Spatial Distribution of Fisheries Variables and Oceanographic Parameters in the Upwelling Ecosystem off Colombia, Caribbean Sea. A Geographic Information System Approach

FELIX CUELLO.[1], LUIS ORLANDO DUARTE[1], LUIS MANJARRÉS[1], and CAMILO GARCÍA[2]
[1]*Laboratorio de Investigaciones Pesqueras Tropicales*
Universidad del Magdalena
Cra 32 # 22-08
Santa Marta, Colombia
[2]*Departamento de Biología, Universidad Nacional de Colombia*
CECIMAR/INVEMAR
AA 1016, Santa Marta, Colombia

ABSTRACT

Geo-referenced data of fisheries and oceanographic variables collected between 1970 and 2001 in the Upwelling Ecosystem off Colombia, Caribbean Sea (UECC) were exhaustively gathered, validated and standardised. A total of 14 demersal trawl surveys, 17 bottom long-line surveys, 23 commercial bottom long-line and depth hand line fishing trips recorded onboard by observers, 4 annual catch and effort evaluations of the artisanal fleet and 8 oceanographic cruises were examined. Using a geographic information system, 814 thematic maps were constructed in order to introduce the spatial dimension in fisheries analyses for the 25 dominant fish species of the UECC. Due to its economical and ecological importance an integrated analysis for the lane snapper (*Lutjanus synagris*) was performed relating fishery and oceanographic variables. A number of patterns were identified: (a) lane snapper showed a broader spatial distribution in upwelling seasons that indicates a seasonal enlargement of its habitat; (b) higher values of abundance indexes tend to be associated with locations near upwelling centers; (c) individual sizes tend to decrease towards the south-western UECC, suggesting a nursery area in that sector; and (d) artisanal fleet uses a variety of fishing gears (gillnet, long-line, hand line and pot) for accessing a wide habitat spectra, so spatial distribution of effort is more widespread in artisanal than in industrial fleet which catches lane snapper as bycatch only in trawlable upper shelf areas.

KEY WORDS: Geographic Information System, *Lutjanus synagris*, upwelling

Distribución Espacial de Variables Pesqueras y Parámetros Oceanográficos en el Ecosistema de Afloramiento de Colombia, Mar Caribe. Aproximación Mediante un Sistema de Información Geográfica

Se recopiló, validó y estandarizó exhaustivamente información geo-referenciada de variables pesqueras y oceanográficas colectadas entre 1970 y 2001 en el Ecosistema de Afloramiento del Mar Caribe de Colombia (EACC). Se examinaron un total de 14 cruceros de arrastre demersal, 17 cruceros con palangres de fondo, 23 faenas comerciales con palangres de fondo y líneas de profundidad registradas por observadores a bordo, 4 evaluaciones anuales de captura y esfuerzo pesquero de la flota artesanal y 8 campañas oceanográficas. Empleando un sistema de información geográfica, se construyeron 814 mapas temáticos con el propósito de incluir la dimensión espacial en los análisis pesqueros de las 25 especies de peces que dominan el EACC. Se efectuó un análisis espacial integral de la asociación entre variables pesqueras, parámetros oceanográficas y el pargo rayado (*Lutjanus synagris*), ya que esta especie es de particular importancia económica y ecológica en el sistema. Se identificaron los siguientes patrones: (a) el pargo rayado tuvo una distribución espacial mayor en la época de afloramiento, indicando una ampliación estacional de su hábitat; (b) los valores más elevados de los índices de abundancia tienden a asociarse con áreas cercanas a los núcleos de afloramiento; (c) las tallas individuales tienden a disminuir hacía la parte suroccidental del EACC, lo cual sugiere la existencia de una zona de crianza en ese sector; y (d) la flota de pesca artesanal emplea una serie de artes (red de enmalle, palangre, línea de mano) que le permite acceder a un amplio espectro de hábitats, por tanto, la distribución espacial de su esfuerzo es más amplia en que la observada en la flota industrial que captura al pargo rayado en calidad de fauna acompañante, solo en las zonas arrastrables someras de la plataforma.

PALABRAS CLAVES: Afloramiento, *Lutjanus synagris*, Sistema de Información Geográfica

INTRODUCTION

Traditional methods of fisheries assessment do not consider the dimension of space. However, in the last decades spatial patterns of exploited populations has been emphasized as their population dynamics, abiotic forcing factors and fishery pressure are structured in space (Holms *et al.* 1994, Dunning *et al.* 1995). Spatial dependence is a common phenomenon in marine ecology. Individuals are not distributed randomly in time and space but tend to have aggregated distributions usually in response to particular features of sea environment. Distribution range varies strongly in different scales from a few meters to many kilometers (Steel 1988). The spatial dimension influences then the structure and function of animal populations and allows a more complete understanding of populations that the one obtained by just the temporal analysis (O´Neill 2001). As a consequence the design of population and ecosystem models is increasingly conducted in a spatially explicit context (Dunning *et al.* 1995, Duarte and García, 2001).

Indeed, the scientific community involved in the study of fishery resources has recognized that approaches seeking to contribute to the development and management of living marine resources should be integrated, i.e., including the temporal and spatial dimensions of their variability (Mangel *et al.* 1996). Populations and marine communities are structured spatially, hence the strategies of exploitation should consider such structure in order to optimize yield in a context of responsible use. As a consequence, creating maps of the fishery, the resources and the biotic and abiotic factors with which they interact, should be a priority task when planning fishing development and management (Caddy and Garcia 1986, Meaden and Do Chi 1996). As it has been seen in other fields of science in which problems in relation to space do occur, the application of a new and promising tool, Geographic Information Systems (GIS), can be translated in a remarkable improvement in spatial management, in particular when combined with other analytical and modelling tools (Meaden and Do Chi 1995). GIS can be defined as the integration of a computerized platform, a software and a database spatially referenced that allows the collection, storage and analysis of information geographically referenced (Rolf 2001).

The aim of this paper is to present a GIS application for exploring spatial distribution of fisheries variables and oceanographic parameters in the Upwelling Ecosystem off Colombia, Caribbean Sea (UECC) based on geo-referenced data collected during the last 30 years in the region. As a study case that allows showing synthesis possibilities of the GIS application, the spatial distribution of biological, fishery and oceanographic variables associated to the lane snapper (*Lutjanus synagris*) was examined in order to detect patterns that may improve management schemes including spatial and temporal dynamics.

METHODS

The study area embraces the continental shelf of the Colombian Caribbean Sea characterized by upwelling processes (Figure 1). The wider sector of the shelf is located between Cabo de la Vela and the Palomino River mouth, while in the sector of Parque Nacional Natural Tayrona the continental slope is very steep reaching depths of 500 m just 5 nm off the coast (CORPES 1992). Climate of the southern Caribbean is dominated by the interplay of the trade winds and the latitudinal displacement of the intertropical convergence zone. As a result, rainy (April to November) and dry seasons alternate in the Caribbean and the north part of South America (Longhurst and Pauly 1987). Two centers of high upwelling intensity have been detected in the UECC: in front of Cabo de la Vela and in front Santa Marta area (Figure 1) (Andrade-Amaya 2000).

A total of 14 demersal trawl surveys of demersal resources, 17 bottom long-line surveys, 23 commercial bottom long-line and depth hand line fishing trips recorded onboard by observers, 4 annual catch and effort evaluations of the artisanal fleet and 8 oceanographic cruises were examined (Table 1). Data were gathered in two information systems (SIEEP, Duarte *et al.* 2004 SICEP, Manjarres *et al.* 2004) as the informative basis for the implementation of the SIG.

According to their relative importance in the total abundance recorded in the surveys, on board samplings and artisanal landings, 24 species were selected for GIS analysis. These species may be considered as dominants in terms of biomass as they were selected for showing the highest biomass densities in the surveys cruises or for showing the highest catch rates in the on board sampling of the commercial fleet or for showing the highest landings registers of the artisanal fleet (Table 2).

The base map was digitalized from marine charts of the UECC and the application was developed with the GIS software Mapinfo Professional 7.0© (MAPINFO 2002). On the base map spatially referenced data (scientific surveys, CPUE based on board samplings and oceanography data) were represented by symbols, i.e. thematic maps were constructed. A polygon was generated including the shore line and the isobath of 200 m. Inside such polygon a grid was traced to place the approximate fishing spots by the artisanal fleets, of 1 nm x 1 nm in the southernmost part of the study area and of 5 nm x 5 nm in the northern zone (Figure 1). In all thematic maps data were represented in quartiles by symbols in colour to aid analysis of the spatially distributed variables. In each map a convention table is provided for the numeric equivalences. In the demersal trawl surveys, maps were constructed for both cruise and climatic season, integrating corresponding cruises. For some species data on sizes at capture were available, thus mean size was calculated for each haul, and maps for seasons and cruises were constructed (Table 2). On the basis of information collected from the bottom long line surveys, maps were created also discriminating between cruises and seasons. Maps were constructed for on board sampling of commercial captures with horizontal long-line and depth hand line aggregating data per month and season. For total landings (multi-specific landing) monthly, seasonal and annual mean of the index LPUE (landing per unit effort) were calculated. LPUE was standardized in terms of the area of the cells in which the UECC was divided. The unit of effort applied was the journey because in the artisanal fishery a journey corresponds in general to a working day at sea, thus LPUE comes in kg/journey/km^2, so that the effect of different areas in the periphery cells due to irregular coast line contours was controlled. Additionally maps on seasonal and annual mean LPUE were constructed per each type of fishing gear or method. In order to distinguish cells where fishing effort was exerted but there was no capture and cells where no fishing effort was exerted, the former appear sky-blue and the latter appear white in the maps. Furthermore, maps of oceanographic variables were made for both cruise and season.

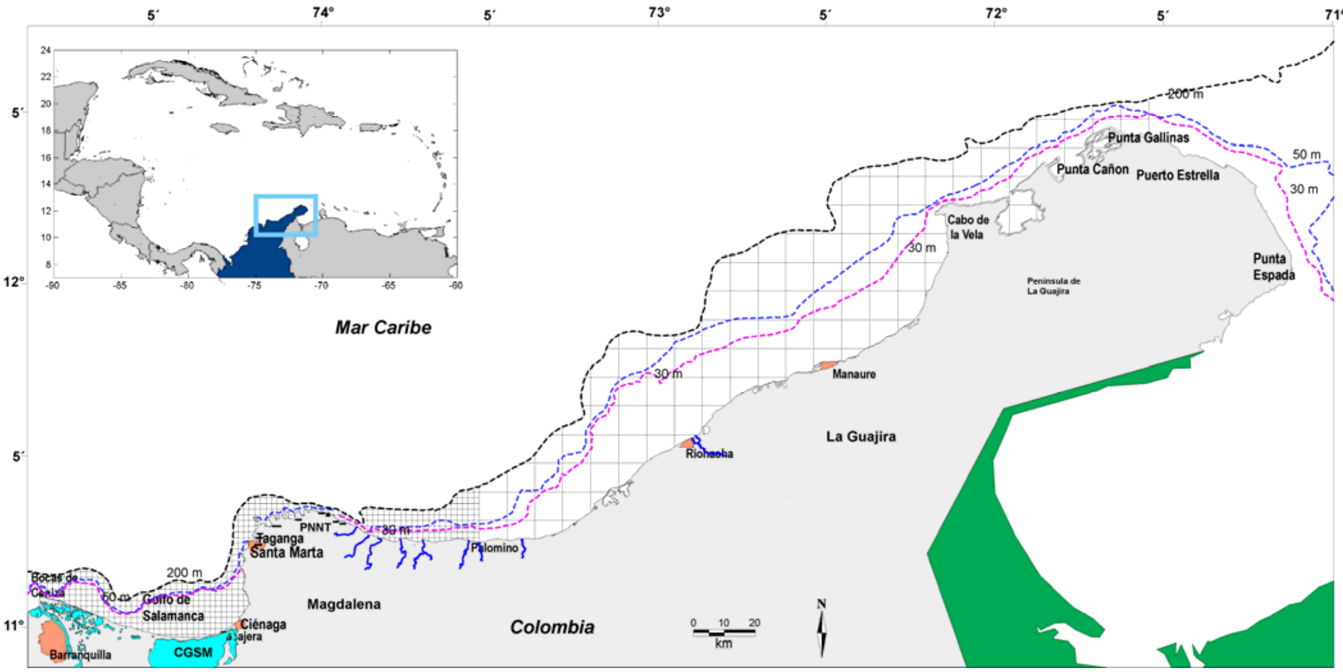

Figure 1. Upwelling Ecosystem of the Colombia, Caribbean Sea. The grid system used to geo-referencing artisanal landings in the GIS (5 nm x 5 nm for the northern area and 1 nm x 1nm for the southern area).

Table 1. Number and temporal coverage of samples gathered by thematic section for the SIG application

Thematic sections	Samples	Period
Onboard sampling	17	Aug/95 - Jun/01
Bottom long-line surveys	91	May/92 - Jun/96
Demersal trawl surveys	14	Dec/70 - Dec/01
Landing records	11602	Jan/97 - Dec/98 Jan/00 - Jun/01
Oceanographic surveys	8	Jun/95 - Dec/01

Table 2. Balance of number of thematic maps per species, thematic section and oceanographic variable. AL, Artisanal landings. OSH, Onboard sampling of depth hand line. OSL, Onboard sampling of bottom long-line. DT, Demersal trawl surveys. BL, Bottom long-line surveys.

Scientific Names	AL	OSH	OSL	DT	BL	Total
Auxis thazard	24	-	-	-	-	**24**
Balistes capriscus	-	-	-	14	-	**14**
Caranx crysos	24	-	-	9	-	**33**
Carcharinus porosus	-	-	-	5	-	**5**
Chlroroscombrus chrysurus	-	-	-	15	-	**15**
Dasyatis guttata	-	-	-	8	-	**8**
Epinephelus morio	-	-	19	5	6	**30**
Euthynnus alletteratus	27	-	-	-	-	**27**
Lutjanus analis	33	-	26	21	19	**99**
Lutjanus bucanella	-	9	13	6	6	**34**
Lutjanus synagris	33	-	28	20	19	**100**
Lutjanus vivanus	-	10	9	8	17	**44**
Micropogonias furnieri	-	-	-	15	-	**15**
Mycteroperca bonaci	-	5	10	8	2	**25**
Ocyurus chrysurus	27	-	-	16	-	**43**
Opisthonema oglinum	-	-	-	15	-	**15**
Pomacanthus paru	-	-	-	13	-	**13**
Rhomboplites aurorubens	-	8	10	17	9	**44**
Scomberomorus spp.	24	-	-	-	-	**24**
Scomberomorus caballa	27	-	-	-	-	**27**
Selar crumenophthalmus	24	-	-	13	-	**37**
Selene vomer	-	-	-	13	-	**13**
Seriola dumerili	-	8	8	7	13	**36**
Trichiurus lepturus	24	-	-	12	-	**36**
All species	40	-	-	15	-	**55**
Total	**307**	**40**	**123**	**255**	**91**	**816**

RESULTS

A total of 814 interactive maps were generated and published in a digital book (Table 2). Due to the demersal emphasis of the surveys more maps were produced for species inhabiting that habitat, which allowed broader possibilities of graphical comparisons of the spatial distribution of abundances, sizes, captures, landings and physical variables for these species.

Due to its ecological and economical importance (Duarte *et al.* 1997, Manjarres (ed.) 2002, Arevalo *et al.* 2004) an integrated analysis for the lane snapper (*Lutjanus synagris*) was performed relating fishery and oceanographic variables. In the demersal trawl surveys, highest biomass densities were found to the north of the Cabo de la Vela and in the Gulf of Salamanca during the rainy (calm) season (Figure 2a), whereas during the dry (windy) season high biomass densities expanded to embrace the coastal line but sectors near Cabo de la Vela and Golfo de Salamanca remained as showing the highest biomass densities (Figure 2b). In both climatic seasons maximum individual size of lane snapper were found in the northern sector off Cabo de la Vela (deeper than 50 m depth) and individual size tend to become smaller towards the southwest (Figures 2c and 2d). Maps of bottom long-line surveys and on board sampling of commercial fleet catches showed that fishing effort was more widespread in calm season than in windy season (not shown), probably as a consequence of rough oceanographic conditions during the windy season which difficult the activities at sea. During calm season, spatial distribution of LPUE standardized by area shows that fishing activity concentrates in the southermost and central area of the UECC, while sectors with marginal or nil activity are highlighted in the northern zone (Figure 3a). During windy season fishing activity tends to concentrate in places close to the coastline, in particular in the southern area (Figure 3b). In general mean LPUE is lower in the windy than in the calm season.

Bottom temperatures are indicative of cooler waters during the windy season (Figure 3c) than in the calm season (Figure 3d) concomitantly with the upwelling phenomenon that affects the area. Coldest waters in the windy season were found in a wider area than in the calm season when were restricted near the Cabo de la Vela.

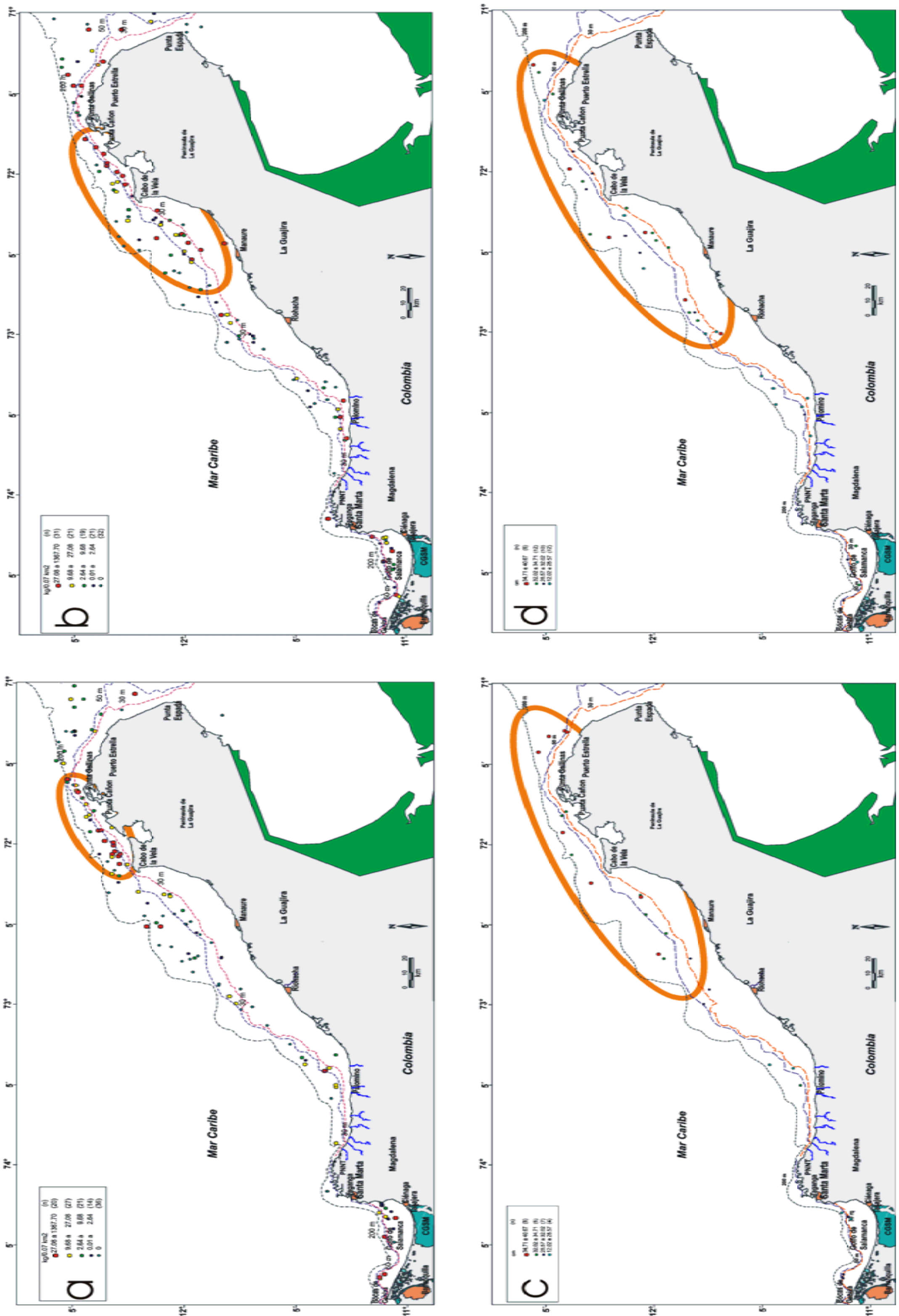

Figure 2. Thematic maps for the spatial analysis of lane snapper (*Lutjanus synagris*). a) Distribution of biomass density (kg/0.07 km^2) as shown in demersal trawl surveys conducted in the calm season (April-November) between 1970 and 2001. b) Distribution of biomass density (kg/0.07 km^2) as shown in demersal trawl surveys conducted in windy season (December-March) between 1970 and 2001. c) Distribution of mean size in the bottom trawl survey of October 1995 (calm season). d) Distribution of mean size in the bottom trawl survey of December 2001 (windy season).

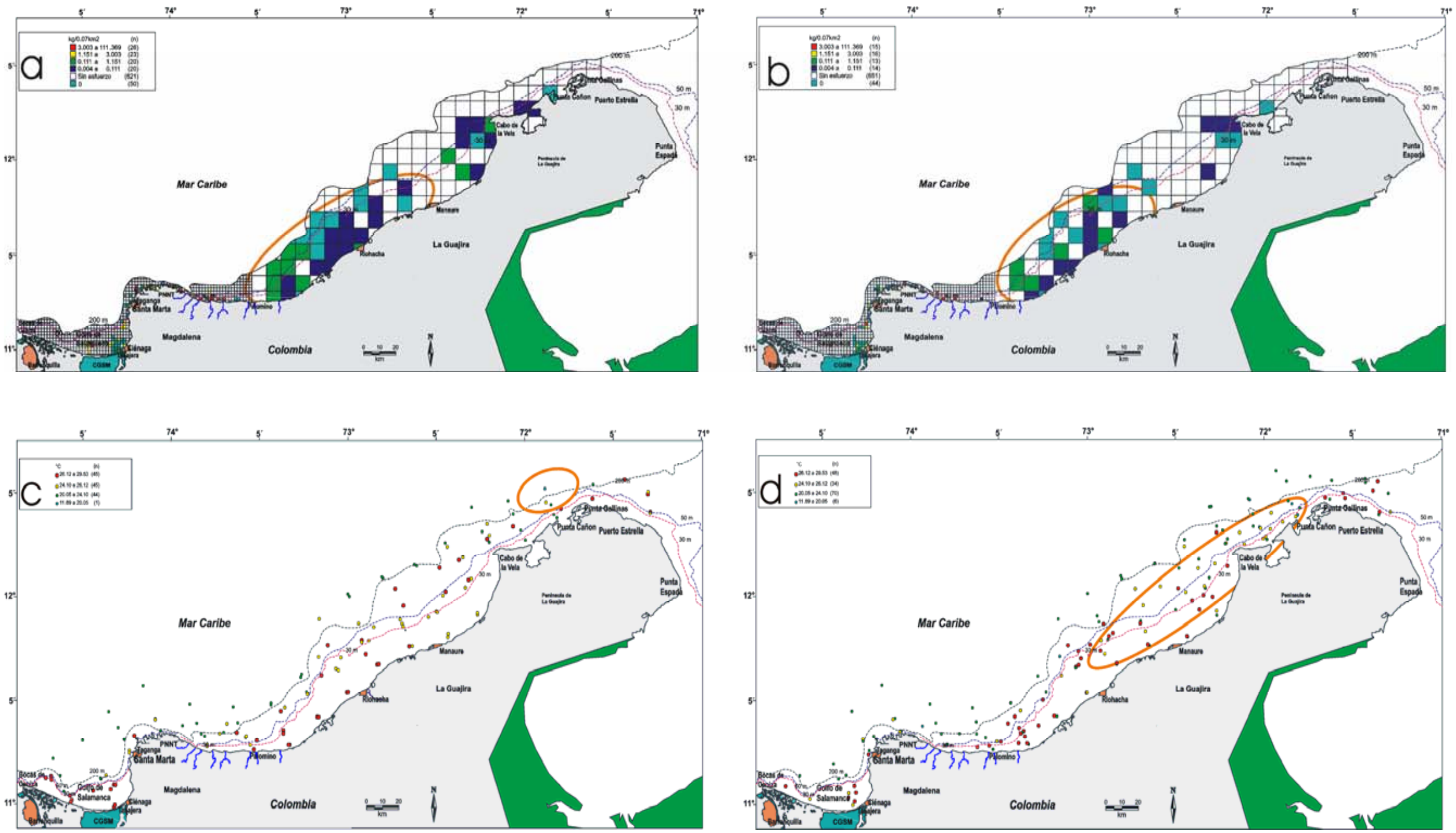

Figure 3. Thematic maps for the spatial analysis of lane snapper (*Lutjanus synagris*). a) Distribution of mean seasonal LPUE (kg/trip/km^2) during the calm season. Data cover the period 1997 to 1998 for the sector Bocas de Ceniza to Santa Marta, and 2000 to 2001 for the sector Taganga to Punta Gallinas. b) Distribution of mean seasonal LPUE (kg/trip/km^2) during the windy season. Data coverage as in a. c) Distribution of bottom temperature in the calm season from scientific cruises conducted between 1995 and 2001. d) Distribution of bottom temperature in the windy season from scientific cruises conducted between 1995 and 2001.

DISCUSSION

A number of patterns related with the spatial distribution of lane snapper were identified through the analysis of the thematic maps constructed using the SIG approach:

i) Lane snapper showed a broader spatial distribution in upwelling (windy) seasons indicating a seasonal enlargement of its habitat. This seasonal difference in distribution of lane snapper was previously reported and attributed to the influence of the upwelling and continental run off events that alternate in time (Manjarres *et al*. 2002). Seasonality of lane snapper is connected to short time events of notorious increment in abundance documented for the southern sector of the UECC during the windy season (Manjarrés *et al.* 1996 Barros and Manjarrés 2004) which could be triggered by vertical migrations associated with the presence of cold waters near the coast line and the physical stimuli induced by heavy sea events.

ii) Higher values of abundance indexes tend to be associated with locations near upwelling centers. Near Santa Marta City and off Cabo de la Vela have been detected upwelling centers that would explain a bigger biological and fishing production (Andrade-Amaya 2000, Manjarrés *et al.* 2004; Manjarrés *et al.* 2003).

iii) Individual sizes tend to decrease towards the south-western UECC, suggesting a nursery area in that sector. Previous studies on reproductive aspects of the lane snapper agree with this idea (Arévalo 1996).

iv) Artisanal fleet uses a variety of fishing gears (gillnet, long-line, hand line and pot) for accessing a wide habitat spectra, so spatial distribution of effort in the southern and central zones of the UECC is more widespread in artisanal than in industrial fleet operating in trawlable upper shelf areas, which catches lane snapper as bycatch.

Future analysis will allow a detailed assessment of the spatial distribution of lane snapper, its monthly and seasonal changes, as well as of the biological, oceanographic, and fishery determinants of its distribution. In view of the availability of a huge number of maps this digital book opens the possibility of developing similar analysis for species of fishery interest in the region which, doubtless, will be very useful in establishing scientific criteria for their management.

ACKNOWLEDGEMENTS

This study was financed by COLCIENCIAS (Grants 3135-00-11245 and 1117-09-13723), Universidad del Magdalena, INCODER and Universidad Nacional.

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