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FISHERIES REGULATIONS BASED ON YIELD PER RECRUIT ANALYSIS FOR THE COMMON SOLE *SOLEA SOLEA* (SOLEIDAE) AT BARDAWIL LAGOON, MEDITERRANEAN COAST OF SINAI, EGYPT

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SUMMARY

Based on length frequency data, age and growth, mortality and exploitation and relative yield per recruit were examined for the common sole collected from Bardawil lagoon along two fishing seasons 2009-2010. A total of 2179 specimens were collected between April and December for the two fishing seasons and the examined individuals were aged between 1 and 6 years for length range of 12 – 39 cm Total length The von Bertalanffy growth parameters were identified (K= 0.33 year^{-1}, L_∞ = 44.36 cm and t_0 = -0.45 years). The rates of total mortality (Z) and natural mortality (M) were 2.49 and 0.66 year^{-1}, respectively. Rates of fishing mortality (F) = 1.83 year^{-1} and exploitation ratio (E) = 0.73 indicate that the population of this species is being heavily exploited. The estimated total length at first capture (L_c) was 17.06 cm. According to the relative yield per recruit analysis, the common sole stock in Bardawil lagoon is overexploited. It is recommended that the commercial fishery of Bardawil lagoon should be subjected to a total allowable catch, a maximum size limit should be implemented as well as all fishing techniques in the lagoon should be re-evaluated and the destructive ones must be prohibited.

Keywords: Bardawil lagoon; Soleidae; Solea solea; age and growth; per-recruit analysis; fisheries regulation.

INTRODUCTION

Soles (*Solea* spp. and *Pegusa* spp.) are common in the Mediterranean Sea, the Black Sea and along the Eastern Atlantic coasts from Great Britain to Senegal. These species are found in marine to slightly brackish environments such as coastal lagoons and estuarine areas.

Common sole *S. solea*, which locally known as Mousa is one of the most important commercial fish species in Bardawil lagoon. Despite the great importance of soleid species to the economy of the Egyptian fisheries, they have been sparsely studied. El- Gharabawy (1977) studied the taxonomy of soles in Egyptian Mediterranean waters. Kirolus (1977) studied the meristic characters and used the vertebrae in age determination of *Solea vulgaris* in Lake Qarun. Zaki and Hamza (1986) studied the reproductive biology and induced spawning of *Solea solea* in Egypt. Mosaad and El-Sayed (1991) studied the female reproductive cycle of *Solea vulgaris* from the North-Western part of the Red Sea. El-Gammal *et al.* (1994) estimated the mortality and yield per recruit of *S. solea* from Lake Bardawil. Ali (1995) studied the biology of the Egyptian flatfish of the genus *Solea*. Mehanna (2007) studied the rational exploitation and management of *Solea aegyptiaca* stock in the southeastern Mediterranean (Port Said region, Egypt). Mehanna *et al.* (2010) studied the population dynamics and management of *Solea aegyptiaca* stock in Bardawil lagoon. The present study fills the gap with information about age and growth and the mortality of the common sole population in Bardawil lagoon. This may help to suggest the required fisheries regulations to sustain and manage this valuable fish resource.

MATERIAL AND METHODS

Bardawil lagoon is a shallow (0.3 -3 m depth) and hyper-saline lagoon on the northern coast of Sinai (Fig. 1). It lies between Lat 33^o 0' East 31^o 9' North and covers an area of about 650 km^2, with about 85 km length and a maximum width of 22 km. It is separated from the sea by a sandbar that varies in width between 100 m and 1 km. Three openings connect the lagoon with the sea; two artificial openings at the West side (Boughaz I and Boughaz II) and one natural opening at the East (El-Zaranik). (Mehanna, 2006).

A total of 2179 individuals of *S. solea* (12-39 cm TL) were randomly collected from the commercial catch of the Bardawil lagoon through two fishing seasons, 2009-2010 (from April to December). Each fish was measured to the nearest mm for total length and weighed to the nearest 0.1 gram total weight. Sex, maturity stage and otoliths were taken for each specimen of *S. solea*. Otoliths were cleaned

and stored dry for later age determination. Annual rings on otoliths were identified and counted using optical system consisting of Nikon Zoom-Stereomicroscope and Heidenhain's electronic bidirectional read out system V R X 182, under transmitted light (Fish Population Dynamics Lab, NIOF, Suez). The total radius of each otolith and the radius of each annulus were measured to the nearest 0.001 mm. Regression analyses of otolith maximum radius on total length was calculated by the method of least squares.

To estimate the relation between total length (L) and total weight (W), the variables were log-transformed to meet the assumptions of normality and homogeneous variance. A linear version of the power function: $W = a L^b$ (where a and b are constant) was fitted to the data. Confidence intervals of 95% were calculated for the slope (b) to see if these were statistically different from 3.

The growth parameters of the von Bertalanffy growth model (L_∞ and K) were computed by fitting the Ford, 1933 –Walford, 1946 plot while the growth performance index was computed according to the formula of Pauly and Munro (1984) as ø = Log K + 2 Log L_∞. Total mortality coefficient (Z) was estimated by the analysis of catch curve based on length frequency data using the method of Pauly (1983). The natural mortality coefficient (M) was estimated as the geometric mean of two methods (Pauly, 1980 and Djabali *et al.*, 1993) and the fishing mortality coefficient (F) was estimated as F = Z - M. The exploitation rate "E" was estimated using the formula of Gulland (1971) as E = F / Z.

The length at first sexual maturity L_{50} (the length at which 50% of fish reach their sexual maturity) was estimated by fitting the maturation curve between the observed points of mid-class interval and the percentage maturity of fish corresponding to each length interval. Then L_{50} was estimated as the point on the X-axis corresponding to the 50% point on the Y-axis. The length at first capture L_c was estimated by the analysis of catch curve as described by Pauly (1984a, 1984b).

Relative yield per recruit (Y/R)' and relative biomass per recruit (B/R)' were estimated using the model of Beverton and Holt (1966) as follows:

$(Y/R)' = E\ U^{M/K}\ [1-(3U/1+m)+(3U^2/1+2m)-(U^3/1+3m)]$

$(B/R)' = (Y/R)'/ F$

where $m = (1-E)/(M/K) = (K/Z)$

$U = 1 - (L_c/L_\infty)$

Z, M and F are the total, natural and fishing mortality coefficients respectively E is the exploitation rate K is the growth parameter.

RESULTS AND DISCUSSION

Sole production and economic value:

The soles are one of the most important fish resources at Bardawil lagoon. In biomass, the mean annual catch is about 240 metric ton (2005-2010) which gives income of about eight million LE annually. The catch is sorted according to size into two categories, large or Mousa 1 and small or Mousa two and the market prices detected depending on the species size. The annual mean prices of small ones was about 20 LE, while the large ones was about 40 LE. It was noticed that the small sizes (9-20 cm) were dominant in the catch and represent about 63% of the total sole catch (Fig. 2). The decline of the sizes at first capture in recent years and the increase of juveniles in the catches could be attributed to the increasing of the exploitation effort on the small sizes.

Age and Growth:

Ages of *S. solea* at Bardawil lagoon were determined by counting the growth annuli on sagittal otoliths. The results revealed that the maximum observed ages were six years and the age group one was the most frequent group in the catch constituting 47% followed by the second group which contributed 42%.

It is found that *S. solea* attained its highest growth rate in length during the first year of life, after which a gradual decrease in growth increment was noticed with further increase in age. The only available work dealing with age determination of *S. solea* was conducted by El-Gammal *et al.* (1994) at Bardawil lagoon. Who found that the maximum lifespan was six years for length range of 9 – 28 cm total length.

Length – weight relationship:

The length measurement values of the individuals used for determining the relation between length and weight ranged from a minimum of 12 cm to a maximum of 39 cm, while weight values ranged from 14 to 655 g. The equation of length-weight relationship (Fig. 3) was as follows: $W = 0.0064\ L^{3.106}$ ($R^2 = 0.911$).

Positive isometric growth was observed for common sole, as the value of (b) was not deviated significantly from the value three (95% Confidence Interval = 3.0652-3.1468).

Growth parameters:

The constants of the von Bertalanffy's growth model was estimated and the obtained equations were:

For growth in length $L_t = 44.36\ (1-e^{-0.33(t+0.45)})$

For growth in weight $W_t = 835.02\ (1 - e^{-0.33(t+0.45)})^{3.106}$

Table (1) demonstrated the values of growth parameters obtained from the present study compared with those reported by other researchers for the same species. The difference in growth parameters between different localities can be attributed to the difference in size-composition of the species.

Growth performance index (ø):

The growth performance index (ø) of *S. solea* was estimated as 2.81. Based on the calculated growth performance index, the growth rate of *S. solea* in Bardawil lagoon is higher than that in other localities (Table 1).

Mortality and Exploitation Rates:

The total mortality coefficient (Z) was estimated as 2.49 year^{-1} (Fig. 4). The geometric mean value of natural mortality coefficient (M) was 0.66 year^{-1}, while the fishing mortality coefficient (F) was 1.83 year^{-1}. Exploitation rate (E) was computed as 0.73. Gulland (1971) suggested that the optimum exploitation rate for any exploited fish stock is about 0.5, at F_{opt} = M. More recent, Pauly (1987) proposed a lower optimum F that equals to 0.4 M. In the present study, F was higher than the two values of F_{opt} given by Gulland (1971) and Pauly (1987) indicating that the stock of *S. solea* in Bardawil lagoon is heavily exploited.

Length and age at first capture L_c and length at first sexual maturityL_{50}:

The length at first capture at which 50% of the fish are vulnerable to capture for common sole, *S. solea* was estimated at 17.06 cm (Fig. 5), while it attains its first sexual maturity at 19.9 cm. The estimated L_c was less than the L_{50}, which was further evidence of over-fishing. It was noticed that the majority of common sole caught in Bardawil lagoon were immature, therefore, in order to protect this species and to enable it to share at least for one time in reproduction, an urgent increasing in mesh size of used nets as well as the evaluation of all fishing techniques in the lagoon and prohibiting the dangerous ones must be done.

Relative yield per recruit and relative biomass per recruit:

The relative yield per recruit (Y/R)' and relative biomass per recruit (B/R)' of *S. solea* from Bardawil lagoon were estimated (Fig. 6). The results showed that the present level of exploitation rate of *S. solea* (E=0.73) was higher than that produces the maximum relative yield per recruit (E_{max} = 0.63). Also the present level of exploitation rate was higher than the exploitation rate ($E_{0.5}$ = 0.33) which maintain 50% of the stock biomass as spawning stock. To insure that at least 50% of the individuals can be maintained for spawning and recruitment, the present level of exploitation rate should be reduced from 0.73 to 0.33 (54.8%).

To determine the most appropriate length at first capture (L_c) for *S. solea* at Bardawil lagoon, the (Y/R)' was estimated using different value of L_c (Fig. 7). The results indicated that with increasing L_c a higher relative yield per recruit could be obtained at higher levels of exploitation. When L_c was raised to 20 cm (L_{50}) instead of 17.06 cm, the maximum (Y/R)' was obtained at exploitation rate of 0.73 which is the same as the present level. The corresponding value of $E_{0.5}$ was 0.35. This means that, the present L_c is not the optimum L_c for *S. solea* population in Bardawil lagoon and it must be around 20 cm.

It could be concluded that the *S. solea* stock in Bardawil lagoon is in a situation of overexploitation, and to sustain this valuable fishery resource some management regulations, including reduction of the present level of fishing mortality and increasing the length at first capture should be applied. This could be achieved through regulation of mesh sizes, proposing the total allowable catch from the lagoon and protecting the spawning stocks during their spawning season. Also, the destructive fishing gears such as kalsa and dahbana nets should be banned.

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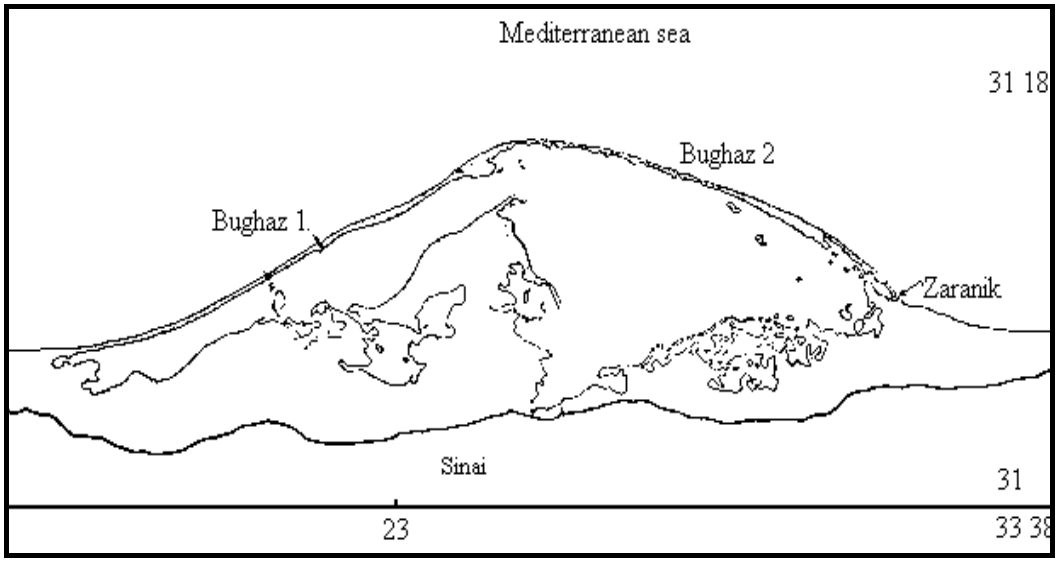

Fig. 1. Bardawil lagoon

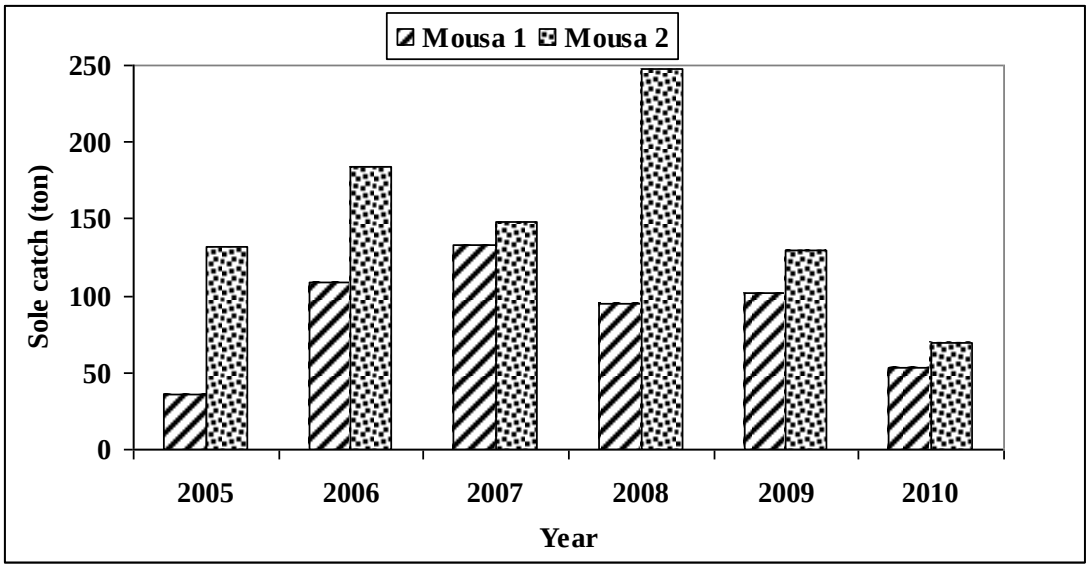

Fig. 2. Sole production in Bardawil lagoon during the last six years

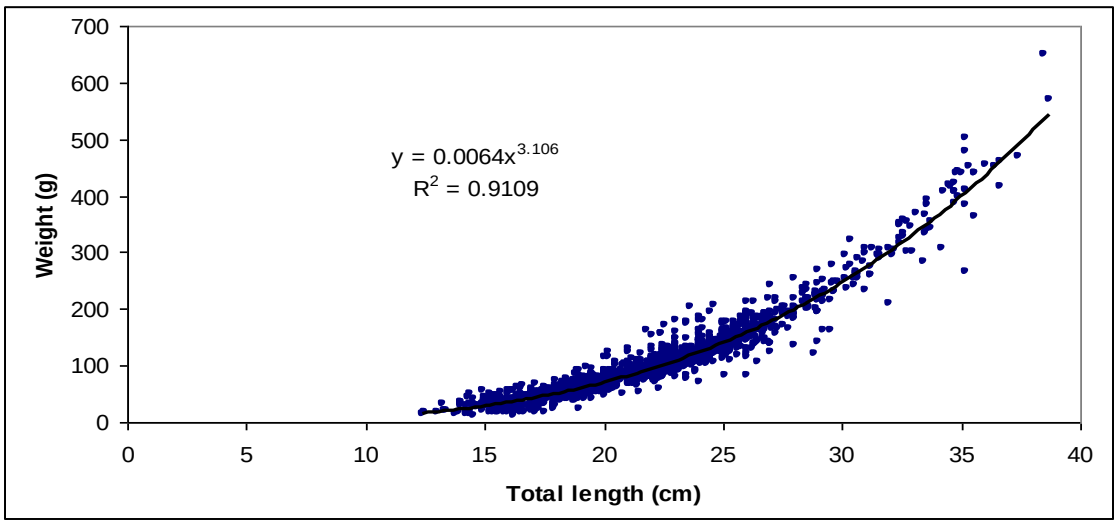

Fig. 3. Length-weight relationship of *Solea solea* in Bardawil lagoon

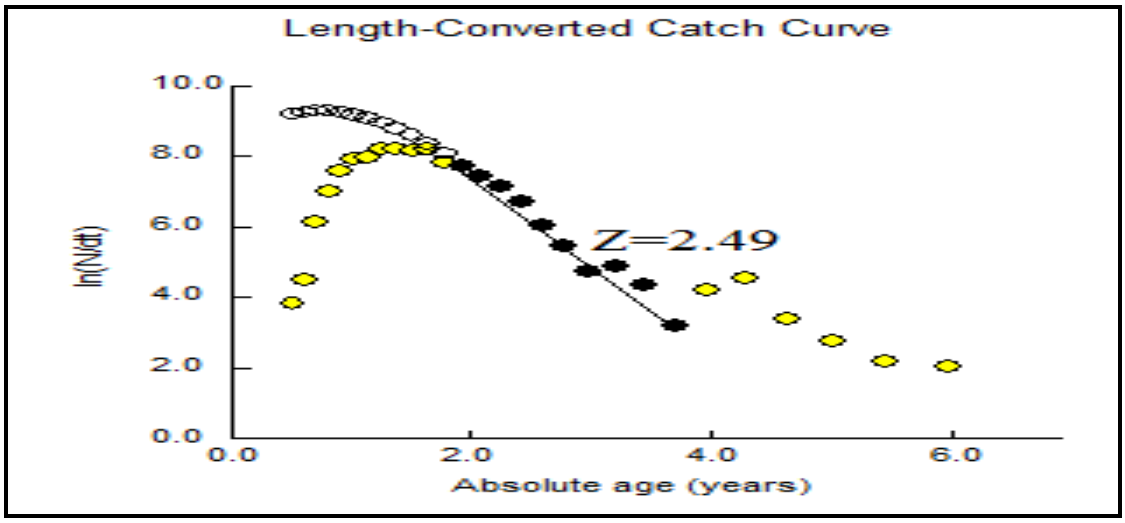

Fig. 4. Z-estimation for *Solea solea* from Bardawil lagoon

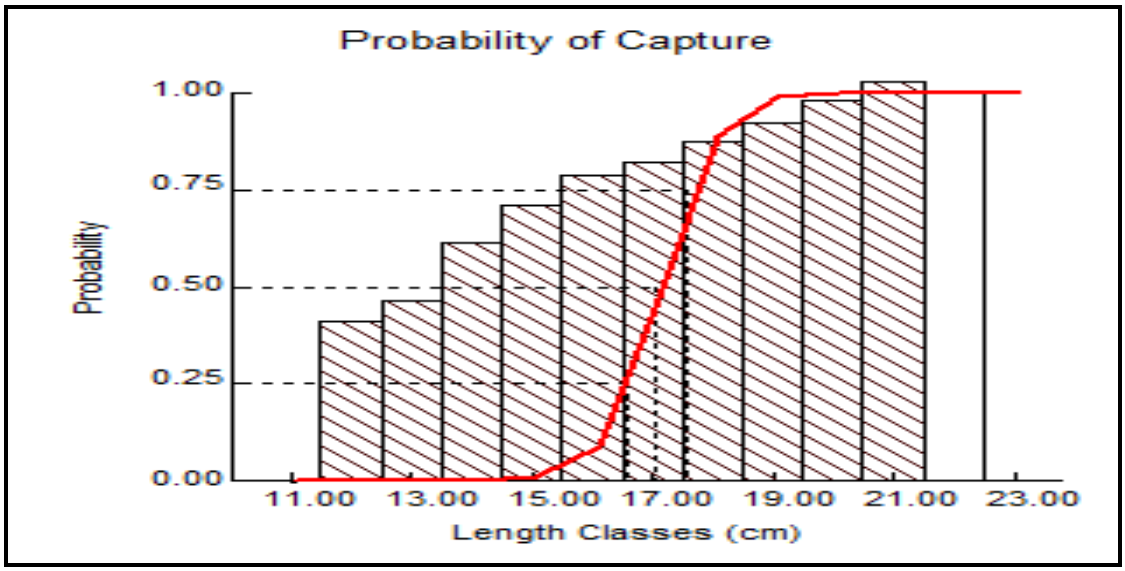

Fig. 5. Probability curve for estimation of L_c for *Solea solea* from Bardawil lagoon

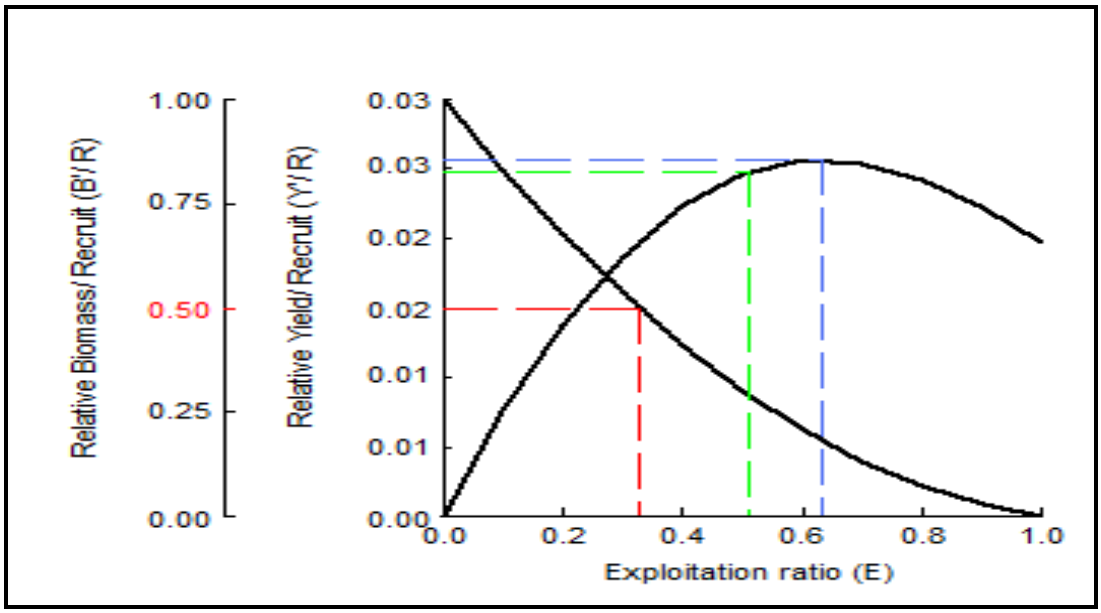

Fig. 6. Yield per recruit analysis for *Solea solea* from Bardawil lagoon

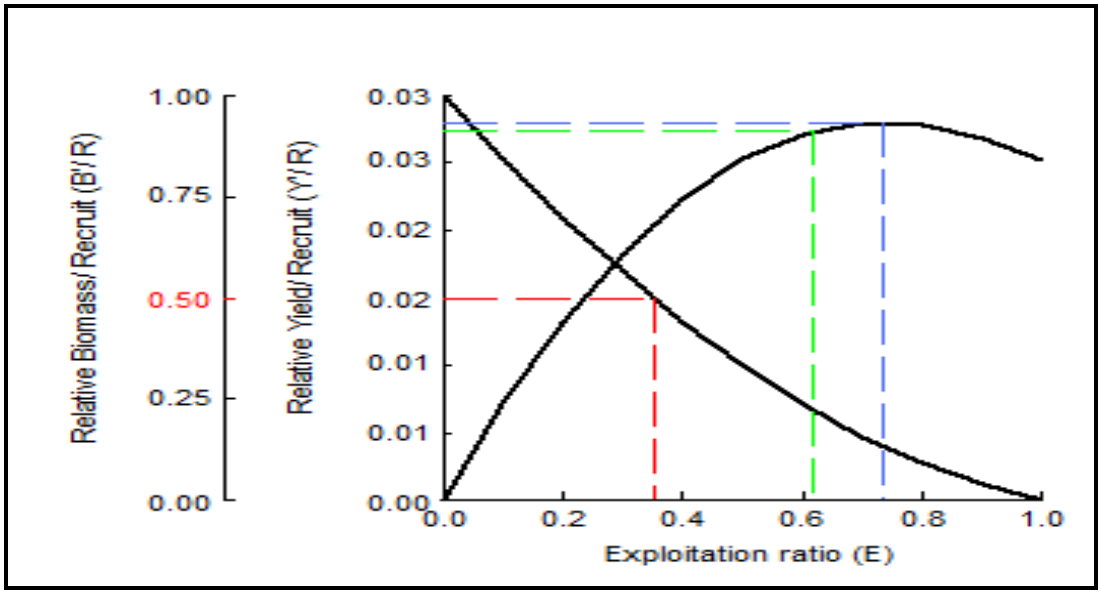

Fig. 7. Yield per recruit analysis for *Solea solea* from Bardawil lagoon using $L_c=L_{50}$

Table 1. Population parameters for the common sole from different localities

Locality	K (yr^{-1})	L_∞ (TL)	M	ø	Age (yr)	Author
North Sea						De Veen, 1976
	0.18	31.2		2.24		(1960)
	0.29	30.1		2.42		(1962)
	0.25	28.2		2.30		(1966)
Spain	0.22	46.4		2.68		Ramos, 1982
France	0.24	48.8		2.76		Vianet *et al.*, 1989
Lake Bardawil	0.33	30.04	0.21	2.47*	6	El-Gammal *et al*., 1994
Izmir Bay	0.28	34.7		2.53*		Hoflsucu *et al.*, 1999
Iskenderun Bay			0.5		8	Türkmen, 2003
Male	0.22	26.03				
Female	0.18	29.95		2.17*		
Bardawil lagoon	0.33	44.36	0.66	2.21*	6	The present study
				2.81		

* Ø estimated by the present authors

تنظيم المصايد بناءاً على تحليل الإنتاج لكل جيل لأسماك موسى *Solea solea* بمنخفض البردويل, ساحل البحر المتوسط , شمال سيناء

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إستنادا إلى بيانات تحليل الأطوال تم فحص العمر والنمو, النفوق ومعدل الاستغلال والإنتاج النسبي لأسماك موسى التي جمعت من مصايد منخفض البردويل خلال موسمي صيد ٢٠٠٩-٢٠١٠. وقد تم جمع ٢١٧٩ عينة بين ابريل حتى ديسمبر لمدة موسمين صيد وتم تحديد الأعمار مابين ١ و٦ سنوات لطول كلى في مدى من ١٢ إلى ٣٩سم كطول كلى. قيم معاملات النمو لفون بيرتلانفى كانت كالتالي: معامل النمو = ٠.٣٣ /سنة، الطول عند مالانهاية = ٤٤.٣٦ سم، والعمر الصفري = - ٠.٤٥ سنة. أمكن حساب معدلات النفوق على النحو التالي: النفوق الكلى = ٢.٤٩، النفوق الطبيعي = ٠.٦٦ و النفوق بالصيد = ١.٨٣ /سنة. وقد وجد أن معدل الاستغلال الحالي ٠.٧٣. وهو يدل على معدل استغلال عالى. حددت الدراسة الطول عند بداية الصيد بحوالي ١٧.٠٦ سم. وتبعا لتقدير الانتاج النسبى فى هذه الدراسة يدل على ان مخزون اسماك موسى ببحيرة البردويل تحت صيد جائر.

وتوصى الدراسة بضرورة إخضاع عمليات الصيد بمنخفض البردويل إلى كمية الصيد المسموح بها، وينبغي أن ينفذ الصيد عند الحجم الأقصى المسموح بصيدة فضلا عن إعادة تقييم تقنيات الصيد العاملة في البحيرة ، ويجب أن يحظر العمل بالحرف المدمرة.