Traditional Ecological Knowledge and the mapping of benthic marine habitats

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A B S T R A C T

Traditional Ecological Knowledge (TEK) is the empirically accumulated knowledge of local communities whose livelihoods depend directly on natural resources. TEK has a considerable potential as a reliable, rapid and low cost information source. However, its use for decision making in environmental management is frequently challenged due to the lack of scientific validation and the multiple and poorly understood biases deriving from measurement and analytical errors, as well as from political, cultural and religious sources. During the planning stage of a Marine Protected Area (MPA) in Southeastern Brazil we assessed fisherfolk TEK regarding seabed features, comparing it with results from a conventional oceanographic assessment. TEK was acquired and synthesized during a survey involving 19 fishing villages and a consensus analysis that minimized variation among individual fisherfolk and communities. The oceanographic survey included high resolution benthic habitat mapping tools such as sidescan sonar and ground-truthing with SCUBA near the interfaces of benthic features identified by fisherfolk. Nearly 3000 km² of seafloor were mapped by local fisherfolk as “gravel”, “sand”, “mud” and “reef structures”, while side-scan sonar surveys covered approximately 360 km with an average 400 m swath. Analyses of overlap and proximity showed that TEK is relatively cost-effective and accurate for large-scale benthic surveys, especially as a starting point for planning oceanographic surveys. Moreover, including TEK in the planning stage of MPAs may increase communities’ participation and understanding of the costs and benefits of the new access and fishing effort regulations.

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1. Introduction

Traditional Ecological Knowledge (TEK) encompasses the knowledge, practices and beliefs developed across generations by traditional cultures (Berkes, 1993, 1999; Johannes, 1989), being associated with both individuals and groups. Applications of TEK range from urban planning (Rantanen and Kahila, 2009) to environmental management (Friedlander et al., 2003; McClanahan et al., 2005). The foremost role of TEK in environmental planning and management is being increasingly recognized by governments, development agencies and NGOs (Calamia, 1999), including several marine and coastal issues such as Marine Protected Area (MPA) planning and fisheries management (e.g. Berkes et al., 2001; Wilson et al., 2006; Aswani and Lauer, 2006; Begossi, 2008).

Despite its great potential for improving environmental management, sources and magnitudes of errors and biases in TEK are variable and poorly understood (Ellen et al., 2000), deriving from measurement and analytical errors, as well as from political, cultural and religious sources. Thus, TEK usage in decision making is frequently challenged (Silver and Campbell, 2005), and it is recommended that TEK-derived data is coupled with some level of scientific validation before application (Huntington, 2000; Usher, 2000). However, incorporating TEK into decision making processes is not only potentially useful or cost-effective for managers. Under appropriate conditions it indeed may increase participation of the local stakeholders that are expected to be more directly affected by new regulations for accessing natural resources, maximizing credibility and minimizing criticisms from the several stakeholder groups (Silver and Campbell, 2005).

The use of TEK for mapping coastal and marine landscapes (“mental maps”: e.g. Gerhardtin et al., 2009) can be valuable for grouping and interpreting topography, bathymetry and other research data into Geographic Information Systems (GIS) (Close...
and Hall, 2006; De Freitas and Tagliani, 2009; Lauer and Aswani, 2009; Hall et al., 2009). For instance, in developing countries it is generally impossible (due to cost constrains) to obtain detailed and large scale benthic habitat maps for planning and managing MPAs, but mental maps of seabed features can be more easily obtained and rapidly validated (Wright and Heyman, 2008; Aswani and Lauer, 2006). Actually, seafloor habitat maps are still lacking for most tropical continental shelves, impeding a more systematic approach for defining access rules coupled with ecological representation and functionality (e.g. connectivity among benthic habitats).

Oceanographers employ a broad array of tools and techniques for seafloor habitat mapping, from multibeam echosounders and sidescan sonar on scales greater than 1 km² to in situ dive surveys on smaller-scale (<1 km²), sediment samples. Generally, a combination of acoustic and direct methods produces the more accurate picture of seabed types (Diaz et al., 2004), and the choice of a benthic habitat survey method largely depends on the objectives and cost constrains (e.g. availability of equipment and specialized personnel).

In data deficient contexts, TEK has the greater potential for contributing with relevant information for developing targeted research and filling large geographic knowledge gaps (Stoffle et al., 1994). Close and Hall (2006) developed a protocol for integrating information about fishing areas into GIS through semi-formal interviews. Techniques of Participative Rural Diagnostics were also adapted into GIS (Participatory Geographic Information Systems – PGIS) and are being steadily employed (e.g. Bemighisha et al., 2009). Thus, integration of TEK into marine and coastal management deserves increased attention from managers and scientists.

In the present study we compared TEK-derived seafloor habitat maps obtained during the planning stage of a Marine Protected Area (MPA) with habitat maps derived from a conventional oceanographic assessment. Analyses of overlap and proximity showed that TEK is relatively cost-effective and accurate for large scale benthic habitat mapping, especially as a starting point for planning detailed “scientific” sampling. We also emphasize that including TEK in the planning stage of MPAs may increase communities’ participation and understanding of the costs and benefits of the new access and fishing effort regulations (Obermeyer, 1998; Craig et al., 2002).

2. Material and methods

2.1. Study area

The study region is located in the southern coast of Espírito Santo State, Southeastern Brazil (18°22’S–21°19’S; Fig. 1), a tropical—subtropical transition zone with predominance of oligotrophic waters and seasonal (summer) upwelling in its southern...

Fig. 1. Study area showing local fishing communities and the places where participative workshops were carried out.
Anchieta and Piuma do not operate on the reef and rhodolith areas. For instance, the shrimp trawling although the participants were professional. The inner shelf is characterized by the temperature (Nimer, 1989). The inner shelf is always above 20.5 °C. Coastal geomorphology is heterogeneous and encompasses Quaternary coastal plains, Tertiary coastal plateaus and coastal hills/hilllocks. Hard bottom reefal structures are widespread in the continental shelf, including outcrops of ferruginous rocks ("lateralities"), igneous rocks, banks and slabs of calcareous algae, and biogenic paleoreefs ("hilllocks"). Terrigenous sand predominates from the coast to depths of up to 20 m, followed by calcareous and biogenic sediments such as bryozoans and calcareous algae reefs, with remarkable occurrence of policevalleys near the 20 m isobaths (Albino and Gomes, 2005) (Fig. 1).

In the study region, algal diversity is the highest in the southwestern Atlantic, including endemic calcareous algae species (Amado-Filho et al., 2007). Due to its unique attributes, the region is a National Priority Area for marine biodiversity conservation (MMA, 2007), but still lacks a comprehensive coastal zone management framework. Most fisheries resources are already overexploited (Martins et al., 2009), and calcareous algae and carbonatic sediments are being steadily exploited for the cosmetic, fertilizer and animal feed industries.

### 2.2. Fishing communities

Fishers from the study region were engaged into the survey through interviews (n = 37) and participation of 100 selected local experts in workshops convened in the five localities with larger numbers of fisherfolk (Table 1) and better logistical conditions. Fishers represent the main economic activity in three of these main localities, Ubú, Itaoca/Itaipava and Barra/Ponta do Itapemirim, while in the other two, Anchieta and Piuma, there are several other important economic sectors related to the steel industry and commerce. Representatives from 5 smaller (<50 fishers) neighboring villages (Mãe-bá, Ponta dos Castelhanos, Iriri, Ihauema, Sede de Marataizes) were also invited to participate in the workshops (Fig. 1). In the larger localities fishers are oriented to local and regional markets, while in the smaller villages fishers also play an important role in subsistence. Fishing systems involve mainly benthic and demersal resources, with operation of gears with great interaction with the bottom. All workshop participants were professional fishers who work daily at sea, although the fishing grounds may not overlap within the study area. For instance, the shrimp trawling fishers that predominate in Anchieta and Piuma do not operate on the reef and rhodolith areas where fishers from Barra and Pontal do Itapemirim capture reef fishes and lobsters. Fishers have no exclusive use rights over fishing grounds and there are virtually no restrictions to entry if the fisher requesting a licence is registered as a professional in a guild ("Colônia de Pescadores"). No quota system exists and the only regulations concern mesh sizes and annual seasons (fishing bans) for peneaod shrimps, lobsters (Panulirus spp.) and snook (Centropomus spp.).

Semi-formal interviews using the “snowball” technique (Davis and Wagner, 2003) aiming to characterize fishing systems and identify key informants. From the identification and targeted engagement of community leaders and the most experienced fisherfolk, participative workshops were convened with ~20 key informants from each locality.

#### 2.3. Traditional Ecological Knowledge assessment

Focus group techniques might be biased toward the opinion of a few outspoken or politically powerful participants (Morgan, 1993). We minimized this weakness by carrying out a stepwise process in order to strengthen the relationship between participants and convenors (Silver and Campbell, 2005; Usher, 2000), always targeting consensus in the interpretation of benthic habitat features and distribution, as follows:

Stage 1. Semi-formal interviews using the “snowball” technique (Davis and Wagner, 2003) aiming to characterize fishing systems and identify key informants. From the identification and targeted engagement of community leaders and the most experienced fisherfolk, participative workshops were convened with ~20 key informants from each locality. These informants were generally older fishers (40–70 years old) with broad credibility within their communities, many of them being considered as local leaders, both formally (e.g. associations’ presidents) and informally.

Stage 2. Five workshops (see Fig. 1 for locations) with an initial presentation of the aims and methodology, followed by the division of participants into working groups of 4–6 people themed around fishing system. Each group received transparencies and scrap paper with a base map (scaled in km and nm) showing territorial limits, coastline, rivers, bathymetry, and the magnetic and geographic north. A facilitator explained the references to fisherfolk, who drew their mental maps of the seabed on the scrap paper and on the transparencies. Groups’ findings were analyzed by all participants, through the projection of overlapped transparencies, i.e. highlighting coincidences and discrepancies. Rejection and confirmation of features was then based on consensus during this final stage of the workshops.

Stage 3. Systematization of TEK in a GIS using ArcInfo 9.3/ESRI® software with polygon shapefiles. Discrepancies were filtered by the subsequent application of two criteria: 1) features similarly classified in more than one workshop prevailed over a single or fewer divergent views; 2) features mapped by fisherfolk from the nearest locality prevailed over features mapped by fisherfolk from distant localities. The resulting map (MTEK) was coded in four

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**Table 1**

<table>
<thead>
<tr>
<th>Locality</th>
<th>Number of fishers per fishing system</th>
<th>Ornamental fish/invertebrates</th>
<th>Spearfishing/lobster</th>
<th>Gill nets</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom trawl</td>
<td>Line/longline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anchieta Sede</td>
<td>80</td>
<td>80</td>
<td>2</td>
<td></td>
<td>92</td>
</tr>
<tr>
<td>Itaoca/Itaipava</td>
<td>28</td>
<td>50</td>
<td></td>
<td>8</td>
<td>98</td>
</tr>
<tr>
<td>Barra/Ponta do Itapemirim</td>
<td>25</td>
<td>60</td>
<td>12</td>
<td>905</td>
<td>1108</td>
</tr>
<tr>
<td>Piuma</td>
<td>150</td>
<td>8</td>
<td></td>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td>Ubú/Parati</td>
<td>–</td>
<td>45</td>
<td></td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>283</strong></td>
<td><strong>243</strong></td>
<td>**14                **</td>
<td><strong>928</strong></td>
<td><strong>1716</strong></td>
</tr>
</tbody>
</table>

categories that were initially pointed out by the fisherfolks: 1) sandy bottom \(\text{sand}_{\text{TEK}}\); 2) muddy bottom \(\text{mud}_{\text{TEK}}\); 3) rocky and/or biogenic reefs \(\text{reef}_{\text{structures}}_{\text{TEK}}\); 4) biodetrital bottom or rhodolith beds \(\text{gravel}_{\text{TEK}}\). 2.4. Oceanographic surveys

Acoustic surveys were undertaken with an Edgetech 4100 sidescan system with a 272TD towfish operated with 100 kHz and 400 m swath. Bathymetric data was acquired with a Skipper 417 echosounder. Acoustic seabed mapping with sidescan sonar is a well-established geophysical technique in oceanography (Blondel and Murton, 1997; Morang et al., 1996), in which indirect images (sonograms) are generated by different return intensities of acoustic signals (backscatter). Backscatter patterns reflect sediment types and bottom morphology, also depending on depth and incident angle and attenuation of acoustic waves, among other factors. The spatial sampling design of the oceanographic survey was based on the TEK map and covered the interfaces between seabed features identified by fisherfolks, covering a linear extent of 360 km \((\sim 130 \text{ km}^2)\). Sidescan data was processed with SonarWiz Map4® software, and georeferenced mosaics were exported into the GIS with a 1.0 m/pixel resolution. Images were interpreted based upon reflection intensity, roughness, shapes, shadows and bed texture. Benthic habitat classes were validated during 29 SCUBA dives across all seabed types before being inserted in the GIS (100% correspondence). Thus, we did not conduct a more thorough ground-truthing of the sonar records (i.e. ground-truthing in hundreds of points) and considered the sonographic records as good descriptors of the seabed (Blondel and Murton, 1997). The resulting map (MSONAR) was coded in four benthic habitat categories: 1) sandy bottom \(\text{sand}_{\text{sonar}}\); 2) muddy bottom \(\text{mud}_{\text{sonar}}\); 3) rocky and/or biogenic reefs \(\text{reef}_{\text{structures}}_{\text{sonar}}\); 4) biodetrital bottom or rhodolith beds \(\text{gravel}_{\text{sonar}}\). 2.5. Comparative analyses

Comparisons between maps generated by the oceanographic survey (MSONAR) and the TEK assessment (MTEK) were done with the ArcToolbox/Intersect tool of ArcInfo 9.3/ESRI®. Overlaps were rasterized (100 m pixels) and coded based on the four seabed classes. Each pixel was further transformed in central points \((100 \text{ m}^2)\) using Erdas Imagine 8.7/Leica Geosystems®, preserving the four classes in the attribute table. This procedure resulted in two shapefiles with the overlaps, which were compared in terms of the percentage of coincidences for each seabed type.

In order to verify if fisherfolk knowledge depends on the distance offshore we employed the non-parametric Wilcoxon–Mann–Whitney test \((p = 0.05)\). In order to assess if seabed classes identified by conventional oceanographic methods (MSONAR) are closer to equivalent classes identified by fisherfolks (MTEK) than to different seabed classes, analyses of proximity were carried out with the ArcToolbox/Proximity/\texttt{Near} function, calculating the distance between each centroid of MSONAR to the closest MTEK class. This procedure was carried out separately for each seabed class. Average proximity of equivalent seabed classes represents the margin of error (distance between the feature mapped by sidescan sonar and fisherfolks’ mental maps) and was assessed with pairwise comparisons between seabed types (Wilcoxon–Mann–Whitney test; \(p = 0.05)\).

Sidescan sonar images are able to identify features of a few meters, while fisherfolks’ mental maps represent seabed areas of a few square kilometers. During the workshops, fisherfolk were given a nautical chart (scale 1:130,000) with isobaths and depth references (Supplementary Material 1), and were advised to identify significant and extensive areas of muddy, sandy and carbonate beds, and also areas with high concentration of reefs. Although the scale of the maps drawn by fisherfolk are different from those of acoustic surveys, potential mismatches are minimized by the regional scale of the study.

Analyzing the mean proximity between sidescan-mapped features and TEK-traced polygons allowed us to verify how TEK polygons fit within sidescan mapped area. Thus, the comparisons between mapped areas were relative to each other, and the differences in the scale of the two information sources did not influence our final conclusions (Supplementary Material 2).

3. Results

The 3000 km² of seafloor mapped by fisherfolks (MTEK) included 8% of sand, 8% of silt/mud, 68% of calcareous/gravel, and 16% of rocky/biogenic reef bottom, while the oceanographic survey (MSONAR) included 15% of sand, 13% of silt/mud, 68% of calcareous/gravel and 4% of rocky/biogenic reef bottom (Figs. 2 and 3). Features identified by the acoustic survey were 100% corroborated by the SCUBA ground-truthing.

Fisherfolk’s mental maps of mud/silt and calcareous/gravel bottom showed 49 and 78% overlap with the oceanographic survey results. On the other hand, features identified by fisher folks as reefs and sand corresponded largely to calcareous/gravel bottom habitat (Fig. 4). Fisherfolk’s correct assignment of benthic habitat classes did not vary significantly with the distance from the coast (Mann–Whitney test \(p = 0.055)\).

Areas classified by fisherfolks as calcareous/gravel and silt/mud bottom were indeed closer to these habitat classes as identified by the oceanographic survey, while areas identified by fisherfolks as rocky/biogenic reef and sandy bottom were not significantly related to these bottom types (Wilcoxon–Mann–Whitney \(p = 0.314 \text{ and } 0.293\), respectively; Fig. 5). Reef areas identified by fisherfolks are as close to reefs as they are to gravel bottom, while areas identified as sandy bottom are as close to sand as they are to gravel bottom (Fig. 6). Gravel bottom estimates were the most coincident, owing considerably to the predominance of this bottom class across the study region.

For the scales of coastal and marine planning, the average margin of error of up to 1600 m found in the TEK-derived maps is relatively small (Blondel and Murton, 1997). For instance, mental maps of silt/mud bottom and calcareous/gravel bottom had average displacements of 900 and 728 m relative to the oceanographic survey mapping, respectively. Mental maps of reef structures were displaced between 400 and 850 m, while mental maps of sandy bottom were displaced between 600 and 1600 m from actual sand or gravel banks (Fig. 6).

4. Discussion

Seabed habitat mapping provides the much needed spatial planning units for environmental conservation and management (Friedlander et al., 2003; Murray et al., 1999; Edgar et al., 2008), but cost and technology availability constrain the availability of habitat maps for most continental shelves of developing countries. Interpretation of seabed classes derived from geophysical methods not only requires the sampling of complete habitat mosaics, but also extensive ground-truthing with video transections and/or SCUBA (Cochranea and Lafferty, 2002; Kendall et al., 2005; Lathrop et al., 2006), meaning that seabed habitat maps can cost several hundreds of dollars per square kilometer.

Traditional Ecological Knowledge can fill several important knowledge gaps in terms of seabed habitat classification and distribution, but its biases are generally poorly understood (Silver
and Campbell, 2005). In this study we demonstrate that TEK is a valid alternative for mapping seabed features, being cost-effective and with good results, also providing a major opportunity for fisherfolks’ engagement in the planning processes that will ultimately affect their activity. Mental maps of fisherfolks can also be an optimal starting point for the design of conventional oceanographic surveys for mapping seabed habitats for management and systematic conservation planning purposes, decreasing their costs under no-data scenarios.

The TEK about seabed configuration in the study region was assessed through a stepwise participatory process aiming to engage fishing communities, through incorporation of their accumulated knowledge in the planning process for a new MPA. Such community involvement allows fishing communities to become conservation partners, rather than opponents, adding an indirect benefit for marine conservation (Friedlander et al., 2003; Drew, 2005). When fisherfolks and decision makers manage to work together, from planning to implementation of regulations, uncertainties in public policies, as well as management costs (e.g. enforcement), can be greatly reduced (McClanahan et al., 2005; Gerhardinger et al., 2009).

The margin of error of TEK-derived seabed habitat mapping reached only up to 1600 m in relation to standard oceanographic methods, with no significant correlation between errors and distance from the coast. Overlap and proximity analyses allowed for the identification of seabed types that are more difficult to be identified and positioned by mental maps. Features identified by fisherfolks as gravel were strongly corroborated by the oceanographic survey. However, ground-truthing with SCUBA dive showed that this type of seabed, as identified by fisherfolks and the conventional oceanographic methods, is considerably heterogeneous, including gross biodetritic calcareous sand, slabs of calcareous algae/bryozan/fouling invertebrates and rhodoliths associated to macroalgae.

Conversely, features classified as reef structures by fisherfolks presented a high percentage of gravel. Relevantly tough, the large extensions of smaller rocky or biogenic reefs are intermingled by gravel and calcareous algae nodules (rhodoliths) in the entire study area (Albino and Gomes, 2005), impeding the identification of individual reefal structures at the scale at which TEK operates. Therefore, despite lowered detailed description for these related seabed classes, the TEK-mapping identified the larger reefal realm correctly. Areas identified as mud by fisherfolks were also relatively well corroborated, and the correctness of TEK may have been influenced by the increased trawling and seabed flattening that is taking place in the region (Pinheiro and Martins, 2009). Similarly, areas identified by fisherfolks as sand are as close to sandy bottom as they are to gravel/calcareous beds. This can be explained by the limited differentiation, by the fisherfolks, between biodetritic gavel and gross sand. The oceanographic survey indeed showed that sand features were frequently intermingled with gravel beds, resulting in the lumping of this benthic classes by TEK, as both show similar

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**Fig. 2.** Seabed classes identified by the fisherfolks during the workshops (MTEK). A) Integration of types of seabed mapped in all workshops; B) Transparency resulting from the work of one group.
Fig. 3. Seabed classes identified during the oceanographic survey (MSONAR).

Fig. 4. Comparison of TEK-based mapping with the geophysical survey results. A) Percentages seabed class coverage in TEK-derived mapping (MTEK) and in the oceanographic survey (MSONAR). B) Composition of MSONAR classes for each type of MTEK seabed.
Thus, features described as sand by fisherfolks shall be interpreted as unconsolidated sandy sediment and/or biodetritic gravel. Potential mismatches of scales are overcome by first assessing TEK (coarser lines drawn by fisherfolks) and then refining the habitat map with higher resolution acoustic data. For instance, fisherfolks shall not be asked to draw specific habitat patches, but the general region of reefs and other habitats.
5. Conclusion

Our study has found, from a detailed case study in Southeastern Brazil, that TEK mapping can reliably fill important knowledge gaps in terms of seabed habitat classification and distribution, and also allows for stronger community engagement in the planning phase of MPAs and other coastal management interventions. A great amount of relevant information such as fishing areas, numbers of fisherfolk per fishing system, conflicts, and ethnoecological information can be acquired during TEK assessments, complementing the standard oceanographic methods used for habitat mapping. The effectiveness of participatory processes involving traditional fisherfolks depends on how participation is structured and incorporated into decision-making processes, especially because a mere consultative process do not guarantee community engagement, even if it successfully decodes TEK (Craig et al., 2002; Obermeyer, 1998). Community engagement shall be built up across various stages of involvement, in order to break down resistance and minimize conflicts arising from the lack of legitimacy of the information being incorporated in the discussion. When TEK is
incorporated as a reliable data source and further validated, the participatory approach has the greater potential to strengthen the decisions regarding access rules to fishing grounds (Usher, 2000). Indeed, local knowledge about the environment is much more than a static, predetermined, intergenerationally transmitted set of mental models, limiting the usefulness of strictly cogitative-based models of categorization of human action (Ellen et al., 2000; Lauer and Aswani, 2009). Finally, we emphasize that the dynamic situational dimensions, which are inseparable from the very activity of engaging with the environment (e.g. fishing), need to be acknowledged by researchers and managers incorporating TEK in their agendas and toolboxes.

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Appendix A. Supplementary material

Supplementary material related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2012.11.020.

References


