A bioeconomic multispecies analysis of an estuarine small-scale fishery: spatial structure of biovalue

Mario Rueda and Omar Defeo


We estimated the spatial population structure by size and the economical potential (biovalue) of a multispecies fish resource in an estuarine lagoon in Colombia, based on fishery-dependent (catch and effort) and independent (seasonal fishing surveys) data. Model-based (geostatistics, kriging) estimations of such performance variables were used to quantify the uncertainty in abundance, individual price by size and variable costs per haul. Monte Carlo analysis was used to assess the status of the fishery. The spatial dimension of risk analysis was explored by indicator kriging, whereas effects of biovalue on the spatial allocation of fishing effort were evaluated using contingency tables. Fish abundance, individual sizes and biovalue were spatially structured, but the spatial patterns varied between seasons and species. Analysis of biovalue showed a moderate risk that fishers had economic losses derived from the fishing activity. Spatial risk analysis showed that no more than 30% of the total area from the lagoon registered profitable levels of fish abundance, which affected the spatial allocation of fishing effort. Management implications supported by our study suggest seasonal and spatial fishing closures to protect juveniles and spawning stock of fish species.

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Keywords: fish abundance, population structure, biovalue, geostatistics, spatial risk analysis, tropical estuarine lagoon, Colombia.

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Introduction

The spatial structure of the environment and of the biological communities is not only one of the most important determinants of ecosystem functioning (Legendre, 1993), but it also defines the spatial allocation of fishing effort which affects fishery management (Castilla and Defeo, 2001). Indeed, spatially explicit analyses of exploited fish populations have demonstrated a strong spatial structure in abundance and in the fishing process (Pelletier and Parma, 1994; Orenzanz and Jamieson, 1998; Caddy and Carocci, 1999; Rueda, 2001). However, the integrated analysis of the spatial dynamics of the composition by size and population abundance, jointly with concurrent spatio-temporal changes in the economic benefit, has been rarely documented (Anderson, 1989; Caddy, 1999; Pauly et al., 2001). This is relevant in small-scale fisheries located on tropical estuaries, where the unselective harvest of a multispecies stock of short-lived species (Blaber, 1997) together with economic pressures, cause fishers to allocate fishing effort in areas closer to port (Defeo and Castilla, 1998; Cabrera and Defeo, 2001).

The application of spatial models, both analytical (Hilborn and Walters, 1987; Caddy and Seijo, 1998) and empirical (Caddy and Carocci, 1999; Taconet and Bensch, 2000) arise as a powerful tool for stock assessment and fishery management. In this setting, geostatistics has obtained increasing acceptance to address the spatial structure of variables observed across geographical space. Such applications in marine science have been mainly used to describe spatial patterns of benthic and pelagic species (Maravelias et al., 1996; Rueda, 2001; Defeo and Rueda, 2002) and to interpolate abundance at unsampled locations (Petitgas, 1993; Maynou et al., 1998; Rueda and Defeo, 2001). In this study we integrate biological and economic information for modeling and interpolate the spatial structure of fish abundance, individual size and the economic potential of the abundance (biovalue) in the Ciénaga
Grande de Santa Marta (CGSM). This is a multispecies (Rueda and Urban, 1998; Sánchez and Rueda, 1999) and multifleet fishery (Rueda and Defeo, in press) based on the exploitation of the fishes Eugerres plumieri, Mullgil incilis and Cathorops spixii, whose harvestable biomass is mainly formed by juveniles (Rueda and Defeo, 2001). In addition, the effect of the abundance of different population components on the biovalue was assessed to quantify the uncertainty in fishery performance variables and to estimate the probability of exceeding limit reference points (LRPs) defined in terms of critical threshold values of biovalue. Potential consequences of biovalue spatial dimension on the spatial allocation of fishing effort are also explored.

Methods
Study area and sampling
The CGSM is the most important estuarine lagoon of Colombia (Figure 1), because its fishery constitutes the main source of both food and income for ca. 20 000 persons (3500 fishers: Botero and Salzwedel, 1999). Four alternating seasons affect the life history traits of the fish fauna in the CGSM (Rueda and Santos-Martínez, 1999; Sánchez and Rueda, 1999); however, for the purpose of this study, we only considered data gathered in the contrasting rainy and dry seasons. One fishing survey was conducted in November 1993 (rainy season) and another in March 1994 (dry season), based on a systematic design of 115 stations spaced 2000 m apart and located using a GPS, covering the whole CGSM (Figure 1). At each station, a haul was carried out using a “boliche” or encircling gillnet, which enclosed an average circular area of 5000 m². Eight “boliches” were used simultaneously to conduct each survey, which took approximately 8 h to be completed (see Rueda, 2001; Rueda and Defeo, 2001 for details). Individuals of E. plumieri, M. incilis and C. spixii collected per station were counted and measured for total length to the nearest 0.5 cm. Information on fishing effort of the “boliche” and bio-economic variables was obtained from a fishery monitoring program conducted between 1993 and 1994 (Santos-Martínez and Viloria, 1998). Effort data (number of trips...
Spatial structure of biovalue

Variographic analysis (Matheron, 1971) was used to characterize the spatial structure of fish abundance, size and biovalue. Each variable was considered as a spatial process observed in each season by means of 115 observations measured at a location x, defined by latitude and longitude in a two-dimensional space. Seasonal experimental semivariograms were estimated. Confirmation of a second-order stationarity assumption and assessing the possibility of isotropic and anisotropic processes were conducted by computing semivariogram surfaces (Isaaks and Srivastava, 1989). Structure functions for fish abundance, size and biovalue were estimated fixing the active lag distance to 20 400 m (65% of the maximum lag). This was done after looking for the large number of pairs available to estimate semivariograms which avoids the situation where the variables cease to be autocorrelated (Isaaks and Srivastava, 1989). Maps of fish abundance, size and biovalue per species and seasons were computed as a linear combination of block estimates, with each estimate receiving a weight proportional to the sampled area (Journel and Huijbregts, 1978). Global estimates were corrected by the vulnerability of each species to the sampling gear experimentally estimated as 0.5, 0.43 and 0.4 for E. plumieri, M. incilis and C. spixii, respectively (Rueda and Defeo, 2001).

Risk analysis and indicator probabilistic kriging

We estimated multispecies biovalue (BV) by summing up the global biovalues obtained for each species, given by multiplying the mean fish abundance of block kriging analyses by its mean unit price per size. Thus, estimates of BV, VC and minimum threshold profit (Z) in each season were obtained by block kriging (Matheron, 1971). Kriging predictions were evaluated using jackknife cross-validation, fitting observed (O) and estimated (E) values to a linear regression of the form \( O = \alpha + \beta E \) and testing the significance of \( \alpha \) and \( \beta \) (t-test) under the null hypotheses \( \alpha = 0 \) and \( \beta = 1 \) (Power, 1993). Maps were performed over a regular interpolating grid of \( 424 \times 414 \text{m}^2 \) (internodal distances) covering the whole area of the CGSM (450 km\(^2\)), whereas the neighborhood comprises at least the 16 nearest neighbors. Global biovalue and the standard deviation per species and seasons were computed as a linear combination of block estimates, with each estimate receiving a weight proportional to the sampled area (Journel and Huijbregts, 1978). Global estimates were corrected by the vulnerability of each species to the sampling gear experimentally estimated as 0.5, 0.43 and 0.4 for E. plumieri, M. incilis and C. spixii, respectively (Rueda and Defeo, 2001).

Spatial prediction of fish abundance, size and biovalue

Maps of fish abundance, size and biovalue per species and seasons were obtained by block kriging (Matheron, 1971). Kriging predictions were evaluated using jackknife cross-validation, fitting observed (O) and estimated (E) values to a linear regression of the form \( O = \alpha + \beta E \) and testing the significance of \( \alpha \) and \( \beta \) (t-test) under the null hypotheses \( \alpha = 0 \) and \( \beta = 1 \) (Power, 1993). Maps were performed over a regular interpolating grid of \( 424 \times 414 \text{m}^2 \) (internodal distances) covering the whole area of the CGSM (450 km\(^2\)), whereas the neighborhood comprises at least the 16 nearest neighbors. Global biovalue and the standard deviation per species and seasons were computed as a linear combination of block estimates, with each estimate receiving a weight proportional to the sampled area (Journel and Huijbregts, 1978). Global estimates were corrected by the vulnerability of each species to the sampling gear experimentally estimated as 0.5, 0.43 and 0.4 for E. plumieri, M. incilis and C. spixii, respectively (Rueda and Defeo, 2001).

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could be considered as risk-prone, on the basis that BV \( \leq \) VC implies economic losses or zero quasi rent, whereas scenario (2) is a risk-averse desirable profit margin. Monte Carlo analysis was used to explicitly account for the uncertainty associated with fish abundance, unit price per species and the variable costs per haul in order to quantify the BV risk of falling below the LRPs mentioned above. These variables were randomly generated by Monte Carlo resampling with lognormal (N and P; Chi-square test: \( p > 0.05 \) in all cases) probability density functions, which allowed us to estimate the mean and standard deviation parameters needed for the simulation process. The VC was fitted to a uniform distribution, assuming that all values between the minimum and maximum, both fixed, occur with equal likelihood (Werckman et al., 2000). Two Monte Carlo runs of 1000 simulation trials were conducted for each year to obtain the probability distributions of BV by which the LRPs were assessed.

To provide adequate signs of fishery status, the spatial dimension of the LRPs (Seijo and Caddy, 2000) were determined by indicator kriging (Burrough and McDonnell, 1998), by which we estimated the probability that the BV exceeds desirable thresholds [prob(BV > VC) and prob \( (BV > Z) \)] over the study area in each season. For this purpose, original BV data were transformed from a continuous to a binary scale to apply ordinary indicator kriging (Goovaerts, 1997) as follows:

\[
i(X_i; Z_k) = \begin{cases} 
0 & \text{if } BV(X_i) \leq Z_k \\
1 & \text{if } BV(X_i) > Z_k
\end{cases}
\]

where \( X_i \) is the BV datum location and \( Z_k \) are the k thresholds (VC and \( Z \)). Indicator kriging is a non-linear form of ordinary kriging, where semivariograms are computed for the binary data in the usual way, and ordinary kriging proceeds with the transformed data (Burrough and McDonnell, 1998). The resulting maps displayed continuous data in the range 0–1, indicating the probability that BV has exceeded desirable thresholds.

Effects of biovalue on temporal and spatial allocation of fishing effort

Seasonal variations in fishing effort (daily number of fishing trips) were tested using a standard t-test. We do not have effort allocation data with the same spatial resolution as fishing surveys. To circumvent this, potential effects of the spatial structure of BV on spatial allocation of fishing effort were explored by dividing the CGSM area into three discrete sub-areas (fishing zones). These zones were defined according to the number of fishing trips per season allocated on each one, which significantly differed from a hypothesized 1:1:1 ratio for the rainy (\( \chi^2 \) test = 159.34; \( p < 0.01 \)) and the dry (\( \chi^2 \) test = 381.96; \( p < 0.01 \)) seasons. The distribution of the occurrence of the binary scale of BV (1 if BV > VC, and 0 otherwise) in each fishing zone was analyzed for each season by computing a 2 \( \times \) 2 contingency table to test the null hypothesis that fishing effort between fishing zones is independent of the prob(BV > VC).

Results

Fish abundance and population structure by size

Abundance of \( E. \) plumieri and \( C. \) spixii did not differ between seasons (Kruskal–Wallis test \( H_{1.228} = 0.29 \) and \( H_{1.228} = 0.31; \ p > 0.05 \), respectively). However, fish abundance in the rainy season showed higher variability (Table 1). Although \( M. \) incilis presented higher abundance in the rainy season, seasonal comparison was not tested due to high number of hauls with zero catch in the dry season. The population structure by size of \( E. \) plumieri and \( C. \) spixii did not differ between seasons (K–S test: \( p > 0.05 \)), while \( M. \) incilis presented significantly lower mean lengths in the dry season (22.5 ± 3.1 cm) with respect to the rainy season (26.3 ± 2.6 cm) (K–S test: \( p < 0.05 \), Table 1).

Table 1. Seasonal mean (± s.d.) values of fish abundance and individual fish length in the CGSM. Different sample sizes (n) are due to a breakdown of the “boliche” (abundance data for rainy season) or stations with zero individuals (length data).

<table>
<thead>
<tr>
<th>Species</th>
<th>Abundance (ind 5000 m(^{-2}))</th>
<th>Total length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( X ) s.d. n</td>
<td>( X ) s.d. n</td>
</tr>
<tr>
<td>1993/Rainy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( E. ) plumieri</td>
<td>6.2 11.1 113</td>
<td>17.6 3.1 70</td>
</tr>
<tr>
<td>( M. ) incilis</td>
<td>4.6 14.7 113</td>
<td>26.3 2.6 59</td>
</tr>
<tr>
<td>( C. ) spixii</td>
<td>2.0 4.4 113</td>
<td>22.3 2.6 48</td>
</tr>
<tr>
<td>1994/Dry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( E. ) plumieri</td>
<td>3.3 4.0 115</td>
<td>17.5 2.3 85</td>
</tr>
<tr>
<td>( M. ) incilis</td>
<td>0.1 0.5 115</td>
<td>22.5 3.1 12</td>
</tr>
<tr>
<td>( C. ) spixii</td>
<td>2.3 3.5 115</td>
<td>23.3 2.0 62</td>
</tr>
</tbody>
</table>
spatial dependence in the dry season (Figure 2). C. spixii showed different distribution patterns between seasons, whereas E. plumieri consistently presented high-abundance patches in the north of CGSM. Mean sizes for each species tended to show patchy distribution with smooth autocorrelation between stations, as indicated by the best fit of exponential models in most cases (Table 2). Semivariograms for E. plumieri and C. spixii differed between seasons (ARSS analysis: F test > 80; p < 0.01). This was consistent with the variability in the spatially structured component of sizes, which ranged from 53 to 96%. Kriging maps of individual size evidenced the spatial segregation of different population components in each species, which varied seasonally (Figure 2). A simple visual inspection of abundance and size maps showed that high-abundance patches and larger sizes did not overlap in space (Figure 2), mainly in the rainy season. Negative correlations between mean size and abundance for E. plumieri \( (r = -0.40; \ p = 0.009) \) and C. spixii \( (r = -0.26; \ p = 0.047) \) corroborate our observations.

The relationship between price and size was statistically significant for each species, accounting in all cases for ca. 50% of the total variance; moreover, parameters a and b were highly significant in all cases \( (p < 0.001; \) Figure 3).
For a same size, the price of *E. plumieri* was higher in the dry season (ANCOVA $F_{1,147} = 6.32; p = 0.012$), whereas the price of *M. incilis* was higher in the rainy season (ANCOVA $F_{1,51} = 4.71; p = 0.034$). Alternatively, the L–P relationship for *C. spixii* did not differ between seasons (ANCOVA $F_{1,162} = 0.009; p = 0.924$).

The spatial structure of BV for *E. plumieri* and *C. spixii* differed between seasons (ARSS analysis: $F$ test $>112; p < 0.01$), with areas of spatial dependence well defined by spherical models (Table 2). The spatially structured component of BV ranged between 51 and 99%, confirming different spatial features in the economic potential denoted by kriging maps (Figure 4). The distribution patterns of BV were very similar to those shown for abundance data (Figures 2 and 4). *E. plumieri* presented high-BV patches mainly in the north of CGSM in both seasons, with some important clusters in the dry season located toward southern, eastern and western ends of the lagoon. Consistently, *C. spixii* showed an aggregated distribution in each season, whereas the BV of *M. incilis* was clustered on the eastern coast during the rainy season. In all cases, cross-validation analysis showed that kriging predictions for fish abundance,

Figure 2. Ordinary kriging maps overlaying fish abundance (Ind.0.176 km$^{-2}$) and individual mean size (cm) for rainy (1993) and dry (1994) seasons in the CGSM. Darker surfaces correspond to fish abundance, whereas the numbers labeling isolines indicate mean length estimates for each species. For *M. incilis*, maps of fish abundance and sizes were not performed in the dry season, due to the lack of spatial autocorrelation.
size and biovalue were suitable, because the null hypotheses $\alpha = 0$ and $\beta = 1$ were never rejected ($p > 0.05$; Table 2). Global estimates of biovalue were higher in the dry season than in the rainy season, both for *E. plumieri* (13%) and *C. spixii* (37%) (Table 3). These estimates evidenced the combined effect of abundance by size and individual size price variations for each species on the economic potential of fish abundance.

Risk analysis and indicator kriging

Both LRPs [prob(BV $\leq$ VC) and prob(BV $\leq$ Z)] varied between seasons (Figure 5). For the first scenario, the probability that the BVs were equal or less than the variable costs (US$0.68 haul$^{-1}$ in the rainy season and US$0.81 haul$^{-1}$ in the dry season) was 0.47 and 0.58, respectively, suggesting a moderate risk that fishers obtain zero quasi rent or economic losses. The second scenario showed a high risk (0.79 and 0.92 for rainy and dry seasons, respectively) that fishers obtain a minimum profit threshold equal or less than that expected ($Z = US1.48 haul^{-1}$ in the rainy season and US$1.6 haul^{-1}$ in the dry season). Consequently, the probability of obtaining some fishing profit ranged between 0.53 in the rainy and 0.42 in the dry seasons. Such probabilities were substantially reduced under the second scenario (0.21 in the rainy and 0.08 in the dry season).

Spatial risk analysis showed that probabilities of exceeding desirables thresholds of biovalue had spatial structure, which differed between seasons consistently with changes in the spatial variance explained by spherical (50%, rainy season) and exponential models (87–90%, dry season) (Table 2). Cross-validation analysis corroborated the appropriateness of the semivariogram models ($0.33 < r < 0.47; p < 0.05$). Risk maps (Figure 6) showed that patches with probability of getting some profit [prob(BV $> VC$)] varied in location and size, being the smaller patches when the probability of achieving the expected rent by fishers was considered [prob(BV $> Z$)]. Taking into account an arbitrary value of probability higher than 0.7, the potential areas for getting profits did not exceed 30% of the CGSM total area.

Effects of biovalue on temporal and spatial allocation of fishing effort

The number of fishing trips day$^{-1}$ was significantly higher in the dry season than in the rainy season ($t$-test $= -6.84; p < 0.01$) (Figure 7b). Moreover, the number of trips was significantly higher on fishing zone A, both in the rainy (55% of 571 trips) and dry (48% of 1882 trips) seasons. The lowest number of trips was allocated on zone B (12 and 13% of the total trips in rainy and dry seasons, respectively), whereas zone C had intermediate values (33 and 39% of the total trips in rainy and dry seasons, respectively) (Figure 7a, c, d). Consistent with this spatio-temporal pattern, the number of fishing trips between zones was dependent on the probability of obtaining some profit prob(BV $> VC$) in the rainy ($\chi^2 = 10.07; p < 0.01$) and in the dry ($\chi^2$ test $= 6.06; p < 0.05$) seasons. In this sense, zones A (in the rainy season) and C (in the dry season) were the most successful, considering that the higher frequency of indicators revealed the probability of finding fish abundance at profitable levels (Figure 7c, d).

Discussion

The spatial dimension has played an important role in building paradigms in ecological research, and currently
constitutes one of the challenges to overcome in fisheries science for the present century (Caddy, 1999). In this study, model-based (e.g. geostatistics) approaches allowed us to describe successfully the spatial structure of fish abundance, individual size and biovalue in a tropical estuarine small-scale fishery. Such an approach was also useful to test hypotheses related to the spatial dynamics of those performance variables and to assess the status of fishery using bioeconomic reference points.

Abundance of *E. plumieri*, *M. incilis* and *C. spixii* showed a strong spatial structure in the CGSM, and this was consistent with spatial variations in the population composition by size and the BV (Table 2). Fish distribution of these species has been related to gradients in salinity and to habitat features like substrate type (Rueda, 2001). The reproductive migration of *M. incilis* toward adjacent marine waters (Sánchez et al., 1998) precluded the determination of spatial structure for the abundance, size and biovalue in the dry season. Size distribution maps showed different spatial structures of population components (e.g. juveniles, spawning stock) within and between seasons, as a result of the co-occurrence of multiple annual cohorts (Sánchez

Figure 4. Ordinary kriging maps of biovalue (US$ 0.176 km^{-2})$ for each species in rainy (1993) and dry (1994) seasons in the CGSM. The kriged map was not performed for *M. incilis* in the dry season, due to the lack of spatial autocorrelation.
High-abundance patches corresponded to juveniles, mostly for *E. plumieri* (L < 17 cm) and *C. spixii* (L < 23 cm) in the rainy season, whereas most aggregations of adults were present in the dry season (Figure 2). This picture was consistent with recruitment and sexual maturity peaks reported for these species during the rainy and dry seasons, respectively, in the CGSM (Tijaro et al., 1998; Rueda and Santos-Martinez, 1999). Negative correlations between mean size and abundance for *E. plumieri* and *C. spixii* suggest spatial density dependence in the rainy season, thus giving strong support to our findings. Alternatively, *M. incilis* showed adult individuals (L > 24 cm) in the rainy season, mainly clustered in the eastern part of the CGSM before migrating to the sea to spawn.

The L–P relationship fitted for each species was very useful to estimate spatial and temporal variations in the biovalue. In spite of this, abundance and structure by size did not differ between seasons for *E. plumieri* and *C. spixii*, and BV of these species was consistently higher in the dry season as a response to seasonal price-at-size variations. This demonstrates one of the main characteristics of artisanal fisheries, where market forces regulating prices affect the potential value of the catch (Defeo and Castilla, 1998; Castilla and Defeo, 2001). Higher BV values (Figure 4) coincided with scarce high-abundance patches for the three species (Figure 2). Such spatio-temporal heterogeneity of the economical potential determined that fishers had moderate probabilities of realizing economic losses from their fishing activity; whereas the risk of falling below an

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**Table 3. Block kriging estimates of fish biovalue during rainy and dry seasons in the CGSM.**

<table>
<thead>
<tr>
<th>Species</th>
<th>BV</th>
<th>s.d.<em>BV</em></th>
<th>BVt</th>
<th>s.d.<em>BVt</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>1993/Rainy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. plumieri</em></td>
<td>0.37</td>
<td>0.08</td>
<td>28712</td>
<td>6208</td>
</tr>
<tr>
<td><em>M. incilis</em></td>
<td>0.37</td>
<td>0.09</td>
<td>28786</td>
<td>7002</td>
</tr>
<tr>
<td><em>C. spixii</em></td>
<td>0.48</td>
<td>0.11</td>
<td>31680</td>
<td>7260</td>
</tr>
<tr>
<td>1994/Dry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E. plumieri</em></td>
<td>0.42</td>
<td>0.08</td>
<td>32424</td>
<td>6176</td>
</tr>
<tr>
<td><em>M. incilis</em></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><em>C. spixii</em></td>
<td>0.66</td>
<td>0.21</td>
<td>43560</td>
<td>13860</td>
</tr>
</tbody>
</table>

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**Figure 5. Risk analysis by season.** Probability of falling below the LRP (shaded bars) given by prob(BV ≤ VC) and prob(BV ≤ Z). The corresponding probability values are also shown. BV is the multispecies biovalue by haul. VC denotes variable costs by haul of the “boliche”, and Z is a minimum threshold profit (see text for details). Probabilities of falling below these undesirable thresholds are based on 1000 Monte Carlo simulation trials for rainy and dry seasons.
undesirable threshold of rent expected was always high. In agreement with this scenario, maps of risk emphasized that only a small portion of the stock could be harvested with high probabilities of obtaining profits and that, in general, when fish abundance was low variable costs were higher than the biovalue. The above situation determines high concentrations of fishers over the most productive grounds, generating crowding externalities (Seijo et al., 1998). Conflicts between fishers of different ports employing several gears support this assertion due to overlapping of fishing grounds (Santos-Martinez and Viloria, 1998). These findings were confirmed by the analysis of commercial fishing data, which showed: (1) higher amounts of fishing effort in the dry season in accordance with higher BV levels and (2) dependence between fishing effort allocated among zones and the probability of finding profitable levels of abundance \( \text{prob}(BV > VC) \) and \( \text{prob}(BV > Z) \) for rainy and dry seasons in the CGSM. Maps were produced by ordinary indicator kriging. BV, VC and Z are as defined in Figure 5.

In conclusion, the analysis of spatial structure of fishery performance variables allowed us to map variations in abundance of different population components and in the economical potential of targeted species. These model-based estimates were useful to quantify spatially explicit probabilities of exceeding bioeconomic LRPs, which may be used to explain potential changes in the spatial and temporal allocation of fishing effort. In this context, a precautionary approach could include the reduction of fishing effort in areas and seasons with high concentration of juveniles (e.g. \( E. \) plumieri on the north of the lagoon during the rainy season), even though high abundance could generate high economic revenues. Moreover, effort
on *M. incilis* should be restricted at the northeast of the lagoon during the rainy season, in order to protect the spawning stock. Such strategies might be combined with selectivity controls of the “boliche” (Rueda and Defeo, in press) and an appropriate institutional framework directed to strengthen the actually poor implementation and enforcement of management measures in this artisanal fishery.

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**References**


Figure 7. Linkage between biovalue and spatial allocation of fishing effort in the CGSM. (a) Fishing zones (A, B and C). (b) Seasonal variations in fishing effort (fishing trips day$^{-1}$ : mean ± SE). Frequency of indicators (—–, BV > VC; ——, BV ≤ VC) and total fishing effort (fishing trips) discriminated by fishing zones for rainy (c) and dry (d) seasons.


Rueda, M., and Defeo, O. Linking fishery management and conservation in a tropical estuarine lagoon: biological and physical effects of an artisanal fishing gear. Estuarine, Coastal and Shelf Science, in press.


