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A LPUE (LANDING PER UNIT EFFORT) ANALYSIS OF THE TRAWL FISHERY FOR THE COASTAL SHRIMPS *Artemesia longinaris* AND *Pleoticus muelleri* OFF SOUTHERN BRAZIL

Cassiana Baptista Metri[1,]* *and José Angel Alvarez Perez*[2]

[1]Universidade Estadual do Paraná, Campus Paranaguá
(Rua Comendador Correia Junior, 117, 83203-280 Paranaguá, PR, Brasil)

[2]Universidade do Vale do Itajaí - UNIVALI
(Caixa Postal 360, 88302-202 Itajaí, SC, Brasil)

*Corresponding author: cassiana.metri@unespar.edu.br

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ABSTRACT

The Argentine stiletto shrimp (*Artemesia longinaris*) and the Argentine red shrimp (*Pleoticus muelleri*) currently sustain an important fishery in terms of tonnage and revenues in southern Brazil. This study analyzed the factors affecting the abundance of both species through the application of Generalized Linear Models to landing-per-unit-of-effort (LPUE) data of the trawl fleet operating on the main fishing grounds between 1998 and 2005. The main patterns of LPUE variability of both species were attributed do the effect of seasons and annual cycles. Larger yields were obtained in the southern shallow areas of Rio Grande do Sul State. No tendency either to an increase or a decline in stock abundance was observed, but the effort in one year was affected by the success of the captures of the previous year. In the last two years analyzed the abundance and the total captures declined.

RESUMO

O camarão-barba-ruça (*Artemesia longinaris*) e o camarão-santana (*Pleoticus muelleri*) são espécies que sustentam uma pescaria responsável por elevadas capturas das frotas de camaroeiros no sul do Brasil. Este trabalho teve como objetivo analisar a variabilidade da abundância das duas espécies à variação dos dados de DPUEs da frota de arrasteiros em operação entre 1998 e 2005, por meio do ajuste de Modelos Lineares Generalizados (MLG). As principais variações de abundância das duas espécies estão relacionadas aos ciclos anuais e a temporada de pesca. As áreas rasas ao sul do Rio Grande do Sul proporcionaram maiores rendimentos. Não foram observadas tendências de aumento ou declínio na abundância do estoque, mas o esforço de um determinado ano é condicionado pelo sucesso das capturas do ano anterior. Nos dois últimos anos analisados a abundância e as capturas totais foram reduzidas.

Descriptors: Shrimp, MLG, DPUE, Argentine stiletto shrimp, Argentine red shrimp, Bottom trawl.
Descritores: Camarão, MLG, DPUE, Camarão-barba-ruça, Camarão-santana, Arrasto de Fundo.

INTRODUCTION

Management strategies for fishing resources have been based on the monitoring of the population structure and the dynamics of the commercially-exploited stocks. Among the population and fishing parameters, the portion of the stock removed by fishing activities (catches), the rate of removal (fishing mortality), the stock biomass (abundance) and the related temporal variability of all those factors are essential for the establishment of sustainable management (GULLAND, 1983).

The stock biomass dynamics can be assessed from the analysis of temporal and spatial variability of Catch per Unit of Effort, or CPUE, provided that important assumptions can be satisfied. Firstly, because although a fraction of the catches may be discarded onboard, only the landed fraction tends to be effectively quantified. If discard rates are relatively stable, landings (LPUE) can provide reliable approximations of CPUE.

More importantly, LPUE is a proxy for the relative abundance of the exploited stock only if catchability is kept constant throughout the period and area analyzed. However, in the real world several mechanisms may disturb catchability masking the effect of fishing effort, including changes in: (1) the vulnerability of the target species on the fishing grounds during the fishing season, (2) the efficiency of the fishing gear and/or the fishing vessel and (3) the experience of the fishing crew, among other factors (GULLAND, 1983). Therefore, understanding the influence of such mechanisms is critical to determining the real oscillations of stocks (HILBORN; WALTERS, 1992; QUINN; DERISO, 1999).

Models can be applied to standardize CPUE so as to remove the bias introduced by these factors. Therefore the variability in the CPUE was broken down to assess the relative effect of the factors that affect the catch patterns, such as fishing vessel characteristics or fishing methods, latitudinal zone and depth stratum and period of time (from weeks to years) (HILBORN; WALTERS, 1992; QUINN; DERISO, 1999). An encouraging method widely used in fishery science (VENABLES; DICHMONT, 2004) to take into account the biases and variability that naturally affects the estimation of the CPUE is the use of General Linear Models (GLMs), which allows for the estimation of standardized abundance indexes from the variable CPUE obtained from a given fleet acting on a given stock unit (GAVARIS, 1980). The resulting standardized index is a valid index of abundance of the fishery target species and its analysis may help us understand the time and space dynamics of the species.

There are six species with high economic value in southeastern and southern Brazil: pink shrimp (*Farfantepenaeus paulensis* and *F. brasiliensis*), white (*Litopenaeus schmitti*), seabob (*Xiphopenaeus kroyeri*), Argentine red (*Pleoticus muelleri*) and Argentine stiletto (*Artemesia longinaris*) (D'INCAO et al., 2002). The pink shrimp was the most important resource responsible for 50% of the income of industrial trawlers. These captures reach a peak of 16,629 t in 1972, but decreased in the subsequent years, to 1,792 t in 1987 and to less than 1,000 t in 1999 (VALENTINI et al., 1991; D'INCAO et al., 2002). Due to the decreasing yields of pink shrimp several species previously regarded as by-catch became progressively valued by the pink shrimp fleet, so this fishery originally monospecific became a multispecific activity (PEREZ et al., 2001; VALENTINI et al., 2012).

Among these, the Argentine stiletto shrimp *Artemesia longinaris* and the Argentine red shrimp *Pleoticus muelleri* became important target species both in terms of catches and sources of income (KOTAS, 1991; PEREZ; PEZZUTO, 1998). Present-day data obtained from monitored landings show that both species figure in the first place in terms of average yields of the trawl fleet in Santa Catarina State (UNIVALI/CTTMAR, 2001 to 2010), sustaining a directed fishery that acts seasonally on the Rio Grande do Sul continental shelf (29–32°S).

Despite the current importance of both shrimp species for the trawl fishery off southern Brazil, only very poor data on the biomass dynamics of their stocks are available. The present study aims to evaluate the dynamics of the standardized LPUE obtained from the trawl fleet operations that landed their catches in Santa Catarina between 1998 and 2005.

MATERIAL AND METHODS

Data Collection and LPUE Estimation

Data were gathered from log-books and interviews held with skippers during landings of trawling operations targeting *A. longinaris* and *P. muelleri* that were made in the harbors of Santa Catarina state (southern Brazil) between 1998 and 2005. In general these landings were made by double-rig trawlers operating on a 24h regime from October to February between 27º00'S and 33º45'S. The latitudinal range was divided into five sectors (fishing areas 1 to 5) in view of the patterns of spatial concentration of the trawler fleets in southern Brazil throughout the year by PEREZ et al. (2003, Fig. 1). These sectors were limited offshore by the 150m isobath. The data recorded for each fishing operation included: (1) the targeted species (i.e. *A. longinaris* or *P. muelleri*), (2) the number of fishing days, (4) the number of hauls during each trip, (5) the time duration of each haul (in hours), (6) the location of the trawled area and (7) the fishing depth.

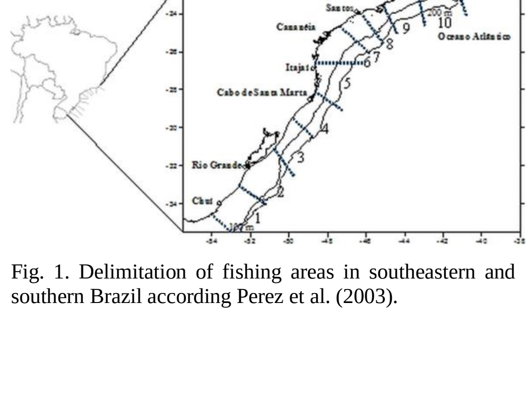

Fig. 1. Delimitation of fishing areas in southeastern and southern Brazil according Perez et al. (2003).

Total fishing effort (hours of haul) was calculated by multiplying the number of effective fishing days by the number of hauls and the average duration of each haul. The LPUE was estimated as the ratio between the catches landed and the total fishing effort, and expressed as kg*hour^{-1}. The landing frequency for each vessel was considered as indicative of the experience level factor.

LPUE Standardization

The relative abundance of *A. longinaris* and *P. muelleri* during the study period was evaluated by fitting a General Linear Model (GLM) (GAVARIS, 1980), where the ln of the LPUE of each species was the dependent variable. The LPUE variability was broken down from the effects of time (year and month), space (fishing area and depth) and the physical characteristics of the fishing vessels, including: vessel length (m), hold capacity (t), power of the engine (HP) and age of the vessel (years). In addition, the level of experience of the vessel at catching each shrimp species was included and expressed as the frequency of *A. longinaris* and *P. muelleri* landings made by each vessel. All those variables were considered as factors within the GLM and subdivided into levels taking into account a homogeneous data distribution among the levels. A Tuckey test was applied to the ln LPUE to identify, within those variables, which level had a significant effect on LPUE. This analysis was used to evaluate the possibility of the regrouping of those discrete variables in accordance with a balanced number of observations within each class.

The resulting model considered that the LPUE was proportional to the abundance of both species in time, fishing areas and the effects related to the fishing power of each vessel. The relationship between the LPUE (U) and the abundance can be expressed as:

$$U_{jk} = U_{11} * \theta_{jk} * \varepsilon_{ki} \qquad (1)$$

where U_{11} is the reference LPUE, i.e., the U value obtained when all the factors are at the reference level (named level 1), θ_{jk} is the effect of the k^{th} level of the j^{th} factor on U in relation to the reference level of each co-variable, and ε_{ki} is the deviation between the estimated and observed LPUE U_{jk} at each level of the co variables included in the model. When the model is linearized by logarithmic transformation, we obtain:

$$\ln(U_{jk}) = \ln(U_{11}) + \ln(\theta_{jk}) + \ln\varepsilon_{ki} \qquad (2)$$

This linearized model allowed the estimation of the values of U_{11} and θ_{jk} by extracting the anti-logarithms of the estimations obtained from the GLM. The model was fitted using the least square method and the error distribution of ε_{ki} was assumed to be normally distributed.

The inclusion of the factors with their respective levels in the GLM was carried out taking into account the significance of their effects on the variability of the LPUE. This was estimated using a multi-factorial ANOVA to evaluate the magnitude of the effect of each factor on the ln LPUE (ln U_{jk}), assuming equal variances tested by the Brown-Forsythe test. A power analysis was performed to verify the reliability of the estimates. All the estimations and statistics were performed using the Statistica 7 program. All statistical tests were considered to have a significance level of 0.05.

Finally, the values of catches and efforts against ln LPUE were presented in order to infer how these parameters influence the real abundance. Pearson´s correlation test was performed to verify the significance of these relations.

RESULTS

Overall Patterns

A total of 2,133 fishing trips (1,077 for *A. longinaris* and 1,056 for *P. muelleri*) were analyzed. Between 35 and 40% of them provided information on the physical characteristics of the trawlers (Table 1).

Table 1. Number and frequency (%) of the monitored landings of *A. longinaris* and *P. muelleri* between 1998 and 2005 in Santa Catarina used in this study.

	A. longinaris		*P. muelleri*	
Number of landings	1077		1056	
Length (m)	379	35.19 %	369	34.94 %
Holding capacity (t)	415	38.53 %	404	38.26 %
Age (years)	435	40.39 %	419	39.68 %
Engine power (HP)	443	41.13 %	429	40.63 %

All continuous variables were grouped in classes (levels) by the analysis of their distributions and the values of their respective quartiles. The factors previously categorized as month, fishing ground and fishing depth stratum were kept in the model if considered significant according to the Tukey test applied to the ln LPUE. These analyses were performed separately for each species resulting in balanced categories to be applied to the GLM (Table 2).

Selecting Significant Factors

The multifactor ANOVA applied to the log transformed LPUE showed that all temporal and spatial factors had a significant effect on *A. longinaris* and *P. muelleri* catches (Table 3). Regarding the physical characteristics of the fishing vessels, only the hold capacity and age influenced the catches of *A. longinaris*, whereas only experience was significant for *P. muelleri* (Table 3).

Table 2. Class definition for explaining continuous co-variables for the *A. longinaris* and *P. muelleri* models, treated as factors in the GLM. The % observation means the relative frequency of observations at each class. The southernmost latitudinal limit of each fishing area is shown in brackets.

		Alonginaris			*P. muelleri*		
Variable (j)	Level (k)	Interval/observation	% observation	n	Interval/observation	% observation	n
Year	1	1998	4.0	43	1998	4.0	42
	2	1999	10.6	114	1999	10.8	114
	3	2000	13.7	148	2000	14.3	151
	4	2001	18.8	202	2001	19.0	201
	5	2002	23.2	250	2002	23.5	248
	6	2003	8.5	92	2003	8.7	92
	7	2004	12.3	132	2004	12.4	131
	8	2005	8.9	96	2005	7.3	77
Season (months)	1	Sep - Oct	27.9	301	Sep	9.9	105
	2	Nov	27.2	293	Oct	21.5	227
	3	Dec	20.6	222	Nov	29.5	311
	4	Jan - Feb	24.2	261	Dec - Jan	29.4	310
	5	-	-	-	Feb	9.8	103
Fishing area	1	A1 (33º45'S)	8.3	89	A1 (33º45'S)	6.9	73
	2	A2 (32º40'S)	35.3	380	A2 (32º40'S)	34.3	362
	3	A3 (31º20'S)	36.9	397	A3 (31º20'S)	37.2	393
	4	A4 –A 5 (30º00'S)	19.6	211	A4 –A 5 (30º00'S)	21.6	228
Depth (m)	1	< 40	84.6	911	< 40	84.9	897
	2	41 – 150	15.4	166	41 - 80	12.5	132
		-	-	-	80 - 150	2.6	27
Holding capacity (t)	1	1 – 25	31.7	120	9 - 25	30.9	114
	2	27 – 30	23.7	90	27 - 30	24.9	92
	3	34 – 45	20.3	77	34 - 45	20.3	75
	4	50 – 95	24.3	92	50 - 95	23.8	88
Length (m)	1	14 – 20	36.6	152	14 - 19.8	25.7	104
	2	20.5 - 21.5	14.0	58	20 - 21.5	25.0	101
	3	21.8 - 22.3	25.8	107	21.8 - 22	24.3	98
	4	22.5 – 45	23.6	98	22.1 - 45	25.0	101
Age (years)	1	0.01 - 11.7	24.4	106	0.01 - 11.4	24.3	102
	2	11.8 - 15.5	24.6	107	11.5 - 15.3	25.5	107
	3	15.6 - 20.7	26.9	117	15.4 - 20.3	25.3	106
	4	20.8 - 39.9	24.1	105	20.6 - 39.9	24.8	104
Fishing experience (landing frequency)	1	1 – 4	30.6	330	1 - 4	31.7	335
	2	5 - 8	22.0	237	5 - 8	22.3	236
	3	9 - 13	22.8	246	9 - 13	22.3	236
	4	14 - 29	24.5	264	14 - 29	23.6	249
Engine power (Hp)	1	115 - 270	28.7	127	115 - 270	29.6	127
	2	275 - 300	31.6	140	275 - 300	30.5	131
	3	320 - 325	21.2	94	320 - 325	20.0	86
	4	330 - 425	18.5	82	330 - 425	19.8	85

Table 3. Effect of the factors on the log-transformed landing rate of *A. longinaris* and *P. muelleri* as detected by the ANOVA.

	A. longinaris				*P. muelleri*			
Factors	DF	Sum of squares	F	*p*	DF	Sum of squares	F	*P*
Year	7	39.96	7.21	<0.0001	7	25.80	4.70	<0.0001
Season	3	29.36	12.36	<0.0001	4	88.35	28.18	<0.0001
Fishing area	3	11.25	4.74	0.003	3	7.88	3.35	0.0194
Depth	1	21.59	27.28	<0.0001	2	14.74	9.40	0.0001
Holding capacity	3	11.78	4.96	0.002	3	3.93	1.67	0.1733
Length	3	4.02	1.69	0.168	3	0.43	0.18	0.9075
Engine power	3	1.36	0.57	0.634	3	1.89	0.80	0.492
Age	3	9.28	3.91	0.009	3	0.51	0.22	0.8849
Fishing experience	3	3.65	1.54	0.204	3	6.67	2.84	0.0384
Error	309	244.77			297	232.79		

A. longinaris. Fitness of Model

The GLM model applied for *A. longinaris* used 6 explanatory variables and only 348 out of the 1,077 fishing trips recorded due to the lack of data on the physical characteristics of the fishing vessels of some of the fishing trips. Power analysis results showed a 0.10 size effect with 99% explicability. The combined effect of all the factors included in the GLM explained 40% of the total variance of ln *U* and the residuals were normally distributed (Fig. 2). The total sum of the squares was lower than their degrees of freedom (259.82 and 311, respectively), indicating a good fit of the model. The results of the GLM model are shown in Table 4.

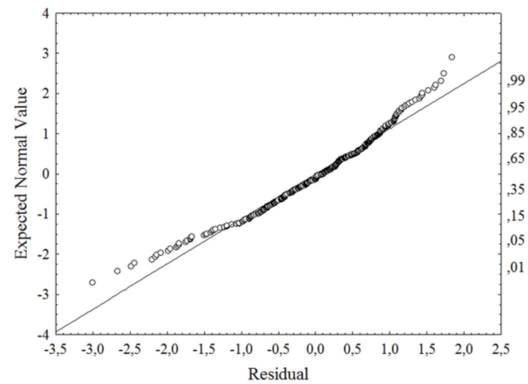

Fig. 2. Normal probability plot of residuals for *A. longinaris*.

Table 4. GLM estimated coefficient for each factor included in the *A. longinaris* model. SE: standard error. T: calculated Student's t. p. probability. U: standardized LPUE. R2=0.40; F=31.23; p<0.001. Deviance=1.15; Residual deviance=0.87. n= 348. Bold: p<0.05.

Factor level	Coefficient	SE	r^2	*t*	*p*	Estimation	U
Reference LPUE	1.93	0.37	-	5.25	**0.000**	6.91	6.91
1999	1.33	0.34	0.79	3.91	**0.000**	3.78	26.13
2000	1.39	0.33	0.84	4.22	**0.000**	4.00	27.63
2001	0.72	0.32	0.88	2.25	**0.025**	2.06	14.24
2002	1.05	0.32	0.89	3.27	**0.001**	2.85	19.67
2003	1.53	0.36	0.75	4.29	**0.000**	4.63	31.98
2004	0.50	0.37	0.68	1.35	0.178	1.64	11.35
2005	0.26	0.39	0.67	0.67	0.505	1.29	8.94
November	0.27	0.14	0.35	1.98	**0.049**	1.31	9.03
December	-0.27	0.15	0.40	-1.78	0.075	0.77	5.30
January - February	0.76	0.14	0.36	5.33	**0.000**	2.14	14.76
Area 2	-0.41	0.19	0.70	-2.24	**0.026**	0.66	4.57
Area 3	-0.23	0.19	0.72	-1.20	0.233	0.80	5.50
Area 4	-0.65	0.20	0.64	-3.23	**0.001**	0.52	3.61
> 40 m	-0.74	0.15	0.18	-4.85	**0.000**	0.48	3.29
Holding: 27-30 t	0.38	0.14	0.33	2.72	**0.007**	1.47	10.12
Holding: 34-45 t	0.64	0.15	0.38	4.29	**0.000**	1.89	13.09
Holding: 50-95 t	0.18	0.14	0.36	1.27	0.206	1.19	8.26
Age: 11.8-15.5 yrs	0.14	0.16	0.55	0.89	0.375	1.15	7.96
Age: 15.5-20.7 yrs	0.13	0.15	0.42	0.85	0.395	1.14	7.85
Age 20.9-39.9 yrs	-0.59	0.15	0.42	-4.02	**0.000**	0.56	3.84

A. longinaris. Variations from the reference LPUE

The reference LPUE was 6.91 kg hour^{-1} (± 1.23 SE), corresponding to the LPUE obtained by vessels with engines of 115–270 HP between September–October 1998 on < 40 m deep bottoms in Area 1 of 1998, with experience of up to 4 fishing trips. Thus, for instance, the LPUE estimated for the 2001 season was 2.06 times higher than that obtained in 1998 (Table 4). Most of the coefficients estimated were different from 1 ($p < 0.05$), except for the years 2004 and 2005, Area 3, hold capacity of 4 t and experience of 2 and 3 fishing trips.

The coefficients obtained for all the years pooled were between 1.3 and 4.6 times larger than the reference LPUE (Table 4; Fig. 2). There was little variation of *A. longinaris* CPUE over the years, which peaked in 1999–2000 and 2003, when the coefficients were 4 times higher than the reference LPUE. LPUE increased towards the end of the season, increasing 2.1 times in January–February in relation to September–October. Conversely, the LPUE declined at higher latitudes (Areas 2, 3 and 4), which had abundances 20–48% lower than that recorded in Area 1. From a bathymetric perspective, *A. longinaris* was 52% less abundant at bottoms deeper than 40 m (Fig. 4). Regarding the factors related to fishing power, it was observed that vessels with higher hold capacity (between 30–40 t) had catches up to 89% greater than the reference LPUE. Finally, age of the vessel had a negative effect on LPUE, as older fishing boats (> 20 yrs), had LPUE 44.4 % lower than that obtained by younger vessels (Fig. 4).

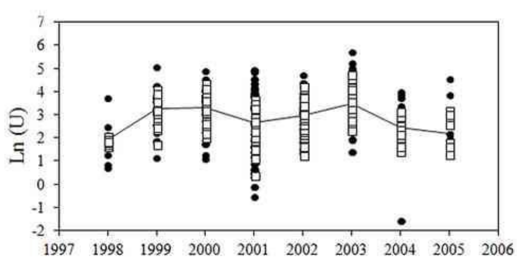

Fig. 3. Variability of catch rates of *A. longinaris* between 1998 and 2005 off Santa Catarina. Black circles: actual LPUE (*U*) values. White squares: *U* values as estimated by the GLM. The line links the averages of the estimated *U*s.

A. longinaris. Annual variability of landing and effort

Catches were positively related to the LPUE in most years (r=0.63). However, low catches contrasted with high LPUEs in 1999, 2000 and 2002 (Fig. 5A), possibly related to the lower fishing effort expended in those years (Fig. 5B), which kept the LPUE high. In contrast, a high fishing effort was employed by the fleet in 1998, but the catches were also low. The highest LPUE recorded in the time series analyzed was found in 2003, despite a low fishing effort (Fig. 5A). In fact, LPUE and the catch landed in one year tended to be affected by the effort expended in the previous year. The correlation between LPUE and the next year's effort was 0.64.

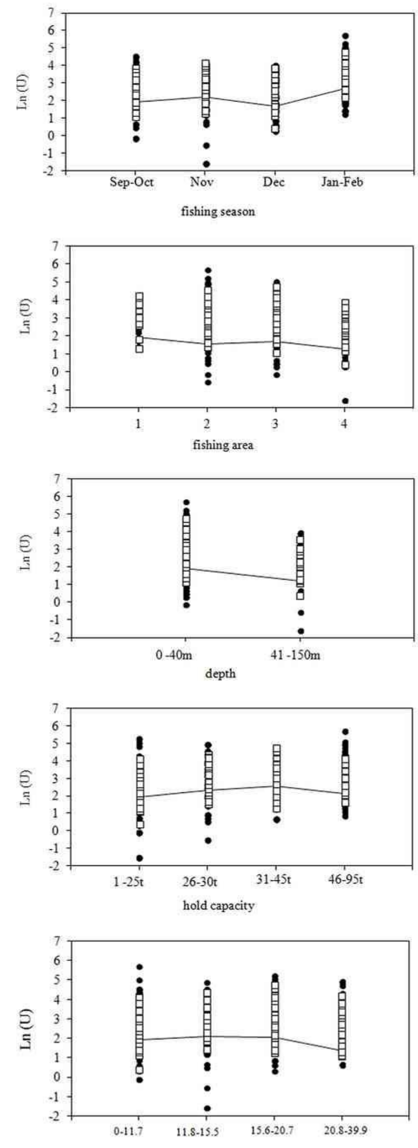

Fig. 4. Variability of catch rates of *A. longinaris* according to the co-variables included in the GLM. Black circles: actual LPUE (*U*) values. White squares: *U* values as estimated by the GLM. The line links the averages of the estimated *U*s.

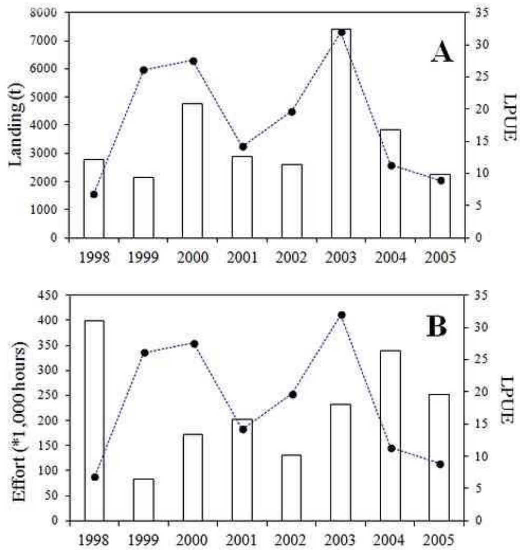

Fig. 5. Annual variability of (A) landings and (B) effort of *A. longinaris* fishery (bars) in relation to the LPUE as estimated by GLM (lines).

P. muelleri. Fitness of model

The GLM fitted for *P. muelleri* was built using 5 explanatory variables and all the trips for which data were available during the study period (N = 1,056), because the variables related to the physical characteristics of the fishing vessels had no effect on the LPUE. Power analysis results showed a 0.02 size effect with 96% explicability. The coefficient of determination obtained (R^2) was 0.37, the residuals were normally distributed (Fig. 6). The total sum of the squares (870.85) was smaller than the degrees of freedom (1.036) of the model, indicating a good fit.

P. muelleri. Variations from the reference LPUE

The estimated coefficients of the levels of each factor are shown in Table 5. The reference LPUE was 9.62 kg hour^{-1} (± 0.20 SE) estimated for catches in Area 1 at < 40 m in September 1998 by fishing vessels with experience of up to 4 landings during the study period. The LPUE estimates for most years and months were significantly different from the reference LPUE. On the other hand, the estimates of LPUE for fishing area, fishing depth and level of experience were close to 1, except for area 4 and depths of between 40 and 80 m (Table 5).

The LPUE of *P. muelleri* was stable throughout the time series, oscillating between 0.9 and 2.8 times in relation to the reference LPUE. There were three discernible peaks (2000, 2003 and 2005) that were 152–279% higher than the reference LPUE (Table 5 and Fig. 75). The monthly estimated LPUE tended to decrease gradually (between 15–84%) in relation to the reference LPUE. The same was detected in relation to the fishing areas, with an average decrease of 19.2% in relation to the reference LPUE. LPUE was higher on the shallower bottoms (< 40 m), decreasing between 17 and 35% towards the deeper strata (Fig. 8). The fishing power was highly stable in relation to the vessel's experience (Fig. 8).

P. muelleri. Annual variability of catches and effort

The observed catches and LPUE were positively correlated (r=0.71). Clear differences were found in 1999 and 2005 due to the lower volumes landed (Fig. 9B) resulting from the lower fishing effort in those two years (Fig. 9B). Landings were highest in 2000 coinciding with the great fishing effort expended that year. Conversely, landings were very low in the following year (2001) despite the great fishing effort employed. Annual LPUE was found to affect effort levels in the following years; while the correlation between the LPUE and effort was 0.11, the correlation with the next year's effort was 0.93.

DISCUSSION

In general, the GLMs applied for the LPUEs of *A. longinaris* and *P. muelleri* presented a good fit and satisfactory result of power analysis, suggesting that estimates of abundance obtained in the present study were reliable and unbiased (GOÑI et al., 1999). However, the combined effect of all the factors included in the models explained only 40 and 37%, respectively, of the variance of LPUE of the two species which implies that factors other than those included in the model may play a role in explaining the fluctuations in the abundance of those species (KIMURA, 1981). At least some of those variables could be related to the oceanographic conditions which obtained during the study period but which were not available in the analyzed data set (BRANDER, 2003; GATICA; HERNÁNDEZ, 2003).

Usually, up to 2–3 interactions may take place during a GLM fitting, though these may have no biological significance, bearing only a pure mathematical meaning (GATICA; HERNÁNDEZ, 2003). Thus it was that we chose to perform the GLM fitting without secondary interactions, because there was no good reason (such as, for instance, a clear evidence of seasonal migrations among the fishing grounds), to do otherwise.

Table 5. GLM estimated coefficient for each factor included in the *P. muelleri* model. SE: standard error. T: calculated Student's t. p. probability. U: standardized LPUE. R2=0.36; F=32.07; p<0.001. Deviance=1.14; Residual deviance=0.91. n= 1,056. Bold: p<0.05.

Factor level	Coefficient	SE	r^2	*t*	*P*	Estimation	U
Reference LPUE	2.26	0.20	-	11.17	0.000	9.62	9.62
1999	0.44	0.17	0.72	2.61	**0.009**	1.56	15.00
2000	1.03	0.17	0.76	6.21	**0.000**	2.79	26.84
2001	-0.05	0.16	0.80	-0.29	0.771	0.96	9.19
2002	-0.11	0.16	0.82	-0.72	0.470	0.89	8.59
2003	0.44	0.18	0.68	2.48	**0.013**	1.55	14.92
2004	0.03	0.17	0.73	0.20	0.842	1.03	9.94
2005	0.42	0.18	0.65	2.29	**0.022**	1.52	14.61
October	-0.17	0.12	0.64	-1.49	0.138	0.84	8.12
November	-0.38	0.11	0.68	-3.53	**0.000**	0.68	6.55
December–January	-1.09	0.11	0.68	-10.02	**0.000**	0.34	3.23
February	-1.89	0.13	0.47	-14.45	**0.000**	0.15	1.46
Area 2	-0.20	0.12	0.75	-1.64	0.101	0.82	7.92
Area 3	-0.15	0.12	0.76	-1.27	0.204	0.86	8.26
Area 4	-0.30	0.13	0.72	-2.30	**0.022**	0.74	7.15
41 – 80 m	-0.44	0.09	0.09	-4.91	**0.000**	0.65	6.21
81-150 m	-0.19	0.18	0.03	-1.04	0.299	0.83	7.96
Experience: 8-13 landings	-0.03	0.08	0.26	-0.37	0.713	0.97	9.35
Experience 13-14 landings	0.05	0.08	0.26	0.61	0.545	1.05	10.09
Experience 15-29 landings	0.06	0.08	0.29	0.76	0.445	1.06	10.22

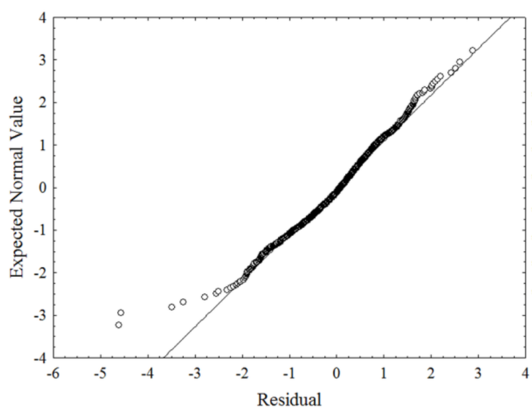

Fig. 6. Normal probability plot of residuals for *P. muelleri*.

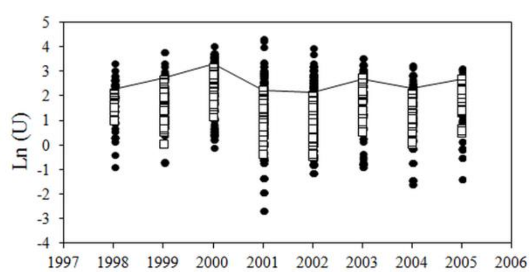

Fig. 7. Variability of landing rates of *P. muelleri* between 1998 and 2005 off Santa Catarina. Black circles: actual LPUE (*U*) values. White squares: *U* values as estimated by the GLM. The line links the averages of the estimated *U*s.

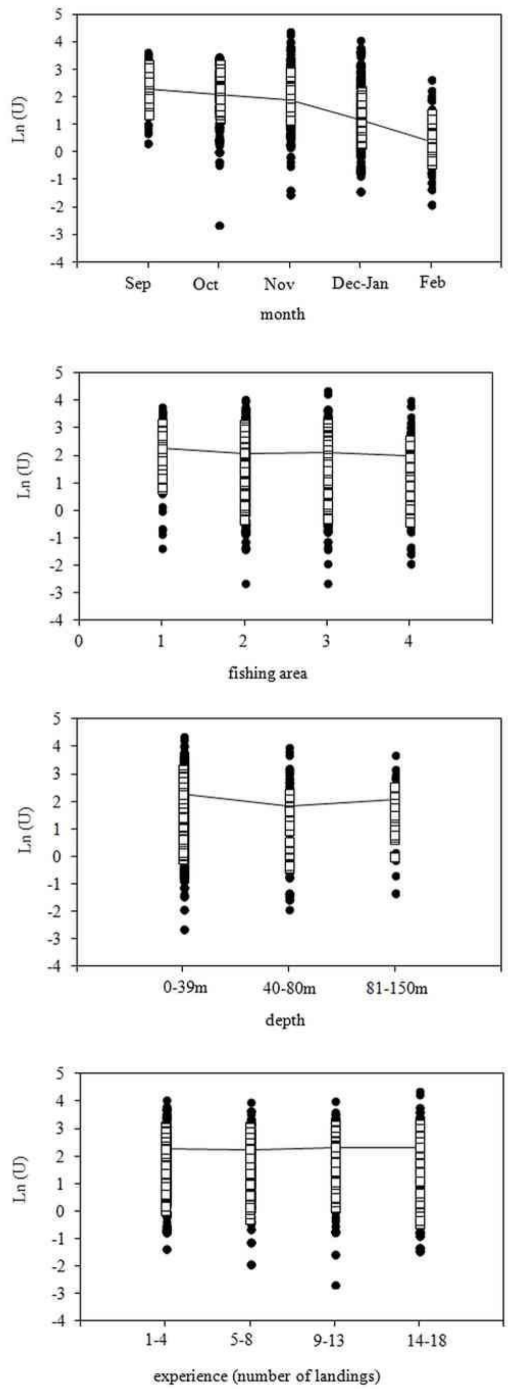

Fig. 8. Variability of landing rates of *P. muelleri* according to the co-variables included in the GLM. Black circles: actual LPUE (*U*) values. White squares: *U* values as estimated by the GLM. The line links the averages of the estimated *U*s.

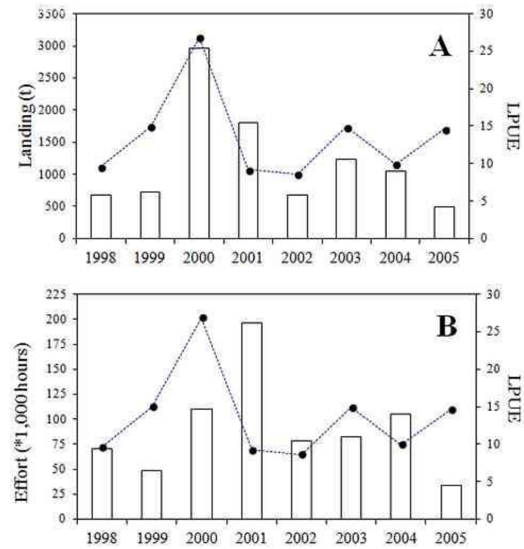

Fig. 9. Annual variability of (A) catches and (B) effort of *P. muelleri* fisheries (bars) in relation to the LPUE as estimated by GLM (lines).

Overall, the LPUE analyses indicate that both species alternate their availability in the fishing grounds off southern Brazil during the spring-summer fishing season; i.e. while *P. muelleri* abundance gradually decreases towards the summer, *A. longinaris* tends to peak in the last month of that season. These patterns explain the marked seasonal variability in the catches of both shrimp species previously observed off southern Brazil and the Mar del Plata (PEREZ et al., 2003; GAVIO; BOSCHI, 2004). *A. longinaris* and *P. muelleri* are, further, often caught together off southern Brazil, although their proportions in the catches seem generally to be uneven. This suggests that whereas both species may share at least some similar environmental requirements (DUMONT, 2005), they are likely to compete for similar resources in the fishing area and therefore one species (*A. longinaris*) seems to benefit from the decrease of the other's (*P. muelleri*) abundance, as the fishing season progresses.

The highest *A. longinaris* LPUEs concentrated in the southernmost Brazilian fishing area decline towards the north. Off Argentina concentrations also exhibit latitudinal variations, although there catches decrease towards the south (BOSCHI, 1997). By contrast, *P. muelleri* seems to be more abundant off Argentina (BOSCHI, 1997), but the species is apparently more evenly distributed off southern Brazil. DUMONT (2005) observed that *P. muelleri* is less abundant and more homogeneously distributed than *A. longinaris* off

Rio Grande do Sul. Regarding bathymetric distribution, the abundance of both shrimps decreases toward deeper bottoms (> 40 m), as previously observed by HAIMOVICI and MENDONÇA (1996) and DUMONT (2005). However, good catches of *P. muelleri* were still obtained up to 150 m deep, indicating that this species is more homogeneously distributed seaward than is *A. longinaris*.

Considering the physical characteristics of the fishing vessels, the highest catch rates of *A. longinaris* were obtained by vessels with intermediate capacity (27–45 t), suggesting that vessels with small and large holding capacities tend to catch this shrimp less efficiently. A similar relationship was found in relation to the age of vessels, but this pattern may be interpreted with reserve, because the LPUEs were close to the reference LPUE and had no statistical significance in the model. However, it seems evident that old vessels (21 to 40 yrs) were less efficient at catching *A. longinaris* than their newer counterparts.

Interestingly, the physical characteristics of the fishing vessels had no significance in the *P. muelleri* models. This suggests that *P. muelleri* abundance variability is not correlated to the physical characteristics of the fleet, indicating that the latter are better adapted to catching *A. longinaris*.

The influence of the trawlers' physical characteristics and the vessels' experience in fishing for these shrimps off southern Brazil are not conclusive, although they may be significant in some cases. The marked concentration of this species in time and space, coupled with the structural and technological similarity of the fishing vessels, may explain the similar efficiencies displayed by vessels of the fleet during the fishing seasons.

The abundances of *A. longinaris* and *P. muelleri* showed marked interannual fluctuations, with years of high abundances followed by a “crash” (i.e. low abundances) in the following year. Despite those fluctuations, there was no discernible tendency to increase or decrease. Fluctuations in the catches of both species have been observed off southern Brazil and Argentina, and seem to be related to recruitment variability rather than fishing effort (HAIMOVICI; MENDONÇA, 1996; BOSCHI, 1997).

However, we also found that high abundance in some years resulted in high catches. Interestingly, this pattern was not constant during the study period, since some years of high abundance were found to be coupled with low catches, due to the low fishing effort. Overall, the fishing effort of one fishing season tended to increase if the LPUE of the previous season was high, especially for *P. muellery*. This suggests that that the trawl fleet may exploit this stock more or less intensely one year depending on the perceived abundance in the previous year. That scenario has also been described for other seasonal stocks vulnerable to trawl fishing such as squids (PEREZ, 2002) and is consistent with the opportunistic behavior displayed by the trawl fleet of southeastern and southern Brazil (PEREZ; PEZZUTO, 1998, 2006), which tends to exploit different resources in specific areas and depths in order to maintain economic yields at compensatory levels (PEREZ et al., 2003).

Considerations about management strategies

The results of this study suggest some strategies for sustainable management of these fisheries. Although no stock-recruitment relationship has been formally established, the limitation of effort should contribute to avoiding excessive mortality in the years that follow years of high abundances and catches. This would be possible if the number of boats or the intensity of the activity seeking the resource was limited. The control of the performance of the vessels is possible by satellite-tracking, established in Brazil by IN n° 2/2006 (BRAZIL, 2006). However, the definition of the effort in terms of fleet size and the activity of each vessel depends on estimates of the abundance of the stocks in each fishing area. Similarly, a spatial definition of fishing areas on the southern Brazilian shelf and the specific licensing of vessels could improve the conservation and productivity of these stocks as discussed by PEREZ et al. (2001).

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