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PRELIMINARY APPLICATION TO THE OCTOPUS STOCK IN SENEGAL

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A preliminary application of a Geographical Information System (GIS), based on a georeferenced database including data from commercial fishing and oceanographic surveys, and on geographical objects describing the physical and juridical environment, trawl operations and artisanal fishing sites, is presented. An ArcView environment is used to show spatial and temporal phenomena. Seasonal distribution charts for *Octopus vulgaris* and for the main associated finfish species on the Senegalese continental shelf reveal that octopuses are particularly abundant on the deep part of the continental shelf off Casamance and the Grande Côte during the cool season. Warm-season distribution seems to be more coastal. The results allow the interactions between artisanal and industrial fisheries and areas of potential conflicts to be identified. The intensity of these interactions for resource access and space allocation is highly correlated to season. The results also provide alternative explanations for fisheries management, e.g. on the degree of respect for or the relevance of the limits of regulated fishing areas and spatial fishing unit strategies according to the main seasons.

The development of Geographical Information Systems (GIS) has made significant advances since the early 1980s. This is particularly due to advances in computer science and an easier accessibility to remotely sensed data (Peuquet and Marble 1990, Laurini and Thompson 1992, Laurini and Milleret-Raffort 1993). From its first use in the fields of urbanization and network management (hydrography and roads), GIS has become an even more important management tool for natural resources. Information is playing an increasingly crucial role in the process of decision-making, especially in developing countries.

In Africa, various fields of application have been covered recently by GIS, particularly in agriculture. Examples include monitoring of desertification, management of natural resources, study of bush fires, management of water resources, health and environment (AfricaGIS'95 1995). However, for fisheries, the GIS approach is not yet widely used.

An F.A.O. project on the development of GIS in West African fisheries has enabled pilot applications to be developed in collaboration with four West African countries, including Senegal. This project has a dual purpose: first to reorganize those countries' fisheries databases to a common design; and second, to advance a new tool to assist in decision-making. Each of the four countries has developed its own pilot GIS with their own data and particular objectives, but with a common design for information and geographical coverage. In Senegal, interactions between artisanal and industrial fishing fleets constitute a major problem for the development of a fishing system, for levels of resource exploitation on the one hand and for the allocation of fishing space on the other. Therefore, in an attempt to address the problem, this pilot application establishes distribution charts of the resources (the octopuses and the main associated finfish species) from data collected during trawl surveys.

In this paper, the general organization of the database is presented. The mapped results, the spatial problems of management and the answers which the GIS can bring to the decision-making process are then outlined.

MATERIAL AND METHODS

The pilot fishery GIS in Senegal was based on two types of information. Data were either collected from trawl surveys carried out on board the M.R.V. *Louis Sauger*, or from commercial industrial or artisanal fishing. All data were georeferenced for spatial analysis.

Design of the database

The data were organized into indexed files, with unique keys linking them, according to a DBASE-type design (the database management system uses Fox Pro software). The data from fishery surveys

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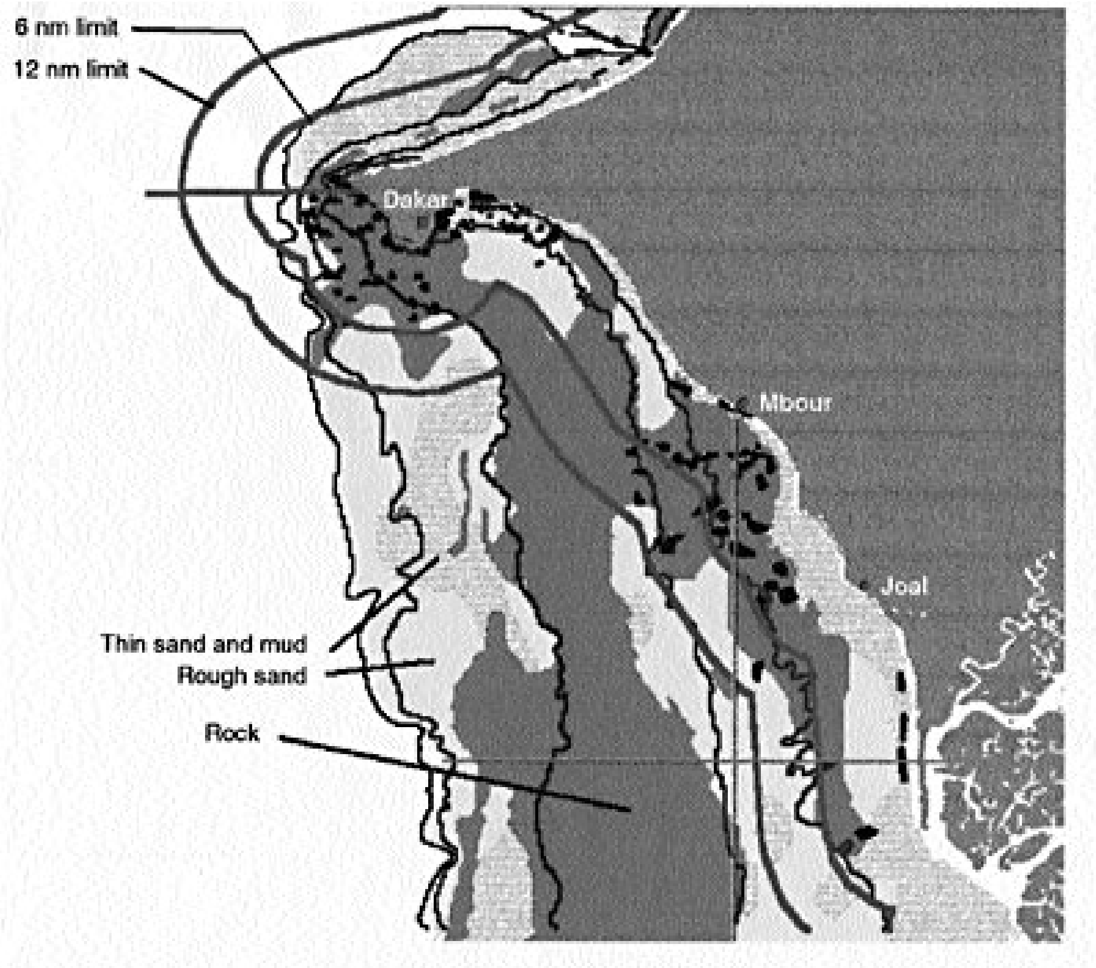

Fig. 1: Environment of the study area, showing different types of ground (thin sand and mud, rough sand, discontinued rocks) and the trawling limits (trawling is forbidden between the coast and the 6-mile limit, and only small trawlers are allowed between 6 and 12 miles from the coast)

were integrated into a "resources model". All trawls conducted were systematically recorded, together with a single identifier, into a central file. From that identifier, secondary files were accessed that contained information relevant to each trawl, e.g. position, duration, depth, number of species caught and mass of each species.

The commercial fishing data were used in the development of a "fleet activity model". These data were classified into three categories:

- *Register* – overall data from the landing site per fleet;
- *Trips* – fishing units (each ship), grouped at off-loading and related to one trip ; they enable large maritime areas to be differentiated;
- *Fishing operations* – each trawl is individually identified so that its exact position can be determined.

Within each category, the database is organized according to a design comparable to that used in the "resources model". This involves construction of a central file containing basic fisheries information (port, trip or fishing operation) identified by a unique code, and linked to secondary files by indexed keys.

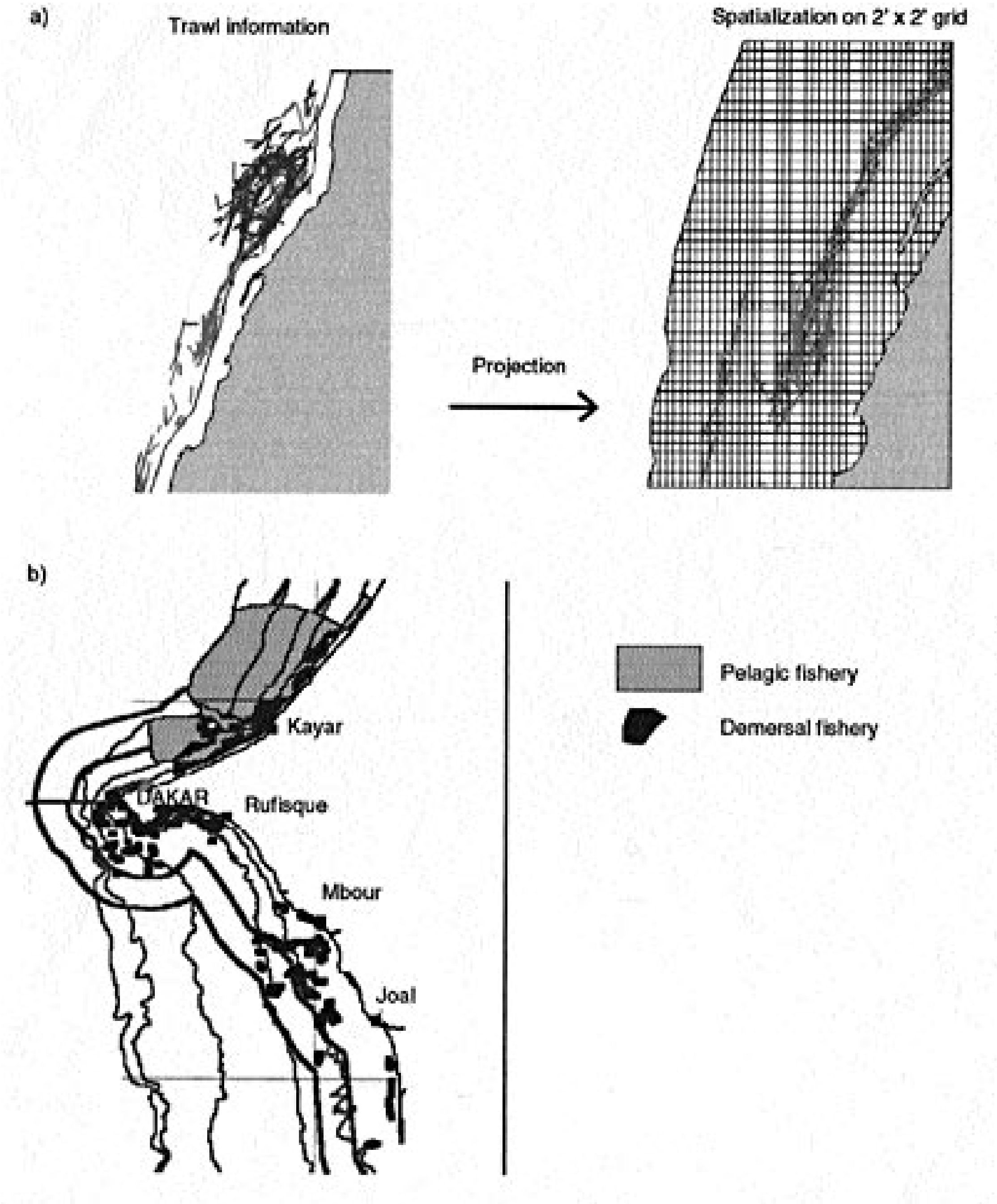

Fig. 2: Localities of fishing - (a) industrial trawling, based on information from ship-borne observers (catch and effort of each trawl are allocated to the square containing its gravity centre, (b) artisanal fishing

Choice of relevant application data

The spatial problems and the management implications of this GIS application have been identified and described by Barry-Gérard *et al.* (1995). The data necessary for the construction of maps, for the "resources model", were obtained from demersal trawl surveys conducted seasonally on board the *Louis Sauger* between 1986 and 1993. Based on a stratified random sampling procedure (Caverivière and Thiam 1992), those surveys covered the whole of the Senegalese continental shelf between 10 and 200 m deep.

For the "fleet activity model", two groups of fishing vessels targeting fish of the family Sparidae (the so-called Sparidae community, species living between 30 and 100 m deep on mixed rocky and sandy grounds) were identified in the catch and effort database of foreign trawlers operating in the Senegalese EEZ (between 16°04′ and 12°20.25′ N). The data were collected on board the trawlers by trained observers. The two groups were:

- foreign coastal demersal trawlers (with a licence to catch fish and cephalopods) authorized to operate beyond 6 nautical miles from the coast in the Grande Côte and Casamance areas or beyond 7 nautical miles from the coast in the Petite Côte area (coastal trawlers);
- foreign coastal demersal trawlers (with the same licence) authorized to operate beyond 12 nautical miles from the coast in all maritime zones (deep-sea trawlers).

The data were deemed appropriate to develop a GIS as a result of their good spatial and temporal resolution. They have been described by Ferraris *et al.* (1993). For the purpose of this paper, only data from the coastal trawl fishery have been analysed. For the "artisanal fleet activity model", the units used are handline and handline-cuttlefish trapfishing canoes.

The spatial and temporal organization of the resource and the fishing activities, both artisanal and industrial, constituted the basic coverage of this pilot application. They facilitated the identification of localities of major areas of conflict between the various fisheries involved in the exploitation of octopuses and associated species (groupers, sea-breams, red mullet, etc.).

Geographical coverage

Two types of geographical coverage were created by the software ARC INFO. The first type relates the physical and juridical (fishing areas allowed for each type of boat) environment of the Petite Côte. It includes coastal features, bathymetry, sedimentology and regulation limits (Fig. 1). For sedimentological aspects, available charts (Domain 1977) allowed the identification of three substrata types or "habitats" of the Sparidae community (rocky, sandy and muddy bottoms).

The second type relates to the geographic locality of each fishing operation (Fig. 2). Information on trawls was used to identify industrial trawling areas (Fig. 2a). Fishing sites were used for artisanal fisheries (Fig. 2b), identified beforehand in the field using a GPS system. Geographical coverage can also relate to an area given by the maximum range of activity of canoes from a given landing site.

Spatialization of information

Using the information contained in the database, it was possible to construct distribution maps relating to resource distribution, abundance and fishing effort. This information was analysed together with other geographical coverage, such as abundance in relation to sediment, depth, distribution of fishing gear according to distance from port, and the power of the engines used in artisanal fisheries.

According to the level of observation, the different maps provided varying levels of resolution, such as per large fishing area at trip level or per 2′ square grid at fishing operations level. In fact, for industrial fishing, the grids can be compared with the trawl data from each haul (catches, specific composition, etc.) in a corresponding grid square (Fig. 2a), either using the centre of the area covered by the haul or by calculating percentages of the length (in nautical miles) of the corresponding haul in each grid square crossed during the trawl respectively. These percentages are used in a second step to estimate the catch and the number of fish of each species for each grid square.

For artisanal fisheries, the fishing operations are allocated to the fishing site visited (Fig. 2b).

RESULTS

Maps of the mean seasonal biomass indices obtained from the trawl survey (1989–1993) show a seasonal difference in the distribution of octopus (Fig. 3), i.e. greatest abundance in the cool season in depths >50 m and inshore, and lesser abundance in the warm season (shallower than 30–40 m). In the Petite Côte area, both these distributions are found during the cool season.

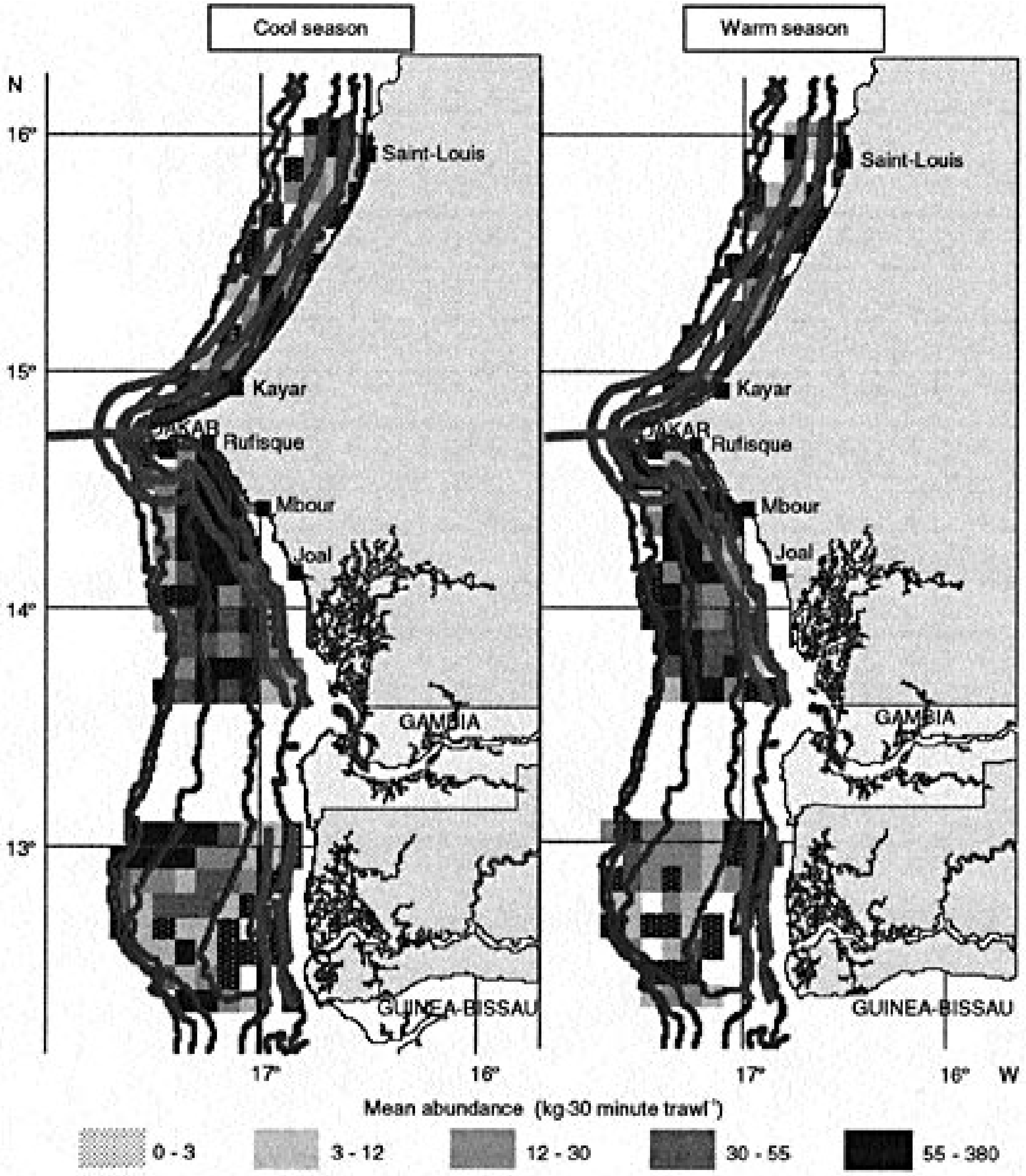

Fig. 3: Seasonal distribution of *Octopus vulgaris* deduced from trawl surveys, 1986–1993

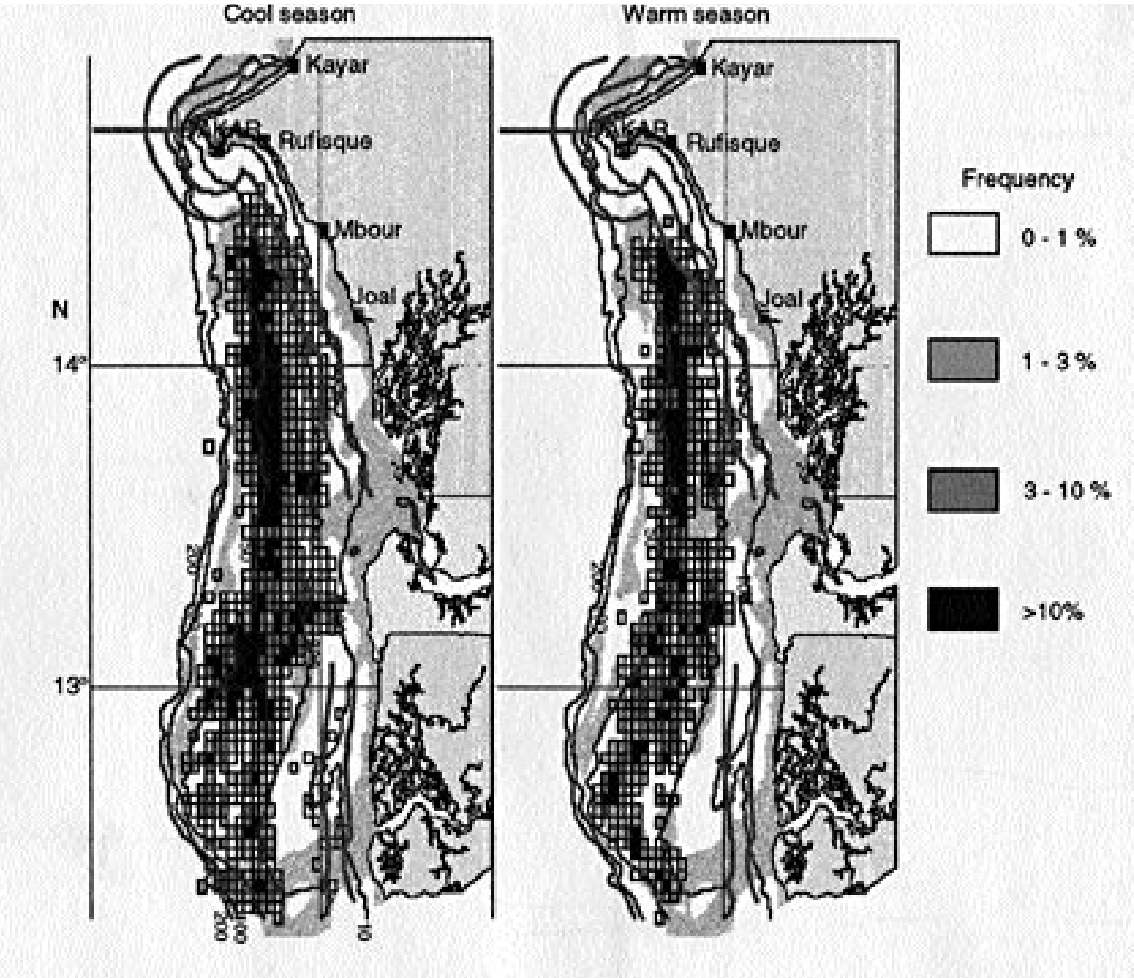

Fig. 4: Distribution of coastal demersal trawler fishing effort

The distributions seem to indicate movement of the resource towards the coast and from south to north. They also show that abundance of octopuses and the activity of the artisanal fishery in the warm season are closely linked. It should be noted, however, that no correlation was found between abundance of octopuses and the spatial distribution of coastal trawler fishing effort off Casamance, Gambia or Petite Côte (Fig. 4). The fleet is rather more opportunistic in its operations, targeting all the species of the Sparidae community (red mullet, sea breams, octopus, cuttlefish, groupers) according to their abundance.

The seasonal distribution of the Sparidae community over the central part of the continental shelf is illustrated in Figure 5. Senegalese trawlers operating at the edge of the continental shelf, two or three months before the beginning of the main fishing season for octopuses (July – October) attain relatively large yields of octopuses in the Casamance and Grande Côte areas, correlating with the cool season results (Fig. 3). It must also be noted that the periods of oceanographic survey (March/April and October/November) are before or adjacent to the main fishing season for octopuses. The standard finfish trawl used for the research surveys would not yield the same levels of octopus abundance as that obtained by fishing units.

Two seasonal maps have been compiled by overlaying the following coverages:

- substrata, i.e. rocky, sandy or muddy bottoms;

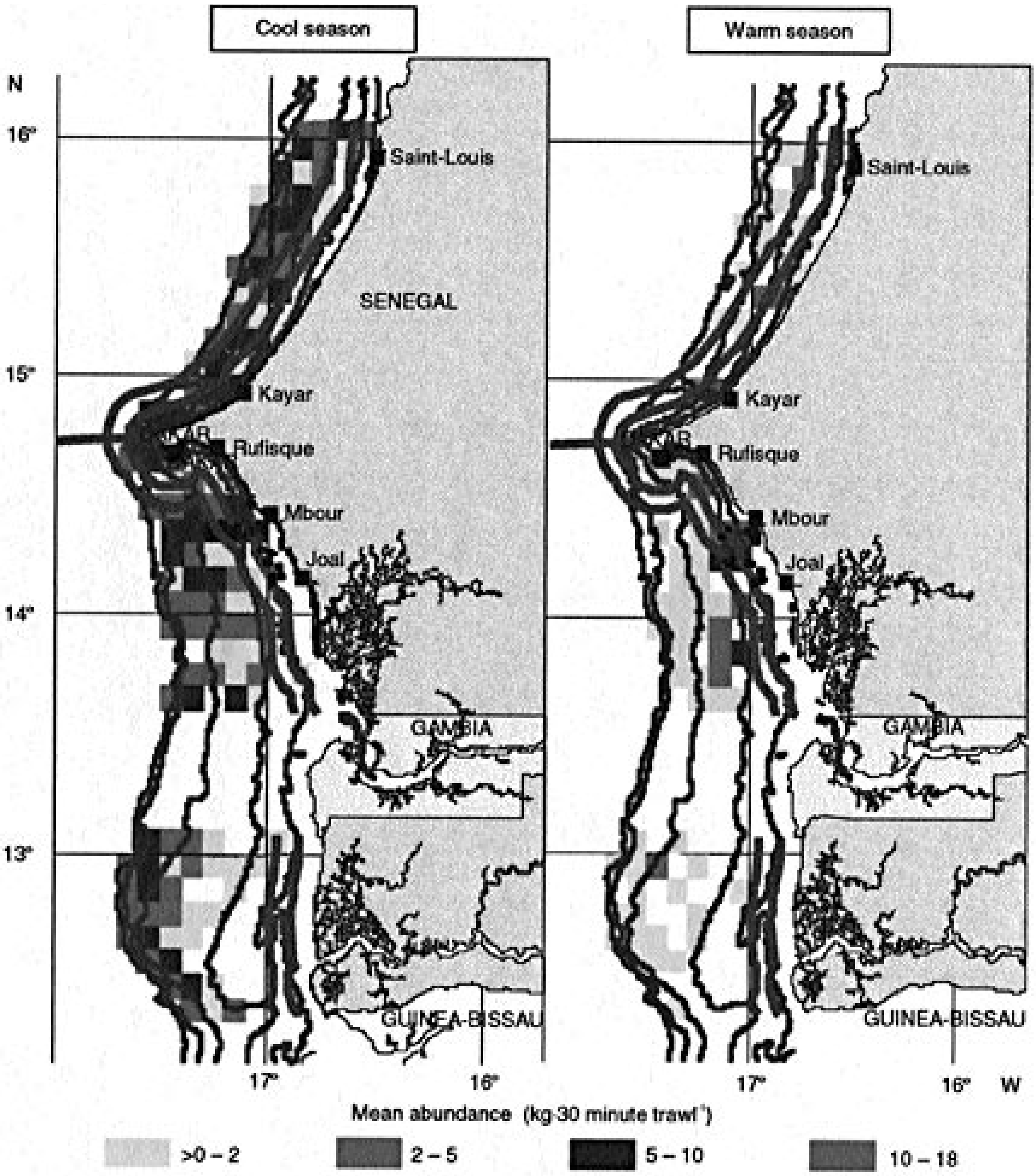

Fig. 5: Seasonal distribution of the Sparidae community deduced from trawl surveys, 1986–1993

- abundance of octopus, sea breams and groupers;
- activities of coastal demersal trawlers targeting these species;
- activities of handlines, and handlines and cuttlefish traps.

The maps illustrated in Figure 6 show that spatial interaction between artisanal and commercial trawl fisheries was stronger during the cool (Fig. 6a) than during the warm season (Fig. 6b), especially between the regulation limits of 7 and 12 miles offshore. Such

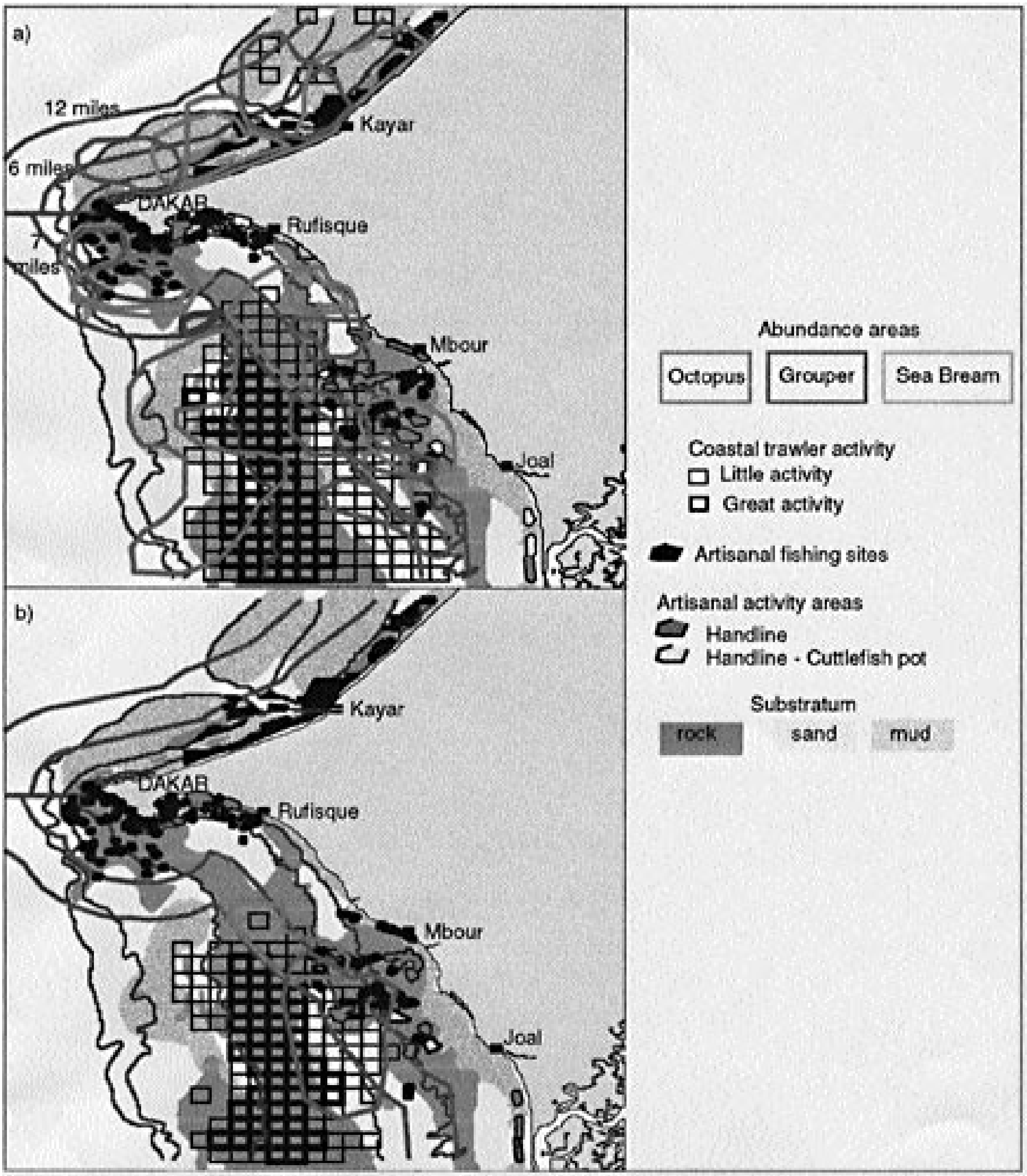

Fig. 6: Interactions between artisanal and industrial trawl fisheries in (a) the cool season, (b) the warm season. The areas of abundance are shown for octopus, groupers and sea breams

interactions were mainly in the Petite Côte area where the abundance of these resources (Sparidae community as well as octopuses) is great, because the effort there of the coastal trawlers is most intense and there is intense activity too of the artisanal fleet.

These different results highlight a potential area of conflict for resource access and fishing space allocation, between Mbour and Joal between 7 and 12 miles offshore. During the cool season, most areas of resource abundance (grouper, sea bream, octopus) were concentrated between the coastline and the 12-mile limit of operations. The species were also accessible to both artisanal and industrial fisheries. During the warm season, only the octopus stock was very abundant, but it was concentrated in an area accessible to both artisanal and industrial fishing fleets.

Analysis of coastal demersal trawler activities shows that, during the cool season, their fishing effort in the Petite Côte area (Fig. 6a) was mainly focused on depths of 40–60 m, correlating with the rocky grounds. Fishing effort between 6/7 and 12 miles offshore was low, during both warm and cool seasons. During the cool season, trawling operations were geographically more spread out within the same limits of 6/7 and 12 miles offshore, and octopuses, groupers and sea breams were targeted. During the warm season, the main target species were octopuses and groupers. The total trawl activity in the warm season was <24% of that during the cool season.

These maps of interaction indicate that artisanal fishing sites were located mainly on coastal rocky grounds, some extending beyond the limit of 7 nautical miles (cartography of the artisanal fishing sites is not complete beyond this limit), an area also much visited by coastal demersal trawlers. Artisanal handline activities, mainly targeting octopuses, were important between 7 and 12 miles offshore during the warm season. Figure 6 illustrates the relationship between the distribution of the resource (groupers, sea breams and octopuses) and the activity of canoes with handlines and with handlines and cuttlefish traps. The only correlation is between the strong index of abundance of octopuses and the intense artisanal fishing activity in the warm season (and to a lesser extent for sea breams in the cool season). Groupers do not, therefore, appear to be target species for the artisanal fishermen of Petite Côte.

It should be noted from these results that, regardless of season, coastal demersal trawlers respect the 7-mile regulation limit. However, management measures recommended for the future in terms of legal limit should take into account the seasonality of the resources and the distribution of the fleet activities.

DISCUSSION

The results obtained using the GIS are not fundamentally new in terms of scientific knowledge. Nevertheless, this new approach in fisheries analysis has a dual purpose. On the one hand, it permits fresh visualization of known phenomena which are otherwise difficult to conceptualize. This is the case for the inter-fleet interactions illustrated, such as the competition between artisanal canoes and industrial trawlers for fishing certain species, as well as for occupying preferred fishing space. On the other hand, the didactic role of the GIS, in particular for fisheries managers, is interesting. Distribution charts of fishing effort and catches of the different fleets can be used as a tool for debating issues concerning the politics of fisheries in a multispecies, multi-gear context.

Care should still be taken, however, with the initial results from this application. It must be remembered that this is a pilot project, into which few fishing units have been integrated, because the object of the project was to identify interactions between artisanal and industrial fleets. Senegalese trawlers that target cephalopods have not been taken into account, and if they were, the resulting fishing maps for octopus could change. Furthermore, not all of CRODT's database has been included, only the most recent years having been incorporated. Having introduced the older data into the GIS, it may be possible to envisage new GIS applications for the octopus data. For example, by studying mean catches per square and per month (or fortnight) over the whole fishing period for the past 15 or 20 years, it may be possible to investigate the population dynamics of the octopus stock, including exploitation and migratory patterns, along the Senegalese coast. Analysing data by year- and age-group, the evolution of the harvesting patterns can be studied and possible fisheries management scenarios proposed.

Finally, it should be noted that there are no satellite data currently integrated into the GIS that has been developed, although these data (such as sea surface temperature) are available at CRODT. Such data could permit the impact of the environment on fisheries resources in general and on octopuses in particular (e.g. the impact of temperature and upwelling intensity on recruitment) to be studied in detail.

CONCLUSION

Despite the inherent limits of a pilot methodological project, the GIS approach to a fishery system is extremely promising, for scientific reasons (permitting the spatial aspects of a species' population dynamics, that are difficult to visualize and measure using classical methods, to be investigated) as well as for development of the fishing sector. Therefore, these results could have a strong impact on decision-makers, who will need to understand the maps of the resource and fleet activities for them to have a direct application to fisheries management and organization.

Nevertheless, much development remains to be carried out before the Senegalese fishery GIS is fully operational. Transition from a pilot stage to an operational stage is imminent. No doubt, the GIS developed will in future have a role as a tool in helping decision-making (by producing management scenarios) and in providing recent exploitation reports (monitoring of fisheries or even of fishing units and their evolution).

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