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Stock Assessment and Potential Management of *Trichiurus lepturus* Fisheries in the Arabian Sea, Oman

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ABSTRACT

The present study was carried out to determine the mortality parameters, stock status and potential management of large head hairtail, the *Trichiurus lepturus*, Fisheries in the Arabian Sea. Length cohort analyses and yield per recruit were performed by simulating changes in fishing effort, in first catch length and closing season for trawlers. To carry out this analysis a data base including biological parameters, length frequency distributions and catches of *Trichiurus lepturus* in Oman according to fleet components has been established. Exploitation parameters of this species such as fishing mortalities and yield per recruit were estimated through the ANALEN software while natural mortality was calculated using Pauly equation. The results showed that: (1) the average fishing mortality rate is relatively high (0.5), but acts in majority on the adult fraction of the stock. The exploitation pattern differs, however, among fleets with some fleet components fishing in part immature Largehead hairtail (trawlers) and others largely the adult fraction of the stock (gill nets and hand lines). (2) An increase in total fishing effort would not lead to a significant long-term gain in total catch but the spawning stock biomass would decrease. This measure affects differently the fleet components. (3) A moderate increase of minimum length limit in catches would not affect, significantly, the long term yield and the stock spawning biomass. (4) A significant long term gain would be obtained when closing season (for trawlers) is regulated during April-June.

Key words: *Trichiurus lepturus*, mortalities, yield per recruit, métiers, interactions, Arabian Sea

INTRODUCTION

The Largehead hairtail, *Trichiurus lepturus* is a bentho-pelagic species occurring along continental shores and islands in tropical to temperate seas (Randall, 1995) it occurs between latitude 60°N and 45°S (Kowk and Ni, 2000). It is found from shallow inshore to 350 m depth, occurs in dense schools and reaches approximately 160 cm in length. This species is a pscivorous marine struggler (Costa *et al.*, 2009) and feeds on a variety of fishes, squids and crustaceans (Randall, 1995). *Trichurus lepturus* spawns later spring (April-May) and attains the size of first maturity at around 79 cm total length (Ben Meriem *et al.,* 2002a).

The total world catch of cutlass fishes is about 750.000 ton year^{-1}, essentially catches (80%) are reported from China (Claus, 1995). Also, in India this species is very important and its landing constitutes around 5% of the total marine fish production (Reuben *et al.*, 1997). The largehead hairtail is considered overexploited in the main fishing area in the Northwest Pacific, but its state of exploitation is unknown elsewhere (FAO, 2009).

The largehead hairtail is one of the most important species in the demersal Oman fisheries. The average annual catch reported for Oman is around 5.000 ton year^{-1} but fluctuated between 4.000 and 10.000 ton during the period 1994-2003 with a maximum catch of 10.000 ton in 1998 (Ministry of Agriculture and Fisheries, 2003). Along the coast of Oman, *T. lepturus* is caught by a traditional fishing sector using gillnets and hand-lines and by a commercial sector using demersal trawling. In Japan, this species could be catched by the set net (Matsuoka *et al.*, 2008).

The development of fishing fleets, especially trawlers (foreign boats, especially from Korea and Taiwan) in the mid of the 90's, in the Arabian Sea has generated some conflicts between artisanal and industrial fleets and raised concerns relating to resource management. Confront to this problem, the Ministry of Fisheries Wealth has decided in late 90's to limit the access of trawlers to the fishery and the number of trawlers operating in the Arabian Sea had been, substantially, reduced (from 60 to 5 trawlers) by the beginning of 2000. At the time, the ministry initiated a research project in order to carry out, for the first time, a stock assessment of the main seven species of the demersal fisheries in Oman; *T. lepturus* is one of these species (Ministry of Agriculture and Fisheries, 2003).

The aim of this study is to provide, the first detailed assessment of the fisheries for *Trichiurus lepturus* in the Arabian Sea by: assessing the exploitation status of the species (2) providing the necessary information required for stock assessment of the species and for management of its fisheries through the use of Length Cohort Analysis (LCA) and yield per recruit based on the demographic structure of the catch and biological parameters for the species. The sensitivity of the results to the natural mortality value has been also tested.

MATERIALS AND METHODS

Definition of fleet components: Five fleet components are identified in *T. lepturus* Arabian Sea fishery. Among them, only one fleet component is constituted by industrial large boats (>40 m) that use trawler to target this species; this component represents the large dominated fleet in the fishery; its contribution to the total catch exceeds 80%. The other four fleet components are, all of them, constituted by small artisanal boats of around 5.5-7.5 m (18-24 feet) length. The first component of these artisanal fleets uses hand lines and operates in Sharqia region (Fig. 1). The second of artisanal boats operates also in Sharqia region but exploits *T. lepturus* by gill nets. The third uses, also, gill nets to catch the species but operates in Al-Wusta region (Fig. 1). The fifth component fleet uses hand lines and exploits Dhofar region (Fig. 1). The five fleet components (métiers) were abbreviated as follows:

Industrial trawlers	: trawl
Artisanal boats of Sharqia region using gill nets	: shagn
Artisanal boats of Sharqia region using hand line	: shahl
Artisanal boats of Dhofar region using hand line	: dhohl
Artisanal boats of Al-Wusta region using hand line	: wusgn

The relative contributions to the total catch of these 5 fleet components are, respectively, 83, 12, 2, 2 and 0.1%.

Catch data and length frequency distributions: The catch per fishing gear data is obtained from the Omani Fisheries Statistics Department covering the period 2001-2002

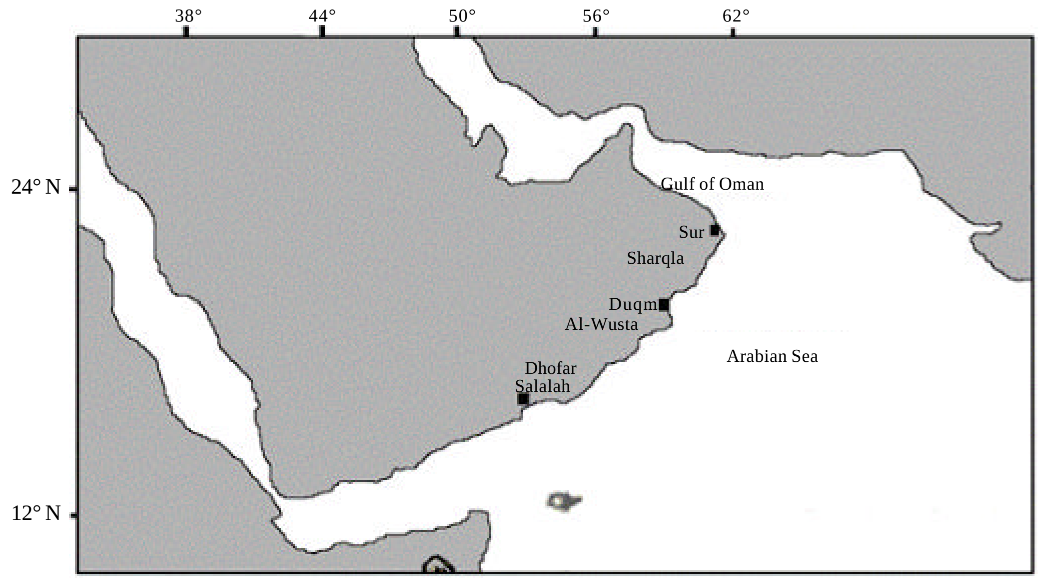

Fig. 1: Map of *Trichurus lepturus* fishing regions and sampling sites in Oman

(Ministry of Agriculture and fisheries, 2003). These data were collected for each type of fishing gear separately and from all defined fishing boats operating in either the artisanal fishery or the industrial fishery in the Arabian Sea. For each of the traditional fishing gears (fleets), a number of boats (5-15 boats) were sampled every month by data collectors who completed collecting forms about the fishing activities and catch from each boat and landing site. For the industrial, catch was recorded on board. Each trawl boat, one or two observers monitored the trawling and recorded the catch (landing) and fishing effort. It's important to underline that all trawlers in activity are monitored and sampled.

It's important to underline that catch is synonymous to landing because all catches are (including discards) recorded for this species.

The length frequencies of *T. lepturus* were acquired from the 5 fleet components (Table 1) that contribute to the exploitation of the species. The length distributions are based on length samples collected during the demersal fish project conducted by the Marine Sciences and Fisheries Center over a two year period between 2001 and 2002. Random samples were taken monthly for each fishing gear/technique utilized. The fish length sampling program covered the three regions which contribute to the traditional *Trichiurus lepturus* fishery: Sharqia, Al-Wusta and Dhofar (Fig.1); the total length measured to the nearest cm for more 200 randomly fish per month per site for each fleet component identified above. To estimate the demographic structures of the whole catches, length frequency samples were extrapolated to the total landing (catch) per fleet and fishing region (Table 1). In addition, quarter length frequencies (pooled from monthly data) were prepared separately for trawlers in order to simulate the impact of close season to this fleet.

Biological parameters: Parameter estimates used in the length cohort analysis are taken from the biological studies on the *T. lepturus* in Omani waters (fish project cited above); including Von-Bertalanffy growth curves ($L\infty$, K and t_0), length-weight relationships, length at sexual maturity (L_{50}), natural mortality (M) and Selectivity Factor (SF). The parameters estimates used in the present study are:

Table 1: Catch in number per fishing fleet of *T. lepturus* stock in the Arabian Sea, Oman

Length class	Shagn	Shahl	Wusgn	Dhohl	Trawl	Total
32					745	745
34					1381	1381
36					4653	4653
38					4034	4034
40					3339	3339
42					1381	1381
44					1138	1138
46					1253	1253
48					603	603
50					1140	1140
52					1322	1322
54					1801	1801
56					3817	3817
58		1238			4585	5823
60		2339		8	3946	6293
62	416	9080		59	4249	13804
64	3302	10318		303	6295	20218
66	4390	6466		587	5638	17081
68	4361	18022		398	11203	33984
70	5264	19993		631	35428	61316
72	3229	7429		180	34133	44971
74	3455	14857		87	43862	62261
76	4590	12840		29	54887	72346
78	2509	2344		130	81004	85987
80	4675		6	55	96147	100883
82	6197		24	38	84750	91009
84	5447		337	64	99871	105719
86	5103		489	114	110730	116436
88	8759		623	199	104570	114151
90	13462		1197	321	139140	154120
92	18247		1266	200	140690	160403
94	28140		1378	269	146530	176317
96	24192		1899	263	132200	158554
98	27399		2256	137	112130	141922
100	30779		2102	134	123230	156245
102	18636		3056	153	83040	104885
104	8821		3717	160	93592	106290
106	5246		3038	50	72573	80907
108	5111		3479	22	51447	60059
110	8206		2779	15	63503	74503
112	7349		2708	13	44745	54815
114	4752		1240	9	31369	37370
116	3296		1442	5	23952	28695
118	3199		1450	7	20901	25557
120	3783		945		18807	23535
122	2878		585		3948	7411

Table 1: Continued

Length class	Shagn	Shahl	Wusgn	Dhohl	Trawl	Total
124						
126						
128						
130	1018		270		2322	3610
	1047				321	1368
	2009					2009
	536					536

- **L∞ (asymptotic length):** 127 cm (Ben Meriem *et al.*, 2004)
- **K (growth rate):** 0.39 (Ben Meriem *et al.*, 2004)
- **t_0:** -0.9 (Ben Meriem *et al.*, 2004)
- **SF:** 3.5 (Gears and techniques in Oman artisanal fishery, unpublished data). This value is used for artisanal fishing gears
- **L_{50}:** 79 cm (Ben Meriem *et al.*, 2002a)
- **Length-weight relationship:** $W = 1.23X\ 10^{-6} * \text{Length}^{2.99}$ (Ben Meriem *et al.*, 2002b)
- **M:** 0.46 (present study)

Length cohort analysis: Gulland (1965), Jones (1981) and Sparre and Venema (1992) provide a clear description of this method. The analysis supposes that the stock is in equilibrium state: constant recruitment, F and M vectors. However, the exploitation pattern can vary slightly from one year to another according to the mobility of different fishing fleet components. Also, there is limited information on fish recruitment. To attenuate the effect of the eventual variation of the exploitation pattern and/or the recruitment intensity, an average of size distributions enlarged over a period of two years (2001 and 2002) were therefore used.

Length cohort analysis was applied to estimate the fishing mortality and abundance vectors by length class using the ANALEN software (Chevaillier and Laurec, 1990). The length (L+) from which calculations of fishing mortalities are initiated has been determined, according to the recommendations of Pereiro and Pallares (1984) who recommended using a «group+» around 70% of L∞. However, in this case the numbers of fish larger than 70% of L∞ are very represented in the catch length distributions so L+ was set to 122 cm in the present analysis. It is generally considered, that the value of Ft fixed for the group+ must be in continuity (similarly value) with the fishing mortalities of the previous size groups. The catches in number are estimated by fleet and results are also presented for the global balance and by fleet component.

Exploitation pattern: Each fleet component participating in the *T. lepturus* fishery has its own exploitation pattern. For each fish length, the fishing mortality fraction of the fleet j could be estimated according to the contribution of this fleet in the total catch. Considering C_i and F_i be the total catch of *T. lepturus* and fishing mortality of the length class i. $C_{i,j}$ and $F_{i,j}$ are the contribution of the fleet j. The estimation of the fishing mortality per fleet component is based on the following equations.

$$F_{i,j}/F_i = C_{i,j}/C_i$$

$$F_i = \sum_{j=1}^{n} F_{i,j} \qquad C_i = \sum_{j=1}^{n} C_{i,j}$$

where, n is the number of fishing fleet components participating in the exploitation of the *T. lepturus* fishery in Omani waters.

Yield-per-recruit model: This analysis, using the Jones (1974) model of yield per recruit, investigated the impact of modifications of the fishing effort, minimum (first) catch size and fish closing season regulations on the yield per recruit. It should be noted that, any modification of effort, first length in catches or period of closing season has an immediate impact (immediately) and long-term effects (sustainable) which occur after the new equilibrium conditions of the stock have established. Chevaillier and Laurec (1990) provide a clear description and mathematical equations used in this yield-per-recruit model.

Simulations: Changes in following parameters were considered in the simulations:

- **Modification of the fishing effort:** simulation variation in total effort in the same proportion for the different fleet components (métiers); the actual minimum length limit in catches (current size at first capture) is not modified (set constant at 32 cm)
- **Modification of current size at first capture:** the simulations suppose that the different fleets keep their actual level of fishing effort, while their exploitation pattern is changed by setting the fishing mortality to 0 for length classes lower than the simulated length
- **Fishing close season regulation:** This regulation limits, solely, the access period for trawlers to the fisheries accompanied by increasing of their fishing effort. These simulations have been tested because the fishery administration in Oman plans to develop the activities of trawlers (actually only 4-5 trawlers). Keeping their quotas (catch) unchanged, four management scenarios have been tested for trawlers period activities; these scenarios suppose a closing season for the trawlers between 3 and 6 months deferring in time. So, quarterly length frequencies have been prepared for these simulations. During closing season period, catches of trawlers are supposed equal zero and the corresponding length frequency is removed from the input database. The managers of the fishery sector in Oman require analyses of the following periods: July-December, October-December, April-June and April-September

RESULTS

Natural mortality: The value of natural mortality was obtained from the equation:

$$(\log(M) = -0.0066-0.279\log(L\infty)+0.6543\log(K)+0.4634\log(T))$$

Pauly (1980) with T indicating the mean temperature of the water; its value equals 25°C (Hydrographic of Oman, unpublished data). The Pauly (1980) equation gives a value of 0.46 for M; this value was adopted in the present stock assessment.

It is difficult to estimate with precision the natural mortality and none of the available methods can provide adequate precision to perform an analytical stock assessment; so, the value obtained in this study (0.46) should be considered as a preliminary estimation. In addition, a sensitivity analyses to this parameter was carried out on LCA results, especially in case of overestimation of M. For this analysis a value of 0.3 was chosen and tested as input estimates to highlight sufficiently the trends of the LCA results. Also, it is likely that the correct M is in this range (compared to values generally used for similar species).

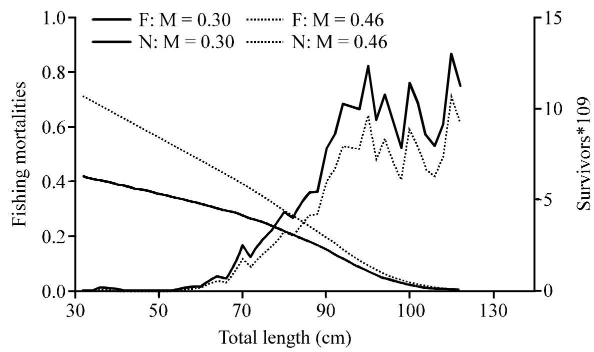

Fig. 2: Fishing mortality profiles and survivor numbers, using different values of M, for *T. lepturus* in Arabian Sea, Oman

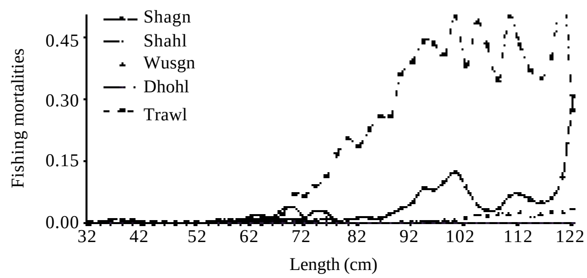

Fig. 3: Fishing mortality profiles for the different fishing fleet components of *T. lepturus* in Arabian Sea using M=0.46

Fishing mortality $\bar{F}$: Different terminal fishing mortalities (Ft) have been tested to estimate total fishing mortality (F) of *T. lepturus*. The most probable value of F_t was considered to be equal to 0.6; this value is closely to those of fishing mortalities of the previous lengths (Fig. 2). Total fishing mortality was on average 0.5 corresponding to the rate of exploitation F/Z = 0.6, but F differs significantly in relation to size. F was low (<0.2) for fish sizes lower than the size at which sexual maturity is attained (79 cm). Above this size F increased quickly and reached 0.5 for size range around 100 cm and reached its maximum value 0.6 for the largest size categories. The fishing mortality per fleet component is shown in Fig. 3. The trawl fleet contributed largely to the total fishing mortality of the stock. This fleet targeted largely adult specimens with high fishing mortalities in the length range 90-120 cm but it contributes to the catch of some younger fraction of the stock while fishing hand lines fleet of Sharqia region targeted exclusively the younger fraction of the stock that has not yet reached the length of first maturity. In contrast, the gill net fleets of Sharqia and Wusta targeted mainly the adult fraction of the stock.

To estimate the sensitivity of fishing mortalities to the M value used in the analysis, the value of M = 0.30 was tested. The results (Fig. 2) showed a similar trend of the pattern exploitation (the same shape oriented to adult fraction of the population) and a moderate sensitivity to this parameter. The mean value of F was nearly (0.40) of that found with M = 0.46.

Recruitment and stock biomass: Recruitment number was estimated as the number of fish in the smallest class size, in this case 32 cm, i.e., 6.3×10^9 individuals (Fig. 2). Figure 2 also shows the number of survivors per length class. The proportion of survivors larger than 79 cm (L_{50})

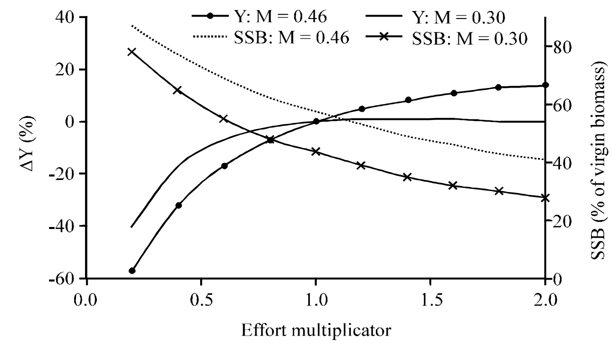

Fig. 4: Relative variations in long-term yield and SSB versus fishing effort, using different values of M, for *T. lepturus* in Arabian Sea, Oman

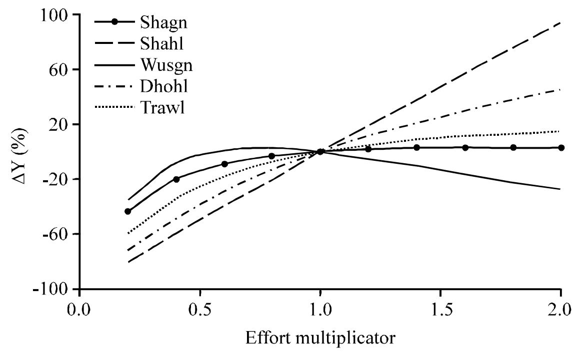

Fig. 5: Relative change in sustainable yield versus fishing effort per fishing fleet, using a value of M = 0.46, for *T. lepturus* in Arabian Sea, Oman

is around 55% of the recruits. The sensitivity of the survivors number to the M value used was substantial only for juvenile fraction.

Yield per recruit and exploitation pattern

Effort regulation: Assuming a linear relationship between F and effort (f), any increase of the actual fishing effort (effort multiplicator =1) would not, in the long-term, lead to a significant increase of the long term production (Fig. 4), when the minimum length limit is not modified. An increase of 50% of the actual fishing effort would lead to a gain of only 8% in long-term yield. A reduction of the effort would, in the long-term, lead to a loss of the production, e.g., an effort reduction of 50% would result in decrease of 30% in yield.

In order to diagnosis the sensitivity of the yield per recruit to the M, A value of M = 0.3 is tested. In this case, a moderate increase of fishing effort would not lead to a modification of the long term yields but if effort is substantially increased yields could be negatively affected. Also, the level of the Stock Spawning Biomass (SSB) decreases from 78% to around 28% of the virgin SSB. So, no increase of actual effort should be considered.

An increase in total effort would lead to long-term gains for hand lines fleet components of Sharqia and Dhofar region (Fig. 5) while gill net fleets of Al-Wusta and Sharqia loss for any increase of effort; trawl fleet kept their actual catch.

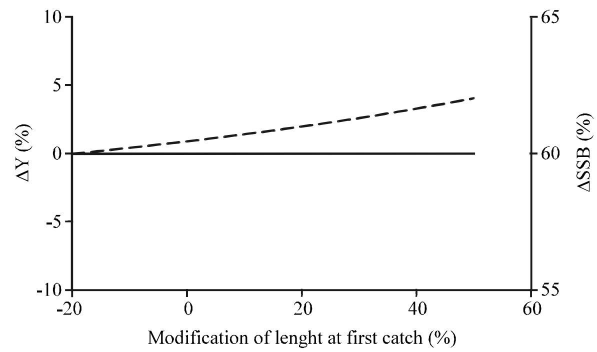

Fig. 6: Changes in long-term yield (%) and SSB (%) versus minimum length at first capture of *T. lepturus* in Arabian Sea, Oman

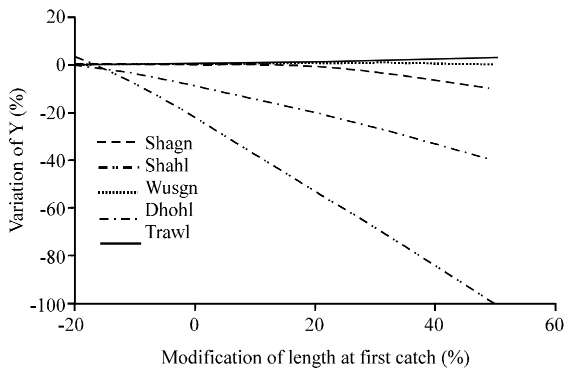

Fig. 7: Relative change in sustainable yield per fishing fleet versus minimum length at first capture, using different values of M, for *T. lepturus* in Arabian Sea, Oman

Size at first capture regulations (Minimum length limit): Keeping the actual fishing effort unchanged, a moderate change (increase/decrease by 20%) in the length at first capture would not affect significantly the long term yield (Fig. 6). If the minimum length limit is substantially increased (50%) the sustainable catch would not be affected but the long term gain in stock spawning biomass of such measure would be significant (Fig. 6).

The increase of minimum length limit would not lead to a major modification of the long-term catches of trawl fleet and gill net fleets of Al-Wusta and Sharqia regions while this regulation would lead, in the long-term, to significant losses for the hand lines fleets of Dhofar and especially for Sharqia (Fig. 7). On the other hand, the two value of M tested in this analysis (0.46 and 0.30) lead to similarly conclusion.

Close seasons regulations and increase fishing effort of trawlers: As a result of the low level of fishing effort for the trawlers (only 5 trawlers in activity), a closed season does not seem to have any significant impact on the total long-term catches. However, if effort is considerably increased, closing season during April-June would lead to a significant gain in the total catches (Fig. 8a). Also, this regulation would, in the long term, lead to the highest gain for the artisanal and industrial fleets (Fig. 8b, c).

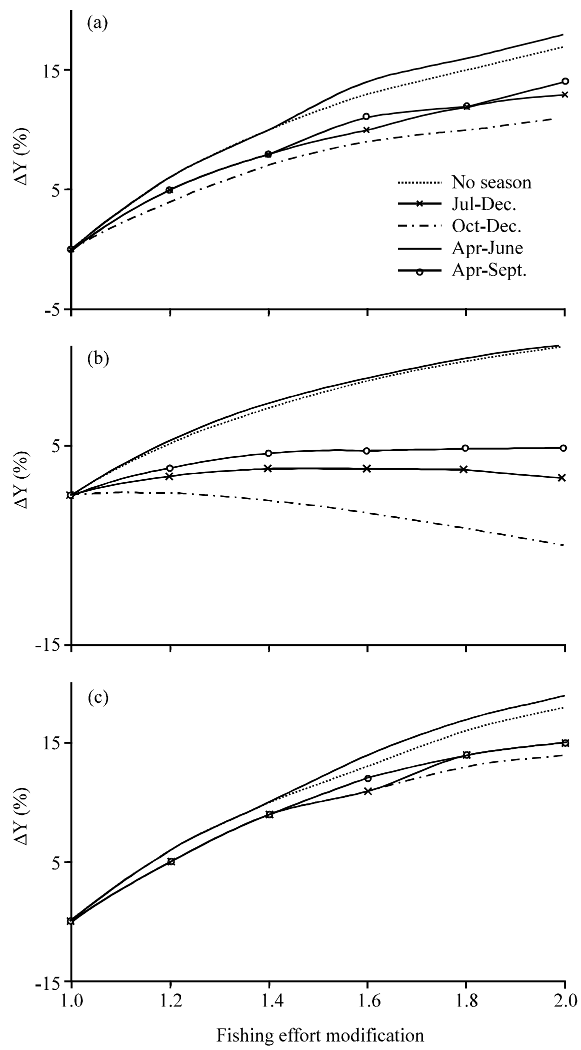

Fig. 8: (a) Impact of seasonal ban regulation to trawlers on total long-term catches of *T. lepturus* in Arabian Sea, Oman (M = 0.46), (b) impact of seasonal ban regulation to trawlers on artisanal long-term catch of *T. lepturus* in Arabian Sea, Oman (M = 0.46) and (c) impact of seasonal ban regulation on trawlers long-term catch of *T. lepturus* in Arabian Sea, Oman (M = 0.46)

DISCUSSION

Estimation of M rises some problems in tropical multispecies fisheries where time series data of total mortality and effort are generally not available; so the value obtained in this study (0.46) should be considered as a preliminary estimation and a sensitivity analyses to this parameter was carried out on LCA results, especially in case of overestimation of M.

A long time ago, Narasimham (1983) indicated a value of M = 0.7 for this species along the Andhra coast (India). More Later, Chakraborty (1990) indicated a value of M as 1.05 and Thiagarajan *et al.* (1992) estimated a value of M (around 1.1) for this species in the east and West coast of India. Recently, Abdussamad *et al.* (2006) indicated a value of 0.98 for this species in East coast of India. In coast of Brazil Marizilda (2006) estimated values of M substantially lower

(0.20-0.29) then those found in India waters. The M value estimated for the *T. lepturus* in Oman is 0.46; it could be considered as intermediate between the 2 extreme values. It`s important to underline that each estimation is properly to the species in its geographic area and relatively to the data and method used; also the status of the fishery influenced this parameter. So, the different values could not be compared and each of them is specific to the considered stock and constitutes an added data.

The Mean fishing mortality of *Trichiurus lepturus* stock is moderate highly (F = 0.5). The values provided on others stocks of *T. lepturus* varied from a minimum of 0.3 to a maximum of 3.34. In Fact, Narasimham (1983) had shown a value of F = 0.3 in Kakinada (India). More later (from the 90's to late 2000's). The studies carried out on this species in India Waters showed a higher value of F which varies from (0.99 Somvanshi and Antony (1989); 0.91 Chakraborty (1990); 2.2 Thiagarajan *et al.* (1992); 3.34 Abdussamad *et al.* (2006). The high estimates F explains the intensive exploitation of this species.

The fishing mortality vector differs, substantially, from one fleet component to the other; it definite, then, a sequential aspect of the fishery. However, the global pattern exploitation seems target, in general, the adult fraction of the stock. At the opposite of this exploitation strategy targeting adult fraction, many others stocks are exploited at early stage of their life and had lead to growth overfishing. Appanasastry (1984) showed that 61.3% of the trawlers catches of *T. lepturus* consisted of 0+ year class fish and 32.3% of 1+ year class fish. In the same context, El-Ganainy and Sabra (2008) showed that the juvenile individuals of the filfish stock are the target of the fishery. Chen and Zhu (2008) indicated that the small-sized fish accounted for most of the yield in Lake Taihu (China). Gabral-Solis and Espino-Barr (2007) indicated that a greater fishing yield could be obtained by increasing the length at first catch of Mugil stock. So, the fishing profile aqpplied on the *T. lepturus* in Arabian Sea should be preserved by keeping the actual selectivity of the fishing gears used in the fishery. Also, it could be improved in order to avoid the juvenile individuals by conversion of the fleet component fishing juveniles (hand lines in Sharqia region). This action aims to protect immature fish in order to utilize the growth potential, which is high in the first stages of the species lifespan.

The long-term yield according the fishing effort is not very sensitive to the natural mortality value used in the analysis. For the two value of M tested (M = 0.46 and 0.30), the stock seems near of the fully exploitation status. In the two simulations with different M values, the stock spawning biomass would decrease substantially if the effort is increased considerably. This measure affect negatively fleet component targeting adult fraction of the population. So, any increase of the actual effort should not be recommended.

A moderate increase of the size at first catch doesn’t seem lead to a significant impact on the long-term yield of the stock. So, this measure is not actually recommended as management option for the *T. lepturus* fisheries in Oman.

The fishing close season regulation for trawlers would not affect in the long-term the long-term yield of the stock, but if their effort is, considerably, increased the appropriate season would be April-June.

At the opposite of our results, the analysis of yield per recruit carried out by Abdussamad *et al.* (2006) showed that *T. lepturus* in east coast of India is under heavy fishing pressure. Also, the FAO (2009) indicated that the *T. lepturus* is considered overexploited in the main fishing areas in the North West Pacific, but its state of exploitation is unknown elsewhere.

The healthy status of the *T. lepturus* stock in Arabian Sea is resulting of its pattern exploitation oriented, essentially, on the adult fraction of the stock so it should be preserved and hand line fleet of Sharqia should be controlled in order to avoid the growth overfishing. If fishing pressure is set to increase, it will be affect negatively the fleet targeting adult fraction of the stock and then will affect negatively the pattern exploitation of the fishery. No increase of effort should be envisaged but only reallocation of effort between fleet components (effort increase of fleet targeting exclusively adult fraction). Also, this management measure should be accompanied by a monitoring system of the resources status and an economical study should, previously, be carried out to argument the sustainability of economic profitability of such effort increase. A more elaborate estimation of natural mortality is recommended to improve this first assessment.

In conclusion, it should be noted that the present results on stock assessment of *T. lepturus* stock in Arabian Sea constitute an added data on the status of the species in the world and provide for the first time a management options of its fishery in the Arabian Sea.

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