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Factors affecting purse seine catches: an observer-based analysis

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Abstract

A total of 72 fishing trips were carried out by fishery scientists onboard a purse seiner in the Pagasitikos Gulf (Greece) in an attempt to identify factors affecting total and individual species' catches. As trawling is completely banned in the study area, purse seining is the main fishing method. It was found that month, water depth and fishing area affected total and Trachurus spp. catches of the purse seine fishery, with month and water depth alone explaining 77.8% and 6.4% respectively of the total variation of the data. Significant interactions observed indicate that the fluctuations in total catches differed by month and fishing area as well as fishing area and water depth. Fishing area and water depth interaction were found to affect Trachurus spp. catches significantly. Results also suggested that generalized linear modelling of the purse seine catches can be used to obtain representative abundance indices by reducing the observed variability. Fishery scientists' onboard observations alongside fish market recordings during the same period confirmed that each fisher has developed an individual decision-making fishing process. Fisher's trip choice behaviour was found to be modulated by several factors, such as distance of fishing grounds from the port, market demands (both in terms of species and market prices), weather conditions, alternative fishing strategies, previously gathered information, economic pressure and personal skills. These findings are discussed in the light of the need to incorporate additional quantitative information to stock abundance estimates if improved fisheries management scenarios are to be advanced.

Keywords: Purse seiner; Catches; Mediterranean; Fisher; Abundance.

Introduction

In the absence of research surveys, estimation of fish abundance relies heavily on collecting representative data from the commercial fishing fleet. The main drawback of the official Greek fisheries statistical system, in particular catch and effort statistics, is that utilizes a problematic census method, i.e. fishers are asked to complete a monthly statistical questionnaire referring to their catches and activities during the previous month. The estimated fishing effort derives from a number of factors such as the number of boats, the engine horsepower (HP) and the vessel tonnage and the number of fishers. This system has many deficiencies, such as errors of memory, inappropriate survey procedures, biased estimations and processing operations and poor coverage of fishing effort (STERGIOU *et al.*, 1997a; PAPACONSTANTINOU & FARRUGIO, 2000).

Purse seining constitutes one important fishing method in the Mediterranean

Sea. In Greece, the purse seine fleet consists of about 281 units with an average gross tonnage (GT) of 36.9 and an average horsepower (HP) of 176.3 (KAPANTAGAKIS, personal communication). Management regulations currently in force include mesh size regulations (>14 mm stretched), technical measures such as closed seasons/areas and fishing prohibitions within specific distances from the coast (100 m).

The Pagasitikos Gulf (Fig. 1) is a semi enclosed bay in the western Aegean Sea that constitutes an interesting study area as a) trawling is completely banned in the area and fishing is mainly conducted with purse seiners b) the small number of purse seiners operating exclusively in the Gulf (only 3) facilitates their monitoring, and c) due to the absence of any discards, landings are identical to catches.

In the present study we analyzed the total catches and the catches of two commercially important fish species [i.e. horse mackerel, *Trachurus trachurus* (L.) and Mediterranean horse mackerel, *Trachurus mediterraneus* (Steindachner)] of a purse seiner in the Pagasitikos Gulf during 2002 and 2003. In Greece, *Trachurus* spp. are target species for purse seining with an average catch of more than 6.5% of the total Greek yield (NSSG, 1989-1995). Reported catches are known to be biased for the reasons mentioned above. In order to obtain more realistic catch estimates it was decided to place fishery scientist observers onboard a purse seiner operating in the Pagasitikos Gulf. This study is the first attempt to a) analyse commercial catches from the Greek purse seine fishery using generalized linear models (GLMs) in order to identify the factors affecting pelagic commercial purse seine catches and to improve the applicability of catch and effort data to assess abundance trends and b) collect onboard qualitative information on factors modulating fishers' trip choice behaviour in the multispecies Greek purse seine fishery.

Materials and Methods

Study area

Purse seining is one of the most important fishing methods in the Pagasitikos Gulf since trawling is prohibited (STERGIOU & POLLARD, 1994; NCMR, 2000). The inflow of marine fishery products into the market is mainly from purse seiners (61%) and small inshore boats (39%) (STERGIOU *et al.*, 1997b). Closed season regulation on the Gulf extends from 1st December to the end of February.

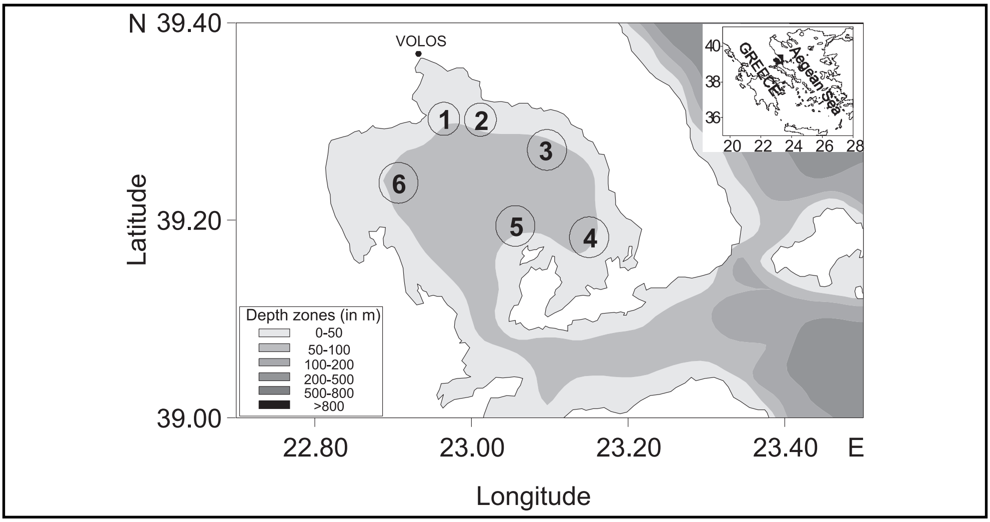

Fig. 1: Map of the study area (Pagasitikos Gulf).

The total number of purse seiners registered with the Volos port authorities is 14 boats with an average gross registered tonnage (GT) of 44.3 and an average horsepower (HP) of 297.1. The purse seiners operate only during the night (approximately from 19:00 to 06:00). The smaller seiner vessels, which are three, operate only inside the Gulf.

Data collection

The data used for the analysis were the total catches and the catches of two commercial fish species (Mediterranean horse mackerel and horse mackerel) of a purse seiner operating in the Pagasitikos Gulf during two fishing periods from March 2002 to November 2002 and from March 2003 to November 2003. Data were recorded by the authors serving as fishery scientist observers onboard the purse seiner during the fishing operations (one fishery scientist observer per trip). The data collection scheme included four days of sampling (randomly chosen) on a monthly basis. The fishery scientist observers managed to attend a fishing operation once in a week so as to succeed objectivity in the sampling procedure. A total of 72 trips were conducted during the study period with fishery scientists onboard. A reasonable co-operation with the fisher was developed that enabled the collection of the required data. The data recorded for each trip were: date of the survey, fishing area, water depth, species composition and weight of each species and total weight of the species fished. It should be mentioned that the factor of water depth corresponds to the depth of the water column and not to the depth of the sampling station. The fishing areas are represented in Figure 1. In the absence of a Global Position System (GPS) instrument, each fishing area represents not a hole but rather a small area of approximately 50 m.

The discards of each fishing operation were negligible due to the proper management handling of the fisher. Local market demands drove the fisher to target species which would meet the expectations of the local market and give him the best selling prices. Thus, the recorded landings during the operations represent the catches of the purse seiner.

Analytical methods

Trends of catches (i.e. total and catch for each of the two species) were analyzed as a function of month of fishing (merging the two year series), fishing area and water depth using Generalized Linear Models (GLMs, McCULLAGH & NELDER, 1989; CHAMBERS & HASTIE, 1992). Prior to the statistical analysis the data were tested for normality and homoscedasticity. Total catches were found to be approximately lognormally distributed; this variable was therefore log transformed to stabilize its variance and to linearize the relationships. The catches of the two *Trachurus* spp. catches were found to be normally distributed. The analyses were performed by applying the routines contained in the SPLUS programming environment. A GLM provides a way to estimate a function of the mean response (called a link function) as a linear function of the values of some sets of predictors. The GLMs general form is given by McCULLAGH & NELDER (1989):

$$E[y] = g^{-1}\left(\beta_0 + \sum_k \beta_k x_k\right) \qquad (1)$$

where E[y] is the expected value E of the response of a random variable y (here catches), $g()$ is the link function defining the relationship between the response and the linear predictor,

$\beta_0 + \sum_k \beta_k x_k(x)$, β_o is an intercept term, x_k is the value of the kth spatial covariate and $\beta_k()$ represents linear functions of the k covariates (McCULLAGH & NELDER, 1989; CHAMBERS & HASTIE, 1992). In GLMs the standard linearity assumption is extended to include any underlying probability distribution from the exponential family (including the Poisson, gamma, normal and binomial distributions). Since the probability distribution of the total catches was lognormal,

Table 1
Taxonomic composition and relative frequency of commercial purse seine catches during 2002 and 2003.

	Family	Scientific name	Relative frequency (%)
Cephalopods			
	Lologinidae	*Loligo vulgaris*	4.831
		Todarodes sagittatus	1.448
Fish			
	Carangidae	*Caranx rhonchus*	7.729
		Seriola dumerili	0.489
		Trachurus mediterraneus	15.459
		Trachurus trachurus	14.976
	Clupeidae	*Sardinella aurita*	10.628
		Sardina pilchardus	0.965
	Engraulidae	*Engraulis encrasicolus*	5.314
	Mugilidae	*Mugil cephalus*	1.932
	Pomatomidae	*Pomatomus saltator*	6.763
	Scombridae	*Scomber colias*	8.213
	Serranidae	*Epinephelus aeneus*	0.482
	Sparidae	*Boops boops*	6.280
		Oblada melanura	2.415
		Sarpa salpa	1.449
		Sparus aurata	1.449
	Sphyraenidae	*Sphyraena sphyraena*	9.178

we used Gaussian error distribution on the log-transformed total catches following an examination of diagnostic plots of the deviance residuals (McCULLAGH & NELDER, 1989). For the two *Trachurus* spp. we used Gaussian error distribution on their catches in a similar manner. For regression models, residuals are used to assess the importance and relationship of a term in the model, as well as to search for anomalous values. For GLMs there are two additional tasks: that of assessing how well a model fits and that of verifying the form of the variance as a function of the mean response (VENABLES & RIPLEY, 1994). There was no indication of serious violations of the model assumptions, thus the choice of error distributions was considered adequate (VENABLES & RIPLEY, 1994).

All available variables and their first order interactions were initially included in each of the three models. Backward stepwise elimination was used to select a set of significant covariates (McCULLAGH & NELDER, 1989). Analysis of deviance compared models by analyzing changes in deviances relative to the changes in degrees of freedom. To evaluate these differences and compare the models, approximate F-tests based on the approximate degrees of freedom and the corresponding percentage point of the F-distribution were computed, as suggested by CHAMBERS & HASTIE (1992) and VENABLES & RIPLEY, 1994.

The final model for total catches was of the form:

glm [(log) total catches = month + fishing area + water depth + month: fishing area + fishing area:water depth].

The final model for Mediterranean horse-mackerel was of the form:

glm (catches = month + fishing area + water depth + fishing area:water depth + month: fishing area:water depth).

The final model for horse mackerel was of the form:

glm (catches = month + fishing area + water depth + fishing area:water depth).

Results

A total of 18 species were recorded during the study from the purse seiner: 16 fish and 2 cephalopods (Table 1). The two *Trachurus* spp. were chosen to be analysed for two reasons a) the relative frequency of these two species was high (15.4 % and 14.9 %, respectively) and b) all skippers operating their vessels permanently in the Pagasitikos Gulf consider them as two of the most important target species. This was also evidenced from our personal experience gained through the fishery scientist observers who followed one of these vessels throughout the study period.

Monthly total catches (kg ±SD) are presented in Figure 2. These catches differed considerably between months with the highest values observed in March and the lowest

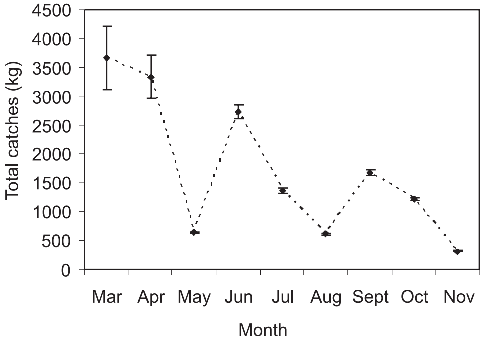

Fig. 2: Averaged monthly variations (error bars represent standard deviation) of total catches (kg) observed in the Pagasitikos Gulf during the studied period, 2002-2003.

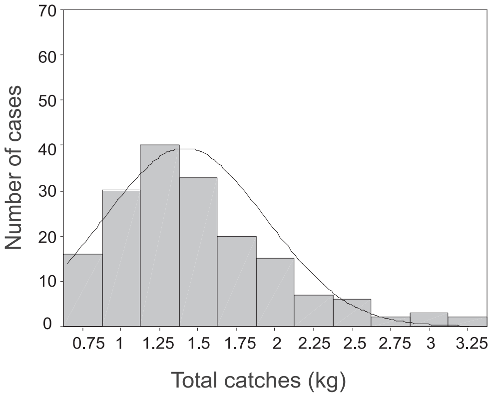

Fig. 3: Frequency distribution of the logged total catches.

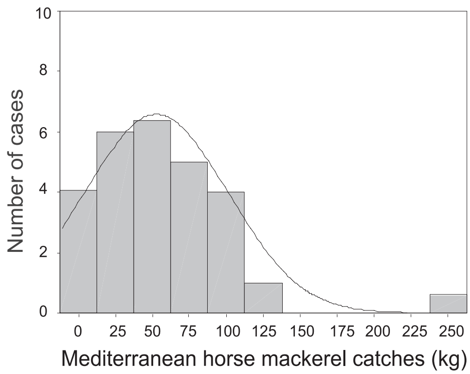

Fig. 4: Frequency distribution of the Mediterranean horse mackerel (*Trachurus mediterraneus*) catches.

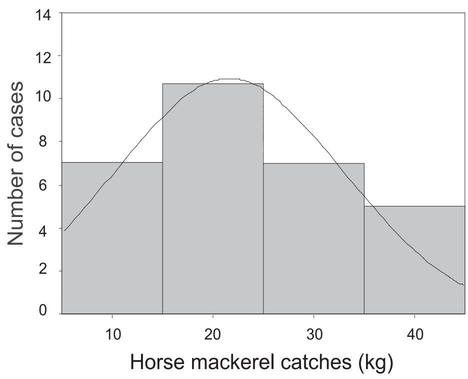

Fig. 5: Frequency distribution of horse mackerel (*Trachurus trachurus*) catches.

Table 2

Analysis of deviance table and significance values (*P*-levels) for all GLM covariates and their interactions of the final models fitted to total catches, Mediterranean horse mackerel and horse mackerel catches. All available variables and their first order interactions were initially included in the model. The (:) sign denotes interaction.

Source of variation	Deviance	Residuals Deviance	F	*P*	% Explained
Total catches					
Null		467.2			
Month	363.6	103.6	1391.6	0.00	77.8 (87.7)
Fishing Area	9.8	93.9	37.4	0.00	2.1 (2.4)
Water Depth	30.1	63.7	115.3	0.00	6.4 (7.3)
Month : Fishing Area	4.8	59	18.2	0.00	1.0 (1.1)
Fishing Area : Water Depth	6.2	52.8	23.7	0.00	1.3 (1.5)
Total explained		414.5			88.7 (100)
Mediterranean horse mackerel catches					
Null		161325			
Month	83147.1	78177.9	43.9	0.00	51.5 (75.5)
Fishing Area	3429.7	74748.2	1.8	0.19	2.1 (3.1)
Water Depth	9294.6	65453.5	4.9	0.03	5.8 (8.4)
Fishing Area : Water Depth	9465.5	55988.0	5.00	0.03	5.9 (8.6)
Month : Fishing Area : Water Depth	4874.9	51113.1	2.57	0.1	3 (4.4)
Total explained		110211.9			68.3 (100)
Horse mackerel catches					
Null		18300			
Month	12650.7	5649.3	94.9	0.00	69.1 (86)
Fishing Area	325.9	5323.4	2.4	0.12	1.8 (2.2)
Water Depth	759	4564.4	5.7	0.02	4.1 (5.2)
Fishing Area : Water Depth	965.2	3599.1	7.2	0.01	5.3 (6.6)
Total explained		14701			80.3 (100)

ones in November (Fig. 2).

The frequency distribution of the total catches (log-transformed) and both *Trachurus* spp. approximated a normal distribution (Figs. 3-5). Assessment of each model's fit through diagnostic plot revealed the errors to be normally distributed since the ordered residuals clustered along the superimposed normal quantile line (Figs. 6A-8A).

In Table 2 the significance values of GLM

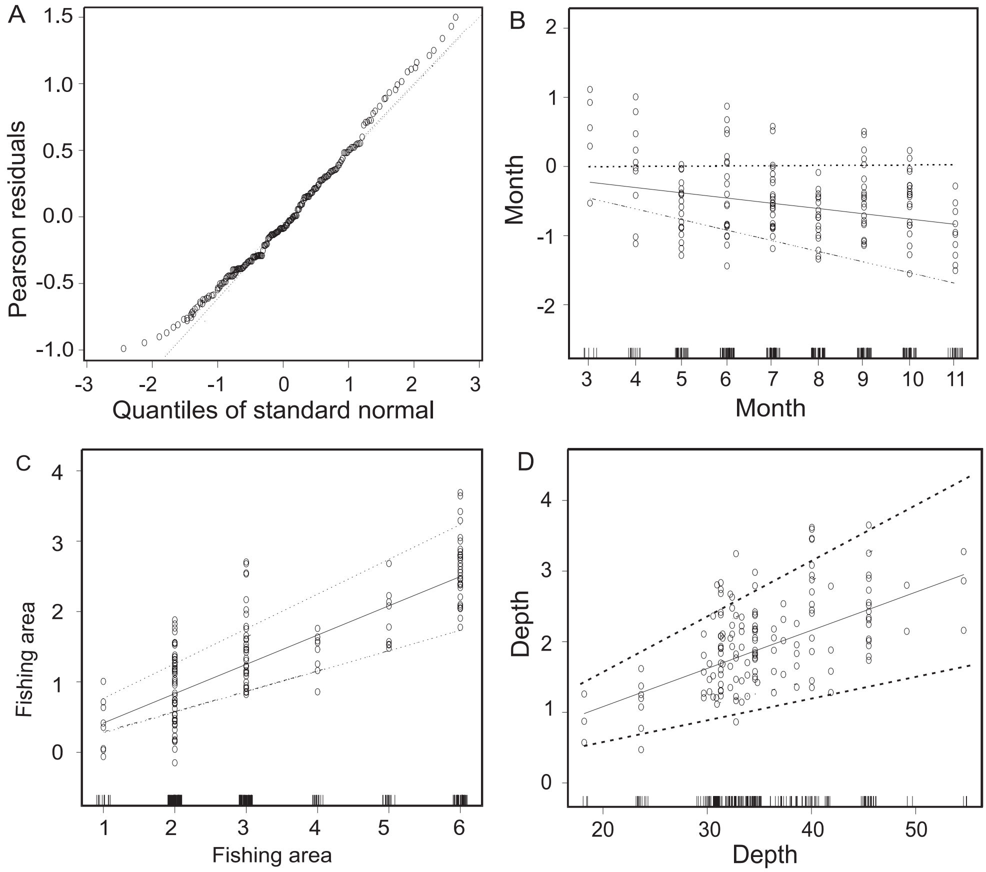

Fig. 6: (A) Diagnostic plot and (B) main effects of month; (C) fishing area; (D) water depth of the model fitted to purse seiner total catches in the Pagasitikos Gulf. Model plots (B) to (D) represent the contribution of the corresponding covariate to the fitted linear predictor. The 'rug' (small vertical lines) on the x-axis shows the density of points for each covariate included in the model.

covariates for all analyses are given alongside parameter estimates of the final models. The analysis of deviance indicates that the differences observed in total catches between months, fishing area and water depth were significant (*P*<0.00). The interactions of month with fishing area and fishing area with water depth were also significant (both *P*<0.00). The final model reduces the null deviance from 467.2 to 52.8 (88.7%). Most of the variance is explained by the differences in the factors month and water depth (77.8% and 6.4%, respectively).

The contribution of each of the main effects included in the GLM to the variation of total catches accounting for the other factors is given in Figure 6. Results indicate the presence of a seasonal trend in total catches in the area during the study period. With the exceptions of May and August, levels of catches were higher during spring and summer months, than during the autumn months (Fig. 6B). Fishing areas 2, 3 and 6 were characterized by higher catches than the areas 1 and 4 (Fig. 6C). The catches also increased with increasing water depth (Fig. 6D).

The differences observed in the two *Trachurus* catches between month and water

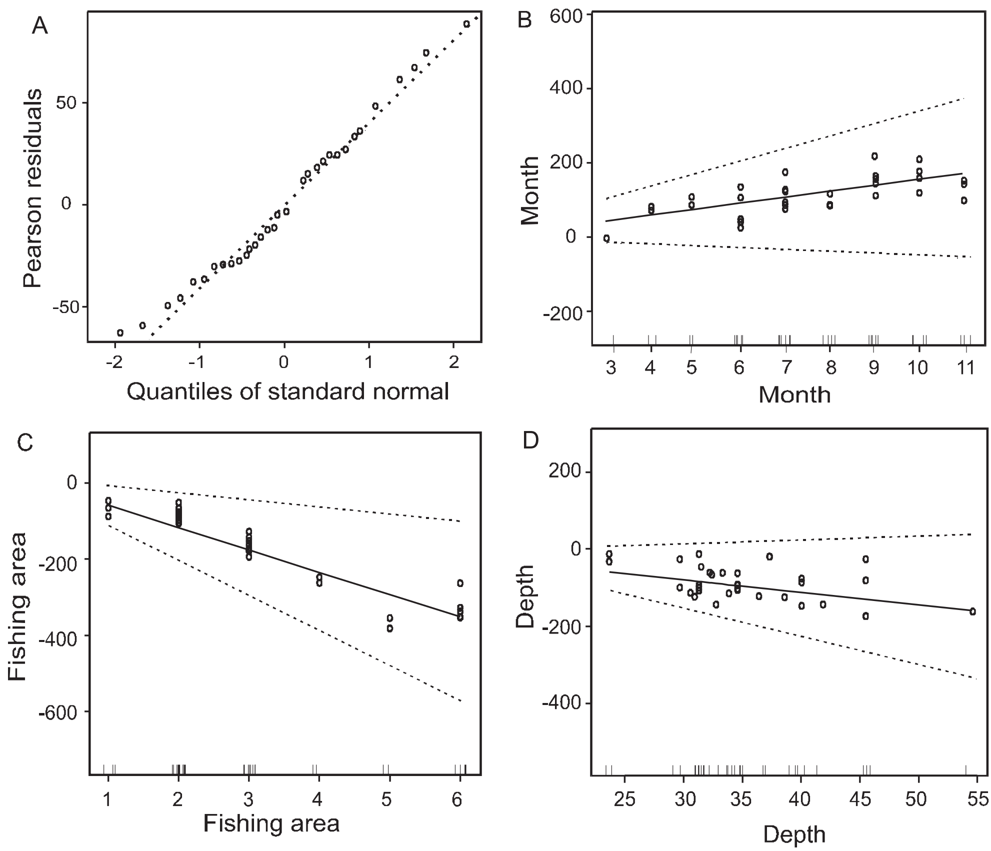

Fig. 7: (A) Diagnostic plot and (B) main effects of month; (C) fishing area; (D water depth of the model fitted in Mediterranean horse mackerel (*Trachurus mediterraneus*) catches.

depth were significant ($P<0.00$ and $P<0.03$ respectively for the Mediterranean horse mackerel and $P<0.00$ and $P<0.02$ respectively for the horse mackerel, Table 2). Although fishing area was not found to directly affect the catches of the two *Trachurus* species, its interaction with water depth was found to be significant in both species ($P<0.03$ and $P<0.01$ respectively). The month: fishing area: water depth interaction was not found to be significantly affect the Mediterranean horse mackerel catches. The final model of Mediterranean horse mackerel catches reduces the null deviance from 161325 to 51113.1 (68.3%), while the final model of horse mackerel catches reduces the null deviance from 18300 to 3599.1 (80.3%). The factor of month explains most of the variance (51.5% and 69.1%, respectively for Mediterranean horse mackerel and horse mackerel catches).

Figures 7 and 8 represent the contribution of each of the main effects included in the GLM to the variation of both *Trachurus* catches accounting for the other factors. The Mediterranean horse mackerel catches increased with month showing higher values during September and October (Fig. 7B). The horse mackerel catches decreased with month showing higher values during spring and summer than in autumn (Fig. 8B). Fishing areas 2 and 3 were characterized by higher catches than the other areas (Fig. 7C and 8C, respectively). The catches of both species decreased with increasing water depth (Fig. 7D and 8C, respectively).

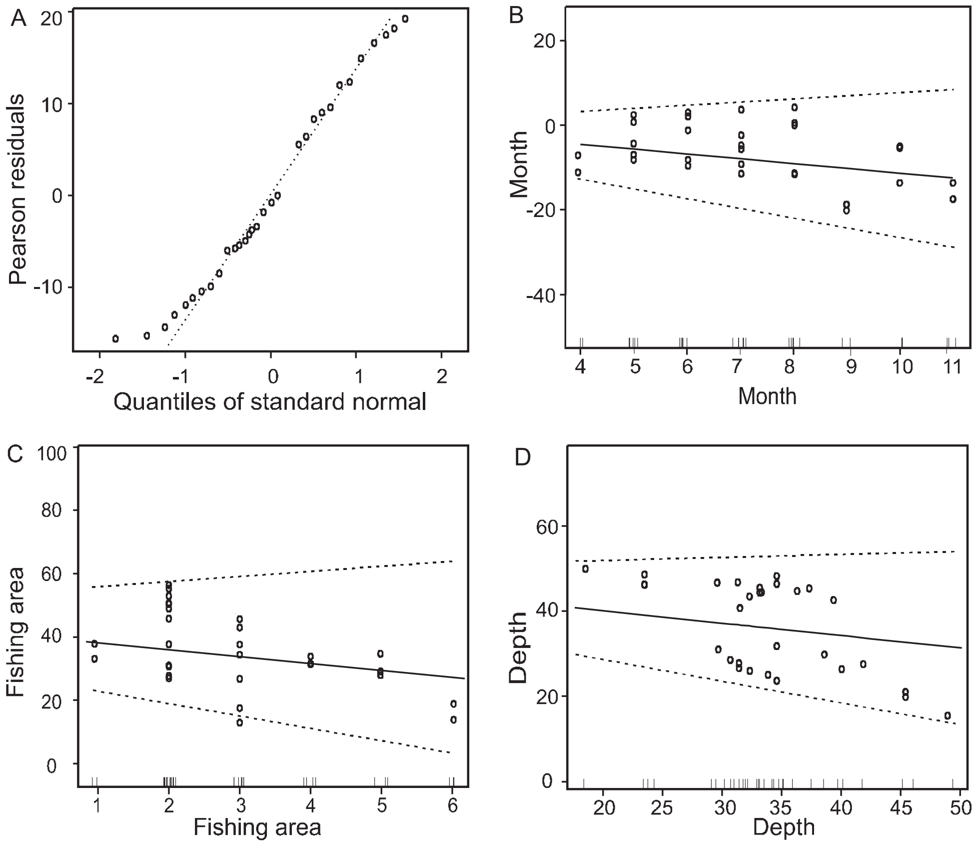

Fig. 8: (A) Diagnostic plot and (B) main effects of month; (C) fishing area; (D water depth of the model fitted in horse mackerel (*Trachurus trachurus*) catches.

Discussion

The large amount of variation explained in all three models by month reflects the importance of this factor for the purse seine total catches in the study area alongside the two *Trachurus* spp. catches. Results confirmed the importance of considering temporal effects when attempting to conduct catch-effort standardizations since species composition and relative abundance differed according to season, depending on a variety of factors, e.g. temperature, reproduction, nutrients, currents, winds (KULKA *et al.*, 1996). The water depth explained only a small part of the observed variation of the catches. The fishing area was significant as having an important effect on total catches and through its interaction with water depth for both *Trachurus* species.

The observed monthly reduction of both total catches and horse mackerel during the study period can partly be attributed to the lower availability of fish resources as the fishing season was progressing and to the decreased probability of a successful fishing operation due to bad weather conditions prevailing after September. Due to a closed season prohibition (December to February), fishing is more intense during the first months following the opening of the area (spring and early summer). High profit expectations urge the need to maximize the economic return of trips, thus adversely affecting fishing pressure on the stocks. Furthermore, bad weather is known to affect the fishing effort and reduces the possibility of a secure fishing activity (CABRAL *et al.*, 2003): strong winds and currents impede the setting of the net and increase the likelihood of escape by fish during fishing. Observations made by the fishery scientist onboard the vessel and their comparison with total landings of the other two purse seiners operating in the same Gulf indicated also that, to some extent, the influence of bad weather on the quantity of the catches depends on fishers' handling abilities and experience.

The Mediterranean horse mackerel catches progressively increased during the examined period (from March to November). In the study area the highest values that were observed during summer - early autumn coincide with the peak of the species' reproductive season (May-September, STERGIOU *et al.*, 1997a). These observations are in accordance with those reported in other studies in the Pagasitikos Gulf (STERGIOU *et al.*, 1997b).

The present findings indicated that depth was an important factor affecting both total catches and the catches of the two *Trachurus* species. Most of the catches were recorded at depths near 30 m. The purse seine fishing strategy is heavily dependent on visual stimuli in the water column (the light deriving from the lamps decreases with increasing water depth). Only the species that are concentrated in the upper water column near the surface lamps are caught. The maximum height of the purse seine net in all fishing trips was approximately 30 m, which implies that any species below this depth was out of reach while most of the fish found within the first 30 m of the water column were caught. In fishing areas with seabeds much deeper than 30 m, *Trachurus* catches cannot be considered as representative of species abundance as they cannot be caught by the purse seine gear. The *Trachurus* schools are known to inhabit deeper waters closer to the sea bottom (BARANGE & HAMPTON, 1994; MASSE *et al.*, 1996) and therefore are not fully susceptible to purse seining. Obviously in such fishing areas (> 30 m), *Trachurus* abundance could be higher than that recorded.

The current study shows that two fishing areas had consistently higher values of total catches and *Trachurus* catches. These were areas 2 and 3 on the map. The geographical position of these fishing areas was probably the reason for the high values of catches observed. The cyclone that is present in the central-western part of the Gulf (PETIHAKIS, 2004) and the anticyclone in the eastern part of the Gulf (MARAVELIAS & PAPACONSTANTINOU, 2003) change both water temperature and nutrient supply, affecting the aggregation of fish schools (CUSHING, 1975; MARAVELIAS & REID, 1995, 1997; MARAVELIAS, 1997, 1999). Observations made by the fishery scientists onboard the purse seiner confirmed that the structure and density of fish schools in these areas influenced fisher's choice. The driving force for the fisher to allocate his fishing effort to specific areas was the greater expectation for economic return associated with them (i.e. higher catches). The current findings are in accordance with those of similar studies (TSIMENIDES *et al.*, 1991; SWAIN & SINCLAIR, 1994; YE *et al.*, 2001; STERGIOU *et al.*, 2002, 2003; CABRAL *et al.*, 2003). Moreover, these preferred areas were in the proximity of the fishing port thus enabling the fisher of the purse seiner to land his catches earlier in the morning and get a good selling price.

In the study area, the purse seine fishery is heavily affected by weather conditions. The strong winds and currents which dominate in the area after September forced the fisher of the purse seiner to adapt his individual decision-making process. Fishing operations were restricted to locations closer to the port as the fisher preferred to minimize personal (physical) and economic risks by selecting these areas. Other researchers also reported this strategy (CABRERA & DEFEO, 2001; SALAS & GAERTNER, 2004) with fishers preferring their personal safety to high catches.

The high values of total catches observed in March and April is attributed to anchovy (*Engraulis encrasicolus*) catches, while the high value observed in June is due to saddled bream (*Oblada melanura*) catches. In both cases the fisher followed a decision-making process governed by the high concentrations and the good selling prices of these two species. It is known that fishers do not operate at random but rather they consider prior information before making choices (SALAS *et al.*, 2004). They rely on their ability to locate particular species according to their selling prices in different seasons (Mediterranean Sea: GOÑI *et al.*, 1999; BELCARI *et al.*, 2002; Solomon Islands: JOHANNES *et al.*, 2000; Balearic Islands: OLIVER, 1993; Mexico: SALAS *et al.*, 2004).

Fishery scientists' observations acquired from a total of 72 fishing trips alongside fish market recordings during the same period (TSITSIKA, 2004) confirmed that each fisher has developed an individual decision-making process regarding fishing trips. Fishers' trip choice behaviour was found to be modulated by several factors such as the distance of fishing grounds from the port, market demands (both in terms of species and selling prices), weather conditions, alternative fishing strategies, previously gathered information, economic pressure, personal skills and even daily mood. Research in the Pagasitikos Gulf is underway to quantitatively evaluate these factors in order to include them in future stock assessment and management plans.

In summary, this study has shown that month, water depth and fishing area all have an effect on total and *Trachurus* spp. catches in the purse seine fishery of the Pagasitikos Gulf. Results also indicate that generalized linear modelling of the purse seine catches can be used to obtain more representative abundance indices by reducing the observed variability. Onboard observations revealed the necessity of incorporating additional quantitative information (e.g. market requirements, allocation of fishing effort, fishing costs, economic incentives, proximity of fishing location to the port and environmental conditions) to future studies.

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