DOI: 10.3856/vol36-issue2-fulltext-7

Research Article

The use of the swept area method for assessing the seabob shrimp *Xiphopenaeus kroyeri* (Heller, 1862) biomass and removal rates based on artisanal fishery-derived data in southern Brazil: using depletion models to reduce uncertainty

Paulo R. Pezzuto, José A. Alvarez-Perez & Roberto Wahrlich

Universidade do Vale do Itajaí, Centro de Ciências Tecnológicas da Terra e do Mar, Rua Uruguai 458, CEP 88.302-202, Itajaí, SC, Brazil

ABSTRACT. The seabob shrimp (*Xiphopenaeus kroyeri*) represents an important fishing resource for artisanal fishermen in coastal areas of southern Brazil. Stock assessments of this species have generally relied on biomass dynamics models as applied to CPUE time-series, which (a) are only available for a small offshore fraction of the exploited population and (b) does not comprise patterns of the shallowest artisanal fishing grounds. This work explores the use of extensive catch and effort data derived from a small-scale trawl fishery to obtain swept-area estimates of abundance and removal rates in a limited coastal area of southern Brazil (Tijucas Bay, Santa Catarina State, 27°15'S-48°33'W). Data were obtained from 7,198 fishing trips monitored at the fishing communities between June 2004 and August 2005. Because three parameters of the swept-area equation (*i.e.* trawl velocity, catch efficiency and wing spread) were unknown, they were defined through a stochastic procedure and calibrated by estimates produced by a Leslie depletion model applied to concurrent catches obtained in one fishing ground. A 21.7% removal rate was estimated for the period June 2004-January 2005; this increased to nearly 34% between February and July 2005. This removal scenario predicted that a five-month fishery would suffice to remove 90% of the biomass available in the Tijucas Bay, nearing the 87% CPUE reduction observed in the same period. Whereas abundance and harvest rate estimates were likely affected by inadequate knowledge of the swept-area equation parameters, the similarity of these estimates with relative abundance indexes supports the convenience of the proposed method and justifies future efforts to improve its accuracy.

Keywords: stock assessment, swept-area, depletion, artisanal fisheries, Penaeidae, *Xiphopenaeus kroyeri*, Brazil.

El uso del método de área de barrido para la evaluación de la biomasa y tasas de remoción del camarón *Xiphopenaeus kroyeri* (Heller, 1862) a partir de datos de la pesca artesanal en el sur de Brasil: la utilización de modelos de reducción de stock para disminuir incertidumbres

RESUMEN. El camarón (*Xiphopenaeus kroyeri*) representa un importante recurso para pescadores artesanales en áreas costeras del sur de Brasil. Evaluaciones de stock de esta especie generalmente resultan de modelos de dinámica de biomasa aplicados a series temporales de CPUE los cuales (a) están disponibles solamente para una pequeña fracción explotada en áreas más alejadas de la costa y (b) que no contienen los patrones de los fondos someros de la pesca artesanal. Este trabajo analiza la utilidad de numerosos datos de captura y esfuerzo obtenidos en una pesquería de arrastre de pequeña escala para el estimado de abundancia y tasas de remoción, por el método de área de barrido, en un área costera reducida del sur de Brasil (bahía de Tijucas, Estado de Santa Catarina, 27°15'S-48°33'W). Los datos fueron obtenidos de 7.198 viajes de pesca monitoreados en comunidades pesqueras entre junio de 2004 y agosto de 2005. Debido al desconocimiento de tres parámetros de la ecuación del área de barrido (*i.e.* velocidad del arrastre, eficiencia y apertura horizontal de las redes), éstos fueron definidos por un procedimiento estocástico y calibrados por los estimados producidos por un modelo de reducción de stock de Leslie aplicado a capturas simultáneas obtenidas en una misma área de pesca. Se estimó una tasa de remoción de 21,7% para el periodo junio 2004-enero 2005, que aumentó casi al 34% entre febrero y julio de 2005. Estos estimados permitieron pronosticar que cinco meses de pesquería serían suficientes para remover el 90% de la biomasa disponible en la bahía de Tijucas, lo que se aproxima al 87% de reducción de la CPUE observada durante el mismo período. Es probable que los estimados de abundancia y tasas de remoción hayan sido afectados por el conocimiento insuficiente de los referidos parámetros de la ecuación del área de barrido, la similitud con índices relativos de abundancia apoyan la utilidad del método planteado y justifica esfuerzos futuros que permitan mejorar su precisión.

Palabras clave: evaluación de stock, área de barrido, reducción de stock, pesquería artesanal, Penaeidae, *Xiphopenaeus kroyeri*, Brasil.

Corresponding author: Paulo Ricardo Pezzuto (pezzuto@univali.br)

INTRODUCTION

Fishing management greatly benefits from the availability of stock abundance estimates at any one time. In that sense, abundance survey procedures have long been developed as experimental solutions to obtain direct estimates of current biomass levels providing that (a) there is a complete understanding of the distribution of the target species and (b) the operation of a determined sampling gear produces realistic records of the species abundance in a known sampled area (Gunderson, 1993).

In the case of demersal species, trawls have been generally used as samplers under the assumption that they tend to represent the abundance of individuals present in an area that is "swept" as they are dragged on the seafloor. This rather simple concept has been the basis of the "swept-area" method largely employed in direct biomass assessment programs for bottom dwelling organisms worldwide (*i.e.* groundfish, shrimps, crabs, clams, and others) (Gunderson, 1993; Sparre & Venema, 1998). Accurate estimates, as provided by this method, however, are sensitive to spatial sampling designs and certain parameters of the trawl and trawling operation that determine both the precise extent of the sampled area and the gear efficiency (*i.e.* the ability to avoid escapement of individuals present in the sampled area). In important demersal fishing areas of the world, such uncertainties have been reduced in long-term abundance survey programs through improved sampling designs and understanding of the sampling gear behavior. In tropical and/or small-scale fisheries, however, mostly in the developing world, the structure and costs involved in the development of such programs are often limiting factors and direct abundance surveys, although methodologically applicable, are punctual, irregular, or nonexistent (see Haimovici, 2007 for example).

The seabob shrimp, *Xiphopenaeus kroyeri* (Heller, 1862), occurs in coastal waters of the western Atlantic and is an important fishing resource throughout its entire latitudinal range from North Carolina (USA) to Santa Catarina (Brazil) (D'Incao, 1995). The species is the most abundant crustacean in commercial catches off Brazil, reaching, in 2005, around 26% of the country's total reported crustacean landings (MMA/IBAMA, 2007). Catches originate mostly from artisanal fishing done on board stern and double-rig trawlers in shallow areas (under 30 m deep); this activity is particularly important for the livelihood of coastal communities (Valentini, 2006; Santos *et al.*, 2006). Despite being the subject of several sampling programs in different areas, specifically off the southeastern and southern Brazilian coast (Nakagaki, *et al*., 1995; Branco *et al*., 1999; Fransozo *et al*., 2000; Castro *et al*., 2005; Natividade, 2006), local seabob shrimp abundances have never been directly assessed by the swept area method. Instead, stock assessments of this species and other penaied shrimps exploited off Brazil have been based on low-cost fishery-derived catch rate time-series analyses and the application of biomass dynamic models (*e.g.* Santos *et al.*, 1973; Valentini *et al.*, 1991; D'Incao *et al.*, 2002). Recently, however, the reliability of these models for some stocks (*i.e.* the pink-shrimp *Farfantepenaeus paulensis* and *F. brasiliensis*) has become uncertain due to changes in the fishing structure and dynamics (D'Incao *et al.*, 2002), requiring that alternative approaches be developed to assess shrimp resources in the region.

In this context, this work aimed to explore the applicability of the swept area method for assessing local abundance of the seabob shrimp off the coast of Santa Catarina, southern Brazil, by using extensive georeferenced fishery-derived catch and effort data. Major limitations regarding such applicability emerge in response to the lack of a proper sampling design and uncertainties about (a) the effective area swept, as determined by unknown wing spread and trawl velocity, and (b) gear efficiency. As an approach to reduce such uncertainties, swept area abundance estimates were compared with concurrent depletion model applications in an attempt to calibrate unknown parameters (Gunderson, 1993; Lasta & Iribarne, 1997). Total biomass estimates obtained after the calibration procedures were confronted with monthly landings and used to calculate removal rates in the fishing grounds. The usefulness of this approach to obtain low-cost abundance and harvest rate estimates is discussed in light of the standard swept area method experimental procedures.

MATERIALS AND METHODS

Study area

Tijucas Bay is located in the central sector of the Santa Catarina State coast, southern Brazil (27°15'S–48°33'W). It encircles an area of 110,000 hectares of soft bottoms and is 10 m deep (Schettini & Klein, 1997; Abreu, 1998). The bay is bordered by the Porto Belo Peninsula and the township of Bombinhas to the north, by the township of Tijucas to the west, and the peninsula of Governador Celso Ramos to the south (Fig. 1). Subsistence and commercial artisanal fisheries are traditional activities in the region. Fishing communities are located around three cities in Tijucas Bay where shrimp trawling constitutes the main fishing practice (Wahrlich, 1999) (Fig. 1).

Biomass assessment

The study was based on the monitoring of the artisanal fleet trawling operations between June 2004 and August 2005. In the region, around 210 trawlers targeted seabob shrimps. Examining a sample of around 70 trawlers revealed that they generally have wooden hulls, are 4.0 to 10.7 m long (mean = 8.5 m ± 1.0 SD), and are powered by 17.2 HP engines (± 4.6 SD). These vessels operate two nets simultaneously with mean head rope and footrope lengths of 9.75 m (SD = 2.0 m) directly attached to the doors. Door weights and cod-end mesh sizes are, in general, between 15-20 kg and 24-26 mm stretched, respectively. Fishing trips last 9.2 h on average (± 14.0 SD) (R. Wahrlich, *pers. com.*).

Fishing data were obtained by monitors selected and trained within each fishing community, using the methodology proposed by Bonilha *et al*. (1999). Catch and effort data were produced by both landing records and skipper interviews. Landing records covered all 7,198 trips carried out during the study period and included information on landing dates, boat names, and by-catch species. Skipper interviews were done for 1,527 trips (21.2% of the total) and provided detailed data on fishing effort (trawling hours, number of trawls per trip), by-catch species, and fishing grounds. The geographic distribution of fishing grounds cited by local fishermen during the interviews enabled us to divide the entire bay area into the eight sub-areas described in Table 1 and Figure 1. These data were transformed into catch per unit effort (CPUE in kg hour^{-1}) and also used to allocate the total catches reported in the landing records in the sub-areas, following the equation:

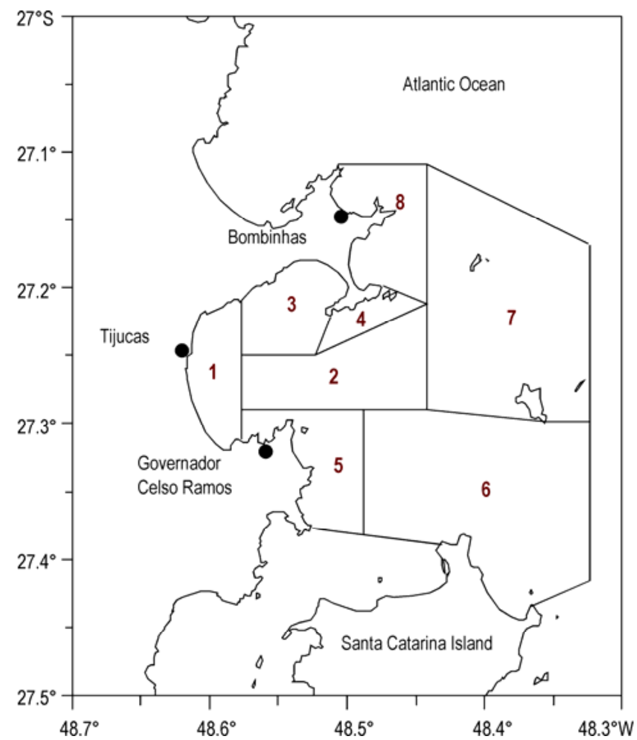

Figure 1. Study area in Santa Catarina State, southern Brazil. Sub-areas are delimited by lines and numbered from 1 to 8.

Figura 1. Area de studio en el Estado de Santa Catarina, sur de Brasil. Sub-áreas delimitadas por líneas y numeradas de 1 a 8.

$$C_{i,j} = C_j \frac{CI_{i,j}}{CI_j} \qquad (1)$$

where $C_{i,j}$ is the total catch in the *i*-eth sub-area in the *j*-eth month; C_j is the total catch reported in the landing records during the *j*-eth month; CI_{ij} is the catch reported during interviews in the *i*-eth sub-area and *j*-eth month; and CI_j is the total catch reported during interviews in the *j*-eth month.

Table 1. Area (in km^2) of the eight sub-areas identified in Tijucas Bay, Santa Catarina, Brazil.

Tabla 1. Área (en km^2) de las ocho sub-áreas identificadas en la Bahía de Tijucas, Santa Catarina, Brasil.

Sub-area	Name	Area
1	Baixio	34.91
2	Baía de Tijucas	89.25
3	Baía de Zimbros	38.13
4	Macuco	13.59
5	Costeira dos Ganchos	51.28
6	Ponta do Bota	206.26
7	Ilha do Arvoredo	197.07
8	Mar de Fora	61.51

Total exploitable biomass was estimated during five different months: June 2004 and January, February, June, and July 2005. These months were selected following several criteria: (a) they corresponded to periods when overall catches were either very high or very low; (b) they were either close to or distant from the fishing closure period to which the fishery was subjected (March to May, until 2006), and (c) the fishing effort was broadly distributed throughout the largest possible number of sub-areas.

Mean biomass estimates per km^2 (± 95% CI) were calculated for each sub-area using the swept-area method (Sparre & Venema, 1998). This procedure demanded the transformation of catch rates reported for each fishing trip (in kg hour^{-1}) into biomass densities (B, in kg km^{-2}) using the equation proposed by Sparre & Venema (1998) modified as:

$$B = \frac{CPUE/Er}{2\ (V \cdot 1{,}852 \cdot Ct/1000\ \cdot Ca)} \qquad (2)$$

where CPUE is catch per unit effort (in kg of shrimp retained per trawling hour); *Er* is the trawl net efficiency, *i.e*. the fraction of shrimps available in the net's path that are actually retained in the net's cod-end; *V* is the trawl velocity (in knots); *Ct* is the net's head rope length (in meters); *Ca* is the wing spread, *i.e.* the width of the path swept by the trawl expressed as a fraction of *Ct*; and "2" refers to the number of nets trawled during one fishing haul.

Mean stratified biomass (kg km^{-2}) and total exploitable biomass (t) were estimated for the set of sub-areas visited by the fleet during each analyzed month, using a stratified random design in which each sub-area was considered to be a statistic stratum and the whole set of sub-areas visited in that month composed the total population. Equations used in the estimates followed Krebs (1989):

$$\bar{x}_{st} = \frac{\sum_{h=1}^{L} N_h \bar{x}_h}{N} \qquad (3)$$

where $\bar{x}_{st}$ is the stratified mean biomass per km^2; N_h is the size of stratum (sub-area) *h*; *h* is the stratum number; $\bar{x}_h$ is the observed mean biomass for stratum *h*; and *N* is the total population size ($\sum N_h$). Total biomass ($\hat{x}_{st}$) in the strata considered was estimated as:

$$\hat{x}_{st} = N\,\bar{x}_{st} \qquad (4)$$

Standard errors for the stratified mean biomass and total biomass in the area were estimated, respectively, by the equations:

$$SE_{\bar{X}_{st}} = \sqrt{\sum_{h=1}^{L} \left[\frac{(N_h/N)^2 (S_h)^2}{n_h} (1 - n_h/N_h) \right]} \qquad (5)$$

and

$$SE_{\hat{x}_{st}} = N^2 SE_{\bar{x}_{st}} \qquad (6)$$

where S_h^2 is the variance in stratum *h* and n_h is the sample size in stratum *h*.

Table 2 shows a summary of the number of trips included in each month's calculations.

In Equation 2, *Ct* was fixed as 9.75 m, which corresponds to the average head rope length used in the fleet. Since the other three parameters of this equation were unknown (efficiency, velocity, wing spread), these were defined through a stochastic procedure. Initially, a set of possible values to be tested for these parameters (Table 3) was chosen based on reference values available in the literature. Three trawl velocities were tested: 1.5, 2.0, and 2.5 knots, as derived from values recently reported for seabob shrimp artisanal boats in southeastern and southern Brazil (ranging from >1 to >2 knots) (Nakagaki *et al.*, 1995; Branco *et.al.*, 1999; Branco, 2005; Campos, 2006; Natividade, 2006). Efficiency values ranging from 0.4 to 1.0 (in

Table 2. Number of trips included in each sub-area and month selected for the assessment of the exploitable seabob shrimp (*Xiphopenaeus kroyeri*) biomass in Tijucas Bay and the total reported catches. * Sub-areas 6 and 7 were added.

Tabla 2. Número de viajes incluidos en cada sub-área y mes seleccionado para la evaluación de la biomasa explotable del camarón (*Xiphopenaeus kroyeri*) en la bahía de Tijucas y capturas totales reportadas. * Las sub-áreas 6 y 7 fueron adicionadas.

Sub-area	Period				
	June 2004	January 2005	February 2005	June 2005	July 2005
1	6	6	13	3	14
2	101	84	78	140	63
3	11	6	2	-	3
4	27	12	27	98	9
5	6	6	88	35	14
6	-	-	-	3*	-
7	-	-	-	-	-
8	24	-	4	34	-
Total catch (kg)	65,949.5	6,094.5	55,158.4	171,483.7	16,694.2

0.1 intervals) were chosen following Sparre & Venema (1998), finding that efficiency values frequently used in swept-area estimations vary between 0.5 and 1.0. Finally, wing spread coefficients (net opening/head rope length) between 0.6 and 0.8 (in 0.25 intervals) were tested, considering that, for the nets used in the seabob shrimp fishery, the doors are attached directly to the head and foot ropes, which tends to increase the horizontal opening of the net (Okonski & Martini, 1987).

Multiple combinations of possible values for these parameters (5 wing spread coefficients x 3 velocities 7 efficiencies) generated 105 possible biomass estimates (± 95% CI) for each of the selected months. Biomass estimates below the total catch reported during each month were regarded as unrealistic. As a consequence, within the total universe of estimates, only those whose lower confidence intervals were higher than the total catch landed during each analyzed month (Table 2) were selected as potentially correct. The next step was to estimate which parameter combination, among those that produced the potentially correct biomass estimates, were the most realistic ones.

For that purpose, a depletion experiment was conducted (Hilborn & Walters, 1992) in order to obtain alternative shrimp biomass estimates in time periods and sub-areas where mean biomass estimates made using the swept-area method were also available. Because a depletion experiment generates abundance estimates that refer to the beginning of the studied period, it was considered that the resulting biomass estimate should be necessarily higher than that produced by the swept-area method for concurrent sub-areas and time periods. The most robust combination of parameter values for Equation 2 was identified by contrasting the results generated by both methods; these were then used to calculate the final biomass estimates for all months and sub-areas considered.

The application of a depletion experiment required the "closed stock" assumption, *i.e.* during particular fishing periods in localized areas, losses due to natural mortality or emigration, and gains by recruitment or immigration can be considered insignificant (Hilborn & Walters, 1992). Consequently, under such a "depletion scenario", all shrimp population losses were caused by fishing removals. If these assumptions were valid, the rate at which the shrimp stock abundance declined as controlled catches were produced by the fishing effort allowed the projection of the amount of catch required to deplete the stock completely. This amount corresponded to an estimate of abundance in the beginning of the experiment.

In this study, the depletion scenario was not experimental, but identified from direct observations of catch rates and landings from 135 fishing trips conducted by seabob shrimp trawlers, which concentrated their operations in sub-area 2 during the first 24 days of June 2005. This same data set was used to produce biomass estimates by the swept-area method taking Equation 2 parameter combinations, previously regarded as the most realistic ones from the stochastic procedure describe above. The initial stock abundance calculation was conducted using a Leslie estimator, which considers the following simplified population model:

$$B_t = B_0 - K_{t-1} \quad (7)$$

where the stock biomass in time period t (B_t) results from the biomass at the beginning of the period (B_0) minus the catch accumulated during the time period immediately anterior to t (K_{t-1}). Considering that CPUE during t (U_t) is an index of the stock relative abundance in t, then:

$$U_t = q\, B_t \quad (8)$$

where q is the catchability (or efficiency) coefficient and:

$$U_t = q\, B_0 - q\, K_{t-1} \quad (9)$$

This equation expresses a linear relationship between CPUE during any time period t (dependent variable) and the catch accumulated in the time period immediately anterior to t (independent variable). A linear model was fitted to the relationships of these variables during the depletion scenario, which resulted in the estimation of the intercept (qB_0) and slope (q) parameters, as well as B_0, which derives from their ratio.

During the depletion experiment, all fishing trips recorded in one day were pooled to produce daily catch, effort, and CPUE values. A linear model was then fitted to the daily CPUEs (U_t) and catches accumulated previous to day t (K_{t-1}) (dependent and independent variables, respectively) using a Monte Carlo procedure in which linear parameters were estimated repeatedly 500 times, each of them including all but one randomly selected day. For each trial, initial biomass (B_0) and the escapement rate were calculated, the latter resulting from the difference between B_0 and the total catch during the depletion period, expressed as a proportion of B_0. A frequency distribution of the estimates allowed the calculation of median values as well as 95% confidence intervals, which were compared then with the biomass estimates produced simultaneously by the swept-area method.

RESULTS

Total catch and mean catch rates

Monitored monthly landings of the seabob shrimp in Tijucas Bay varied from a minimum of 1.2 ton in November 2004 to a maximum of 171.5 ton in June 2005. Production oscillated irregularly during the studied period, with peaks in June 2004 and February and June 2005 (Fig. 2). It is necessary to point out, however, that catches recorded between March and May 2005 were underestimated because most illegal operations conducted during the fishing closure period were not reported. Mean catch rates oscillated between a minimum of 2.0 kg h^{-1} in November 2004 to a maximum of 19.3 kg h^{-1} in March 2005, in a cyclic temporal pattern. The highest catch rates were recorded between February and June, stabilizing around 2.5 kg h^{-1} between July and January (Fig. 2).

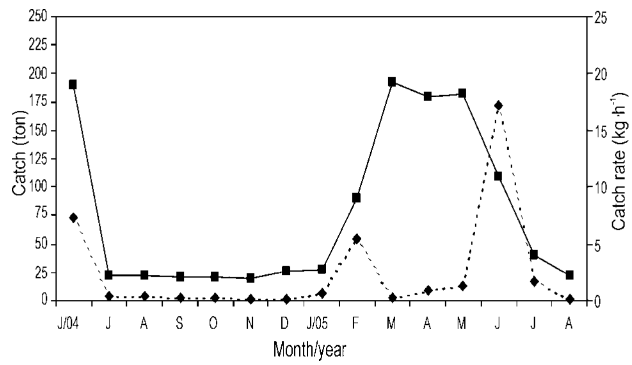

Figure 2. Monitored monthly catches (dashed line) and mean catch rates (continuous lines) of the seabob shrimp (*Xiphopenaeus kroyeri*) fishery in Tijucas Bay from 2004 to 2005.

Figura 2. Capturas mensuales monitoreadas (línea discontinua) y tasas promedias de captura (líneas continuas) de la pesca del camarón (*Xiphopenaeus kroyeri*) en la bahía de Tijucas entre 1004 y 2005.

Biomass assessment

Most combinations of the values indicated in Table 3 produced biomass estimates above monthly landings (i.e. the entire simulation procedure resulted in 96, 105, 60 and 82 plausible biomass estimates for June 2004 and January, February, and July 2005, respectively). As such, this procedure proved to be of little use in the definition of a single set of parameters that could be applied in final biomass estimates. As an exception, in June 2005, only eight combinations were found to produce plausible biomass estimates (Table 4); they were considered essential to the identification of the most likely values of these parameters.

Within the eight possible combinations, the parameters showed reduced internal variability (Table 4). As such, trawl velocity was fixed at 1.5 knots, the value occurring in all but one combination. A wing spread value of 0.65 was adopted because 75% of the combinations included either that exact value or were within its 10% vicinity. As for the trawl net efficiency parameter, both likely values (0.4 and 0.5) were considered equally. This choice was crucial since, all

Table 3. Values assumed for the parameters of Equation 1 for estimating the biomass of the seabob shrimp (*Xiphopenaeus kroyeri*).

Tabla 3. Valores asumidos para los parámetros de la Ecuación 1 para estimar la biomasa del camarón (*Xiphopenaeus kroyeri*).

Wing spread	Trawl velocity	Efficiency
0.60	1.5	0.4
0.65	2.0	0.5
0.70	2.5	0.6
0.75		0.7
0.80		0.8
		0.9
		1.0

other parameters being fixed, biomass estimates were shown to be highly sensitive to this parameter. In fact, a 10% difference in net efficiency would lead to 25% variability in biomass, as evidenced in the first two cases of Table 4. Therefore, a definitive choice of the net efficiency parameter value was dependent on the results of the depletion analysis.

Figure 3 depicts the linear model fitted to the U_t and K_{t-1} relationship, showing that more than 50% of the CPUE variability was explained by shrimp accumulated catches and the consequent abundance decline of the stock during the selected depletion period.

Initial biomass and escapement rates, as estimated by the Monte Carlo procedure, exhibited low variability (Fig. 3). The median biomass estimated for sub-area 2 during the first 24 days of June was 38,557.3 kg (Table 5). Considering that the total catch recorded in this sub-area during this period was 35,140.1 kg, the median estimated escapement rate was 0.14 (Upper CI 95% 0.28 – Lower CI 95% 0.06).

When comparing the biomass values as estimated by both the swept-area and depletion procedures (Table 5), it can be seen that a trawl net efficiency of 0.5 produced a mean biomass estimate slightly lower than that produced by the depletion experiment. Thus, this efficiency value was adopted as the most plausible for Equation 2 and the final biomass estimates were produced for all other sub-areas and months (Table 6). Because the sub-areas were not evenly visited by the fleet during the study period (Table 2), the five last monthly biomass estimates were not totally comparable, but are only valid within their respective sub-areas. On the other hand, direct comparisons were possible between June 2004 and February 2005 and between January and July 2005 since, in those paired months, the fleet visited exactly the same grounds (Table 2). Table 6 reveals that the total biomass increased from 31.8 ton in January to 50.2 ton in July 2005, and decreased from 271.3 ton to 150.7 ton between June 2004 and February 2005.

Constrasting the estimated biomass (Table 6) with the recorded monthly catches (Table 2) shows that, between June 2004 and January 2005, on average, the harvest rate of the available biomass reached 21.7% per month; between February and July 2005, however, this rate increased to nearly 34% (Table 6).

DISCUSSION

The standard application of the swept-area method to estimate density and abundance of demersal stocks involves crucial assumptions about (a) the availability of the stock to the trawl and the trawling operations,

Table 4. Total seabob shrimp (*Xiphopenaeus kroyeri*) biomass estimates for June 2005 and the parameters assumed for the swept-area equation.

Tabla 4. Estimados totales de la biomasa del camarón (*Xiphopenaeus kroyeri*) para junio de 2005 y parámetros asumidos para la ecuación del área de barrido.

Wing spread	Trawl velocity (knots)	Efficiency	Biomass (kg)	Lower CI (kg)	Upper CI (kg)
0.60	1.5	0.4	655,765.4	238,290.8	1,073,239.9
0.60	1.5	0.5	524,612.3	190,632.6	858,591.9
0.60	2.0	0.4	491,824.0	178,740.5	804,907.6
0.65	1.5	0.4	605,321.9	219,967.6	990,676.1
0.65	1.5	0.5	484,257.5	175,974.1	792,540.9
0.70	1.5	0.4	562,084.6	204,262.0	919,907.1
0.75	1.5	0.4	524,612.3	190,650.5	858,574.0
0.80	1.5	0.4	491,824.0	178,740.5	804,907.6

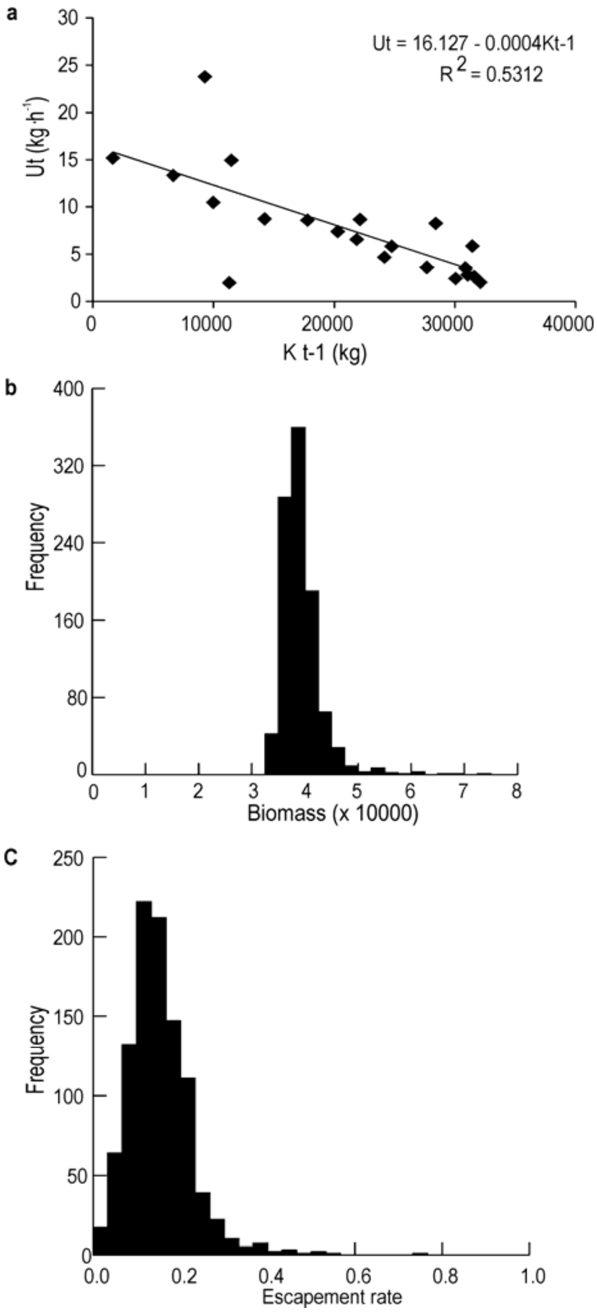

Figure 3. Results of the depletion experiment applied to the seabob shrimp (*Xiphopenaeus kroyeri*) in the first 24 days of June 2005 in the sub-area 2. a) Linear model fitted to U_t and K_{t-1} data, b) distribution of initial biomass estimates, and c) escapement rates obtained in 500 simulations conducted using a Monte Carlo procedure.

Figura 3. Resultados del experimento de depleción aplicado al camarón (*Xiphopenaeus kroyeri*) en los primeros 24 días de junio de 2005 en la sub-área 2. a) Modelo linear ajustado a los datos de U_t y $K_{t-1,}$ b) distribución de las estimativas de biomasa inicial, y c) tasas de escape obtenidas en 500 simulaciones conducidas por un procedimiento del tipo Monte Carlo.

(b) the probability of escapement of the organisms through vulnerability and selectivity processes, (c) precise knowledge of the sampled area and that of the stock distribution, and (d) the representativeness of the sampling design. When only commercial fishing data is available, some of the above assumptions are jeopardized by the profit-oriented nature of the "sampling procedure"; *i.e*. they are highly biased towards high-density areas, comprising sometimes only a fraction of the whole stock distribution area. Additionally, the actual sampled area may also be of great uncertainty because trawl and trawling parameters may be extremely variable among sampling units (i.e. trawlers) or basically unknown. All things considered, biomass estimates made using the swept-area method have been usually limited to specifically designed experimental procedures (Gunderson, 1993).

Nevertheless small-scale artisanal fisheries, associated with significant social but not economic value, may hardly justify the effort, structure, and costs involved in the establishment of such sampling procedures. All too often, such fisheries are characteristic of highly diversified tropical areas in the developing world, where limitations even increase. In that sense, attempts to develop alternative procedures that involve low-cost data generation and provide at least referential values for absolute biomass seem highly justified.

Due to strong data limitations, the assessment and management of seabob shrimp in the southeastern/southern coast of Brazil has been based on the application of the Graham-Schaefer biomass dynamic model, mostly fitted to the CPUE patterns obtained by the São Paulo State industrial fleet (Valentini *et al*., 1991; D'Incao *et al*., 2002). As a consequence, the seabob shrimp trawl fishery (both artisanal and industrial) that is conducted along over 2,300 km of coastal habitats, including the interior of bays, is submitted to management actions that are strongly dependent on a small offshore fraction of the exploited population and that hardly incorporates local peculiarities. In that sense, the present analysis explored the applicability of extensive fishing data to obtain absolute biomass estimates of the seabob shrimp within Tijucas Bay, Santa Catarina, as a contribution to future local community-based management practices.

This exercise required the combination of the swept-area method and depletion estimators as a strategy for reducing the previously mentioned shortcomings and improving absolute abundance estimates. This approach is not uncommon, particularly in invertebrate stock assessments. For example, Otto (1986), Iribarne *et al*. (1991), and Lasta & Iribarne (1997) combined classical depletion models (Leslie & Davis, 1939; DeLury, 1947) to estimate gear efficiency in

Table 5. Total seabob shrimp (*Xiphopenaeus kroyeri*) biomass estimates for the first 24 days of June 2005 in sub-area 2 by both depletion and swept-area methods (efficiency values 0.4 and 0.5).

Tabla 5. Estimativas de la biomasa total del camarón (*Xiphopenaeus kroyeri*) para los primeros 24 días de junio de 2005 en sub-área 2 por los métodos de depleción y área de barrido (Eficiencia de 0,4 y 0,5).

Method	Biomass (kg)	Lower 95% CI (kg)	Upper 95% CI (kg)
Depletion	38,557.3	35,065.1	4,494.7
Swept-area			
Efficiency 0.4	46,015.1	40,988.1	51,042.1
Efficiency 0.5	36,812.1	31,785.1	41,839.1

abundance surveys designed for the king crab off Alaska and scallops off Argentina. Similarly, exercises have also been conducted in other crab and bivalve fisheries by using catch-survey analyses (CSA) and removal and index-removal estimators, all derived from the classical depletion models (Collie & Kruse, 1998; Chen *et al*., 1998, Gedamke *et al*., 2005). Finally, an application of depletion models to calibrate gear efficiency of fishing data-derived abundance estimates can be found in a study by Dallagnolo (2008) on the stock assessment of deep-water shrimps off Brazil.

The present procedure applied to the small-scale seabob shrimp fishery off southern Brazil produced abundance estimates that have been found to be coherent with relative abundance patterns generally described for the species, as will be discussed below. Despite the fundamental limitations related to uncertainties regarding the most relevant parameters of the swept-area equation, the method explored was particularly promising because such uncertainties could be further reduced by field observations, which could provide accurate data on trawl velocities and wing spread coefficients, for example. Because the studied trawl fleet is relatively homogeneous and fishing occurs in a limited area, these observations would be easy to obtain and could be regarded as representative of local fishing characteristics.

Absolute biomass estimates obtained in this work suggest that shrimp abundance available to the trawl fishery in Tijucas Bay exhibits a cyclic pattern. In February, the shrimp seems to recruit in the fishery, keeping the stock biomass elevated until June. Thereafter, abundance tends to decline until the end of the year when it is replaced by a new recruitment and the cycle starts again. Despite the catch reduction produced by the effect of the fishing season closure (March to May), this pattern is confirmed both by catch and catch rate temporal profiles (Fig. 2). The observed cyclicity seems to be characteristic of the species since it has been reported historically by different indices even before the development of an industrial fleet capacity over this resource, which took place in São Paulo State (southeastern Brazil) in the early 1970s (Valentini *et al.*, 1991). In fact, between 1944 and 1945, the artisanal shrimp fleet that operated in the Santos Bay obtained the highest catch rates between May and June and the lowest rates between September and October (Santos *et al.*, 1968). Tremel (1968) observed that the monthly production landed in Santa Catarina State between 1963 and 1967 was highest in the first semester, declining sharply thereafter. More recent scientific surveys conducted off the coast of São Paulo, Paraná, and Santa Catarina states have shown that seabob shrimp catch rates tended to be higher between late austral summer and early winter (Nakagaki & Negreiros-Fransozo, 1998; Branco *et al.*, 1999; Branco, 2005; Natividade, 2006). Finally, mean monthly landings calculated between 1998 and 2005 in São Paulo and Santa Catarina States between 2001 and 2006 showed the highest values in the first semester of the year (except for the fishing closure period), in particular during June (Fig. 4).

This population feature can be partly explained by the species life history which, along the southeastern and southern Brazilian coast, has been characterized by: (a) two reproductive periods during the year, a principal one in spring and a secondary one in late summer and autumn; (b) the predominance of young individuals in summer and/or autumn catches and large individuals in the second semester; (c) first maturation at nearly six months of age and; (d) an approximately 1.5-year life span (Vieira, 1947; Tremel, 1968; Severino-Rodrigues *et al.*, 1993; Nakagaki & Negreiros-Fransozo, 1998; Fransozo *et al.*, 2000; Branco, 2005; Castro *et al.*, 2005; Campos, 2006; Natividade, 2006). Because these life history patterns are consistent throughout the entire distribution area, the traditional hypothesis commonly supported by local fishermen in which the catch rate cycles observed in Tijucas Bay were related to northward migratory movements seems unlikely. Alternatively, some authors (*e.g*. Castro *et al.*, 2005) suggested that the spring reproduction event may occur in deeper waters, limiting the availability of the resource in the fishing grounds exploited by the artisanal fleet. The latter hypothesis, however, is not supported by other studies that have shown that, even in spring, catches in shallow waters are highest (*e.g.* Natividade, 2006), or that mature females are frequently caught in the fishing grounds (*e. g.* Tremel, 1968). Although

Table 6. Total seabob shrimp (*Xiphopenaeus kroyeri*) biomass estimates (± CI 95%) for June 2004 and January, February, June, and July 2005 by the swept-area method (catch efficiency 0.5) and respective removal rates.

Tabla 6. Estimativas de la biomasa total del camarón (*Xiphopenaeus kroyeri*) (± IC 95%) para junio de 2004 y enero, febrero, junio y julio de 2005 por el método del área de barrido (eficiencia 0.5) y respectivas tasas de remoción.

Month-Year	Biomass (kg)	Lower CI (kg)	Upper CI (kg)
Jun-04	271,281.3	209,887.2	332,675.4
Jan-05	31,787.5	25,959.2	37,615.8
Feb-05	159,690.8	111,642.0	207,739.6
Jun-05	484,257.5	175,974.1	792,540.9
Jul-05	50,207.6	43,491.0	56,924.3
	Removal (%)	Lower CI (%)	Upper CI (%)
Jun-04	24.31	31.42	19.82
Jan-05	19.17	23.48	16.20
Feb-05	34.54	49.41	26.55
Jun-05	35.41	97.45	21.64
Jul-05	33.25	38.39	29.33

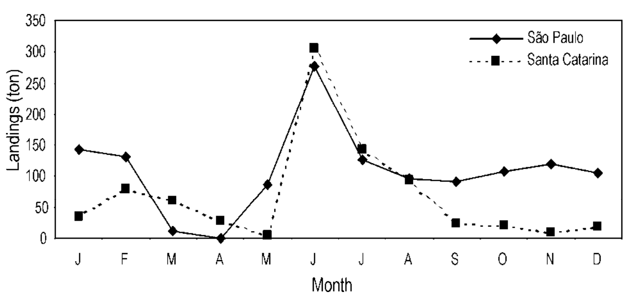

Figure 4. Monthly averages of seabob shrimp (*Xiphopenaeus kroyeri*) landings in the states of São Paulo and Santa Catarina. In the first case, data refer to the 1998-2005 period and include both industrial and artisanal fisheries. In the second case, the data include only industrial fishing monitored between 2001 and 2006. Sources: Instituto de Pesca–APTA–SAA–SP and GEP/ CTTMar/ UNIVALI. Values in tons.

Figura 4. Promedios mensuales de los desembarques del camarón (*Xiphopenaeus kroyeri*) en los Estados de São Paulo y Santa Catarina. En el primer caso, los datos corresponden al periodo 1998-2005 e incluye las pesquerías artesanales y industriales. En el segundo caso, los datos incluyen solamente la pesca industrial monitoreada entre 2001 y 2006. Fuentes: Instituto de Pesca–PTA-SAA–SP y GEP/ CTTMar/ UNIVALI. Valores en toneladas.

further investigation is required to elucidate shrimp within-year abundance fluctuations, a third plausible-explanation raised by the present study is that they reflect the elevated natural mortality expected in a short-lived species boosted by intense removals through local fishing.

Since the 1980s, the species has been included in an annual March-May closure season implemented to protect the pink-shrimp (*Farfantepenaeus* spp.) coastal recruitment migration. Such inclusion not only followed a precautionary action but also derived principally from the fact that coastal trawling for seabob shrimp would eventually produce catches of seaward-migrating pink-shrimp recruits. In the 1990s, however, the seabob shrimp stock abundance dropped 29% (D'Incao *et al.*, 2002), motivating the implementation of a specific annual closure season between October 1 and December 31 from 2006 on.

In order to be effective, however, this measure requires that a sufficiently abundant portion of the biomass recruited in the summer survive throughout the year in order to reach the legally protected reproductive period in spring. A comparison of the available biomass levels estimated in this study with the monthly catches recorded in the Tijucas Bay area suggested that the harvest rates may be excessively high and actually limit the abundance of the spring spawning biomass. If a simple stock biomass decay is simulated (considering negligible growth, mortality, and migrations), it can be predicted that, under a 21.7% monthly removal scenario, such as that observed between June 2004 and January 2005, the stock biomass early in the year would be reduced to less than 50% in only three months of fishery and to less than 10% in nine months (Table 7). If the 34.4% removal rate predicted by the present analysis in 2005 is considered, this scenario becomes even more severe as a five-month fishery would suffice to remove 90% of the biomass available in Tijucas Bay. In fact, the real figures reported in the region have shown that spring mean catch rates (2.2 kg h-1) are 87% lower than those recorded in autumn (17.08 kg h-1) (Fig. 2). That suggests that both removal scenarios previously hypothesized may not be far from reality and that the seabob shrimp fishery in Tijucas Bay is virtually limited to a six-month season. More importantly, it implies that the effectiveness of the newly implemented management strategy aimed at protecting spawning biomass during the main reproductive period of the species might be jeopardized by excessive levels of fishing mortality that reduce the spawning biomass to limiting levels before the reproductive period.

Whereas such conclusions are largely affected by the methodological uncertainties previously highlighted, the coincidence of both a relative abundance index and absolute biomass estimates supports the convenience of the proposed method and justifies the efforts discussed to improve its accuracy through a better understanding of the physical and operational features of the artisanal seabob shrimp trawl fleet.

Table 7. Seabob shrimp (*Xiphopenaeus kroyeri*) biomass decline simulations in Tijucas Bay over 12 months under two different scenarios represented by monthly removal rates of 21.7% and 34.4%. Calculations do not consider the effect of growth, natural mortality, and migrations.

Tabla 7. Simulaciones del la declinación de la biomasa del camarón (*Xiphopenaeus kroyeri*) en la bahía de Tijucas durante 12 meses en dos escenarios diferentes representados por tasas de remoción de 21,7% y 34,4%. Los cálculos no llevaron en cuenta el efecto del crecimiento, mortalidad natural y migraciones.

Time (months)	Remaining biomass (%)	
	21.7% monthly removal	34.4% monthly removal
1	78.3	65.6
2	61.3	43.0
3	48.0	28.2
4	37.6	18.5
5	29.4	12.1
6	23.0	8.0
7	18.0	5.2
8	14.1	3.4
9	11.1	2.2
10	8.7	1.5
11	6.8	1.0
12	5.3	0.6

ACKNOWLEDGEMENTS

The authors are thankful to the team of fishing data collectors and the people of the fishing communities of Tijucas Bay for making available information indispensable to this study. Oceanographers Gislei Cibele Bail, Ricardo Hoinkis, and Tiago Dallegrave Ingletto were critical to data collection supervision in the field and raw data standardization. We are indebted to Rafael Medeiros Sperb for the GIS analysis and the estimation of fishing areas. This study was funded by the National Fund for the Environment (Ministry of the Environment, Brazil; Agreement Contract FNMA CVI 025/2003) and National Council for Scientific and Technological Development (CNPq) research grants to JAAP (Process 306184/2007-9) and PRP (Process 310820/2006-5).

REFERENCES

Abreu, J.G.N. 1998. Contribuição à sedimentologia da plataforma continental interna de Santa Catarina entre a foz dos rios Tijucas e Itapocu. MSc. Thesis, Programa de Pós-Graduação em Geociências, Universidade Federal Fluminense, Rio de Janeiro, Brasil, 75 pp.

Bonilha, L.E.C., M. Polette, J. Matarezi & I.A. Araújo. 1999. Implementação de um programa de Monitoramento Ambiental Voluntário na Zona Costeira: aspectos metodológicos e estudo de caso: Programa Olho Vivo. Revta. Estudos Ambientais, 1(2): 59-70.

Branco, J.O. 2005. Biologia e pesca do camarão sete-barbas *Xiphopenaeus kroyeri* (Heller) (Crustacea, Penaeidae), na Armação do Itapocorói, Penha, Santa Catarina, Brasil. Revta. Bras. Zool., 22(4): 1050-1062.

Branco, J.O., M.J. Lunardon-Branco, F.X. Souto & C.R. Guerra. 1999. Estrutura populacional do camarão sete-barbas *Xiphopenaeus kroyeri* (Heller, 1862), na foz do rio Itajaí-açú, Itajaí, SC, Brasil. Braz. Arch. Biol. Technol., 42(1): 115-126.

Campos, B.R. 2006. Reprodução, crescimento e abundância do camarão-sete-barbas (*Xiphopenaeus kroyeri* (Heller, 1862)) na Baía de Tijucas, Tijucas, SC. Dissertação de Mestrado. Universidade Federal do Rio Grande, Rio Grande, 50 pp.

Castro, R.H., R.C. Costa, A. Fransozo & F.L.M. Mantellato. 2005. Population structure of the seabob shrimp *Xiphopenaeus kroyeri* (Heller, 1862) (Crustacea: Penaeoidea), in the littoral of São Paulo, Brazil. Sci. Mar., 69(1):105-112.

Chen, C.L., J.M. Hoenig, E.G. Dawe, C. Brownie & K.H. Pollock. 1998. New developments in change-in-ratio and index-removal methods, with application to snow crab (*Chionoecetes opilio*). In: G.S. Jamieson & A. Campbell (eds.). Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci., 175: 49-61.

Collie. J.S. & G.H. Kruse. 1998. Estimating king crab (*Paralithodes camtschaticus*) abundance from commercial catch and research survey data. In: G.S. Jamieson & A. Campbell (eds.). Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci., 175: 73-83.

Dallagnolo, R. 2008. A pesca de camarões-de-profundidade (Aristeidae) na região sudeste-sul do Brasil: avaliação da dinâmica de biomassa como ferramenta para gestão. MSc. Thesis, Programa de Mestrado em Ciência e Tecnologia Ambiental. Universidade do Vale do Itajaí, Itajaí, Santa Catarina, Brasil, 215 pp.

DeLury, D.B. 1947. On the estimation of biological populations. Biometrics, 3: 145-167.

D'Incao, F. 1995. Taxonomia, padrões distribucionais e ecológicos dos Dendrobranchiata (Crustacea: Decapoda) do Brasil e Atlântico Ocidental. PhD. Thesis, Programa de Pós-Graduação em Zoologia, Universidade Federal do Paraná, Curitiba, Brasil, 365 pp.

D'Incao, F., H. Valentini & L.F. Rodrigues. 2002. Avaliação da pesca de camarões nas regiões Sudeste e Sul do Brasil. 1965-1999. Atlântica, 24(2): 103-116.

Fransozo, A., R.C. Costa, M.A.A. Pinheiro, S. Santos & F.L.M. Mantelatto. 2000. Juvenile recruitment of the seabob *Xiphopenaeus kroyeri* (Heller, 1862) (Crustacea: Penaeidae), in the Fortaleza Bay, Ubatuba, SP, Brazil. Nauplius, 8(2): 179-184.

Gedamke, T., W.D. DuPaul & J.M. Hoenig. 2005. Index-removal estimates of dredge efficiency for sea scallops on Georges Bank. North Am. J. Fish. Management, 25: 1122-1129.

Gunderson, D.R. 1993. Surveys of fisheries resources. John Wiley & Sons, New York, 248 pp.

Haimovici, M. 2007. A prospecção pesqueira e abundância de estoques marinhos no Brasil nas décadas de 1960 a 1990: Levantamentos de dados e avaliação crítica. Ministério do Meio Ambiente. Secretaria de Mudanças Climáticas e Qualidade Ambiental. Programa REVIZEE: Levantamento de Dados Pretéritos, 330 pp.

Hilborn, R. & C.J. Walters. 1992. Quantitative fisheries stock assessment. Choice, dynamics & uncertainty. Kluwer Academic Publishers, Boston, 570 pp.

Iribarne. O., M. Lasta, H. Vacas, A. Parma & M. Pascual. 1991. Assessment of abundance, gear efficiency and disturbance in a scallop dredge fishery: results of a depletion experiment. In: S.E. Shumway & P.A. Sandifer (eds.). An International Compendium of Scallop Biology and Culture. Selected papers from the "7th International Pectinid Workshop". National Shellfisheries Association. The World Aquaculture Society, Parker Coliseum, Louisiana State University, Baton Rouge, pp. 242-248.

Krebs, C.J. 1989. Ecological methodology. Harper & Row, Publisher, New York, 654 pp.

Lasta, M.L. & O.O. Iribarne. 1997. Southwestern Atlantic scallop (*Zygochlamys patagonica*) fishery: assessment of gear efficiency through a depletion experiment. J. Shellfish Res., 16(1): 59-62.

Leslie, P.H. & D.H.S. Davis. 1939. An attempt to determine the absolute number of rats on a given área. J. Anim. Ecol., 8: 94-113.

MMA/IBAMA. 2007. Estatística da Pesca – 2005 – Brasil. IBAMA, Brasília, 147 pp.

Nakagaki, J.M. & M.L. Negreiros-Fransozo. 1998. Population biology of *Xiphopenaeus kroyeri* (Heller, 1862) (Decapoda: Penaeidae) from Ubatuba bay, São Paulo, Brazil. J. Shellfish Res., 17(4): 931-935.

Nakagaki, J.M., M.L. Negreiros-Fransozo & A. Fransozo. 1995. Composição e abundância de camarões marinhos (Crustacea, Decapoda, Penaeidea) na Enseada de Ubatuba, Ubatuba (SP), Brasil. Arq. Biol. Tecnol., 38(2): 583-591.

Natividade, C.D. 2006. Estrutura populacional e distribuição do camarão sete-barbas *Xiphopenaeus kroyeri* (Heller, 1862 (Decapoda: Penaeidae) no litoral do Paraná, Brasil. MSc. Thesis, Programa de Pós-Graduação em Zoologia, Universidade Federal do Paraná, Curitiba, Brasil, 76 pp.

Okonski, S.L. & L.W. Martini. 1987. Artes y métodos de pesca. Editorial Hemisferio Sur, Buenos Aires, 339 pp.

Otto, R.S. 1986. Management and assessment of eastern Bering Sea king crab stocks. Can. Spec. Publ. Fish. Aquat. Sci., 92: 83-106.

Santos, E.P., G.S. Neiva & Y. Schaeffer. 1968. Dinámica de la población del camarón "Sete-barbas" *Xiphopenaeus kroyeri* (Heller) de la bahía de Santos. CARPAS/4/Doc. Téc., 3: 1-12.

Santos, M.C.F., P.A. Coelho & M.R. Porto. 2006. Sinopse das informações sobre a biologia e pesca do camarão sete-barbas, *Xiphopenaeus kroyeri* (Heller, 1862) (Decapoda, Penaeidae), no nordeste do Brasil. Bol. Téc. Cient. CEPENE, 14(1): 141-178.

Santos, E.P., H. Valentini, G.S. Neiva & J.T.C. Mello. 1973. Curva de rendimento do camarão sete barbas *Xiphopenaeus kroyeri* (Heller), da Baía de Santos e adjacências. Bolm. Inst. Pesca, 2(3): 67-71.

Schettini, C.A.F. & A.H.F. Klein. 1997. Aspectos da dinâmica sedimentar da Baía de Tijucas. Anais da

Semana Nacional de Oceanografia, Itajaí, Santa Catarina, pp. 493-495.

Severino Rodrigues, E., J.B. Pita, R. Graça Lopes, J.A.P. Coelho & A. Puzzi. 1993. Aspectos biológicos e pesqueiros do camarão sete-barbas (*Xiphopenaeus kroyeri*) capturado pela pesca artesanal no litoral do estado de São Paulo. Bolm. Inst. Pesca, 19: 67-81.

Sparre, P. & S.C. Venema. 1998. Introduction to tropical fish stock assessment. Part 1 – Manual. FAO, Roma. FAO Fisheries Technical Paper 306/1, Rev. 2, 337 pp.

Tremel, E. 1968. Recursos camaroneiros da costa de Santa Catarina, Brasil. Resultados preliminares de pesquisas sobre o camarão sete barbas. CARPAS/ 4/Doc. Téc., 21: 1-10.

Valentini, H. 2006. A pesca de camarões nas regiões Sudeste e Sul. In: Oliveira, G. M. (org.). Pesca e Aqüicultura no Brasil 1991/2000. Produção e Balança Comercial. Edições IBAMA, Brasília, pp. 55-64.

Valentini, H., F. D'Incao, L.F. Rodrigues, J.E. Rebelo Neto & L.G. Domit. 1991. Análise da pesca do camarão sete-barbas (*Xiphopenaeus kroyeri*) nas regiões Sudeste e Sul do Brasil. Atlântica, 13(1): 171-177.

Vieira, B.B. 1947. Observações sobre a maturação de *Xyphopenaeus kroyeri* no litoral de São Paulo. Bolm Mus. Nac. n.s. Zool., 74: 22 pp.

Wahrlich, R. 1999. A reserva biológica marinha do Arvoredo (SC) e atividade pesqueira regional. MSc. Thesis. Programa de Pós-Graduação em Geografia, Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brasil, 140 pp.

Received: 12 Jun 2006; Accepted: 8 August 2008