Biomass assessment of the monkfish *Lophius gastrophysus* stock exploited by a new deep-water fishery in southern Brazil

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Received 20 May 2004; received in revised form 9 November 2004; accepted 20 November 2004

Abstract

The monkfish *Lophius gastrophysus* was the first fishing resource that proved abundant enough to sustain profitable deep-water fishing operations off southern Brazil. As a directed fishery was structured in 2001, a preliminary stock assessment was conducted based on biological samples and catch rate data provided by both national trawlers and chartered gillnetters. Catch-at-size, general linearized models (GLM) and depletion models were combined to provide both pristine biomass and abundance index estimates for 2001. Landing statistics and discard estimates, indicated that fishing removed approximately 10,000 t, 16% of the 62,776 t total biomass estimate and approximately 32% of the spawning stock. Alternatively, GLM abundance indices variation, suggested a more severe 30–60% biomass reduction in the main fishing grounds off southern Brazil throughout 2001. The two fishing fleets have (a) concentrated in different areas and (b) exploited somewhat distinct fractions of the available monkfish stock biomass. Hence, fishing mortality, was concentrated both upon (a) fish larger than 60 cm total length (where \( F/Z \) oscillated between 60 and 80%), and (b) most immature 20–60 cm long fish (where \( F/Z \) reached 40%). The adoption of a conservative 2500 t total allowed catch (TAC) combined with biological elements was proposed in order to restrict fishing development to precautionary levels. Despite data-limitations and assumptions, the combination of both catch-at-size biomass estimates and abundance indices variation was shown to provide useful elements for fast precautionary management options in a new, poorly known and fragile deep-water Brazilian fishery.

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Keywords: Southern Brazil; Monkfish; Deep-sea fishery; Stock assessment

1. Introduction

Short-term redirections of overcapitalized multispecific fleets towards valuable and previously untargeted fishing resources, have been commonly observed throughout the history of fishing development off southern Brazil (Pezzuto and Borzone, 1997; Perez...
and Pezzuto, 1998; Perez et al., 2001; Perez, 2002).
During such "gold rush" episodes (sensu Perry et al.,
1999), locally and/or seasonally available species, for-
merly devalued for economic or technological reasons,
have been normally subject to sudden fishing mortality
increases and rarely sustained the development of
structured fisheries.

The region’s latest and perhaps most noticeable
"gold rush" episode has been characterized by the
recent development of deep-water fishing (Perez et al.,
2003b). Since the year 2000, landings of mostly high-
valued deep-water finfish and shellfish targets nearly
tripled, as (a) traditional trawling practices were ex-
panded to slope grounds and (b) chartered fleet opera-
tions were authorized by a government deep-water fish-
ning development policy (Perez et al., 2003a). Because
dee-water stocks are sustained by generally low pro-
ductivity environments and are commonly character-
ized by $k$-strategist life-history features, the sustainabil-
ity perspectives of such fishing expansion process were
uncertain and demanded conservative scientifically-
based regulatory actions to be made effective at a
very short term (Perez et al., 2003b; Large et al.,
2001).

The monkfish *Lophius gastrophysus* was the first
fishing resource that proved abundant enough as to sus-
tain profitable deep-water fishing operations off south-
ern Brazil (Perez et al., 2003b). The species was known
to constitute a valued component of the trawling fish-
ery off the coast of Rio de Janeiro State (23°S), but
biological information was scarce and limited to sys-
tematics and distribution studies produced mostly from
exploratory surveys on Brazilian shelf and slope waters
(Yesaky et al., 1976; Figueiredo and Menezes, 1978;
Haimovici et al., 1994, 1996). As a directed fishery
was structured in 2001, a total of 8831 t were landed
mostly by national double-rig trawlers (58%) and char-
tered gillnetters (36%), which explored and occupied
a fishing area extending along the southern Brazilian
slope, from 21°S to 34°S and within the 100–600 m
isobaths (Perez et al., 2003a). Generating a total rev-
enue estimated around US$ 21,000,000 in export prod-
ucts, this emerging fishery demanded fast regulatory
actions which stimulated: (a) the collection of compre-
hensive fishing and biological data; (b) a preliminary
stock assessment; (c) a public debate involving scien-
tists, government and Brazilian industry; and (d) the
definition of a scientifically-based management plan
for future monkfish fishing off southern Brazil (Perez
et al., 2002).

Crucial for the establishment of this plan, were pre-
liminary estimates of the total biomass available on the
fishing area in 2001, as well as the biomass dynamics
throughout its first intensive fishing year. The data and
analytical procedures involved in such estimation are
summarized in this work and particular emphasis has
been given to the exploration of three different methods
in an attempt to evaluate best cost-benefit approaches
for preliminary assessments of new, poorly known and
fragile deep-water fisheries.

2. Material and methods

2.1. Data collection

We analyzed data derived from three deep-water
fishing monitoring systems, developed as part of a sci-
entific cooperation program established between the
Ministry of Agriculture (Brazilian Government) and
University of “Vale do Itajaí” (Santa Catarina, southern
Brazil). The Santa Catarina Industrial Fishing Statistics
Program provided information on catch, effort and fish-
ing areas of 696 national double-rig trawler operations
as obtained from log books, sales records and skippers
interviews at the main Santa Catarina harbors (Table 1).

A chartered vessel observers program and a chartered
fleet tracking program provided fishing position, depth
and catch/by-catch composition data of all 38 char-
tered fishing trips conducted by nine vessels and four
trawlers off southern Brazil in 2001 (Table 2). Monk-
fish length samples were obtained both at the landings
of the national vessels and during the chartered fleet
fishing operations.

Fishing operations of chartered vessels (Table 2)
were pooled into four trimesters (January–March,
April–June, July–September, October–December),
three latitudinal strata (north, 21°–25°S; center,
25°–29°S, and south, 29°–34°S) and two depth strata
(<350 and >350 m) (Fig. 1). Fishing records of the na-
tional fleet (Table 1) were also pooled into these strata
except depth in which the two strata were delimited
by the 125 m isobath. In these records, individual tows
were normally not discriminated, thus the entire trip
was allocated into one trimester or latitudinal stratum.

In situations when the trip duration and fishing area
Table 1
Summary of monkfish *Lophius gastrophysus* catch rates and characteristics of the double-rig trawlers fishing trips conducted off southern Brazil in 2001

<table>
<thead>
<tr>
<th></th>
<th>January–March</th>
<th>April–June</th>
<th>July–September</th>
<th>October–November</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of vessels</td>
<td>109</td>
<td>131</td>
<td>109</td>
<td>65</td>
<td>213</td>
</tr>
<tr>
<td>Total number of trips</td>
<td>197</td>
<td>208</td>
<td>195</td>
<td>96</td>
<td>696</td>
</tr>
</tbody>
</table>

**North**

- **Monitored trips**: 12
- **Catch rate (kg h\(^{-1}\))**: 13.9 ± 2.6 (28.0)
- **Depth (m)**: 210.8 ± 32.4 (380.0)

- **Monitored trips**: 31
- **Catch rate (kg h\(^{-1}\))**: 13.0 ± 1.5 (35.1)
- **Depth (m)**: 270.7 ± 18.7 (425.0)

- **Monitored trips**: 35
- **Catch rate (kg h\(^{-1}\))**: 6.3 ± 0.9 (21.4)
- **Depth (m)**: 161.3 ± 15.6 (410.0)

- **Monitored trips**: 15
- **Catch rate (kg h\(^{-1}\))**: 9.6 ± 1.5 (18.1)
- **Depth (m)**: 196.6 ± 23.4 (385.0)

**Center**

- **Monitored trips**: 49
- **Catch rate (kg h\(^{-1}\))**: 13.6 ± 2.1 (69.1)
- **Depth (m)**: 232.1 ± 19.3 (400.0)

- **Monitored trips**: 66
- **Catch rate (kg h\(^{-1}\))**: 7.5 ± 1.2 (41.7)
- **Depth (m)**: 182.1 ± 15.2 (420.0)

- **Monitored trips**: 35
- **Catch rate (kg h\(^{-1}\))**: 7.0 ± 1.0 (21.4)
- **Depth (m)**: 202.3 ± 16.7 (375.0)

- **Monitored trips**: 20
- **Catch rate (kg h\(^{-1}\))**: 4.3 ± 1.5 (15.9)
- **Depth (m)**: 140.3 ± 28.2 (375.0)

**South**

- **Monitored trips**: 13
- **Catch rate (kg h\(^{-1}\))**: 1.4 ± 0.5 (0.04–6.3)
- **Depth (m)**: 85.5 ± 9.2 (145.0)

- **Monitored trips**: 18
- **Catch rate (kg h\(^{-1}\))**: 5.9 ± 1.9 (0.04–23.1)
- **Depth (m)**: 153.7 ± 30.5 (450.0)

- **Monitored trips**: 30
- **Catch rate (kg h\(^{-1}\))**: 6.9 ± 3.3 (0.04–100.0)
- **Depth (m)**: 158.0 ± 20.4 (425.0)

- **Monitored trips**: 15
- **Catch rate (kg h\(^{-1}\))**: 3.3 ± 1.5 (0.06–14.3)
- **Depth (m)**: 158.3 ± 28.2 (375.0)

**Mean ± S.E.**

Table 2
Summary of monkfish *Lophius gastrophysus* fishing trip operations conducted by chartered vessels off southern Brazil in 2001

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Number of fishing trips</th>
<th>Period of operation (day/month)</th>
<th>Depth range (m)</th>
<th>Number of fishing sets</th>
<th>Catch rate (gutted) (kg trip(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gillnet</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antonio</td>
<td>7</td>
<td>26/02–26/11</td>
<td>145–508</td>
<td>26.9 ± 1.2</td>
<td>48,026.0 ± 4,950.4</td>
</tr>
<tr>
<td>Belen</td>
<td>3</td>
<td>12/07–30/12</td>
<td>174–458</td>
<td>42.0 ± 1.2</td>
<td>68,405.3 ± 9,712.6</td>
</tr>
<tr>
<td>Eder Sands</td>
<td>3</td>
<td>12/06–17/12</td>
<td>163–519</td>
<td>49.3 ± 0.6</td>
<td>132,357.0 ± 29,096.9</td>
</tr>
<tr>
<td>Jucy</td>
<td>5</td>
<td>12/01–10/11</td>
<td>107–494</td>
<td>49.2 ± 3.1</td>
<td>106,227.0 ± 17,135.4</td>
</tr>
<tr>
<td>San Clementios</td>
<td>2</td>
<td>29/06–26/12</td>
<td>194–521</td>
<td>47.5 ± 5.5</td>
<td>53,593 ± 72,044</td>
</tr>
<tr>
<td>Slebech</td>
<td>2</td>
<td>07/07–20/12</td>
<td>235–549</td>
<td>40.4 ± 11</td>
<td>69,358 ± 97,833</td>
</tr>
<tr>
<td>South Coast</td>
<td>4</td>
<td>24/02–17/12</td>
<td>139–644</td>
<td>70.3 ± 3.0</td>
<td>89,074 ± 7,992</td>
</tr>
<tr>
<td>Suffolk Charlemar</td>
<td>5</td>
<td>04/02–30/12</td>
<td>112–415</td>
<td>52.2 ± 3.2</td>
<td>112,985 ± 12,161.7</td>
</tr>
<tr>
<td>Titan</td>
<td>5</td>
<td>27/01–11/12</td>
<td>126–723</td>
<td>50.0 ± 3.0</td>
<td>85,607 ± 9,738.3</td>
</tr>
<tr>
<td><strong>Trawl</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insung 270</td>
<td>3</td>
<td>23/05–04/12</td>
<td>84–396</td>
<td>257.0 ± 3.9</td>
<td>24,777 ± 3,305.9</td>
</tr>
<tr>
<td>Rio Boutez Usal</td>
<td>1</td>
<td>20/10–10/12</td>
<td>207–400</td>
<td>78</td>
<td>3,412</td>
</tr>
<tr>
<td>Cips</td>
<td>2</td>
<td>02/10–31/12</td>
<td>230–485</td>
<td>130–174</td>
<td>8,449 ± 9,449</td>
</tr>
<tr>
<td>Naveo Aggestino</td>
<td>4</td>
<td>10/09–27/12</td>
<td>186–546</td>
<td>79.2 ± 5.9</td>
<td>6,588 ± 1,002.8</td>
</tr>
<tr>
<td><strong>Mean ± S.E.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
strictly derived from commercial fisheries, all method-ological approaches involved adaptations to cope with model assumptions and data limitations.

Standardized abundance indices, as calculated from a generalized linear model (GLM) (Gavaris, 1980) were used to evaluate seasonal and spatial variability of monkfish abundance on the fishing grounds off southern Brazil in 2001. Models were fitted separately to catch rate data of both gillnet and double-rig trawling vessels (Tables 1 and 2). The models included the factors: latitudinal strata with levels north, center and south; trimester with levels January–March, April–June, July–September, and October–December; depth with levels >350 and <350 m (>125 and <125 m for the national trawlers). Mean catch rates (\( U \)) were calculated for each “cell” (crossing level of the above factors) and two order interaction between factors was also considered. The model assumed was:

\[
U = U_r \prod_i \prod_j \theta_{ij} e^{\varepsilon_{ij}}
\]  

where \( i \) is the index for factors, \( j \) the index for levels of each factor, and \( U_r \) the reference catch rate, assumed as the catch rate for the first level of each factor. \( \theta_{ij} \) the coefficient accounting for the relative effect for the \( j \)th level of the \( i \)th factor with respect to the reference catch rate. If \( U \) is assumed as log-normal variable, \( \varepsilon \) is normal and the logarithm of the model is:

\[
\log U_{ij} = \log U_r + \sum_i \sum_j \log \theta_{ij} + \varepsilon_{ij}
\]

Catch rate and the residuals distributions were evaluated to check if the log-normal assumption holds and ANOVA tests were conducted in order to justify the inclusion of factors into the model.

An index of monkfish biomass available for gillnet fishing during 2001 was also estimated using a Leslie depletion model (Cowx, 1983). This procedure implied the assumption that localized monkfish depletions, as observed from progressively declining catch rate, would occur as gillnet effort was continuously applied in a restricted area. Within this “depletion scenarios”, it was assumed that biomass declines resulted from fishing effort only and the effects of recruitment, natural mortality and/or migration movements were negligible (“closed population” assumption). Such scenarios were identified in individual fishing trip histories as sequential localized fishing sets produced progressively lower catch rates. The search for such scenarios was initiated by defining five fishing areas (blocks) where 76% of all fishing sets were concentrated in 2001 (Fig. 1). Within each block, all fishing sets of individual trips were mapped to allow the identification of effort concentration areas (Fig. 2). These sets were then extracted and considered for the application of the Leslie depletion model defined initially by a simple population model:

\[
B_t = B_1 - K_{t-1}
\]

where \( B_t \) is the biomass available at time \( t \), \( B_1 \) the biomass available at the beginning of the depletion scenario, and \( K_{t-1} \) is the accumulated catch prior to time \( t (t \geq 1) \). If it is assumed that catch rate in the gillnet fishery is proportional to the monkfish stock abundance at any time \( t \), the observational model is:

\[
U_t = qB_t
\]
where $q$ is the catchability coefficient assumed as constant. The relationship between $U_t$ and $K_{t-1}$

$$U_t = qB_t - qK_{t-1}$$

is a linear equation whose intercept is $qB_t$ and the slope is $q$. A total of 42 linear regressions were conducted with data sets selected from the fishing trips, each of them comprising a time interval of 22 days on average ($\pm 3\text{S.E., minimum } = 4; \text{maximum } = 84$ days) (Table 3). This interval was assumed short enough as to support "closed population" assumptions, taking into account (a) low natural mortality rates reported for monkfish species worldwide (i.e. 0.15 year$^{-1}$ Trujillo et al., 1993; ICES, 1995; Marchal and Horwood, 1996); (b) slow growth (Landa et al., 2001); and (c) the unlikely short-term migration movements as suggested by the monkfish life style pattern (Merrit and Haedrich, 1997). The 42 biomass estimates, obtained within the different fishing blocks were interpreted as relative abundance indices, since the effective areas sampled by the gillnets were not known and this made it impossible to estimate absolute biomass values (Gunderson, 1993). A polygon, delimited by the geographic coordinates of all fishing sets included in each of the 42 depletion scenarios, was used to define a smallest possible area affected by the fishing sets sequence (Fig. 2). Therefore, an overestimated "density" value was then calculated dividing each estimated biomass value by its polygon area which, in turn, was analyzed as a relative monkfish abundance index in the fishing block.

A preliminary estimate of the absolute abundance of the monkfish off southern Brazil during 2001 was obtained applying the traditional length-based cohort analysis (Jones, 1981). Catch-at-size was recorded on board the chartered vessels and at the landing sites of the national fleet in Santa Catarina. The length-frequency distribution was constructed by: (a) pooling sampled catches total length data into 1 cm classes; (b) expanding sample frequencies by total catches; and (c) correcting frequencies of smaller classes by the estimated gear selectivity. Because only 1 year data was available, a pseudo-cohort approach and a steady state population assumption was adopted (Sparre et al., 1989). This assumption was not only inevitable in such an early-stage fishery, but also supported by the practically unexploited condition of the species before 2003.
Table 3
Monkfish Lophius gastrophysus relative abundance off southern Brazil in 2001, as estimated by the Leslie depletion model applied to catch rates obtained by the gillnet fleet within five delimited fishing blocks

<table>
<thead>
<tr>
<th>Block</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Block 4</th>
<th>Block 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fishing sets</td>
<td>264</td>
<td>187</td>
<td>236</td>
<td>180</td>
<td>449</td>
</tr>
<tr>
<td>Fishing sets included in the regressions</td>
<td>86</td>
<td>146</td>
<td>87</td>
<td>108</td>
<td>152</td>
</tr>
<tr>
<td>Total number of regressions</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>Depletion time-period (days)</td>
<td>14.0 ± 3.3 (8–33)</td>
<td>41.3 ± 9.1 (22–85)</td>
<td>24.0 ± 7.3 (5–38)</td>
<td>19.3 ± 5.3 (6–40)</td>
<td>20.3 ± 3.5 (5–57)</td>
</tr>
<tr>
<td>Affected polygon area (km²)</td>
<td>169.3 ± 23.2 (107–287)</td>
<td>266.8 ± 60.8 (92–550)</td>
<td>240.0 ± 24.6 (175–292)</td>
<td>217.1 ± 57.6 (33–434)</td>
<td>150.8 ± 26.1 (21–419)</td>
</tr>
<tr>
<td>Biomass estimate (t)</td>
<td>39.3 ± 7.7 (10.1–63.2)</td>
<td>64.4 ± 22.0 (13.2–152.8)</td>
<td>122.4 ± 25.0 (65.7–186.8)</td>
<td>51.4 ± 15.0 (19.1–121.4)</td>
<td>38.6 ± 9.7 (0.2–137.0)</td>
</tr>
<tr>
<td>Biomass index (t km⁻²)</td>
<td>0.236 ± 0.047 (0.094–0.465)</td>
<td>0.245 ± 0.076 (0.071–0.530)</td>
<td>0.494 ± 0.055 (0.376–0.660)</td>
<td>0.373 ± 0.152 (0.122–1.168)</td>
<td>0.379 ± 0.091 (0.001–1.459)</td>
</tr>
</tbody>
</table>

The employed cohort analysis partially followed classical concepts but was elaborated including stochastic procedures concerning uncertainty on natural mortality and on growth parameters. Because mortality and growth studies of L. gastrophysus are not available, transformation of catch-at-length into catch-at-age required the use of von Bertallanffy’s growth curves estimated elsewhere for L. budegassa and L. voverinus (Duarte et al., 1997; Marteens et al., 1999; Landa et al., 2001) whose size ranges most closely approximated those of L. gastrophysus (Table 4). In each simulation, a growth parameters vector was randomly sampled from all the vectors available (Table 4), in a procedure comparable to a non-parametric bootstrap. Besides growth parameters, the natural mortality (M) and terminal rates of exploitation (F/Z) estimates are also required for the length-based analysis. The former was obtained using parametric bootstrap assuming M as a normally distributed variable with mean 0.15 year⁻¹, a value that has been frequently used in Atlantic Lophius stock assessments. The standard deviation for M was chosen to cover the extreme values (0.08–0.22 year⁻¹) as found in scientific publications (e.g. Trujillo et al., 1993; ICES, 1995; Marchal and Horwood, 1996). Similarly terminal F/Z values were obtained assuming values (0.5 as the mean and 0.05 as standard deviation) frequently in assessment models elsewhere (e.g. Trujillo et al., 1993; ICES, 1995).

A total of 5250 simulations was performed taking into account uncertainty in M, terminal F/Z and growth parameters. Empirical probability distributions of biomass estimates were constructed and means, medians and 80% confidence intervals were calculated following the procedure proposed by Efron and Tibshirani (1993) for “bootstrap” simulations. A preliminary spawning biomass index was calculated as the annual mean biomass of monkfish 54 cm and larger. This threshold length corresponded to the size-at-maturity estimated for female L. gastrophysus. The males were scarce in the catches and did not allow consistent estimation of the size-at-maturity. Because the size-at-maturity of males is probably smaller than that of females (i.e. Azevedo, 1996; Durante et al., 2001), calculated spawning biomasses, according only to female size-at-maturity, are somewhat underestimated.
Table 4
Growth parameters of the von Bertalanffy model estimated for two Lophius species in the Atlantic considered for the length-cohort analysis applied for L. gastrophysus stock off southern Brazil in 2001

<table>
<thead>
<tr>
<th>Species</th>
<th>Sex</th>
<th>L∞ (cm)</th>
<th>k (years⁻¹)</th>
<th>t₀ (years)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>L. budegassa</td>
<td>f</td>
<td>111.00</td>
<td>0.07</td>
<td>0.50</td>
<td>Dupoy et al. (1986)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>m</td>
<td>105.00</td>
<td>0.11</td>
<td>0.80</td>
<td>Dupoy et al. (1986)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>m</td>
<td>85.00</td>
<td>0.10</td>
<td>0.56</td>
<td>Dupoy et al. (1986)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>b</td>
<td>94.00</td>
<td>0.09</td>
<td>0.66</td>
<td>Dupoy et al. (1986)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>b</td>
<td>96.00</td>
<td>0.06</td>
<td>−0.20</td>
<td>Azevedo (1996)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>b</td>
<td>94.00</td>
<td>0.09</td>
<td>0.70</td>
<td>Marchal and Horwood (1996)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>b</td>
<td>101.69</td>
<td>0.08</td>
<td>−0.20</td>
<td>Duarte et al. (1997)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>f</td>
<td>105.91</td>
<td>0.06</td>
<td>−0.20</td>
<td>Duarte et al. (1997)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>m</td>
<td>81.66</td>
<td>0.11</td>
<td>−0.10</td>
<td>Duarte et al. (1997)</td>
</tr>
<tr>
<td>L. vomerinus</td>
<td>m</td>
<td>72.29</td>
<td>0.14</td>
<td>−0.30</td>
<td>Marentes et al. (1999)</td>
</tr>
<tr>
<td>L. vomerinus</td>
<td>f</td>
<td>111.98</td>
<td>0.08</td>
<td>−0.36</td>
<td>Marentes et al. (1999)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>m</td>
<td>71.50</td>
<td>0.13</td>
<td>0.05</td>
<td>Landa et al. (2001)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>f</td>
<td>91.50</td>
<td>0.10</td>
<td>0.50</td>
<td>Landa et al. (2001)</td>
</tr>
<tr>
<td>L. budegassa</td>
<td>b</td>
<td>93.50</td>
<td>0.10</td>
<td>0.38</td>
<td>Landa et al. (2001)</td>
</tr>
</tbody>
</table>

f: females; m: males; b: both sexes pooled.

3. Results
3.1. GLM analysis
A total of 1723 fishing sets conducted between January and December 2001 were evaluated in the GLM analysis. Trimesters, latitude and depth strata, were found to affect monkfish catch rate significantly, justifying their inclusion into the model (Table 5). The GLM that best fitted catch rate data ($R^2 = 83.1$, $F = 5.7$, $p = 0.003$) was the one that included the interactions between depth and trimester factors (Table 6).

Estimation of regression coefficients and related statistics are presented in Table 6. These coefficients represent the relative importance of each factor level in relation to the first level of each factor (reference level). For instance, monkfish abundance coefficient estimated for fishing grounds deeper than 350 m (Depth 2, in Table 6) was 0.927. Therefore, it can be interpreted that monkfish abundance in such depth stratum reached 92.7% of the abundance in grounds above 350 m (reference level). Hence, highest and lowest monkfish abundance were found in the southern and central latitudinal strata, respectively (132 and 83% of the northern stratum, respectively) (Table 6). Monkfish abundance was also higher in January–March and tended to decrease in the following trimesters of 2001. In the October–December period, abundance in the fishing grounds was only 64% of the one estimated between January and March (Table 6). Interactions with depth strata showed that these biomass reduction was more pronounced in areas deeper than 350 m (Fig. 3). GLMs fitted to catch rates obtained by the double-rig trawlers included 335 trips monitored between January and December 2001 (Table 1). Catch rate was shown to be significantly affected by depth and latitudinal strata (Table 5) but, because levels of monkfish

Fig. 3. Spatial and temporal variation of abundance coefficients as estimated by the generalized linear model best fitted to mean catch rates of the monkfish Lophius gastrophysus obtained by the gillnet chartered fleet off southern Brazil in 2001.
Table 5
Results of the analysis of variance (ANOVA) to test the effect of trimesters, depth strata and latitude strata (factors) on log-transformed monkfish Lophius gastrophysus catch rate (dependent variable), as obtained by gillnet and double-rig trawl fishing operations off southern Brazil in 2001

Factor level Ln estimate S.E. p UCI LCI Estimate UCI LCI
Gillnet
Depth 8.190 1 13.708 0.0002
Latitude 4.891 2 4.901 0.0089
Trimester 84.104 3 46.922 <0.0001
Depth × latitude 7.552 2 6.320 0.0019
Depth × trimester 18.473 3 10.306 <0.0001
Latitude × trimester 38.776 6 10.817 <0.0001
Depth × latitude × trimester 25.740 6 7.180 <0.0001
Error 908.760 1521

Double-rig trawl
Depth 322.346 1 146.153 <0.0001
Latitude 19.980 2 4.530 0.0114
Trimester 7.940 3 1.200 0.0096
Depth × latitude 17.720 2 4.017 0.019
Depth × trimester 4.278 3 0.646 0.586
Latitude × trimester 19.156 6 1.448 0.195
Depth × latitude × trimester 19.966 6 1.509 0.174
Error 820.457 372

SS: sum of squares; d.f.: degrees of freedom; F: Fisher’s statistics; p: probability.

Table 6
Estimate of regression coefficients, and related statistics in the general linear model (GLM) for the monkfish gillnet and double-rig trawl fisheries off southern Brazil in 2001

Factor level Ln estimate S.E. p UCI LCI Estimate UCI LCI
Gillnet
Depth 8.190 1 13.708 0.0002
Latitude 4.891 2 4.901 0.0089
Trimester 84.104 3 46.922 <0.0001
Depth × latitude 7.552 2 6.320 0.0019
Depth × trimester 18.473 3 10.306 <0.0001
Latitude × trimester 38.776 6 10.817 <0.0001
Depth × latitude × trimester 25.740 6 7.180 <0.0001
Error 908.760 1521

Double-rig trawl
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Depth × latitude 17.720 2 4.017 0.019
Depth × trimester 4.278 3 0.646 0.586
Latitude × trimester 19.156 6 1.448 0.195
Depth × latitude × trimester 19.966 6 1.509 0.174
Error 820.457 372

Monkfish catch rate was the dependent variable. Depth strata (Depth); latitude strata (Lat) and trimester (Trim) were the effect factors. S.E.: standard error; p: probability; UCI: lower confidence interval; LCI: upper confidence interval; F: Fisher’s statistics; n: number of cells; R²: determination coefficient, UCI upper confidence interval; \( \text{Ln}_{U11} \): reference catch rate.

\( R^2 = 81.0, F = 5.809, p = 0.000, n = 22. \)

\( R^2 = 91.7, F = 23.989, p < 0.001, n = 20. \)
abundance throughout the year were of major interest in the analysis, the Trimester factor was also kept in the model (Table 6). Results from models with factor interactions were discarded due to the reduced number of data in relation to the number of estimated parameters (i.e. overparametrized models). Coefficients for the national fleet indicated extremely low abundance in fishing grounds shallower than 125 m and the central and southern strata were around 30% less abundant than the northern stratum. Abundance was slightly higher in the second trimester decreasing towards the end of the year. The October–December period reached 38% of the abundance observed between April and June 2001 (Table 6).

3.2. Depletion analysis

The spatial and temporal patterns of monkfish abundance as addressed by the Leslie depletion model included fishing sets conducted between the 240 and 593 m isobaths. Because new gillnet vessels entered the fishery throughout the year and their spatial fishing strategies were not homogeneous, fishing sets conducted in blocks 3 and 5 were scarce or absent during the first semester (Fig. 4). Therefore, in these blocks, abundance estimates were not possible for this period. Within the defined fishing blocks, polygon areas varied between 21 and 550 km² and estimated biomass indices varied between 0.001 and 1.459 t km⁻², both values been observed in Blocks 5.

Mean monkfish biomass indices were 58 to 110% higher in the central and southern areas (Blocks 3, 4 and 5), respectively than in the northern ones (Blocks 1 and 2, Fig. 5). Abundance increased towards mid 2001 declining sharply after that to levels, on average, 52% smaller than the ones observed in the first trimester and 37–35% of the biomass available in the second trimester (Fig. 5). When each block was analyzed separately (Fig. 6), a drastic biomass reduction after the first trimester occurred in the northernmost Block 1, where nearly 44% of the trimester fishing effort was concentrated (Fig. 4). In Blocks 4 and 5, abundance declines were observed from the second and the third trimesters onwards, respectively, following again the southward displacement of fishing effort (Fig. 4). Slight abundance reductions (Blocks 2 and 3) and increases (Blocks 1 and 2) were also observed in association with incoming and outgoing fishing activity, respectively (Figs. 4 and 6). These patterns suggest both biomass reductions due to intense localized fishing effort and

![Fig. 4](image4.png)

![Fig. 5](image5.png)
partial biomass recovering in areas abandoned by gillnet vessels.

3.3. Cohort analysis

Empirical probability distributions of mean biomass estimates in 2001 always differed from normality (Fig. 7). All distributions exhibited positive asymmetry and thus median values were considered more realistic descriptors of their central tendency than the means. Annual median biomass estimate was 62,776 t, whereas 31,650 t was the spawning biomass estimate considering size-at-maturity of females only.

Size-dependent variation of fishing mortality, as estimated using cohort analysis, indicated that fishing pressures have been concentrated in fish larger than 65 cm (Fig. 8). Similarly exploitation rates increased to 0.4 in fish as large as 28 cm, increasing sharply in individuals larger than 60 cm. Size-dependent abundance (numerical and biomass) variation is also shown in Fig. 8. Most monkfish biomass was concentrated in 50-60 cm length classes, reaching 1500 t in the
58 cm class. A small proportion of the population biomass corresponded to monkfish smaller than 30 cm and larger than 75 cm.

4. Discussion

Two monkfish stock removal scenarios emerged from the interpretation of both overall biomass estimates and abundance index variation off southern Brazil in 2001. First, landing statistics and discards (Perez et al., 2003a), indicated that fishing removed approximately 10,000 t, 15.9% of the 62,776 t total biomass estimate and 31.6% of the spawning stock (31,650 t based on length of female maturity). Alternatively, abundance indices, as provided by catch rates of both national trawlers and gillnetters, suggested that, within the main fishing grounds, a 30–60% biomass reduction has occurred. Whereas, the former scenario indicated the likely impact of fishing mortality over the entire stock, the latter suggested that such impact may have been much more severe over an “exploitable” portion of the stock upon which effort was highly concentrated in 2001. In addition, spatial and temporal patterns of effort were further associated with observed localized biomass depletions, which may have also contributed to the analyzed catch rate-based indices variation. Such fast depletion processes and slow
highly efficient gillnetting. Mostly by intensive and uncontrolled trawling and a significant impact may have been generated in a very short period of time, considering that the fishery had no previous history and the available fishing and biological data comprised only 1 year period. In addition, catch rates, although exhaustively recorded: (a) were poorly connected with “effective sampled areas”, as mostly obtained by passive gear such as gillnets (Gunderson, 1993), and (b) may not have represented the species distribution area homogeneously since they were exclusively derived from commercial fishing operations. Under such circumstances, three abundance assessment approaches, two involving catch rate-derived biomass indices and one involving catch-at-size total abundance estimates, were combined and compared in order to assemble a preliminary empirical framework upon which management measures could be recommended (Perez et al., 2002).

GLM and depletion models provided similar spatial and temporal abundance indices which seem to have produced conservative scenarios as they may have been density recoveries seem reasonable in species of the genus Lophius which are typically slow-moving bottom dwellers, that spend long periods camouflaged in the substrate as an ambush predation strategy and that rarely migrate (Almeida et al., 1995; Hartley, 1995; Azevedo, 1996; Duarte et al., 2001).

Monkfish biomass was concentrated between 125 and 350 m, and, within this range, shallower and deeper fishing grounds were more abundant in northern and southern latitudes, respectively. National double-rig trawlers conducted their multispecies operations mostly in northern 100–200 m deep areas and chartered gillnetters occupied areas as deep as 600 m moving from northern to southern latitudes as the season progressed (Perez et al., 2003a). This patterns suggested that the two fishing fleets have (a) concentrated in different productive areas and (b) exploited somewhat distinct fractions of the monkfish stock biomass available on the fishing grounds off southern Brazil. Hence, fishing mortality, as determined by both the fleet dynamics and the stock size stratification patterns, was concentrated both upon (a) fish larger than 60 cm total length (where FZ reached around 40%) and (b) most immature 20–60 cm long fish (where FZ reached around 40%). Whatever stock removal scenario is considered in 2001, it seems evident that both pre-reproductive and reproductive fractions of the exploited monkfish stock have been affected by it.

Lophius fisheries have long been developed in the NE Atlantic (ICES, 1995). Annual catches of L. budegassa reported between 1986 and 1994 oscillated around 8600 t, for a spawning stock as large as 41,000 t (ICES, 1994). In the same period, the trawl fishery has been evidence in the L. budegassa stock, which has raised concern among management organs (ICES, 1995). When this traditional fishery is compared to the one recently developed for L. gastrophysus off southern Brazil and biological similarities between both species are considered, it seems that a significant impact may have been generated in a very short period of time, mostly by intensive and uncontrolled trawling and a highly efficient gillnetting.
affected by (a) non-homogenously distributed hauls and (b) localized depletion processes observed in slow-moving benthic organisms. Total catch-at-size biomass estimates involved uncertainties as derived from the population stability assumption and the use of non-specific growth parameters; the former less significant, considering the previously unexploited condition of the monkfish stock. Combined, these approaches provided useful elements for fast precautionary management options in such an early stage of the fishery. Efforts have been concentrated into the understanding of $L.\text{gastrophi}us$ stock age-structure, as to improve total biomass estimates, and the less time consuming GLMs have been elected as the main tool for assessing monkfish biomass dynamics off southern Brazil.

Acknowledgements

The authors are indebted to Roberto Wahrlich, Fabio Rodrigo de Alcântara Lopes, Alessandro Agno Maia Pacheco and all the members of the Churched Fleet Observers Program for their hard work and the quality of collected data. We also thank vessel owners, captains and crew members of all monitored vessels for their support and good will during the long fishing trips. The Ministry of Agriculture (Brazilian Government) provided funds for this study through a scientific cooperation program with “Universidade do Vale do Itajaí” (MA/SARC/03–2000; MAPA/SARC/DPA/03–2001; MAPA/SARC/DENACOOP/126–2002).

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