa and Seco drain to the lagoon. The connection to the sea is permanent through the bar of Dos Bocas.

El Carmen - Machona lagoon system is located at 18º 20' - 18º 24' N and 93º 45' - 93º 55' W (Fig. 1b). It has an area of 6,500 ha, with a mean depth of 2.5 m. Its communication with the sea is through the mouth of Panteones. Santoyo and Signoret (1981) classify this lagoon as the most productive, followed by Mecoacan.

Sampling

Sampling took place monthly from January 2004 to January 2005. Samples were collected from commercial beds with oyster tongs at stations located by GPS. Six stations were made per oyster bed, with a minimum of three dredges per station or until fifty organisms were collected per station. Each animal height, length and width were measured as also the weight of the whole individual, its shell and soft parts (Galtsoff, 1964).

Size height frequency histograms were used to analyze the population structure. The von Bertalanffy Growth Equation parameters (VBGEP) with the seasonally effects were estimated using the ELEFAN routine (Equation 1)(Gayanilo *et al.*, 1993):

(Equation1)

$$L_t = L_\infty\left[1 - e^{-K(t-t_0)-(CK/2p)\operatorname{sen}(2p(t-tv))}\right]$$

where L_t is the length at age t, $L\infty$ the maximum theoretic length, K the growth rate or curvature parameter, t_0 the hypothetical age when length is 0, C the amount of growth slowdown, Ts time of the year when growth is highest, inverse to wp (winter point) or time of the year when growth is retarded (wp< 1) or suspended (wp=1).

Table.1 Prevailing environmental conditions reported for the lagoon system of Tabasco. (Adapted from Santoyo and Signoret (1981), Contreras (1993).

	Temperature ºC		**Salinity psu**		**Chlorophyll mg/m^3**		**Carbon mg/m^3/h**	
	Max	Min	Max	Min	Max	Min	Max	Min
Mecoacan	32.5	22.5	36.9	0.3	386	0.1	399	41.4
Carmen	32.5	22	36	14.6	21.9	6.7	89.5	41.4

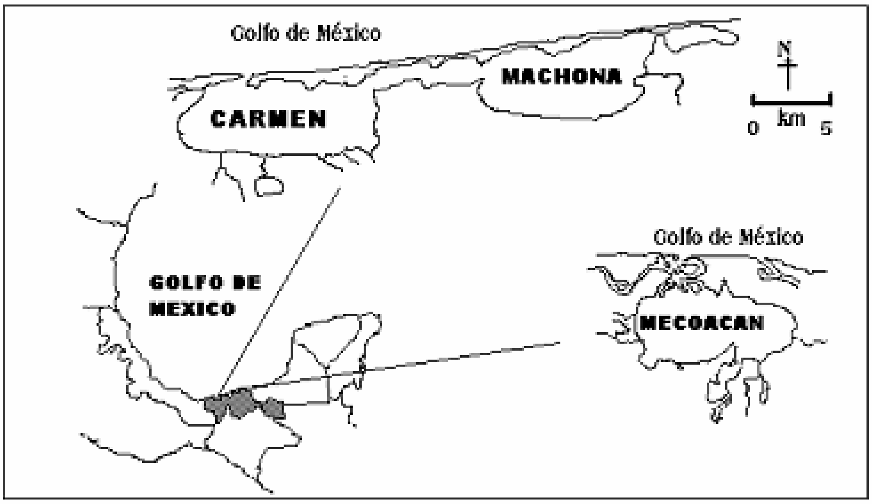

Figure 1. Coastal lagoons of Tabasco, Mexico, where the oyster (*Crassostrea virginica*) populations were described.

Age was estimated from the VBGEP, using equation 2:

(Equation 2)

$$t = t_0 - \left(1/K \right) * \ln\left(1 - \left(L_t / L_\infty \right) \right)$$

As proposed by Pauly (1979) the standard index of growth ∅' (Equation 3) was used to evaluate growth efficiency Ef (Baqueiro and Aldana Aranda, 2003) (Equation 4) among the different populations.

(Equation 3)

$$f' = 2\log L_\infty + \log K$$

(Equation 4)

$$Ef = \varnothing'_i / \varnothing'_{max}$$

Where Ef is the growth efficiency of the population i. ∅'i the standard growth index for that population, and ∅'max the standard growth index from the highest estimated values of L_∞ and K.

Total mortality (Z) was estimated from converted values of catch lengths (Sparre and Venema, 1991; Gayanilo *et al.*, 1993). In order to evaluate the impact of fishing mortality (F) and given the lack of information on natural mortality (M), three scenarios of M were considered with corresponding F values. We took 25%, 50% and 75% of Z to evaluate yield per recruit (Beverton and Holt, 1983).

Recruitment was estimated using the recruitment subroutine of FISAT, based on a backward projection of VBGEP (Gayanilo *et al.*, 1993).

Results

Size structure was similar at all beds, with heights in the range of 1.5 mm to 140.6 mm, mean height was in the range of 56 to 63 mm (Table 2). Fig. 2a shows the sum of height frequencies for the five locations, and for the state of Tabasco. A slight positive skewness was detected at all locations, with significant presence of recruits at the beds of Palma II, Carmen lagoon, and Mulato at Machona.

Growth

Growth is expressed through the VBGEP of the height of the shell (Table 3). Asymptotic height fluctuated from L8 = 124 mm at both beds of Carmen lagoon to L8 = 154 mm at Cascajal bed, Machona lagoon.

The highest growth rate (K = 1.21/year) was found at the bed of Palma II from Carmen lagoon, and the lowest (K = 0.71/year) at Cascajal bed from Machona. At the five localities some growth arrest was registered, the lowest of 0.25 at Mecoacan during February - March (Wp = 0.25), meaning a more or less

constant growth through the year and the largest, C = 0.50 and 0.52 at Palma II from el Carmen lagoon and Mulato bed from Machona lagoon during June – July (Wp = 0.5 and 0.53). The other two localities showed a growth arrest of C = 0.3 during December (Wp = 0).
The standard growth coefficient index ∅ ' varied on the range of 4.15 to 4.27 giving very similar growth efficiency at all localities (Table 3).

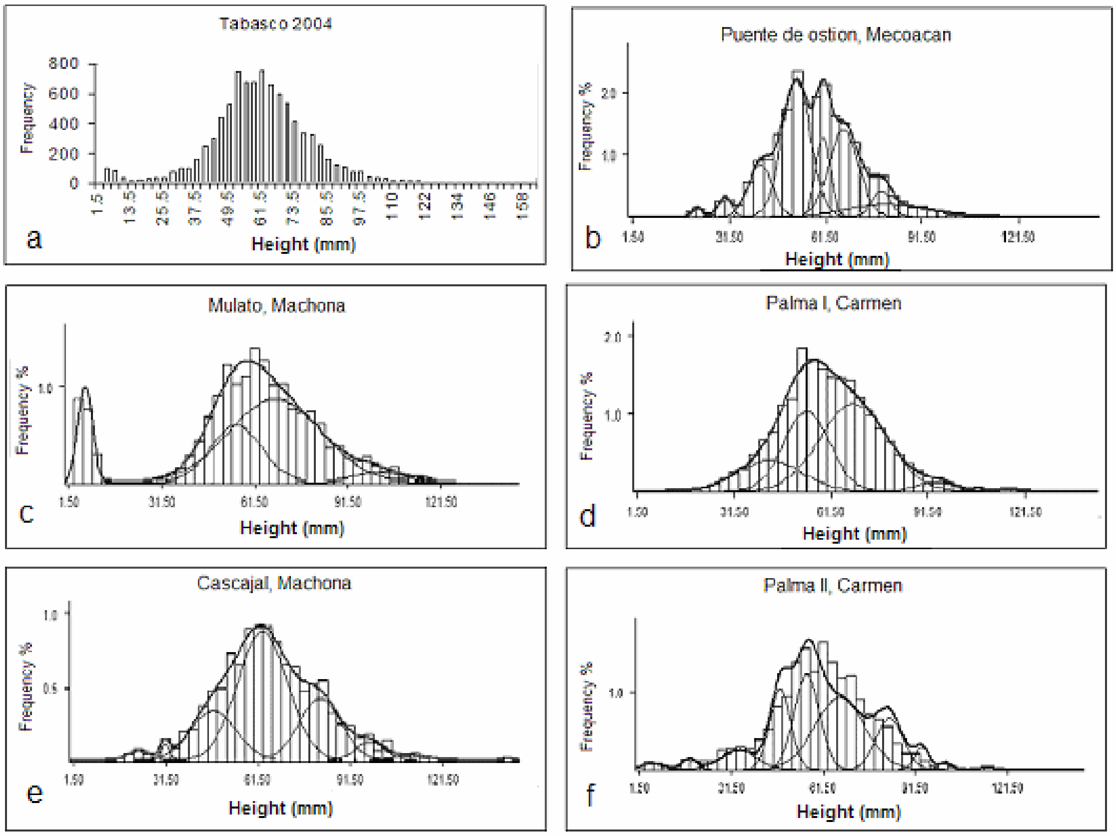

Figure 2. Size frequency histograms of the population structure of *C. virginica* for five beds from three coastal lagoons, Tabasco, Mexico. a) Integration of the five beds from the three lagoons; b) Mulato bed, Machona lagoon c) Cascajal bed, Machona lagoon; d) Puente de Ostion bed, Mecoacan lagoon; e) Palma I bed, Del Carmen lagoon; f) Palma II bed, Del Carmen lagoon. Lines within the histograms represent the number of cohorts in the population.

Height (H) - weight (W) correlations showed a better adjustment to a potential correlation (W = aHb) with the lowest correlation coefficient (R) at Palmas II beds from Carmen Lagoon and the highest at Mulato bed from Machona lagoon (Fig. 3).
The maximum estimated age was 4.02 years al Mulato bed from Machona lagoon; the minimum at Palma II from Carmen lagoon 2.66 years, with the other populations fluctuating within this range.
In all the localities the minimum commercial size of 80 mm is attained within the first year, except at the bed of Palma I from Carmen lagoon where it takes 1.02 years (Table 3).

Recruitment

From the population structure of the height frequency histograms (Fig. 4), the incorporation of recruits can be inferred from the appearance of the smallest size classes or their increase in frequency. Two recruitment periods can be inferred at the five locations: a minor one from December to March, and the main recruitment period from May to August.

Table 2. Maximum, minimum and mean values of height and wet weight of *C. virginica*, with correlation parameters for potential equation fit, from five beds from Machona, Mecoacan and Carmen coastal lagoons, Tabasco, México during the period January 2004 to January 2005.

	Height mm	Weight gr	a	b	r
Machona					
Mulato					
Max	125.60	111.63	0.058	1.5663	0.9514
Min	1.59	0.17			
Mean	58.20	33.33	66.74		
STD	24.34	20.07			
Skewness	0.94				
Cascajal					
Max	140.60	330.31	0.0039	2.1355	0.7831
Min	13.00	0.59			
Mean	63.64	30.49	58.12		
STD	17.70	30.49			
Skewness	1.06				
Mecoacan					
Puente de Ostión					
Max	118.00	225.78	0.007	2.0386	0.6361
Min	18.30	0.53			
Mean	56.86	27.44	67.43		
STD	13.79	12.28			
Skewness	1.44				
Carmen					
Pama I					
Max	120.00	90.30	0.0063	2.0127	0.7048
Min	12.00	0.09			
Mean	59.19	25.69	54.03		
STD	15.34	13.64			
Skewness	1.23				
Palma II					
Max	119.2	330.7	0.6277	0.9267	0.4648
Min	1.67	0.40			
Mean	58.34	29.31	40.62		
STD	17.13	13.19			
Skewness	1.33				

With differences among lagoons, and even among beds of the same lagoon. In Machona lagoon at the Mulato bed the lesser recruitment is limited to December – January and the major one occurs in July and August (Fig. 4 a), while at the Cascajal bed the minor recruitment is during January and February and the major one from August to November (Fig. 4b). The Puente de Ostion bed in Mecoacan lagoon shows a minor recruitment during January and February and a major one from May to August (Fig. 4c).

Palma I and Palma II beds in Carmen lagoon present their minor recruitment period between January and March, and the major from June to August (Fig. 4 d and e). Estimated recruitment patterns (Fig. 5) are bimodal except at the Puente de Ostion bed but there are differences in intensities between seasons. Thus the major recruitment at Mulato bed extends from January to August with up to 20 % during May while the minor period of recruitment extends from June to December being higher during August with just 5 % (Fig. 5 a).

Table 3. Von Bertalanffy growth equation (VBGE) parameters from size structure data of *C. virginica* from five beds in the lagoons of Machona, Mecoacan and Carmen, Tabasco, Mexico. L¥ asymptotic length; K Growth constant; ø'standard growth index; Ef Growth efficiency (F'i/F'max); C Amplitude of oscillation; Wp Winter point; E70 age to minimum legal size; Emax Maximum age.

	$L_{¥}$	K	ø'	Ef	C	Wp	E_{70}	E_{max}
Machona								
Mulato	127	1.01	4.21	0.93	0.52	0.53	0.88	4.02
Cascajal	154	0.71	4.22	0.94	0.3	0	0.93	3.34
Mecoacán								
Puente de Ostión	137	1.05	4.30	0.95	0.25	0.25	0.84	2.43
Carmen								
Palma I	124	0.92	4.15	0.92	0.3	0	1.02	3.53
Palma II	124	1.21	4.27	0.95	0.5	0.5	0.75	2.66

Ef from $ø'_{max}$ = 4.51 for L8 = 164 mm and K= 1.21

At Cascajal bed both recruitments show similar intensities, one recruitment period from January to September and the other from June to December, with a mode during July-August of about 15% (Fig. 5 b). At Puente de Ostion bed (Fig. 5 c) there is a marked difference to what may be inferred from the frequency histogram, with an uni-modal recruitment with a maximum (15 %) during June. At Carmen lagoon the difference shown in the histograms (Fig. 4 d and e) is emphasized in the estimated recruitment patterns (Fig. 5 d and e), being clearly bimodal at Palma I and uni-modal at Palma II, but for both beds the principal recruitment period coincide with their peak in May-June.

Mortality

Total mortality Z values are presented on table 4; as well as estimated natural mortality M for 25, 50 and 75 % of Z. Mortality is high for all beds, fluctuating from 1.64 at Mulato bed from Machona lagoon to 2.39 at Puente de Ostion from Mecoacan lagoon.

From the low number of empty shells collected during sampling, and observed fishing effort it is assumed that most mortality is due to fishing F.

Discussion and Conclusions

Mean size at all the lagoons is well bellow minimum legal size of 70 mm (NOM-015-PESC-1994), with asymptotic length very depressed compared to what is expected for the species maximum length of 150 to 355 mm (Galtsoff, 1964). Previous results for commercial catches taken during 1998, in the same locations (Baqueiro *et al.* 1999) show a slightly higher mean: 40 to 59 mm, and L8 : 150 to 168 mm (Table 5). The authors conclude that this is the result of no observing the minimum legal size. Overexploitation has reduced the mean size within the populations. Growth registered at Tabasco Lagoons fluctuates between 75 and 90 mm a year, reaching minimum legal size of 70 in seven to eleven months. Stanly and Sellers (1986) report growth rates from 50 to 100 mm a year from Louisiana to Florida; with instantaneous monthly growth coefficients ranging from 0.42 to 0.84 (Gilmore, 1982).

Growth of oysters depends on environmental conditions and their position and density in the oyster reef.

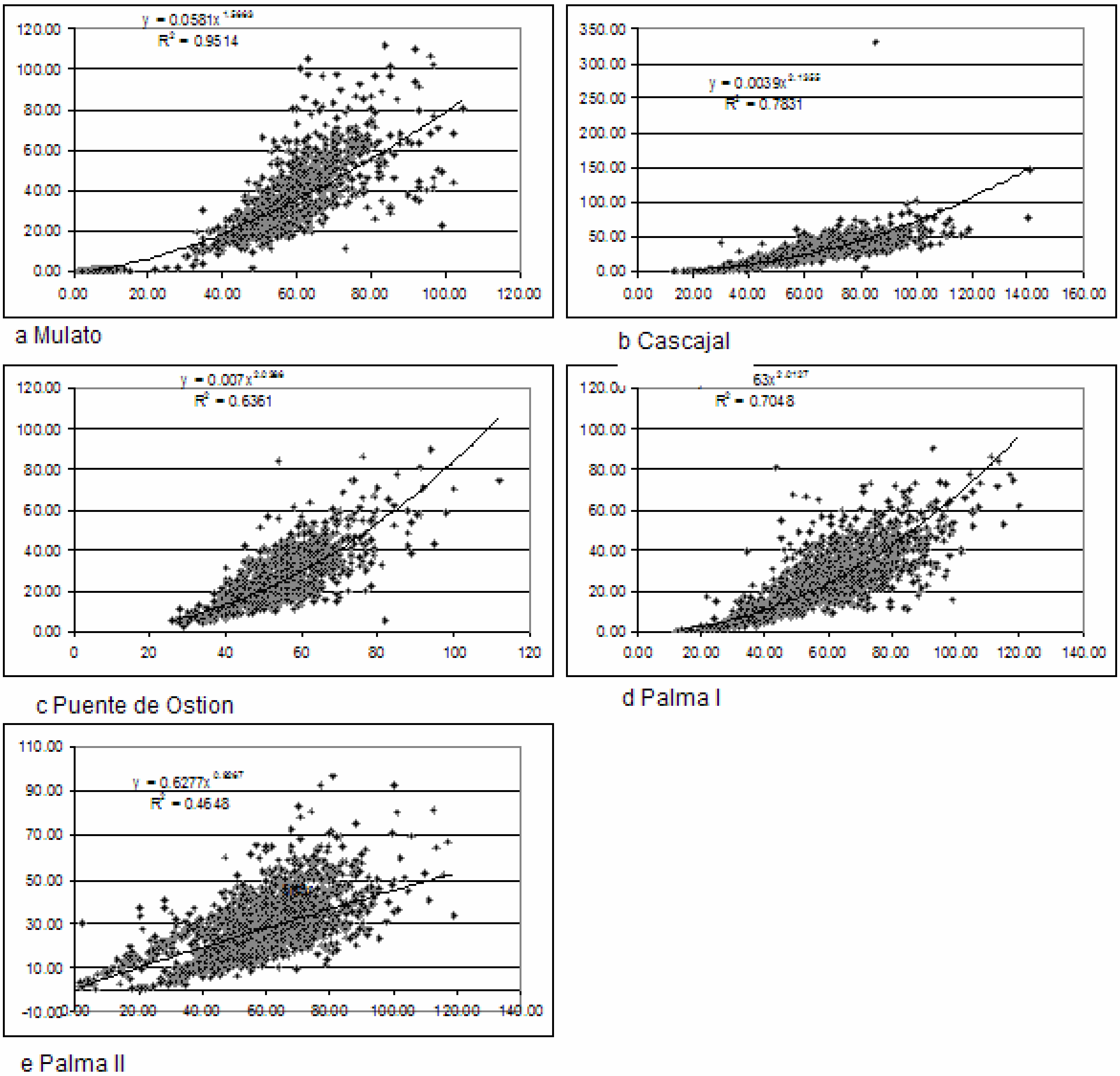

Figure 3. Height – Weight correlation curves of the populations of *C. virginica* from: a) Mulato bed, Machona lagoon b) Cascajal bed, Machona lagoon; c) Puente de Ostion bed, Mecoacan lagoon; d) Palma I bed, Del Carmen lagoon; e) Palma II bed, Del Carmen lagoon.

Fluctuating environments may promote better growth (Pierce and Conover, 1954), but extended periods of air exposure reduces growth rate (Gilmore, 1982). It is food availability that determines growth rate (Manzi *et al.*, 1977). Crowding, however, may inhibit spawning and thus indirectly lead to increased growth (Butler, 1953). Therefore growth at the Tabasco lagoons may be considered good, confirmed by the Efficiency Coefficient (Table 3), which fluctuates between 0.92 and 0.95. The seasonality of VBGE shows that there is up to 50% arrest of growth during June – July, at el Carmen lagoon, coinciding with the beginning of spawn (Aldana *et al.*, 2006) and 25 to 30% arrest during December to March at all the other beds, coinciding with periods of lower salinity and temperature, and higher turbidity, given the presence of northern winds during that time of the year. There was no significant difference between height or weight population structure of the beds. Similar condition indices were observed in Puente de Ostion, Cascajal and Palma I beds; Mulato and Palma II showed a lower condition index, and Palma II bed presented the lowest slope (Table 2).

Table 4. Total mortality (Z) from length converted catch curve (Gayanilo *et al.* 2002), and estimated natural mortality (M) for 25%, 50% and 75% of Z.

Lagoon	**Machona**		**Mecoacán**	**Carmen**	
Bed	**Mulato**	**Cascajal**	**Puente de ostión**	**Palma I**	**Palma II**
Z	1.64	1.92	2.39	1.89	2.15
M					
25%	0.41	0.48	0.60	0.47	0.54
50%	0.82	0.96	1.20	0.95	1.08
75%	1.23	1.44	1.79	1.42	1.61

Although Santoyo and Signore (1981) reported a higher productivity for Machona Lagoon, it is also the one with the higher pollution (Botello *et al*., 2004). The previous study of Baqueiro *et al.* (1999) reported this lagoon with the lowest condition index as well. As stated by Galtsoff (1964), low salinity is an important factor on growth and survival for *C. virginica*, a prevailing factor at Machona for part of the year (Santoyo and Signoret, 1981; Contreras, 1993). No information is available for Carmen lagoon, but as part of the same system with Machona it is assumed that conditions are similar.

Table 5. Von Bertalanffy growth equation (VBGE) parameters from size structure data of C. virginica from the four coastal lagoons from Tabasco, Mexico. L8 asymptotic length; K Growth constant; ø'standard growth index; Ef Growth efficiency (F'i/F'max); C Amplitude of oscillation; Wp Winter point; Z Total mortality; EM age at mean size; Emax Maximum age (Baqueiro *et al*, 1999).

	$L_¥$	K	$ø'$	Ef	t_0	C	Wp	Z	E_M	E_{max}
Mecoacan	164	1.1	4.47	1	0.992	0.1	0.9	6.46	1.2	2.3
Machona	150	0.35	4.09	0.92	0.936	1.0	0.9	1.93	2.5	4.8
Redonda	150	0.61	4.14	0.93	0.853	0.6	0.6	3.48	1.3	2.8
Río Seco	158	0.38	3.98	0.89	0.630	0.2	0	1.41	3	6.3

Differences in recruitment among lagoons may be attributed to differences in spawning in the lagoon. Aldana *et al.*, (2006) report the shortest spawning period at Machona, which is from June to December; spawning extends to January at Carmen lagoon and stretches from March to December at Mecoacan lagoon. But differences between beds within the same lagoon could be attributed to current patterns and local environmental characteristics. Even though, at Tabasco lagoons natural recruitment is overcome by the shell laying and seed management practices. Considering the low number of fresh empty shells found during sampling and the small mean size of the populations most of total mortality observed can be attributed to fishing mortality. Predation and disease are the limiting factors where environmental conditions are otherwise adequate for an optimal population growth (Barber *et al*., 1988; Newel *et al*., 1991). Studies on natural mortality have shown that it can be as low as 0.01% to 90% in adult populations, but in spat 40% survivals is considered good (Stanley and Sellers, 1986). Mortality by predation and diseases in larger organisms is evidenced by broken, perforated or open empty shells (Galtsoff, 1964; Carriker, 1981). Given the growth efficiency and assuming that difference in mortality are due to natural mortality, Fig. 6 shows that although the highest efficiency was found at Puente de Ostion at Mecoacan lagoon, the highest mortality was also registered there.

The opposite was found at Palma I bed from Carmen lagoon, where the lowest efficiency was detected, but with mortality in the average of the other sites. Data presented in figure 6 suggest that all beds except Palma I, given its lower growth efficiency, are susceptible to enhancement practices.

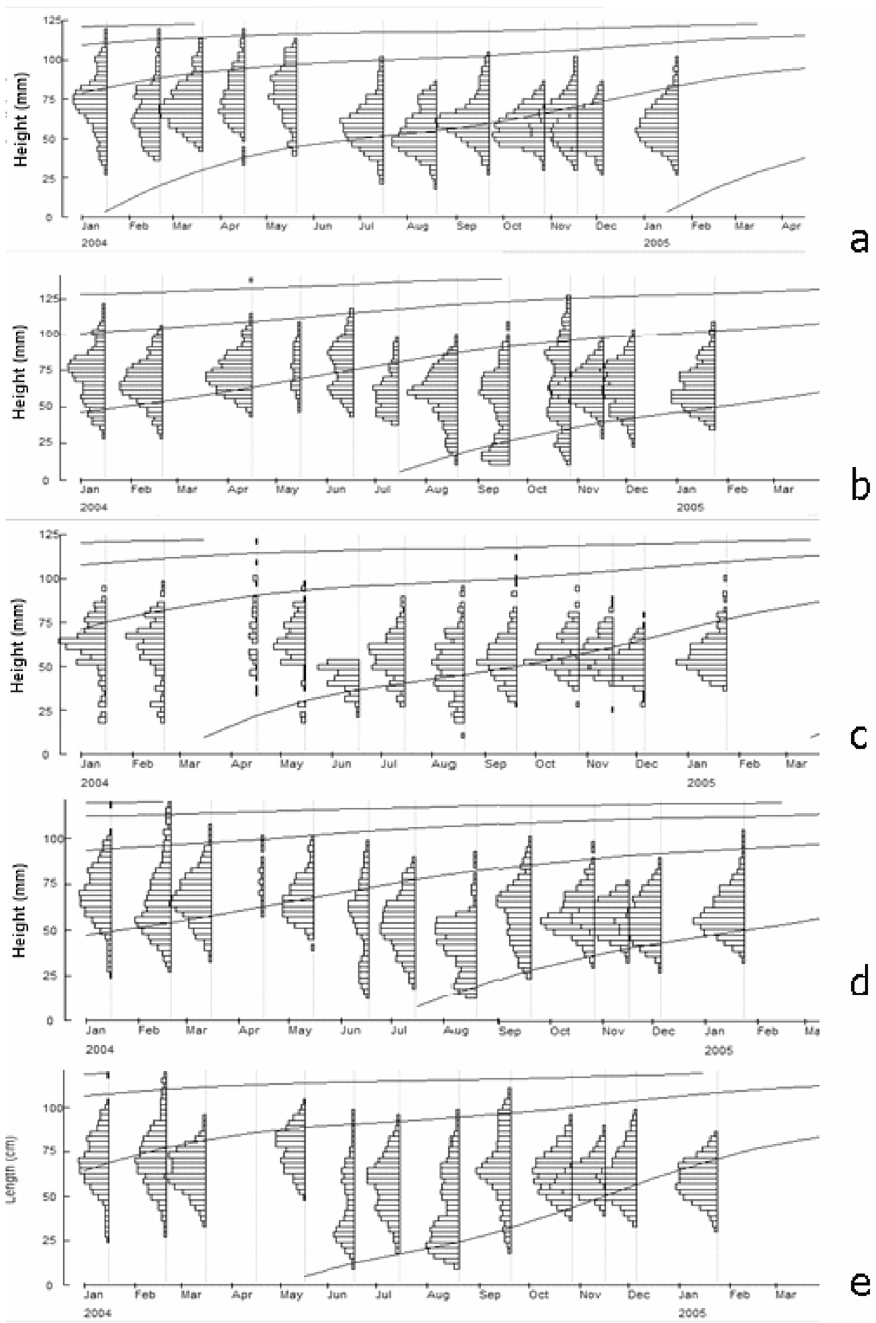

Figure 4. Size structure and VBGE curves of the populations of *C. virginica* from the five beds of three coastal lagoons, Tabasco, Mexico.

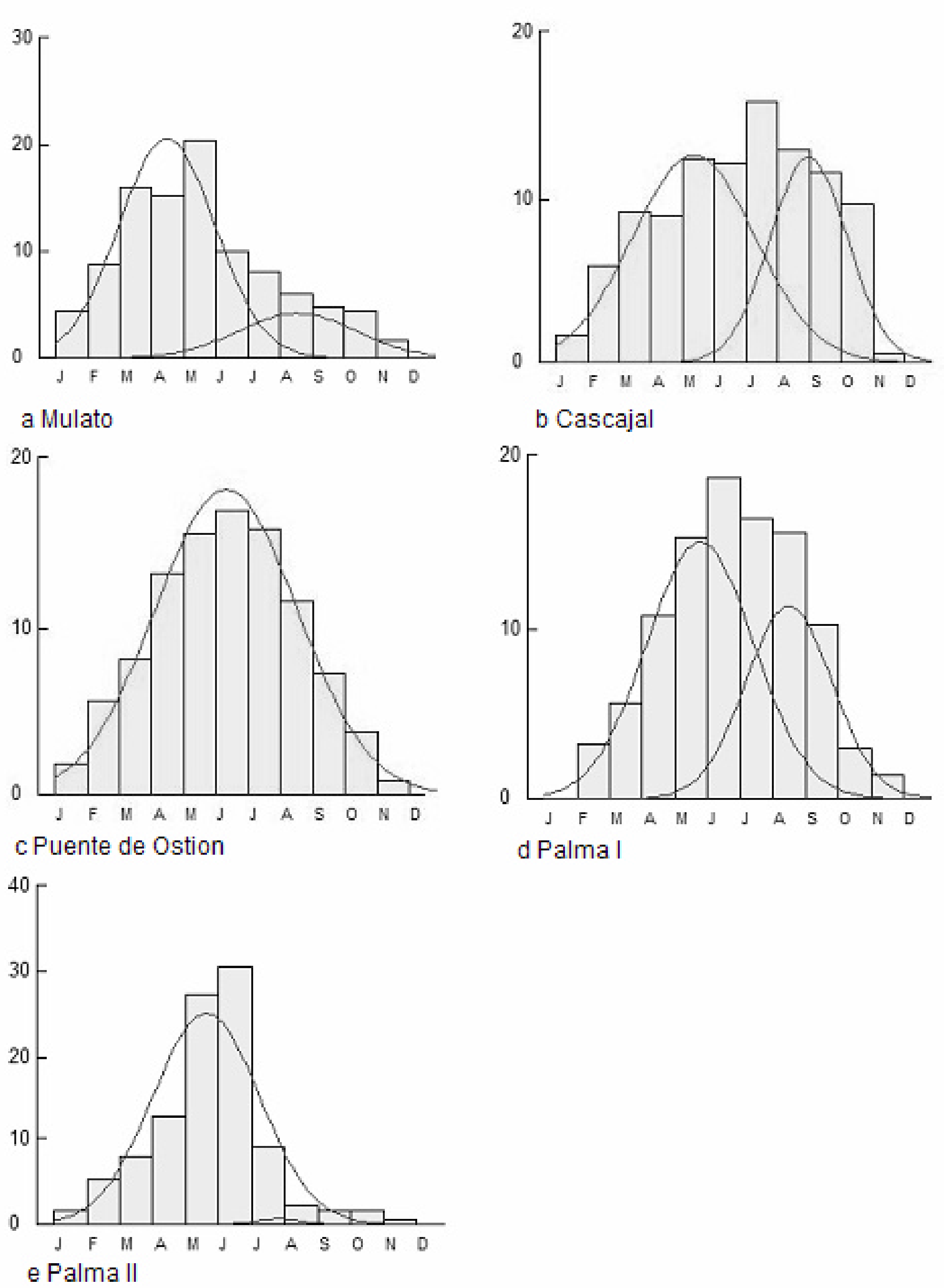

Figure 5. Recruitment patterns for the populations of *C. virginica* from the five beds of the three coastal lagoons, Tabasco, Mexico.

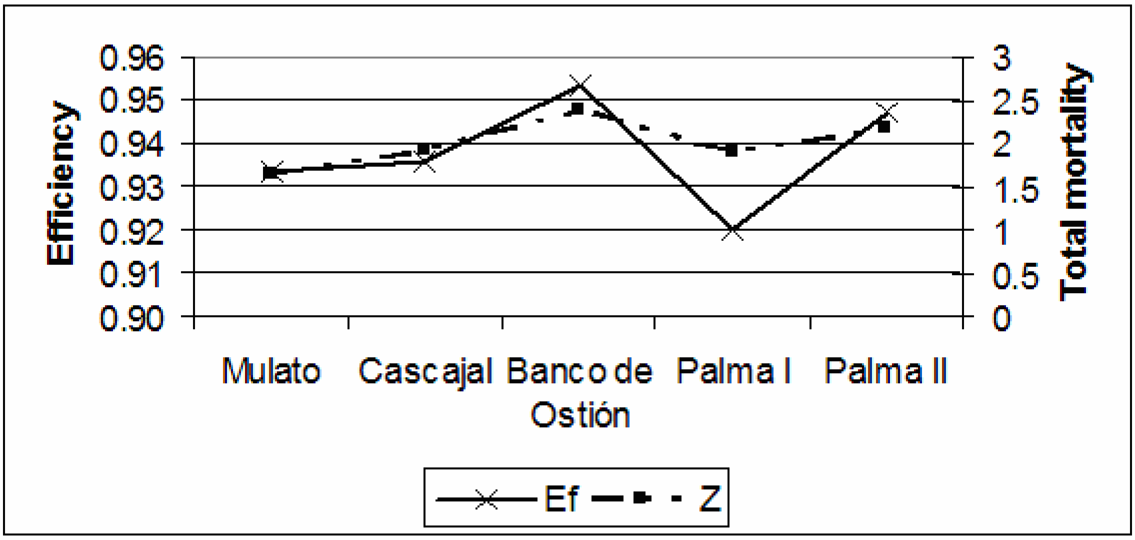

Figure 6. Growth efficiency and total mortality Z for the populations of *C. virginica* from the five beds of the three coastal lagoons, Tabasco, Mexico.

But the cause of the high mortality at Puente de Ostion has to be controlled.

The age structure of the oyster populations at all the beds reveals over-exploitation. It is known from interviews with fishermen that catches are limited by a low demand. Therefore, the situation can only be blamed on mismanagement of the beds.

The practice of shell laying and spat planting helps to improve catches. To an extent that at Chesapeake Bay, USA, natural beds are open to amateur fishing, while commercial production comes from improved beds with spat laying (Cerco and Noel, 2005). But the lack of control on size and volume of exploited oysters at Tabasco is rendering useless the shell laying and spat catching programs. Figure 8 presents a virtual population analysis (VPA) for an assumed natural mortality of 50% of the total mortality for the five beds.

The bars show the fast decrease of the population and limited availability for fishing mortality and the great vulnerability to increase in fishing.

In figure 9 we show the impact of increasing minimum catch size to 70 mm. This raises maximum length to 190 mm and leaves a wide margin for fluctuations of natural and fishing mortality, as well as increasing the quantity of captured organisms by a 100% increase landings in weight. Table 6 shows estimated weight for present and proposed mean height of shell of landed oysters, estimated from height-weight correlation equations of Fig. 3.

Table 6. Mean weight estimated from height – weight correlation presented in Fig. 3 for oysters between 50 and 90 mm height taken form the five beds from three Tabasco coastal lagoons, used to estimate the effect of raising minimum catch size to 70 mm

	Weight (g) for 50 mm shell height	Weight (g) for 90 mm shell height
Mulato	26.58	66.74
Cascajal	16.57	58.12
Puente de ostion	20.34	67.43
Palma I	16.55	54.03
Palma II	23.56	40.62

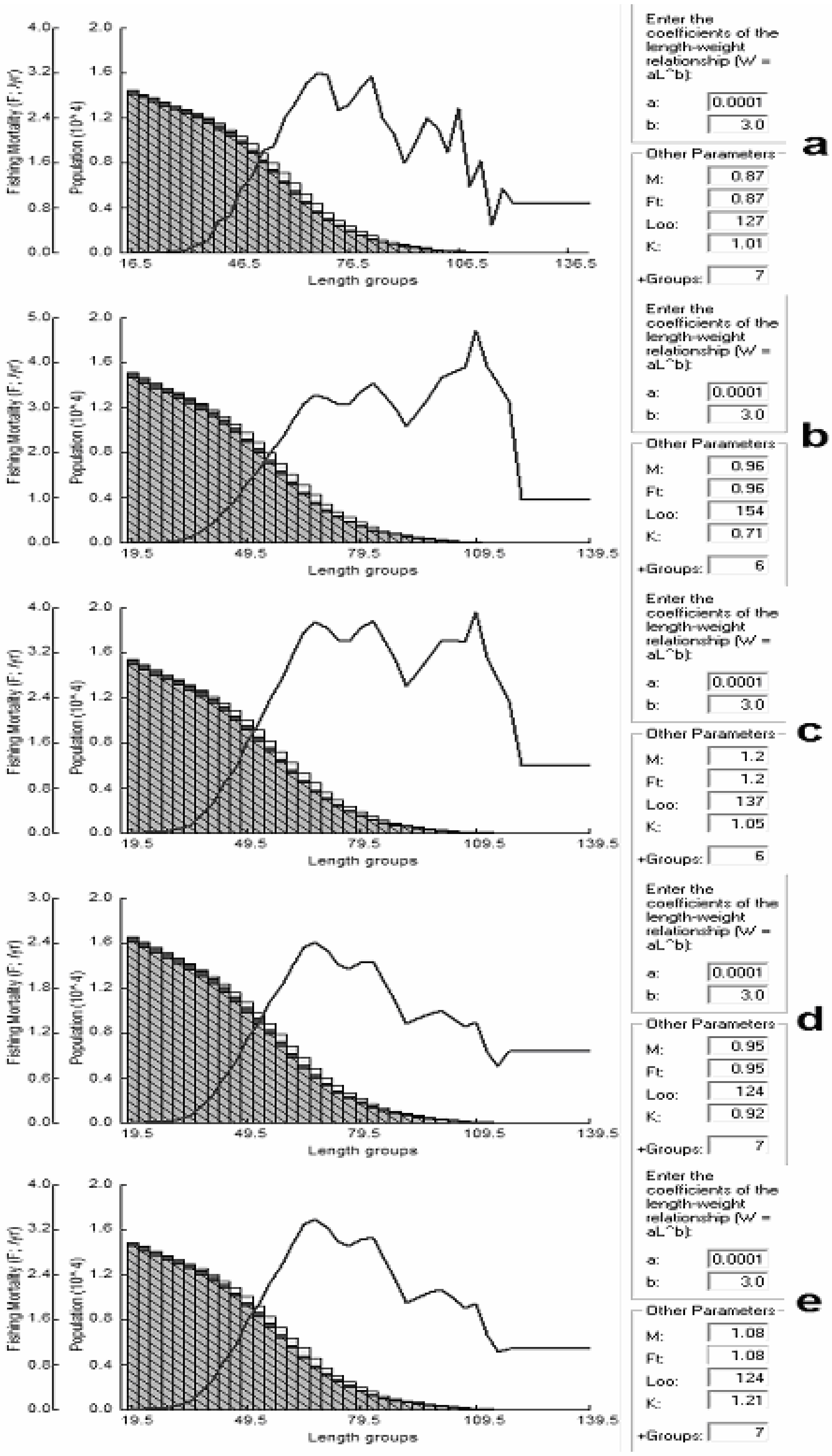

Figure 7. Virtual population analysis based on a natural mortality of a 50 % to total mortality Z for the populations of *C. virginica* from the five beds of the three coastal lagoons, Tabasco, Mexico. Gray bars represent population size, black bars natural mortality, white bars fishing mortality and the line represents fishing effort.

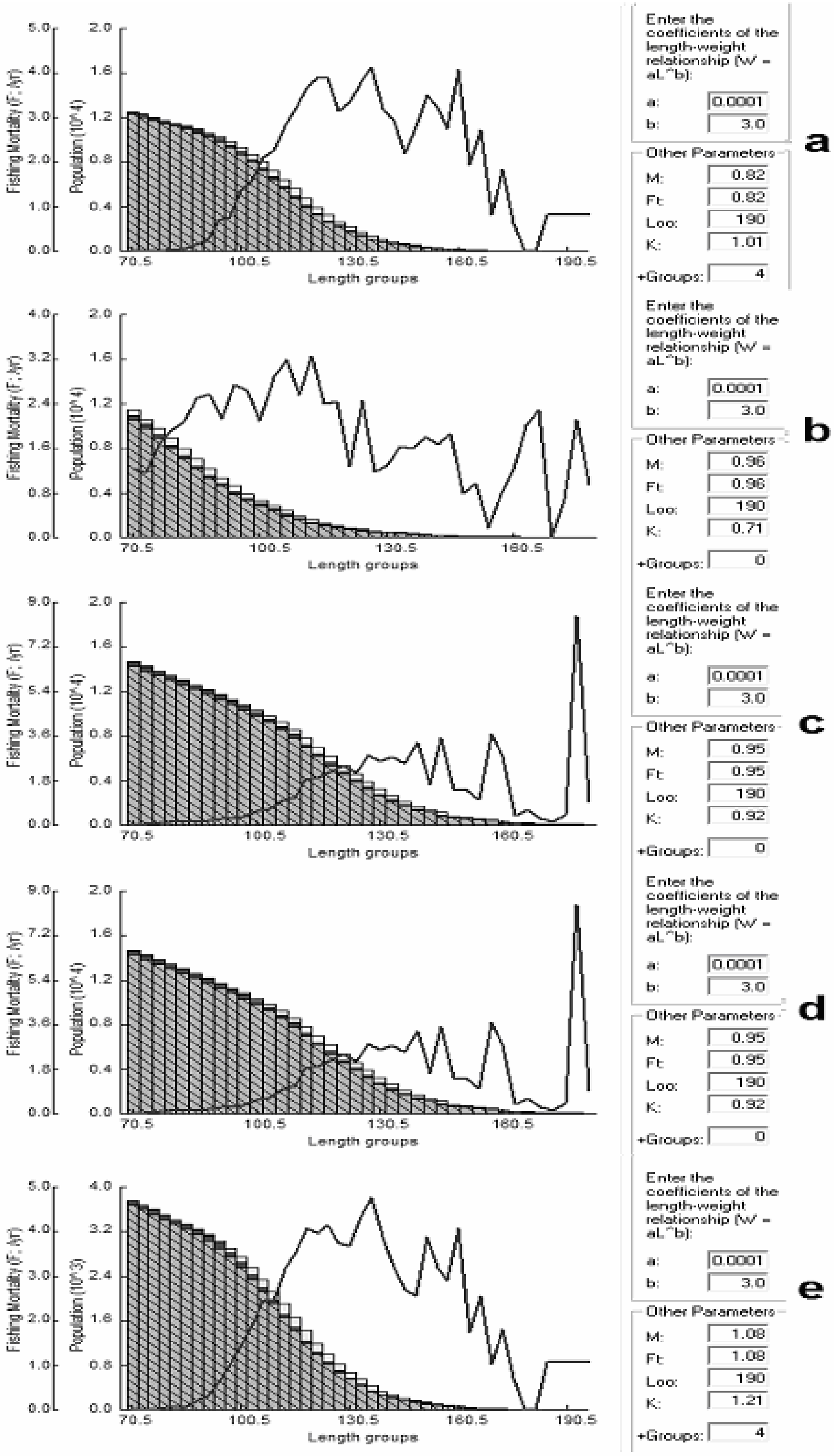

Figure 8. Virtual population analysis showing the impact of rising minimum catch size to 70 mm for the populations of *C. virginica* from the five beds of the three coastal lagoons, Tabasco, Mexico. Gray bars represent population size, black bars natural mortality, white bars fishing mortality and the line represents fishing effort.

Management proposal

As shown in the virtual population analysis in figure 7, the lack of control on minimum catch size has brought down the maximum and mean sizes of the populations with a consequent reduction in yield. A minimum exploitation size of 70 mm is recommended as stated in the official norm (NOM-015-PESC-1994). A measure that will be opposed by the fishermen as it would imply a process of sorting in the field with more hours of work. Considering the population structure found at all localities (Fig. 2), it should take about an extra two months to attain this goal.

Acknowledgements

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