ABSTRACT

On a total of 363 bottom longline sets in the SW lagoon of New Caledonia, 45 were surveyed using visual census. Abundance and biomass estimates were derived from these censuses. These estimates were highly correlated to catch per unit effort in numbers and weight. From these relationships were established contour maps of soft bottom fish abundance and biomass. The total biomass of longline catchable fish was estimated between 11800 and 25500 tons with an average of 5.8 tons/km². It was also estimated that longline catchable fish represented 88% of the total fish biomass of soft bottoms. Comparisons with other soft bottom fisheries in the region are presented.

INTRODUCTION

The study of coralline fishes is often limited to strictly coralline zones. In most places of the Pacific region a large number of coralline species are found on a variety of habitats, in particular over "soft bottoms" which may represent a very large surface. For instance, nearly 80% of the S.W. lagoon of New Caledonia is covered by such soft bottoms.

These surfaces are very variable in nature, but they usually support some coralline formations that preclude the use of trawl nets. In most instances the only convenient methods of fishing are by traps or hook and line, either by handline or by longline. The latter method proved to be easier to standardize and comparison of catch with densities are straightforward when using visual censuses.

METHODS

1-VISUAL CENSUSES

As the longline was set, two divers would take position at the start of the line and wait for the line to lie on the ground. Each diver recorded fish on one side of the line. Only species susceptible of biting on the line were counted. This species list was derived from 220 previous longline sets. Fish size was estimated by 5 cm classes, the accuracy of these visual evaluations being checked on the fish caught on the line. The perpendicular distance of the fish to the line was estimated in meters, fish being recorded at a maximum distance of 15m. In case of several fish seen simultaneously at different distances the nearest and furthest distance were recorded. Fish already caught on the line were not taken into account.

RESULTS

1-BOTTOM LONGLINE

1.1-Sampling strategy

A total of 363 sets were laid which amounts to 41600 hooks. Figure 2 indicates the position of these sets in the S.W. lagoon. There are two sets for every position except for the first 86 sets. The maximum distance between two setting positions does not exceed 3 nautical miles.

Figure 1. Longline diagram.

The gear in use is illustrated on figure 1. Each line was 280m long and had 100 hooks. Circular hooks MUSTAD* 3997L (n=7 to 9) or MUSTAD* (n=8 or 9) were used instead of "straight" hooks, because of their higher yield (Gibson, 1979; ANON., 1982; ANON., 1984a, 1984b). According to Ralston (1982) a 30% difference in hook size does not induce marked difference in catch. The largest size difference in our experiment did not exceed 18%.

Hooks were baited with cut pieces of squid (Notoheterurus sloani). Soaking time was one hour.

Species, size and position on the line was recorded for each fish caught.

Figure 2. Position of the longline sets.
Forty five sets were surveyed. This represents 4977 hooks, or 12% of the total number of hooks. Due to poor visibility it was not possible to survey sets nearshore. Diving time being limited, only one set was surveyed below 30m. The position of the surveyed sets are indicated on figure 2.

1.2 - Species composition:

Table 1 indicates the species caught during all sets and those caught or seen on the surveyed longline sets. A total of 78 species were caught on all sets of which 31 were present on more than 10 sets (these are referred as "common" species). Thirty five species were taken on the surveyed set of which 26 were common species (80% of total common species).

1.2.1 - Size and yields:

The average size of fish on all sets and surveyed sets are identical with the exception of three species: Cephalopholis sonnerati and Gymnocranius robertsi which were larger on the selected sets and Echeneis naucrates which was smaller. The average yields are a little higher on the surveyed sets (10.9 kg/100 hooks) than on all sets (7.3 kg/100 hooks) because nearshore sets, which have lower yields, could not be surveyed due to poor visibility.

2 - VISUAL CENSUSES:

2.1 - Species composition:

A total of 42 species were seen along the longlines (Table 1). Only two common species, Saurida undosquamis and Nemipterus peroni were not recorded during these dives. Both of these species are mainly found nearshore in turbid waters. Most families are well represented in the visual censuses except sharks and trevallies. Identification of most species was accurate, only the Gymnocranius spp. and murray eels could not be identified at the species level. Only two of the species caught on the surveyed lines were not observed during the visual censuses.

2.2 - Size:

The size of the fish underwater was estimated by eye. The divers performing the counts are well trained in this exercise and the error can be assumed to be of 10-20% depending on fish size and species (ANON., 1985; Harmelin-Vivien et al., 1985). Average weights were computed from lengthweight relationships. The estimated size of fish observed by visual census was usually inferior to the fish size in the catch (Table 1). This is due to the selectivity of the gear, the hooks being rather large. One should also take into account that the size of large fish tend to be underestimated by visual censuses (Harmelin-Vivien et al., 1985).

2.3 - Distance to the line:

Most underwater censuses using transects do not take into account the distance of the fish to the transect line (Thresher & Gunn, 1986). It is usually assumed that all fish within a given distance to the line (usually 5m) are detected (Harmelin-Vivien et al., 1985). If fish were distributed at random and not affected by either

<table>
<thead>
<tr>
<th>Table 1. Species composition of catch and visual survey. nb: numbers w: weight (kg) *: species caught on 10 sets or more.</th>
<th>Atlantic</th>
<th>Longline</th>
<th>Visual</th>
<th>Atlantic</th>
<th>Longline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>nb</td>
<td>w</td>
<td>Species</td>
<td>nb</td>
<td>w</td>
</tr>
<tr>
<td>Cephalopholis sonnerati</td>
<td>15</td>
<td>1900</td>
<td>Saurida undosquamis</td>
<td>50</td>
<td>850</td>
</tr>
<tr>
<td>Gymnocranius robertsi</td>
<td>40</td>
<td>950</td>
<td>Nemipterus peroni</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Arothron nebulosus</td>
<td>40</td>
<td>1000</td>
<td>Nemipterus peroni</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Sphyra lewini</td>
<td>30</td>
<td>1500</td>
<td>Nemipterus peroni</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Echeneis naucrates</td>
<td>30</td>
<td>1500</td>
<td>Neomuraena longipes</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Trachinus decius</td>
<td>30</td>
<td>1500</td>
<td>Neomuraena longipes</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Sphyra lewini</td>
<td>30</td>
<td>1500</td>
<td>Neomuraena longipes</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Sphyra lewini</td>
<td>30</td>
<td>1500</td>
<td>Neomuraena longipes</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
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<td>30</td>
<td>1500</td>
<td>Neomuraena longipes</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Sphyra lewini</td>
<td>30</td>
<td>1500</td>
<td>Neomuraena longipes</td>
<td>20</td>
<td>180</td>
</tr>
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<td>Sphyra lewini</td>
<td>30</td>
<td>1500</td>
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<td>20</td>
<td>180</td>
</tr>
<tr>
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<td>30</td>
<td>1500</td>
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<td>20</td>
<td>180</td>
</tr>
<tr>
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</tr>
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<td>30</td>
<td>1500</td>
<td>Neomuraena longipes</td>
<td>20</td>
<td>180</td>
</tr>
</tbody>
</table>

Total number of species: 78
line or divers one would expect a distribution pattern as indicates figure 3 (Burnham et al., 1980). Our data (figure 3) suggest that one can not assume such a random distribution. There is at first a "heaping" phenomenon which is fairly common to transect data (Burnham et al., 1980), certain distances being preferentially recorded. Grouping the data smooths such bias. Most fish tend to avoid either the line or the divers as indicates the depressed distribution at distance 0. This phenomenon varies with species and with size. Thus, small fish are seen at closer distances and large fish tend to be more shy and stay further away from the divers. Figure 4 indicates a number of different types of distance distributions. These illustrate the bias that would be introduced by using fixed width transect counts.

2.4-Density estimates:

Knowing the distance distribution of species i to the line, it is possible, using FOURIER series (Burnham et al., 1978), to calculate $f(0)_i$, which is the estimate of the probability density function at distance zero. This estimate is needed for the calculation of the density $\bar{D}_i$ of species i along the longline, using the following equation:

$$\bar{D}_i = \sum_{i=1}^{k} \frac{n_i f(0)_i}{2L} \tag{1}$$

where $n_i$ : number of fish of species i seen along the line

$L$ : length of the line

The $f(0)_i$ estimates were calculated from the pooled data of all 45 surveys. When there was insufficient data for a given species, the $f(0)_i$ estimate of its family or the overall $f(0)$ estimate was attributed. These estimates are indicated on table 2.

The total density along a longline is given by the sum of the $\bar{D}_i$:

$$\bar{D} = \sum_{i=1}^{k} \bar{D}_i \tag{2}$$

where $k$ : number of species seen along the line.

Knowing the variance of $f(0)$ it is possible to calculate the variance of $\bar{D}_i$. The total variance for $\bar{D}$ was estimated as the weighted sum of the variances of the $\bar{D}_i$:

$$\text{var}(\bar{D}) = \sum_{i=1}^{k} \frac{\text{var}(\bar{D}_i)}{\sum_{i=1}^{k} n_i} \tag{3}$$

This estimate is biased because the variances of the $\bar{D}_i$ are not independent. This will result in a conservative value of var($\bar{D}$).

The biomass density estimate for species i along a longline is calculated from:

$$\bar{B}_i = \bar{D}_i \cdot \bar{W}_i \tag{4}$$

where $\bar{W}_i$ : average weight of species i along the line.

Table 2. Probability density function estimates at distance 0 for species observed along longline sets.

<table>
<thead>
<tr>
<th>species</th>
<th>$f(0)$</th>
<th>var($f(0)$) x 10^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL SERRANIDS</td>
<td>0.1403</td>
<td>0.6043</td>
</tr>
<tr>
<td>Ctenolabrus anguillarum</td>
<td>0.1284</td>
<td>0.8121</td>
</tr>
<tr>
<td>Ctenolabrus acutirostris</td>
<td>0.2840</td>
<td>1.776</td>
</tr>
<tr>
<td>Haemulon polylepis</td>
<td>0.1678</td>
<td>0.1594</td>
</tr>
<tr>
<td>Haemulon niveus</td>
<td>0.1944</td>
<td>0.2551</td>
</tr>
<tr>
<td>Pampus argenteus</td>
<td>0.1493</td>
<td>0.4315</td>
</tr>
<tr>
<td>ALL LUTJANIDS</td>
<td>0.1740</td>
<td>1.451</td>
</tr>
<tr>
<td>Lethrinus spp.</td>
<td>0.2965</td>
<td>3.938</td>
</tr>
<tr>
<td>Gymnocranius spp.</td>
<td>0.3685</td>
<td>2.855</td>
</tr>
<tr>
<td>Diagramma pictum</td>
<td>0.1403</td>
<td>0.1091</td>
</tr>
<tr>
<td>ALL LAMIDAE</td>
<td>0.2591</td>
<td>0.3166</td>
</tr>
<tr>
<td>ALL TRIGGERFISH</td>
<td>0.2591</td>
<td>0.1272</td>
</tr>
<tr>
<td>ALL OTHER FISH</td>
<td>0.2249</td>
<td>0.1727</td>
</tr>
</tbody>
</table>

Figure 3. Theoretical and observed distribution of the distance of the fish to the longline.

Figure 4. Observed distance distribution for Serranids, Lethrinida, Diagramma pictum and Badianus perditio.
The value of $\hat{\alpha}_i$ is evaluated from the visual length estimate. The variance of $\hat{\alpha}_i$ was estimated from:
\[
\text{var}(\hat{\alpha}_i) = \hat{\alpha}_i \cdot \text{var}(\hat{\beta}_i)
\]
and for $\hat{\beta}$ we have:
\[
\text{var}(\hat{\beta}) = \left(\sum_{i=1}^{n} \text{var}(\hat{\alpha}_i) / \sum_{i=1}^{n} \right)
\]

2.6-Correlation between density estimates and CPUE

Figure 5. Relationship between density estimates and CPUE in numbers.

(1) : normal regression (2) : regression through origin.

Density estimates and CPUE by numbers were best correlated after a log-log transformation (Figure 5). From previous work (Kulicki et al., 1987) it was demonstrated that depth and distance to the coast were the most important factors affecting CPUE. These variables were added to the previous model, but their contribution being of respectively 3% and 1% of the fit, they were not kept. In order to make predictions on densities from catch data it was necessary to have a model that went through the origin.

The intercept not being significantly different from 0 ($\alpha = 0.05$) (Figure 5) such a model was unacceptable (equation 6):
\[
\log(\tilde{D} + 1) = A \cdot \log(\text{CPUE} + 1) \quad (6)
\]
This regression through the origin resulted in a drop in the correlation coefficient from $r = 0.881$ to $r = 0.844$. From this relationship it was possible to estimate densities from the CPUE data for each 363 sets. The resulting densities were contoured on a map (Figure 6a).

In order to have a confidence interval on these density estimates two other values of $\tilde{D}$ were used:
\[
\tilde{D}_{\text{min}} = \tilde{D} - t(\alpha = 0.05, n - 2) \cdot s\tilde{D}
\]
\[
\tilde{D}_{\text{max}} = \tilde{D} + t(\alpha = 0.05, n - 2) \cdot s\tilde{D}
\]
where $s\tilde{D}$ : standard error of $\tilde{D}$
$n$ : number of species used to calculate $\tilde{D}$.

This allowed to calculate a minimum and a maximum regression between density and CPUE by numbers (Table 2). These relationships permitted the contouring of minimum and maximum density maps (Figure 6b & 6c). These results are more conservative than if one had used the minimum and maximum values of $A$ (equation 6):
\[
\hat{\alpha}_{\text{min}} = A - t(\alpha = 0.05, n - 2) \cdot sA
\]
\[
\hat{\alpha}_{\text{max}} = A + t(\alpha = 0.05, n - 2) \cdot sA
\]

This allowed to calculate a minimum and a maximum regression between density and CPUE by numbers (Table 2). These relationships permitted the contouring of minimum and maximum density maps (Figure 6b & 6c). These results are more conservative than if one had used the minimum and maximum values of $A$ (equation 6):

Biomass density estimates and CPUE by weight were best correlated after a log-log transformation. Figure 7 and table 2 indicate a high correlation between these two variables. Using these relationships it was possible to draw the maps illustrated by figures 8a, 8b and 8c. An evaluation of the standing stock (Table 3) was then calculated as follows from figure 12a:
\[
S = \sum_{i=1}^{n} \hat{a}_i \cdot a_i
\]
where $B_i$ : mean value of the biomass density for the strata $i$

$a_i$ : surface of strata $i$ (km$^2$)

Similar calculations from figures 8b and 8c resulted in a minimum and maximum value of the standing stock (table 3). These values are only indicative, since we have so far no method to estimate the type I error ($a$) level for $S$, but they are likely to be conservative.

Figure 7. Relationship between biomass density estimates and CPUE by weight (1) normal regression (2) regression through the origin. Lines A & B indicate the 95% confidence interval for (1).

**DISCUSSION**

To our knowledge this is the first work correlating catch data from bottom longlines to visual census data in tropical waters. One of the advantages of the present method is that censusing and fishing were conducted at the same time and the same place, which was not the case with two other similar surveys (Balston et al., 1986; Richards & Schnute, 1986). Preliminary analysis of our catch data (Kulbicki et al., 1987) indicates that there is little variation in CPUE with time of day.

Table 3. Relationships between average, minimum and maximum estimates of density or biomass and CPUE in numbers or weight.

<table>
<thead>
<tr>
<th>First variable (a)</th>
<th>Second variable (b)</th>
<th>Equation</th>
<th>$r$</th>
<th>$a$</th>
<th>$b$</th>
<th>$c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>CPUE (in numbers)</td>
<td>$y = ax + b$</td>
<td>0.89</td>
<td>1.90</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Minimum density</td>
<td>CPUE (in numbers)</td>
<td>$y = ax + b$</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Maximum density</td>
<td>CPUE (in numbers)</td>
<td>$y = ax + b$</td>
<td>0.75</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Average biomass</td>
<td>CPUE (in weight)</td>
<td>$y = ax + b$</td>
<td>1.00</td>
<td>1.27</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Minimum biomass</td>
<td>CPUE (in weight)</td>
<td>$y = ax + b$</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Maximum biomass</td>
<td>CPUE (in weight)</td>
<td>$y = ax + b$</td>
<td>0.75</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Average biomass</td>
<td>CPUE (in weight)</td>
<td>$y = ax + b$</td>
<td>1.00</td>
<td>1.27</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Minimum biomass</td>
<td>CPUE (in weight)</td>
<td>$y = ax + b$</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Maximum biomass</td>
<td>CPUE (in weight)</td>
<td>$y = ax + b$</td>
<td>0.75</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Our bottom longline is characterized by the large number of species caught. Each species has a particular behaviour towards the line and the divers. Richards and Schnute (1986) have presented a number of possible relationships between CPUE from handing and visual census depending on species and densities. Most often the number

Figure 8 a, b, c. Maps indicating the biomass density distribution of catchable bottom longline fish in the SW lagoon.

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Table 4. Data used to estimate standing stocks from biomass density maps.

<table>
<thead>
<tr>
<th>Density (NB/ha)</th>
<th>0-1</th>
<th>1-2</th>
<th>2-4</th>
<th>4-6</th>
<th>6-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lethrinus nebulosus</td>
<td>12</td>
<td>20</td>
<td>22</td>
<td>32</td>
<td>26</td>
</tr>
<tr>
<td>Bodianus perditio</td>
<td>34</td>
<td>35</td>
<td>25</td>
<td>16</td>
<td>12</td>
</tr>
</tbody>
</table>

of fish counted for a single species along a line was too small to warrant the calculation of its density. This problem is frequently encountered when studying carnivorous fish in tropical waters using visual censuses. By pooling all species one smoothes out some large interspecific differences. As an illustration figures 9a and 9b indicate the CPUE – Density relationship for two important species: Lethrinus nebulosus and Bodianus perditio. There is no pattern for the first species, whereas there is nearly a linear relationship for the second. Lethrinus nebulosus is a rather shy species, difficult to see and often found in schools.

**Figure 9a, b.** Relationship between estimated density and CPUE in numbers for Lethrinus nebulosus and Bodianus perditio.

**Figure 10.** Relationship between estimated density and CPUE by numbers for 7 families or genera.

Bodianus perditio is conspicuous, normally not a shy fish except in heavily fished areas and usually found solitary or in small groups. Figure 10 indicates the relationship between the density estimated from visual census and CPUE for the major families. Thus, at similar densities, Wrasses are more vulnerable to the longline than Haemulidae or Lutjanidae. Lethrinus spp. stands aside, being either very sensitive to this gear or largely underestimated by visual censuses.

**Figure 11.** Main bottom type in the SW lagoon of New Caledonia.
Figure 12. Bathymetrical map of the SW lagoon of New Caledonia

The density and biomass density maps (figures 5 and 8) show that the lowest concentrations of fish are near the coast and the largest concentrations near the barrier reef and in the eastern part of the lagoon. This distribution can be correlated to a great extent to the sedimentological and bathymetrical maps of our lagoon (figures 11 and 12), the highest concentrations being found in the deeper parts where the sand is the coarsest.

In order to have a first approximation of the relative importance of the total biomass, the total biomass (17700 tons, table 3) of large carnivores in our soft bottom fish fauna, the data from 59 soft bottom total fish counts were analyzed. These fish counts are 100 visual transects during which all major species are taken into account. By major species one understands fish over 10 cm or relatively abundant (i.e. Apogonids, Anisus and Pomacentridae).

A total of 265 species were recorded of which only 80 were catchable by longline. These latter species accounted for 48% of the estimated biomass. Therefore, one can estimate that the total soft bottom fish biomass in the SW lagoon is approximately 35 000 tons. Knowing that this lagoon covers 3000 km² this implies an average of 11 tons/km². This is much lower than reported standing stocks on coral reefs (38 – 209 tons/km² according to Stevenson & Marshall (1974), Acolala (1981) cites several authors reporting levels of 120 to 195 tons/km²).

The present estimate is higher than densities from tropical trawl surveys in the region (table 5). This is certainly due to the fact that in the present case habitat is more diverse, including some coralline formations.

Table 5. Biomass density estimates from several trawl fisheries in the region.

<table>
<thead>
<tr>
<th>ZONE</th>
<th>ESTIMATED DENSITIES</th>
<th>AUTHORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>WESTERN SULPHUR</td>
<td>3.0 - 5.2</td>
<td>Acolala (1981)</td>
</tr>
<tr>
<td>SOUTH CHINA SEA</td>
<td>1.0 - 5.0</td>
<td>Acolala (1981)</td>
</tr>
<tr>
<td>WESTERN SULPHUR</td>
<td>0.6 - 3.8</td>
<td>Acolala (1981)</td>
</tr>
</tbody>
</table>

The contribution of the soft bottom fish biomass to the total fish biomass of the SW lagoon is likely to be very large. Coral reefs cover less than 200 km² in that zone. Therefore, even if these reefs supported 200 tons/km² they would have a standing stock of 40 000 tons which is of the same magnitude as the soft bottoms.

This indicates that in future research, more attention should be devoted to non-traversable soft bottom fish in tropical fisheries.

REFERENCES


