

Dynamical WEB GIS for Analysis and Control of Environmental Data - Proposing the SIM Tool

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Abstract. The use of Geographic Information Systems (GIS) has becoming very important in fields where detailed and precise study of earth surface features is required. Environmental protection is such an example that requires the use of GIS tools for analysis and decision by managers and enrolled community of protected areas. In this specific field, a challenge that remains is to build a GIS that can be dynamically fed with data, allowing researchers and other agents to recover actual and up to date information. To solve this problem, we propose a tool that includes a model for spatial data treatment on the Web, that we named System for Integrated Monitoring - *SIM*. The research issues involved the acquisition and processing of different types of video and images as Small Format Aerial Images, or simply *SFAI*, acquired by a radio controlled helicopter, used for construction of mosaics to be fed in the GIS, and underwater geo-referenced pictures. The *SIM* continues with the feeding and processing of environmental control data collected in-loco as and finishes with the presentation of all information on the Web. For this dynamic processing, we have developed tools that make *MapServer* more flexible and dynamic, allowing data uploading by the users. As example, on the top of *SIM*, we have developed a module that uses interpolation to aiming spatial data analysis. A complex application that has validated our research is to feed the system with data coming from coral reef regions located in northeast of Brazil.

Keywords: MapServer, Web GIS, coral reefs , AJAX, SIG Web, Recifes de corais.

1. Introduction

The use of geo-referenced information is a fundamental issue for enhancing the understanding, managing and ordering of territories, mainly in countries as huge as Brazil. The need of systems for adequate geo-information managing is crucial on the treatment of urban, non-urban and environmental problems. The availability of spatial data trough the Internet is also very important since managing of actual (trustable) and up to date information can be performed in a shared way by users on different locations. The great importance of Internet is related to its possibility of allowing access to information in a shared way including users remotely connected.

In this work, we use Web technologies developed based on the open-source paradigm in such a way that results can be achieved attending two main characteristics, low-costing and information sharing. The main idea is to allow different users, with distinct needs, to feed the system with data and to have access to all information by way of maps available in the Internet. These characteristics are essential in environmental managing actions, including monitoring.

In this context, we propose the System for Integrated Monitoring (*SIM*) destined to manipulation of geographic data, which has been tested, in a more specifically case study, with environmental coral reef data. Getting input data to the system involves dealing with satellite images, techniques as mosaic construction based on the acquisition of small format aerial images (*SFAI*), and underwater images acquisition, besides other ways of acquiring data (manual counting, water analysis etc), and the feeding and integrating of these data into the system, a dynamic Web GIS (Geographic Information Systems). On the top of this, tools for spatial analysis, as interpolation techniques, could be developed for presentation of data on the Web. The system also allows different users to have different views of the spatial information

using user profiles.

So, the main contribution of this work is the development of a flexible platform that can be used by universities or organizations that may be interested in controlling environmental data on the Web. Also, another contribution is the development of mechanisms that allow more interaction user \times system, in such a way that the user can work on-line, inserting, removing or changing geographic data in several formats, including *shapefile* insertion (standard file used in most GIS (DAVIS; LAENDER, 1999; ESRI, 2008)). An application of interpolation was also developed in order to generating graphics and other presentation objects that facilitate analysis of correlated data in environmental monitoring, which validates our proposal. Further, this work is a contribution not only to the GIS field but also to the communities involved in environmental areas management and protection, as public organisms (State Environmental Institute), tourists, fishermen, and other Internet users that may be interested in such information.

In order to validate the SIM methodology and technical proposals, we use a case study dedicated to environmental monitoring. We have chosen an area in the State of Rio Grande do Norte, northeast of Brazil, called *Parracho of Maracajaú* that is perfectly adequate to this need. The mentioned area has 9 kilometers by 3 kilometers. It is approximately 7 kilometers distant from the shore and partially emerged at low tides. Actually, *Parracho of Maracajaú* is a coral reef formed by rocks and biogenic living organisms.

The remainder of this paper is organized as follows. In section 2, some background is given about GIS and Internet. In section 3, a brief description about the methodology is explained. In section 4, the implementations for users upload and the interpolation method are described. Experiments and results that validate our proposal are presented and discussed in section 5. Finally, in section 6, we suggest conclusion of this paper and the future works.

2. Dealing with geographical data on the Web

The use of GIS has significantly increased in the last two decades. However, we could verify that these are, still, very closed applications, mainly with restricted permission for data insertion. Normally, such permissions are allowed only to the creators and managers of the system, presumable experts in geo-informatics, in most of the cases done off-line. So it is inherent and easy perceivable the lack of dynamism in several Web systems (NMS, 2008; ICRAN, 2008; BHP, 2008).

In part, this is due to the fact that most systems use *MapServer*, that works with a single configuration file (*mapfile*) thus being incrustated to a single graphic representation of the map. Obviously the user is allowed to change the map representation, but such modification is made through standard control tools on the Web GIS, as changing the level of zoom, showing or hiding certain layers, between others.

As well described by Camara (CAMARA, 1996), a GIS generally uses the concept of layers to present maps. Each layer is composed by spatial objects and these are superposed forming the map image. The application environment known as *MapServer* also uses the concept of layers, which are described by a configuration file named *mapfile* (MAPSERVER, 2004). Besides layers description, the *mapfile* also has all information necessary for *MapServer* to reproduce the map image referent to this *mapfile*. Each map image reproduced has a corresponding *mapfile* and each *mapfile* describes only a single map. Thus, the correct generation of *mapfiles* is fundamental for the development of a GIS (MELLO; SILVA; SOUZA, 2007).

A good definition of *mapfile* can be found in the literature (HAGEN; STEINEBACHT; MÜNCHHOFEN, 2004). The GIS component is evaluated on the server by an information conversion into a *mapfile*. The *mapfile* is a configuration tool of the map server and influences the appearance of the generated map. That *mapfile* and the GIS data (out of the database)

generate the desired map. It is important to keep in mind that GIS data is not transferred between client and server. It is stored during the whole process in the database. Only the information about the location where the file is stored and the appearance of the GIS data is transferred.

Further, by analyzing the infinity of variations in personalization of geographic systems that can be represented on the Web, we can observe that the *MapServer*, working with a single *mapfile*, is limited. A solution would be creating and incrusting more than a *mapfile* into a single system. In fact, this is valid and is what we propose in this work. With the association of multiple files of the type *mapfile*, we can, for example, insert, alter, or remove data directly on the map disposed on the Web GIS. So, in order to attend the dynamical needs of the application case (environmental monitoring), a tool with some singular characteristics is developed here. It has to be easy of use, to allow input of data by the users themselves and to allow on-line processing and creation of layers to be presented on the Web.

2.1. Data interpolation for presentation

In order to come up with proposed modifications in the generally used, single *mapfile* approach, in this work we started by studying a well known problem, which is related to how simple data collection can be converted into information (knowledge). In many cases, data need to be converted into contour line maps, diagrams of perspective or images for graphically representing space variation of the data. In other cases, inferring values between given points need to be achieved. In both situations, an interpolation process is necessary (CAMARGO, 1997).

Spatial analysis as part of a GIS offers a variety of tools for estimating unseen points (BUCENE; ZIMBACK, 2003). The use of techniques for interpolation of the measured data allows representing natural phenomena through mathematical calculations that improve understanding of the variations of spatial data. In general, these techniques use models that aim at quantifying the spatial dependence among samples through the use of geo-statistics techniques that presuppose a homogeneous behavior of the structure of spatial correlation in the study area (CÂMARA; DAVIS; MONTEIRO, 2001).

The single question that we faced is: how to allow users to insert data into the system, process these data (for example in the above interpolation procedures) and present them in a raster image form, on-line? The answer is: a *mapfile*, basis for the visualization, would have to be generated on-line. So we decided to open the black-box, generating our own *mapfile*, as necessary, in order to get this facility to all users of our SIM.

3. The SIM Methodology

As depicted above, we propose a full methodology consisting of data acquisition, feeding the system, data processing and presentation of processed information on the Internet. Each one of these steps has an associated module in our system. Actually, this work is an integration of several researches that have been done at our Lab: a complete GIS including several visualization tools is developed for environmental monitoring, a spatial database is modeled for GIS applied to environmental monitoring, techniques are also developed for satellite image processing and for mosaic construction from small format aerial images, and other researches in which we have acquired in-loco data, in the case study region. This integration will be described here. So, a challenging problem solved in this work is to provide dynamic (on the Web) treatment and presentation for data coming from several sources, as hand annotated tables from researchers using scuba diving, satellite, aerial and underwater pictures, and videos.

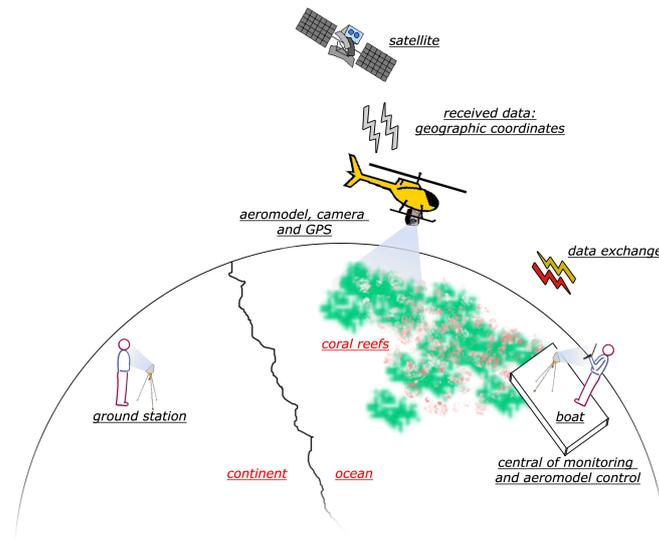


Figure 1: General vision of the acquiring data systems

3.1. Data Acquisition

Figure 1 shows a schema describing our acquisition system. We use satellite images (Landsat) at 30 m resolution for first classifying our interest areas, for visualization when working at low resolutions, and also for serving as basis for other layers coming from other kind of data.

For taking small format aerial images (SFAP) and videos, we have developed an acquisition system consisting of an air model helicopter, a JR GSR260 Voyager Gas, that has a video acquisition and transmission system mounted on a coupled platform under it. The used air-model with the coupled platform is presented in Figure 2. Actually, it has a pan-tilt head with a camera on it, pointing down, with 360 degrees of motion in pan and 90 degrees of motion in tilt (so a complete hemisphere is possibly reached only by moving the head). A computer for receiving data, on-line, is also part of this system that works as a ground station. The platform is capable of taking data on the study region and transmitting it to the ground station, in which it can be processed and presented on-line (in real time). The RC helicopter has a GPS coupled to it that can be used for geo-referencing data. In fact, we have generated geo-referenced mosaics of our study areas using digital images acquired from this system (CORDEIRO; CARVALHO; GONCALVES, 2007). Based on these mosaics, several visual analyses can be carried out and the results presented using the GIS visualization tools.

Other ways for acquiring digital images are also planned in areas where more detailing is necessary based on the visual analysis of the mosaics. For that, we use a digital camera, a Sony DSC-T10, protected by an underwater case. We have taken underwater videos and pictures. Also, hand annotated (geo-referenced) data serve as input to our system, collected by researchers working on the area such as biologists (MENDES, 2007) and geologists (SANTOS; VITAL; AMARO, 2007; AMARAL, 2002).

3.2. Data visualization tools (Web GIS)

With the improvement of Web platforms, there is an increasing number of amazing technologies that bring GIS visualization applications to new levels of power and usability. In this work, we use the open-source platforms *Apache Web Server* and *MapServer* as basis for visualizing geo-referenced data, on top of which we developed a GIS for showing spatial



Figure 2: The small helicopter with the pan-tilt image and video acquisition head

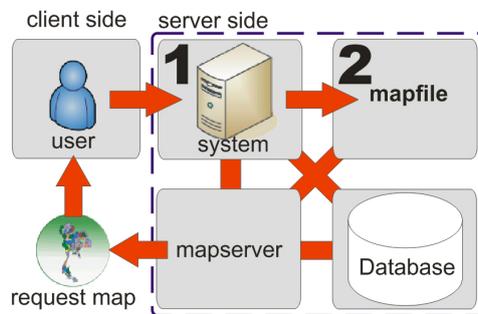


Figure 3: Data communication

information on the Web. We use the PHP Mapscript module as programming interface and the free library PostGIS for adding support to geographical objects to the PostgreSQL database manager, in such a way that it can be used as a spatial repository for geographical information. So, representation of the geometric data is compatible with the open GIS consortium (OGC) standards.

We use AJAX (CRANE; PASCARELLO, 2005) to implement the Web GIS application. This is a powerful and new programming model that has incorporated together and brings several technologies. The XML, JavaScript, HTTP and XHTML are examples of well known and widely-used technologies. Google Maps is an example of a high performance AJAX based application. By integrating these new powerful technologies (SAYAR; PIERCE; FOX, 2006) into GIS systems, we get higher performance results with additional functionalities.

4. Implemented tools (System Architecture)

Figure 3 shows the architecture of the proposed system. Communication among system and *mapfile* (item 2 of Figure 3) normally does not occur in other systems as they do not generate *mapfile*. The SIM uses this communication to guarantee consistency, as a *mapfile* may be automatically generated during system execution. Also, with this characteristic, a system devoted to the coral reef case study could be created with possibility of having different views, by grouping users according to user profiles. Yet, data insertion by the users, themselves, can be done.

4.1. User view based on profile

The case study region involves different users (tourists, managers, researchers, fisherman etc), each one with a different need when visualizing data. So a different view for each class of user (based on a user profile) is initially adopted, which can be changed by the user once he (or she) is working in the system. Besides, for better directing and optimizing the system, the concept of profile access is adopted in this work. Basically, the following types of users have access to our system:

- **Researcher**
 - **Biologist** with major interest, for example, in layers such as seaweed and other plants, fishes, live coral reefs, and other biotic species.
 - **Geologist** with interest in layers as coral reef, rocks, sand, and other types of bottom, water salinity, pollution, and in environmental aspects that may influence changes in the geological formation of the area.
 - **Oceanographers** with interest in layers as water visibility, quantity of fishes and other biotic organisms, and in variables such as level of degradation and tourism flow
- **Tourist** with interest in fishes and other alive organisms, coral reefs, water clarity, floating-boats position etc
- **Govern and other managers** with major interest in environmental variables as pollution, degradation level, amount of tourists per area, tax payments, accessibility and other control variables.
- **Local community** with interest in points where fishing is permitted, including lobster and shrimps, points where it is allowed to go with common boats etc.

In this way, the user initially inform to the system which type of user is intended, being directed to the most interesting layers. We not that this is just an initial indication, that can be changed by the user, mixing layers as desired.

It is important to remark that this treatment inside each profile does not involve use of multiple *mapfiles*, since distinct representations are based only on the concept of exhibition/occlusion of layers.

4.2. Multiple mapfiles, a tool for user inputting data

As described in subsection 2.1, we verified that a mechanism for allowing inserting/updating/removing geographic data by the users themselves is necessary in our application. This has produced significant advances in the system in relation to user interaction and to an increasing in the amount of currently known information about the area. So the concept of multiple *mapfile* is implemented. Basically, a login is associated to each *mapfile*, that can be managed by the data-base management system (DBMS). A specific table stores user data including ids for the associated *mapfiles*.

For creating each *mapfile*, file writing libraries of PHP are used. A module written in PHP verifies in the data base which layers are already shown to the user and then adds new layers to these ones, as necessary, according to the following insertion manners:

- Data insertion by *shapefiles* or raster image.
- Data insertion of points and related values in the map with creation of a new table.

- Data insertion of points and related values in the map in a previous existing table.
- Data insertion using a file of points with related values.

4.2.1. Insertion by shapefiles or raster image

This way makes possible to insert *shapefiles* or even raster images. The use of *shapefiles* is due to the fact that this is an extension standard broadly used in geographical systems in general. A primary advantage of *shapefiles* is that this simple file structure draws faster than a coverage does. This may be why the *shapefile* data structure was developed for the ArcView GIS, a software program that was originally designed for data viewing rather than analysis. The *shapefile* specification is readily available, and a number of other software packages support it. These reasons have contributed to the emergence of the *shapefile* as a leading GIS data transfer standard (THEOBALD, 2001).

In our system, we first define how the *shapefiles* are graphically represented, that is, attributes as layer name, group name, representation symbol (point, line, polygon, circle etc), *srid*, and filling and border color are set firstly. Then, the *shapefile* is uploaded. Each *shapefile* consists of at least three files: *shapefile.shp*, *shapefile.shx*, and *shapefile.dbf*. The latter is the *shapefiles* feature attribute table stored in dBASE format. A *shapefile* can contain only one table. The other two files (*shapefile.shp* and *shapefile.shx*) contain information about feature geometry (LIN; LUDÄSCHER, 2003). With the *shapefiles* in the server side, a script runs automatically in order to insert them in the geographical database.

For raster images representation, the procedure is quite similar, differing only in some attributes definitions and in the upload of only one file in the *geotiff* format.

4.2.2. Insertion with creation of a new table

Here, the user can insert points by directly clicking the mouse in the location in the map and entering the associated values. A table is created for the user data be stored. This is done dynamically as necessary by the user, which has to provide attributes as table name, group name, representation symbol (point, line, polygon, circle etc); *srid*; filling and border color. The definition of the table columns is also made by the user that determines its name, type (text, char, integer etc) and the size of the fields. Besides table creation, it is also realized the elaboration of the *mapfile* with representation characteristics (lines polygons, color etc) and the table name according with data given by the users.

After the definition of the table and the *mapfile*, the user performs mouse clicks on the map and enters for entering the points in the created table including its geographical localization and its n-values.

It is important to note that the *MapServer* uses a cache for storing data transmitted in the user session in such a way that the information flow between client × server is optimized. This mechanism avoids instantaneous visualization of new alterations in the map, once the system searches for previously transmitted data. In this way, it is necessary a mechanism (a script) for cleaning the session cache, allowing immediate visualization of new insertions.

4.2.3. Insertion in a previous existing table

This function allows the user to enter more information in an existing table in the data base. Procedures for insertion of points work in the same way as in the previous case (insertion in a new table). It is important to note that, as it does exist a table and a *mapfile* associated to it, any insertion is performed only on the table and not in the *mapfile* anymore.

4.2.4. Insertion from a file

This function allows the user to insert data with known localization and n -values in the data base, without the need of using any software for generation of *shapefiles*. A window is opened in which the user enters the file name for upload, inserting its data automatically in the corresponding table in the database. The file extension is *.txt* and each line of the file have the position of the point (X and Y coordinates), and n attributes, as necessary, one for each row of the table.

4.3. Implemented interpolation method

To the end of the implementation of the above mechanisms, we could observe that the system has attended the needs for integration of collected data, since it allows, for example, an unknown user that could be realizing a given research in the region to enter with other data in the system. This information can be visualized only by this user or by other ones, once the system has mechanisms for marking data as public or private. Based on these modifications, we could implement another mechanism that facilitates data analysis, using interpolation.

We adopt inverse distance weighting (IDW) as the basic interpolation method. We choose IDW because of its ease of use and low computation charge (COLLINS; BOLSTAD, 1998). And furthermore IDW is a popular method used in several problems such as predicting of rainfall and temperature and mapping of crop spraying (TOMCZAK, 2006). The main assumption of IDW is that values of locations closer to the un-sampled location are more similar to the value to be estimated than values of locations far away (GAO; REVESZ, 2006). IDW interpolations are of the form:

$$X_p = \frac{\sum_{i=1}^n \left(\frac{1}{d_i^2} X_i\right)}{\sum_{i=1}^n \left(\frac{1}{d_i^2}\right)} \quad (1)$$

where X_p is the predicted variable; X_i is the particular measurements at the i -th neighbor point; and the weight function d_i is derived from the inverse square distance from the target point to the i -th neighbor point expressed by Equation 2:

$$d_i = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

So, also as a way to validate the use of interpolation methods as a tool for coral reefs monitoring, the above interpolation module was implemented and incorporated to the system, which helps several types of users to monitoring the region of study.

5. Experiments and results

In order to validate our system, we present results from the system running, depicting its functioning. Figure 4(a) shows a view of the system for the biologist user and the Figure 4(b) for the tourist user.

We also made experiments using the implemented interpolation method. Basically, the interpolation module can be divided into four stages, as shown in Figure 5.

As it can be seen in stage 2 (Figure 5), three stored relational entities were used. They can be described as being data related to: the degree of water visibility (called water-visibility), provision of coral reef (called coral-disp) and quantity of fish (called qtd-fish). For simplicity reasons, the database entities will be called here simply as tables.

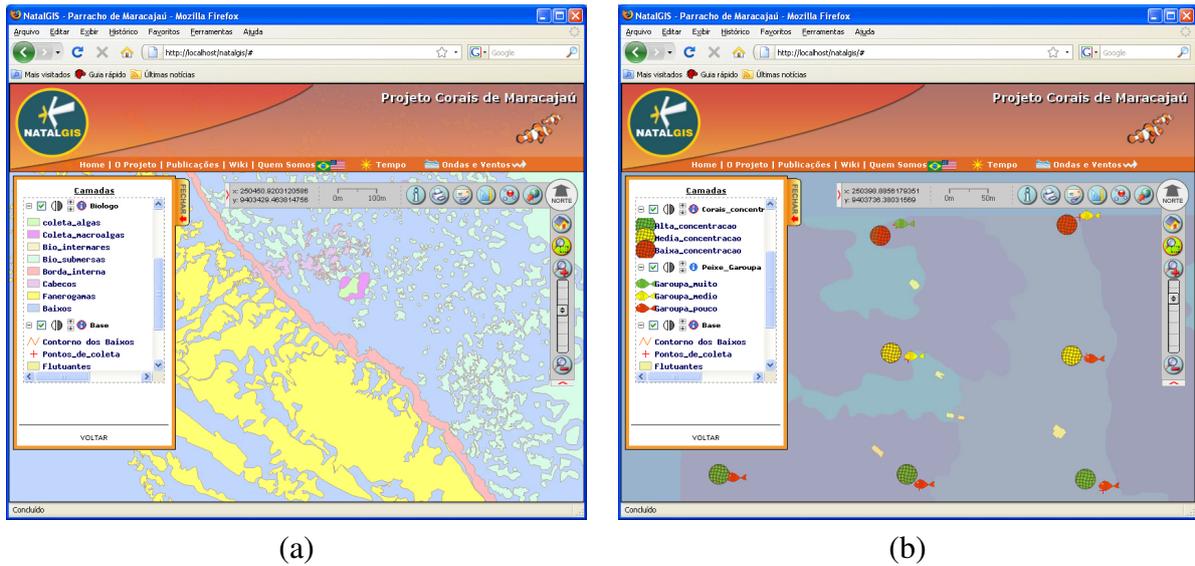


Figure 4: Biologist profile(a) and tourist profile(b)

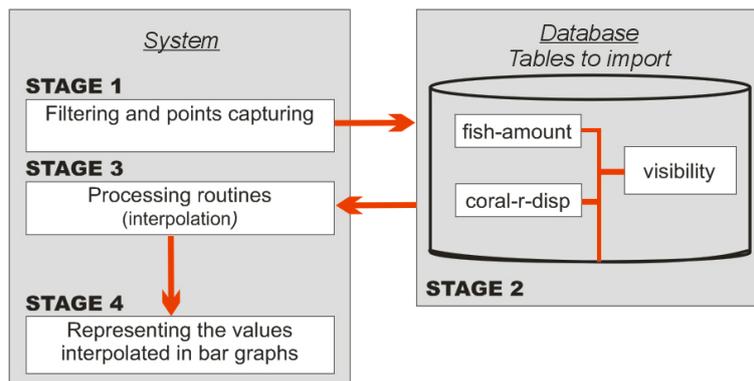


Figure 5: Stages of interpolation process

- The *water-visibility* table is used to store the degree of water visibility of certain points in the region of the coral reefs. This data depends heavily on two factors: depth and water current. In fact, there are different values for water clarity throughout the study area. For this reason, it is important that this type of information can be interpolated for tourism purposes, such as: the best diving places. The values for water clarity may vary from 0 to 10. Zero means low level of visibility, whereas ten means high level of visibility.
- The *coral-disp* table is used to store the provision of coral reef in certain points. This type of information becomes very important due to the high provision of coral reef in certain areas whereas in other areas is observed a low provision of them. So it is important that in addition to representing a layer with graphical information related to marine ecosystems, this information can also be interpolated. In this way, it would be possible to make a comparison with the real quantity (sampling values collected from the study area) versus the dispersion data (information collected through aerial photos). This approach helps the researchers in monitoring coral reef erosion. The values of prevision vary from 0 to 10, which mean low provision and high provision, respectively. This table also stores

information related to the level of coral reef erosion (assumes values from 0 to 10).

- Finally, the *qtd-fish* table is used to store the number of fish species in parts of the study area. It is well known that fishes do not have a fixed habitat. However, by analyzing the sampled data collected in the area, it was observed that in some specific locations, certain species of fish had a higher number than others. Thus, according to the sampling data regularly collected, it is possible to represent the more likely habitat of each specie. The representation of the habitat of the fish in the system helps the scientific community in the study of occupational changes of the species in the region. In addition to providing important data for the tourism in the region, since it can be known in advance the species present in the Maracajaú coral reef, as well as, their provision and location. This table can also assume values from 0 to 10, ranging from low to high fish provision.

The final phase of the interpolation module - stage 4 (Figure 5) - is responsible for representing the estimated values of each selected point chosen by the user. In order to improve the understanding of these values, they have been plotted as bar graphs. All three sets of graphics relate to the tables mentioned above. In the first set (fish set graphics), it is possible to have more sub graphics varying accordingly to the number of species in the region. Figure 6 shows the bar graphs of 3 different regions (a), (b) and (c).

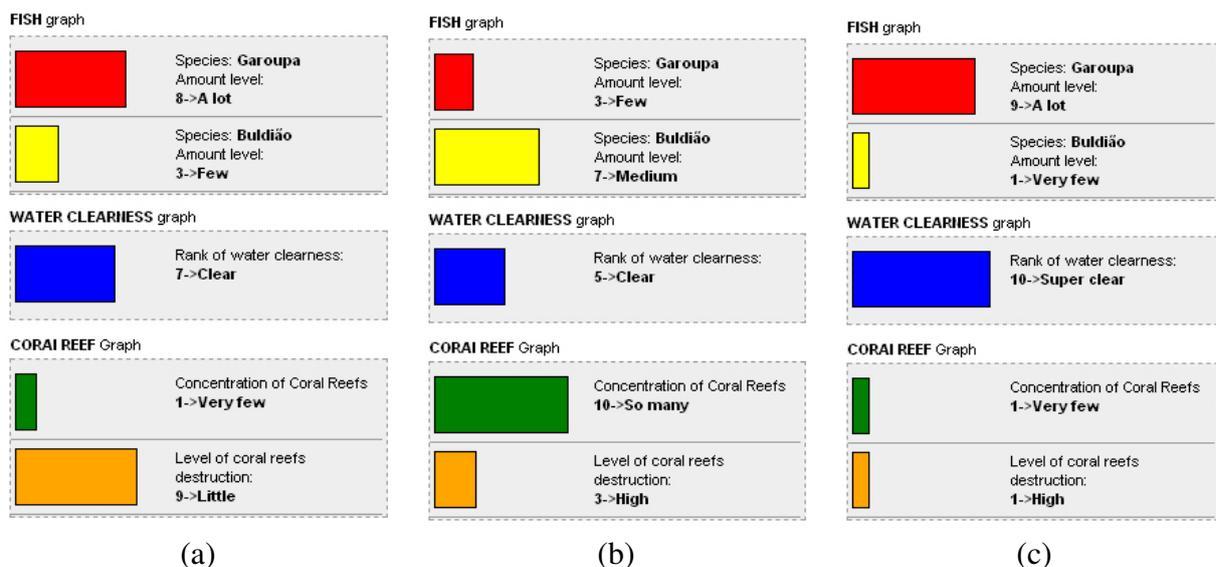


Figure 6: Interpolation graphics

By analyzing the interpolated data, it is possible to identify the relationships between different aspects, such as: good clarity of the water versus high provision of fish in the region; low provision of fish versus high erosion of the coral reef area. For example, from Figure 6 we can infer some questions to be answered by specialists:

- Why does the level of destruction of the coral reefs is substantially increased on points in which the water clarity is better?
- Why does, differently from Budiao fish specie, the incidence of Garoupa is smaller in regions in which there is a larger concentration of coral reefs?

6. Conclusion and Future works

This paper describes main results obtained by working on a Web based system that aims to help the scientific community. An integrated monitoring system is proposed that involves since data capturing until spatial data representation on the Web, including a procedure that helps data analyses based on interpolation. In this paper, to satisfy previously mentioned requirements, new integration methods are proposed and implemented. The method proposed in this paper for enhancing data integration has implemented the concept of multiple *mapfiles*. Each file, related to the user login, makes possible the insertion of dynamical data that can be public and private through the use of *shapefiles*, tables, or even by clicking the position directly in the map.

We can cite several benefits that are generated by this mechanism. A greater amount of data is stored and, consequently, being presented to the user. Independence of systems devoted to the local machine, once all the creation of the system can be done in the server side. A better control mechanism of facts related to coral degradation. The user does not have to know how to create *mapfiles*.

As future work, the interpolation procedure implemented will be used not only for graph generation, but also for creation of polygons and raster data from the point samples. These can be visually represented thus enhancing analysis mainly for managers. For example, dark or clear colors can be used for representing places with more or less amount of fishes, as it happens when using a numerical terrain model in some tools. Yet, an agent architecture is already conceived and will be implemented as a way to determine the user profiles, in a more dynamical way. From user information, the system could infer a transaction set according to the characteristics of each user.

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