Pre-selection of Areas for Shrimp Culture in a Subtropical Brazilian Lagoon
Based on Multicriteria Hydrological Evaluation

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ABSTRACT


This research discusses the application of an objective quantitative analysis over a hydrological dataset in an effort to recognize more favorable lagoon sites for marine water intake to shrimp culture. The applied methodology is based on Multicriteria Evaluation (MCE) techniques, being considered four selected properties as the most adequate to represent local water quality: salinity, turbidity, dissolved oxygen and pH. The proposal is based on the application of a given set of the criteria over a number of spatially distributed sampling stations to represent the hydrological gradients of Tubarão Estuarine-Lagoonal Complex (Santa Catarina State, Brazil).


INTRODUCTION

In the last few years shrimp culture has presented a very fast growth in sub-tropical enclosed systems of the Brazilian coast. Despite the importance of this in Santa Catarina, its aquaculture is up to now limited to a small-scale. Shrimp culture is based on Litopenaeus vannamei farming with a total production of 1800 ton/yr representing 3% of the total Brazilian fishery production (BELTRAME, 2003). Unfortunately, the actual scientific knowledge about the oceanographic characteristics of local lagoons and estuaries is not enough to precisely evaluate the most adequate zones to the sustainable expansion of this activity. However, environmental protection and sustainable economic development require the building of extensive databases derived from physical and chemical monitoring and the application of effective methodologies for environmental and socio-economic variables integration. At the same time, coastal management demand efficient decisions in a reasonable time-scale. Therefore, holistic approaches need be based, at least in this moment, on realistic methods rather than complicated and time-consuming techniques (MORIKI et al., 1996). In this sense, the application of Multicriteria Evaluation (MCE) techniques, based on the assignment of scores to selected variables and the classification of study sites in a ranking list of the more feasible areas, have been well accepted by academic community and decision makers (CARVER, 1991; ANGELL, 1998; MEADEN, 1998; WENZEL, 2001). The basic objective of MCE analysis is to evaluate a larger range of choice alternatives based on several criteria. However, as a general rule, due to practical difficulties most MCE have been developed for evaluating small numbers of alternatives and criteria (CARVER, 1991).

The principal aim of this study is to propose the use of a simple and fast quantitative methodology to evaluate hydrological aspects of estuaries and lagoons, identifying more suitable or restrictive sectors for shrimp culture. This methodology, based on the attribution of a numeric index for each studied sampling station, allows the comparison among different environments in Brazilian coast and also can be used in future studies as part of a wider environmental index, considering other important aspects for mariculture development (socio-economy, land use, environmental legislation, water availability, among others). The test site in which the proposed Hydrological Suitable Index was applied is Tubarão Estuarine-Lagoonal Complex (located in Santa Catarina State, southern Brazil). In this study, the identification of the most favorable sectors to shrimp farm settlement in the area was made considering the accomplishment of two needs, which will ultimately guarantee the sustainability of the activity: 1) most sensible sites must be protected from human intervention and 2) the quality of the marine water to be used in the farms must be guaranteed.

Study Area

Santa Catarina State (Brazil) presents a large extension of its coastal plains occupied by estuaries and lagoons. Among these ecosystems, Tubarão Estuarine-Lagoonal Complex is considered the most important system of the state. It is a shallow brackish water body, bordered by a sandy Quaternary tidal plain, marshes and dunes. To the East it is limited by the Atlantic Ocean, to the West by a granitic group of hills, limited on South by a large coastal plain and in the North by Tabuleiro mountain range (Figure 1). The main fresh water contributors are Tubarão, D’Una and Congonhas rivers. The first one and its affluent compose the principal watershed of southern Santa Catarina. In order to avoid floods this river had its course rectified in the costal plain segment and was dredged to the average depth of 5.0 m. Serious environmental problems have been reported due to disposal of effluents from urban, coal mining and agriculture areas. The main communication of the system with the sea is located in the Santo Antonio lagoon. The connection takes place trough a narrow channel 100 to 200 m wide with an approximate depth of 8.0 m.

Another communication between inner and marine waters is found in Camacho lagoon. This one, nevertheless, has a secondary importance due to its most restrict flux, being necessary regular dredging efforts to keep the local mouth opened. The penetration of tides is a fundamental factor for the renewal of the polluted mixohaline waters and is also beneficial to the development of economically exploited eurihaline organisms, such as fishes and crustaceans.
METHODOLOGY

Collection of Data

Two spatial working scales were adopted following different sampling strategies: (1) transects along the main axis of marine water penetration in the system and (2) regularly spaced sampling points in selected areas, summing 47 sample stations. Repeated temporal samplings were made in order to characterize different hydrological conditions of the area. As a result, data was obtained in four distinct dates: March, June and September 2001, July 2002. In each one of these samplings several hydrological measures were taken in three different depths of the water column (surface, mid water and close to the bottom). The analyzed properties were: temperature, pH, dissolved oxygen, Secchi depth, seston (total, organic and inorganic fractions), turbidity, salinity, alkalinity and dissolved inorganic nutrients (N-NH\textsubscript{3}, N-NO\textsubscript{2}, N-NO\textsubscript{3}, PO\textsubscript{4} and SiO\textsubscript{2}).

In spite of the amount of studied parameters, specifically for this research just four descriptors were used to classify the sites in relation to their importance for shrimp farming: salinity, turbidity, pH and dissolved oxygen. These variables were selected considering the following aspects: facilities related to sampling and in situ determination, their correlation to hydrodynamic dominant characteristics of the water masses and the spatial similarity of their distribution pattern in relation to other investigated properties more difficult to collect (e.g. nutrients).

The relationships were determined by the application of statistical correlation tests. Temperature was considered irrelevant for the purpose of shrimp farming site selection, since inside the ponds it responds directly to solar heating.

Analytical Methods

Salinity (reported in PSU) was measured using a combined salinity-conductivity probe (WTW Multiline P4). Dissolved oxygen (mg.L\textsuperscript{-1}) and temperature (°C) were measured using an oxygen electrode (YSI model F1055) corrected for atmospheric pressure and salinity. Turbidity (NTU) was determined using a turbidimeter Orbeco-Hellige (model 966) calibrated to operate from 0 - 200 NTU and pH derived from a Goulton pH-meter calibrated for acid waters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Salinity (PSU)</th>
<th>Turbidity (NTU)</th>
<th>pH</th>
<th>O\textsubscript{2} (mg/L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Interval (WI)</td>
<td>Variable Weight (VW)</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>&lt; 10</td>
<td>8.0</td>
<td>&gt; 7.0</td>
</tr>
<tr>
<td>4 - 5</td>
<td>20 - 30 or 30 - 35</td>
<td>10 - 20</td>
<td>7.5 - 8.0 or 8.0 - 8.5</td>
<td>6.0 - 7.0</td>
</tr>
<tr>
<td>3 - 4</td>
<td>15 - 20 or 20 - 35</td>
<td>20 - 35</td>
<td>7.0 - 7.5 or 8.5 - 9.0</td>
<td>5.0 - 6.0</td>
</tr>
<tr>
<td>2 - 3</td>
<td>10 - 15 or 15 - 40</td>
<td>35 - 60</td>
<td>6.5 - 7.0 or 9.0 - 9.5</td>
<td>4.0 - 5.0</td>
</tr>
<tr>
<td>1 - 2</td>
<td>5 - 10 or 10 - 45</td>
<td>60 - 100</td>
<td>6.0 - 6.5 or 9.5 - 10.0</td>
<td>3.0 - 4.0</td>
</tr>
<tr>
<td>0 - 1</td>
<td>0 - 5</td>
<td>100 - 150</td>
<td>5.5 - 6.0 or 10.0 - 10.5</td>
<td>2.0 - 3.0</td>
</tr>
</tbody>
</table>

Partial Scores (PS\textsubscript{variable}) = WI\textsubscript{variable} * VW\textsubscript{variable}

Final Score = PS\textsubscript{sal} * PS\textsubscript{turb} * PS\textsubscript{pH} * PS\textsubscript{O2}

Non Linear transformation to interval 0-10: Station Score = 0.85 * (Final Score Value) \(1/4\)
Building of the Hydrological Suitability Index

The general importance of each chosen variable for the characterization of the water destined to fill shrimp culture ponds was hierarchized through weight attribution, following Multicriteria Evaluation methodology (MCE). Weights or criterion priorities were assigned to each variable (or attribute) in the construction of an overall index. A number of weighting methodologies have been already proposed, according to the review presented by VOOGD (1983; apud CARVER, 1991). In this research the Hierarchical Optimization Method was chosen, which allowed to rank all factors according to their importance in the general description of the hydrological characteristics of each sampling point. These weights can stretch or shrink the scales of each attribute score and were given based in previous scientific knowledge. This way, considering the natural variation of the chosen properties on coastal systems and previous ecological data obtained from experiments about optimal marine shrimp conditions, five alternative intervals were proposed for each variable, from the least favorable (weight zero) to the best environmental condition (weight five). A similar methodology was applied by HOQUE et al. 1997 in Sri Lanka.

The main steps of the Hydrological Suitability Index (HI) calculus are synthesized in the Table 1. Salinity and turbidity received a greater weight due to the possibility in using them as proxies for more favorable marine circulation and consequently the presence of cleaner waters, besides salinity is indispensable to shrimp culture. In opposite, pH and dissolved oxygen got the smaller weights because they can be easily corrected during pond management. For each variable one or more polynomial equations were built to allow the assignment of a continuous weight interval, as illustrated in Figure 2.

The final scores were adjusted to a common numerical basis. The chosen method was to normalize the scores in a scale of 0 to 10 by non linear transformation (formula in Table 1 and Figure 2). JIANG and EASTMAN (2000) discussed the advantages in the use of this routine.

The HI value is the result of the average obtained from the four surveying made in the study area. The results for each sampling station (considering surface and bottom waters) allowed its classification in one of five possible classes of water quality (from optimum to not suitable), as demonstrated in Table 2. These results were linked to a reference map and other spatial information in ArcView GIS.

FIGURE 2. Scoring model and equations for each selected variable.

RESULTS AND DISCUSSION

In most measured parameters a large range was observed both among the same station and along transects, testifying a wide temporal and spatial variation. However, on average Tubarão Estuarine-Lagoonal Complex presented mesohaline to polyhaline waters, with no severe dissolved oxygen restrictions (values always above 3.4 mg.l⁻¹). The pH values ranged into the natural interval expected for brackish lagoons (6.6 to 8.5), except in some stations located at the uppermost reach of Tubarão River. These presented more acidic values (with a lower of 4.8) possibly due to the input of coal mining residue lixiviation. The turbidity was relatively low, with maximum values close to the bottom waters of Tubarão River (88 NTU).

Table 2. HI interval values assigned to each class of suitability.

<table>
<thead>
<tr>
<th>Classes</th>
<th>Hydrological Suitability Index Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not suitable</td>
<td>0.0 - 3.0</td>
</tr>
<tr>
<td>Suitable with high restriction</td>
<td>3.0 - 5.5</td>
</tr>
<tr>
<td>Suitable with medium restriction</td>
<td>5.5 - 7.5</td>
</tr>
<tr>
<td>Suitable with low restriction</td>
<td>7.5 - 9.0</td>
</tr>
<tr>
<td>Suitable without restriction</td>
<td>9.0 - 10.0</td>
</tr>
</tbody>
</table>
Turbidity was lower at the lagoons, with higher values at Santa Marta (40 NTU).

The calculated index for surface and bottom waters is presented in figures 3 and 4. They represent average conditions obtained from the selected properties in four field missions.

The results reported by the Hydrological Suitability Index indicated that the study area does not present an optimum average water quality to shrimp farm (HI > 9). This is probably due to the weight methodology adopted, that has been deliberately severe to minimize the risk of polluted area selection and also due to the natural characteristics of this coastal system. This system receives a significant fluvial contribution and has a restricted water circulation in many sectors. Even so, several stations reached scores within the second and third suitability classes, named “suitable with low restriction” and “suitable with medium restriction”, respectively (7.5 < HI < 9.0; 5.5 < HI < 7.5), indicating their hydrological viability to shrimp farm. This is the situation, for example, of the lagoons of Santo Antonio and Camacho. Most of the sites were classified as “suitable with medium restriction”, including the lagoons of Garopaba do Sul, Santa Marta, Imarui and their communication channels. The sites with inappropriate waters (HI < 3.0) are located preferentially along Tubarão River and adjoining areas, being not recommend water intake along this areas.

Considering the index distribution, 14.9% of the surface sampling points were classified as “suitable with low restriction”, 55.3% as “suitable with medium restriction”, 8.5% as “suitable with high restriction” and 21.3% are not suitable. Bottom waters kept the same pattern, except along Tubarão River in which bottom waters presented indexes above 7.5 up to 10 Km from its mouth, located at Santo Antonio Lagoon. This difference is due to the high stratification detected in this salt-wedge estuary.

In general, sites under stronger marine influence, i.e. near to the inlets of the system, scored better than sites more confined or submitted to higher fluvial inputs. The five proposed classes hierarchised the sampling points according to the restriction that the sum of selected descriptors offer to marine shrimp culture. This way, the gradient of restriction represents the potential risk for the intake of water with low quality but also areas submitted to a higher natural variability in their hydrographic characteristics. Although the obtained results may not be limiting to the implementation of a shrimp farm, the suggested higher water quality oscillation should reduce productivity levels and constrain the intensification of the culture. BELTRAME (2003) discusses in detail the adequate spatial location of the farms comprising a proposal of site selection zoning for the area.

CONCLUSION

This work proposes that the investigation of hydrological conditions for shrimp culture development in Brazilian lagoons can be made in a regional scale using a set of few and simple determination water quality variables. As the most appropriate water descriptors for an integrated assessment of oceanographic characteristics, four parameters were identified (salinity, turbidity, pH and dissolved oxygen) which proved to be capable to indicate the sites with more favorable conditions for the activity. An integrating algorithm based on Multicriteria Evaluation showed to be a powerful tool in the analysis of local water characteristics and helpful to its environmental classification. Values were assigned to the sampling points and they were ranked in a scale of water intake aptness related to shrimp culture.

The distribution of the suitability classes obtained by the index proposed in this study also proved to be adequate in the characterization of the potencial use of local waters by shrimp farms. Although not yet quantified, a good correlation was observed between the performance of the already implemented shrimp farms and the classification proposed by this method, since farms with the fewer variation in the production rate are located in the areas with low water quality restriction.

The contribution of this work could be considered an enhancement in planning strategies based on a GIS approach,
since usually water quality is not considered as an information layer in spatial analysis. The proposed index, when associated to other descriptors with relevant information about the environment such as topography, soils, land use and others could be extremely useful in site selection and sustainable development of shrimp culture (Beltrame, 2003).

Although this was not the aim of this research, the results also gave subsidies to the identification of the sectors of the system with more adequate hydrographical characteristics for the disposal of residual waters of the shrimp ponds, which would be preferably the points in which the index showed waters with less quality.

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LITERATURE CITED


