TRENDS IN THE FISHERY AND CATCH PATTERNS OF KITEFIN SHARK, *Dalatias licha* (BONATERRE, 1788), FROM OFF AZORES, THROUGH A *GIS* SPATIAL ANALYSIS

PEDRO BORDALO MACHADO, MÁRIO RUI PINHO & PEDRO NINY DUARTE

MACHADO, P.B., M.R. PINHO & P.N. DUARTE. 2004. Trends in the fishery and catch patterns of kitefin shark, *Dalatias licha* (Bonaterre, 1788), from off Azores, through a GIS spatial analysis. *Arquipélago*. Life and Marine Sciences 21A: 43-55.

During the last two decades the Azorean fishing community has profited from the kitefin shark fishery which in the year 2000 generated an estimated revenue of approximately €12,500. This resource has been targeted mainly by small fishing vessels operating in the Azores archipelago since the late 1970s. The vulnerability of this species to exploitation has raised the concern about the impact of the fishery on the resource. The monthly landings of three artisanal fishing vessels were monitored and possible changes to kitefin shark abundance and catch pattern, for the period between 1986 and 1998, were geographically analysed. A vector-based GIS (Geographic Information System) was constructed to evaluate the changes in the number of individuals captured and squalene oil barrels obtained through a spatio-temporal perspective. In order to investigate which were the most profitable fishing areas. An optimum fishing pathway was generated for one of the vessels in 1997 based on a raster GIS. The results indicated a decrease of kitefin shark catches in several areas around Azores archipelago and over the time period analysed. The analysis of the data in a GIS environment yield a dynamic and integrated view of the species catches off Azores in a temporal and spatial perspective.

Pedro Bordalo Machado (e-mail: bmachado@ipimar.pt), Departamento de Recursos Marinhos, Instituto de Investigação Agrária e das Pescas – IPIMAR, Avenida de Brasília, PT - 1449-006 Lisboa, Portugal; Mário Rui Pinho & Pedro Niny Duarte, Departamento de Oceanografia e Pescas, Universidade dos Açores, Cais de Santa Cruz, PT - 9901-862 Horta, Portugal.

INTRODUCTION

The kitefin shark, *Dalatias licha* (Bonaterre, 1788), is a deep-water squaloid species commonly caught in NE Atlantic slope waters. It is widely distributed from the north of the British Isles to the North-western coast of Africa, being also found in Azores and Madeira waters, and in the Mediterranean (COMPAGNO 1984; MORENO 1995). Its bathymetric distribution extends between 50 and 1800 m depth, however, it is more frequently captured from 200 to 500 m depth (MORENO 1995). While kitefin sharks frequently occur near the bottom, they can readily move off the substrate (COMPAGNO 1984).

Due in part to its large liver, which is rich in squalene oil, the kitefin shark was initially exploited around Azores archipelago by an artisanal hand-line fishery in the late 1970s (GORDON et al. 2001; SILVA 1983). In the beginning of 1980, a more industrial fishery started to catch the species using bottom nets, making it the main demersal fish species caught in weight in the archipelago during the 1980s (SILVA 1987). As a result of the increasing commercial interest of kitefin shark, the exploitation of the species stock in Azores by the two fisheries (hand-line and bottom nets) was investigated in 1987 indicating yields already near Maximum Sustainable Yield (SILVA 1987). These particular characteristics of the fishery have also received the attention of other authors on the application of elasmobranch fisheries assessment models (ANDERSON 1990). More recently, the vulnerability of kitefin shark to heavy exploitation has been responsible for its inclusion as a case study species in the European research project DELASS (CFP 99/055) focused on developing assessments on elasmobranch species.

The evaluation of fisheries condition should, whenever possible, is preceded by a comprehensive analysis of different types of information related to the exploitation of this fishery resource. Most often, fisheries data bear a spatial component (e.g. geodesic coordinates) which allows for their characterisation in a geographic context. This enables researchers to use visualisation tools to assist identify relationships and trends in the data (MEGREY et al. 2002). The popularity of Geographic Information Systems (GIS) and visualization systems among fisheries researchers is, in part, due to the refined capabilities they provide for displaying georeferenced data (KEMP & MEADEN 2002) and the possibility to provide the end-user with better information resulting from the synergy of different types of data (WRIGHT 1998). In light of this, several applications have already been used to get some insights, which lead to a better understanding of fisheries and related issues. These tools also enable scientists to easily create, observe, and interactively manipulate the data as well as the visual presentation of the data (FORTUNATI et al. 2002; KEMP & MEADEN 2002; MEGREY et al. 2002).

This paper investigates catch data from the Azorean kitefin shark fishery throughout a spatiotemporal perspective using GIS visualisation and analytical tools. For this purpose, information from three different fishing vessels, which are representative of the kitefin shark commercial fleet, was used. The changes in the number of kitefin shark individuals caught and oil barrels obtained was analysed seasonaly in a geographic context. Based on the capture positions of one vessel, an optimum pathway for catching kitefin shark was also generated using cost and distance algorithms common in raster GIS analytical operations.

MATERIAL AND METHODS

Samples were obtained from three different Azorean fishing vessels (A, B and C), all with recorded kitefin shark landings. These vessels have similar characteristics and are all around 25 m in total length. The data comprise the geographic positions of kitefin shark captures, the date of capture, the number of individuals caught by haul and also the number of 20 litre squalene oil barrels by haul (only for vessel C). This information portrays the perception of fishermen about the sites that yield catches of kitefin shark. The information from vessel A relates to the period 1986 - 1987, vessel B to the period 1988 - 1989 and vessel C to the period 1992 - 1998.

A vector-based GIS was developed aiming to visualise changes in kitefin shark catches along the time period considered.

After a preliminary analysis of the data, it was observed that capture positions were scattered around the Azores islands. As such, data were aggregated in order to be able to identify larger fishing areas facilitating both data visualisation and analysis (Fig. 1). Analytical visualization depends not only on the real data available but also on derived data sets generated by applying aggregation and algorithmic functions to the base data (KEMP & MEADEN 2002). The final GIS database included both capture data and a fishing area identifier (Fig. 2) obtained by visual identification of spatial clusters.

Based on the referred GIS, two different types of thematic layers were generated: 1) Average, maximum and minimum annual values of the number of kitefin sharks caught by haul and 2) Maximum annual values of oil barrels obtained and number of kitefin sharks caught (only for vessel C). Vector-based GIS operations were conducted with MapInfo™ V5.5 software.

Analysing the annual fishery data trends, it is possible to observe how the exploitation pattern of a vessel shifts with spatiotemporal changes in resource yields. Using the data from vessel C, covering the 4-year period from 1992 to 1996, an optimum pathway for catching kitefin sharks in the study area was generated and compared with the capture positions of the vessel in 1997. It was considered that the pathway would cover shallower fishing grounds at depths < 600 m (where the species is more likely to occur) and two geographic positions with the highest capture values. For this purpose a raster GIS was developed (grid cell size: 3 km) that accounted for bathymetry data, original catch point data (no. of specimens and oil barrels) and coastline location.

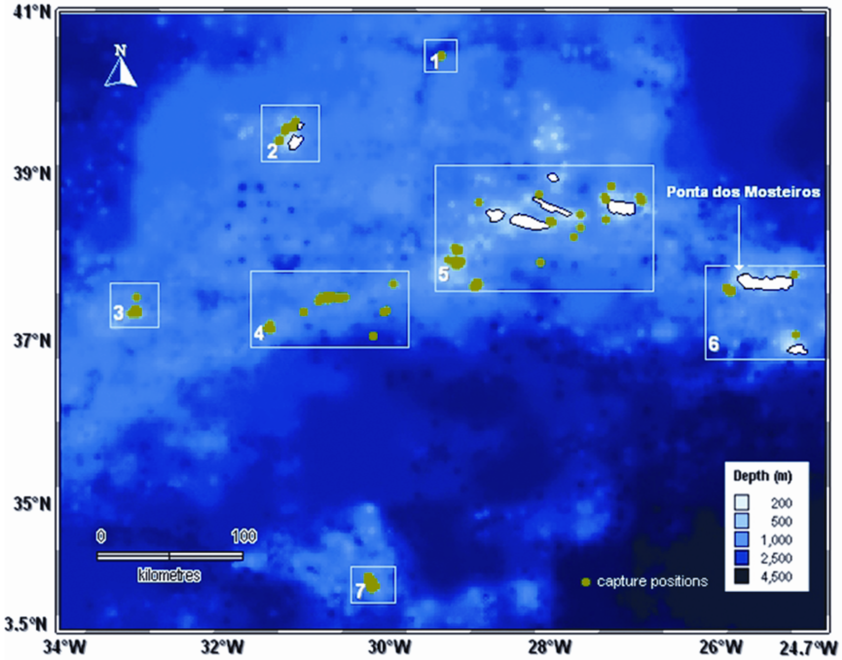


Fig. 1. Study area around Azores archipelago. Fishing areas, kitefin shark capture positions and "Ponta dos Mosteiros" region in São Miguel Island are indicated.

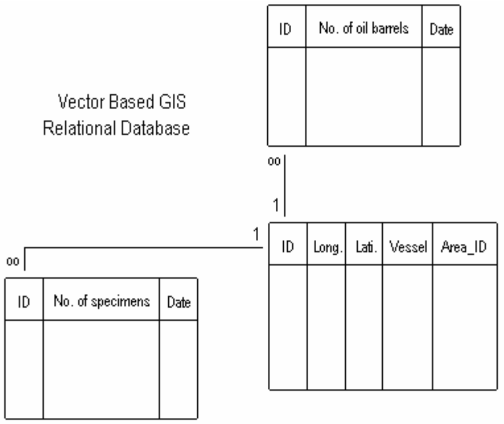


Fig. 2. Schematic representation of the vector GIS database.

The generation of the optimum pathway was the result of the following steps:

i) Weighting of the variables of interest. This is obtained by considering which variables offer more or less *friction* to the fishing activity. This means, for instance, that the points within coastlines will have the maximum value or score (9999) since vessels do not operate on land. Bathymetry, no. of specimens and oil barrels values remained unchanged.

ii) Generation of a friction image. Using a raster overlay operation, land values were added to bathymetric values forming Layer 1. Using this raster layer, another overlay operation was conducted, where:
Friction image = Layer 1 - (no. of specimens + no. of oil barrels + 100)

These variables - no. of specimens and no. of oil barrels - where chosen because they correspond to the product of each catch as well as representing the main purpose of the fishery. Despite having different orders of magnitude (specimens >> oil barrels) by adding them together more weight will be given to number of individuals captured; thus putting more importance to the catch in terms of specimens captured.

iii) Definition of the source object(s). For this procedure, a layer containing the two geographic position(s) where the (no. of specimens + no. of oil barrels) was higher was constructed.

iv) Generation of a cost-distance surface. This type of surface incorporates, not only distance measurements, but also the frictional effects encountered when traversing the study area. Given input images of a set of features from which cost distances should be calculated (in this case the source objects image) and the frictions that should influence movement, a cost raster algorithm produces a surface that expresses costs of movement in terms of distance equivalents (EASTMAN 1995). An isotropic cost function was applied to the source image of point c) using the friction surface obtained in point b).

v) Definition of a target image. Assuming that vessel C has its fishing trip departure point at the Northwest region of São Miguel, near Ponta dos Mosteiros (Fig. 1), a target image was generated containing only the identification of the geographic position from which fishing vessels depart (25º 47' 49'' W; 37º 47' 20'' N).

vi) Generation of a least cost pathway. A distance algorithm is used to find the shortest path between the destination (target specified points of capture) and the source (harbour) specified as the lowest point on a cost surface. The distance algorithm works by choosing the least cost alternative each time it moves from one pixel to the next.

All raster operations described above where performed in IDRISI 3.2 software. Further details on raster operation algorithms as well as distance and cost operators are described in EASTMAN (1989).

For the construction of a bathymetric reference layer, data from GEBCO (General Bathymetric Charts of the Oceans) Digital Atlas CD-ROM (1997 Edition) published by the British Oceanographic Data Centre (BODC) was used. In the vector-based GIS these data were simply used for visualisation purposes. The bathymetric layer was generated by a Inverse Distance Weighting (IDW) interpolation in MapInfo™ 5.5 software – the only interpolation method available in this software version –, where a distance weighted average of the data points was applied to calculate grid cell values (cell size: 3 km). The referred depth information from GEBCO was also important for the raster operations performed. This data was used to construct a Thiessen polygons layer in IDRISI 3.2 software. This is generally applied when the data available comprise a set of irregularly distributed points. The polygons are constructed by connecting a series of point locations with line segments, erecting perpendiculars to those line segments at their midpoints, and then extending those perpendiculars until they intersect. Finally, the original connecting line segments are dissolved leaving irregularly-shaped polygons containing the original points (DRYSDALE 1993).

RESULTS

The number of kitefin shark individuals caught by haul varied between years (Tab. 1). From 1986 to 1998 these values have decreased, as well as their variability. The highest average values of the number of kitefin shark specimens caught (ca. 1700 by haul) occurred in 1987 (Fig. 3).

Table 1

Annual descriptive statistics of the number of kitefin shark caught by haul in two time periods: 1986 - 1989 and 1992 - 1998.

	1986	1987	1988	1989	//	1992	1993	1994	1995	1996	1997	1998
Average	298.6	788.9	203.1	173.7		43.6	55.1	67.1	73.6	52.4	45.9	35.0
Median	273	831	162.5	138		35	35.5	57	58.5	34.5	30	25
Std. Deviation	182.31	359.13	153.57	149.47		45.23	60.82	56.35	46.62	53.99	51.49	38.35
Maximum	786	1687	672	810		191	384	332	182	279	352	120
Minimum	18	230	1	2		1	1	1	8	2	1	2
N	49	28	142	183		53	368	219	36	122	253	18

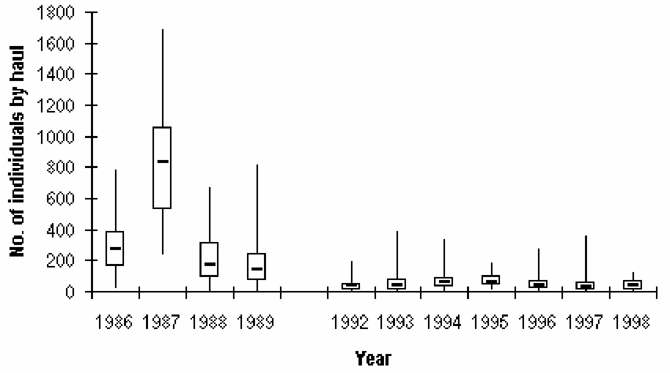


Fig. 3. Box-whisker plot of kitefin shark catches by haul in two time periods: 1986-1989 and 1992-1998.

The total number of sharks caught by month varied with fishing area (Fig. 4). Fishing areas 1, 2 and 6 show the fewest sharks caught (< 1,000) and fishing area 3 show the highest number (≈ 10,200). Areas 4 and 5 were the only locations with monthly records of catches throughout the year. The largest catches generally occur during the late spring and summer months. In addition, during these months captures occurred in the majority of the years analysed (Tab. 2).

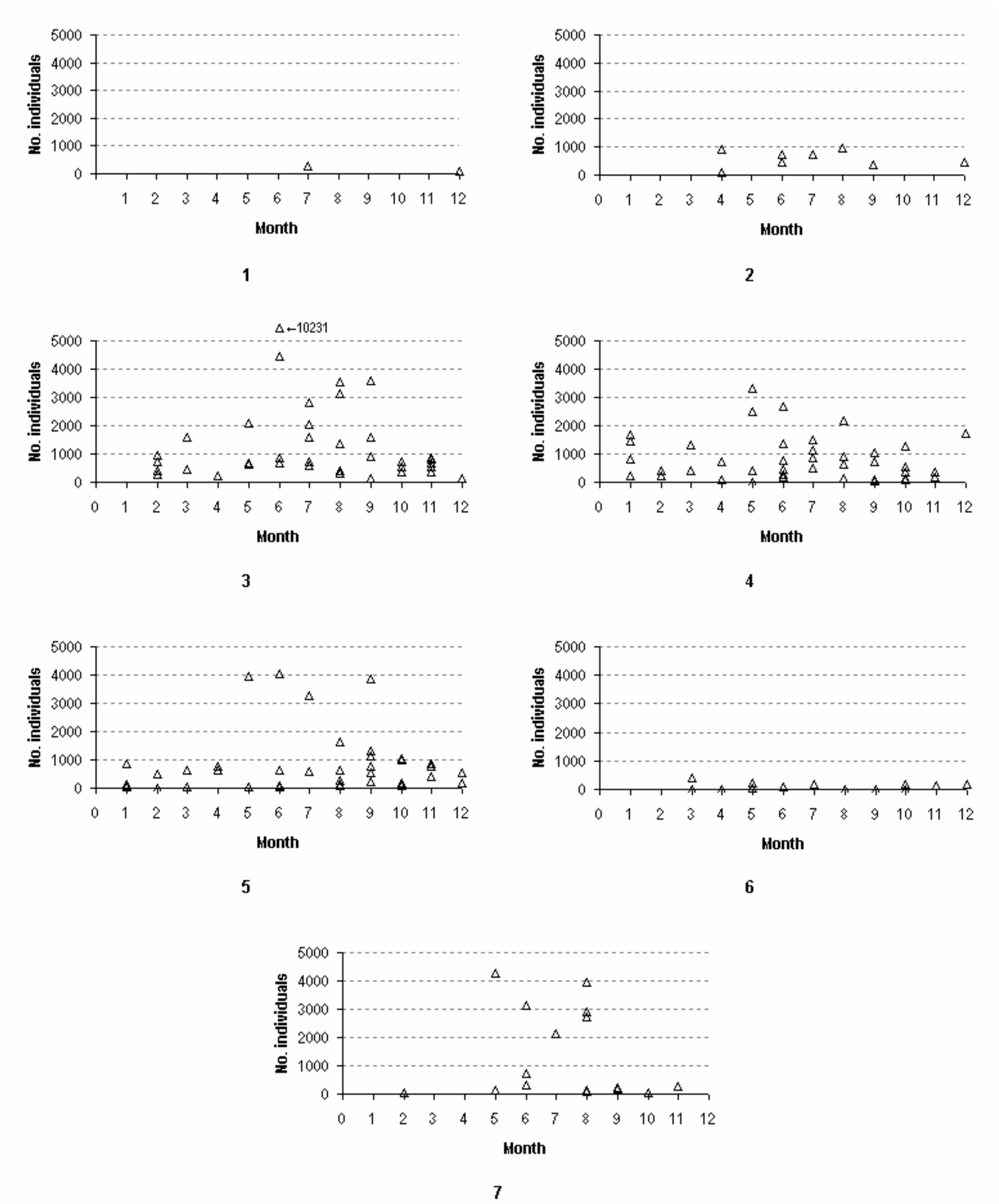
The annual average number of oil barrels by vessel C varied between 5 in 1992 and 9 in 1995 (Tab. 3).

Table 2

Months with catch occurrences of kitefin shark from 1986 to 1989 and from 1992 to 1998.

	1986	1987	1988	1989	//	1992	1993	1994	1995	1996	1997	1998
Jan							■	■	■		■	■
Feb							■	■	■		■	■
Mar							■	■	■		■	
Apr							■	■			■	
May		■		■			■	■			■	
Jun	■	■		■			■	■			■	■
Jul	■	■	■	■			■	■			■	
Aug	■		■	■			■	■		■	■	
Sep	■		■	■			■	■		■	■	
Oct	■		■			■	■	■		■	■	
Nov						■	■	■		■		
Dec			■			■	■	■		■		

■ catches of kitefin shark



1 2 3 4 5 6 7

Fig. 4. Variation of the total number of kitefin shark caught by month in each fishing area.

Table 3
Annual descriptive statistics of the number of squalene oil barrels obtained by haul from 1992 to 1998.

	1992	1993	1994	1995	1996	1997	1998
Average	4.9	5.0	7.5	8.4	6.7	5.6	5.2
Median	3	3	6	9	4	4	4
Std. Deviation	5.741	6.6	6.516	5.028	6.729	5.823	5.801
Maximum	28	48	36	23	35	41	21
Minimum	0.5	0.5	0.5	1	1	0.5	0.5
N	53	368	219	36	122	253	18

Cartographic visualisation of fishing captures

The analysis of type 1 thematic layers revealed a decrease on the average number of individuals caught from 1986 to 1998, in each of the fishing areas (Fig. 5a and 5b). Captures were more frequent in fishing areas 4 and 5, and occurred only in area 1 during 1993. The most profitable area, in terms of the number of individuals captured, was area 3 where, on average, catches were greater than 500. In areas 4 and 5 large catches were also recorded, however, as for other areas, maximum and minimum values vary widely.

Regarding the bathymetric distribution of the catches in the study area, the majority of the capture positions were located in areas with depths ranging from 200 m to 1000 m. In fact, catches seem to be closely related to the presence of seamounts in all of the fishing areas analysed.

Cartographic visualisation of the maximum annual yield of oil barrels by haul and by fishing area was conducted with the vector GIS. Figure 6 shows the variation of these values from vessel C during the period 1992 – 1998, as well as the maximum number of individuals caught. As expected, a large maximum value in the number of barrels produced was also associated with a large maximum number of individual kitefin sharks captured. There is no apparent trend in the variation of the maximum number of oil barrels with the exception of area 4 where the maximum of oil barrels increased from 1992 to 1997.

These thematic maps can be useful to get a first insight into where and when the kitefin shark fishery has been more profitable around the Azores archipelago. Moreover, the underlying data values represented by different colours and symbols can be easily accessed and retrieved in order to conduct a more refined analysis and to be updated whenever necessary.

Determination of the least-cost pathway for fishing

The combination of the several variables in analysis within the raster GIS (bathymetry, coastlines, no. of individuals and oil barrels) produced a friction image with the higher values corresponding to land territory (Fig. 7). The deeper sea grounds were also associated with large friction values, namely areas with more than 3000 m depth.

The geographic position of fishing area 4, in which the highest number of specimens and oil barrels were obtained during the period 1992 – 1996, was chosen for the construction of the cost surface. The cost surface generated exhibited, as expected, the least costs to movement around fishing area 4 (Fig. 8).

The optimum pathway for vessel C catching kitefin shark in 1997 with departure from the Northwest of São Miguel Island extends along the eastern group of Azores islands to the central group representing a distance of nearly 550 km (Fig. 9). The pathway covered several capture positions and shallower depth fishing grounds (< 600 m). Fishing area 3 was not covered by the pathway, yet, in 1997 the maximum capture values registered in areas 4 and 5 were similar to those registered in area 3 (Table 4) for both the number of specimens caught and the number of oil barrels produced.

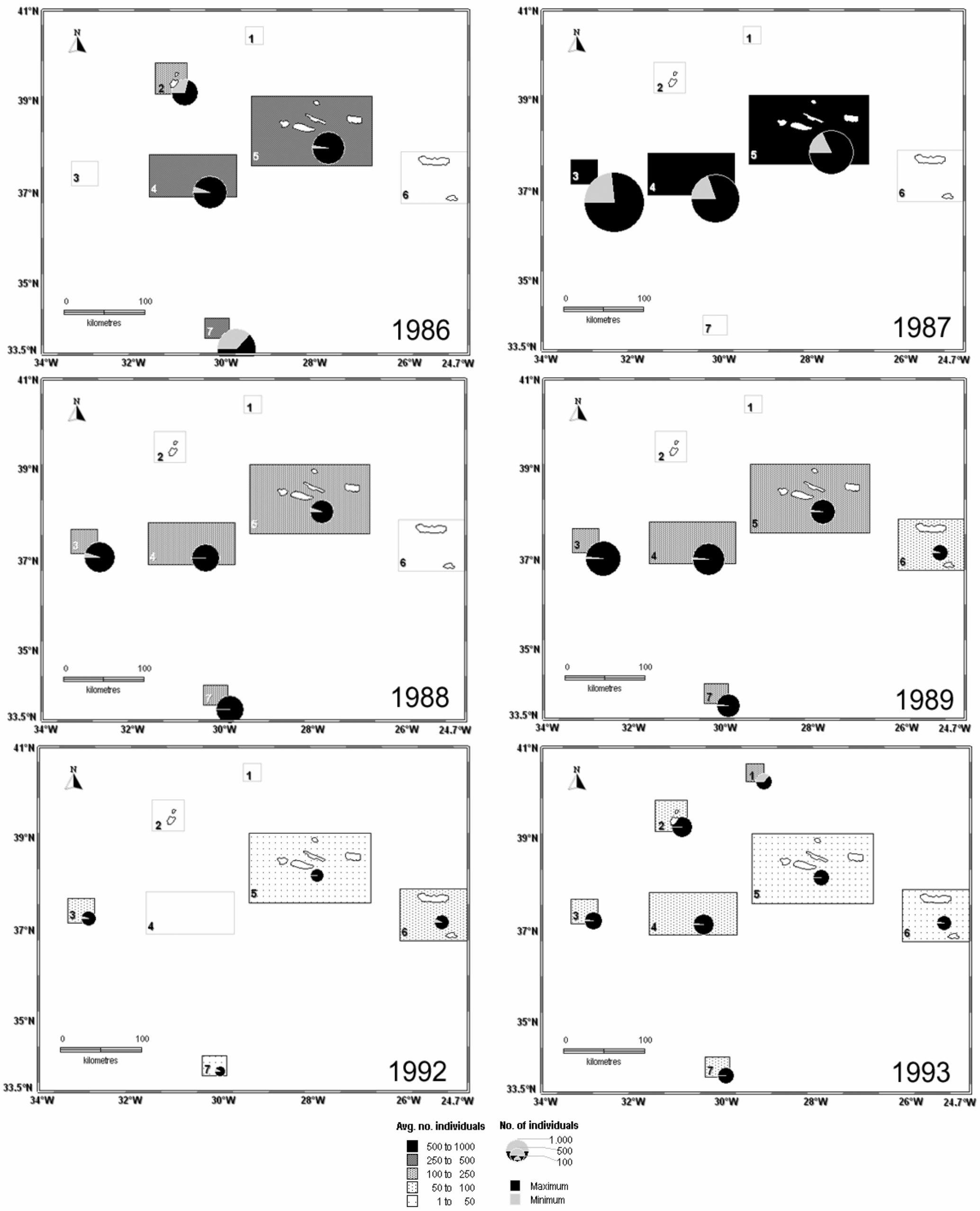


Fig. 5a. Annual variation of the number of kitefin shark individuals caught by haul in two time periods: 1986 - 1989 and 1992 – 1993.

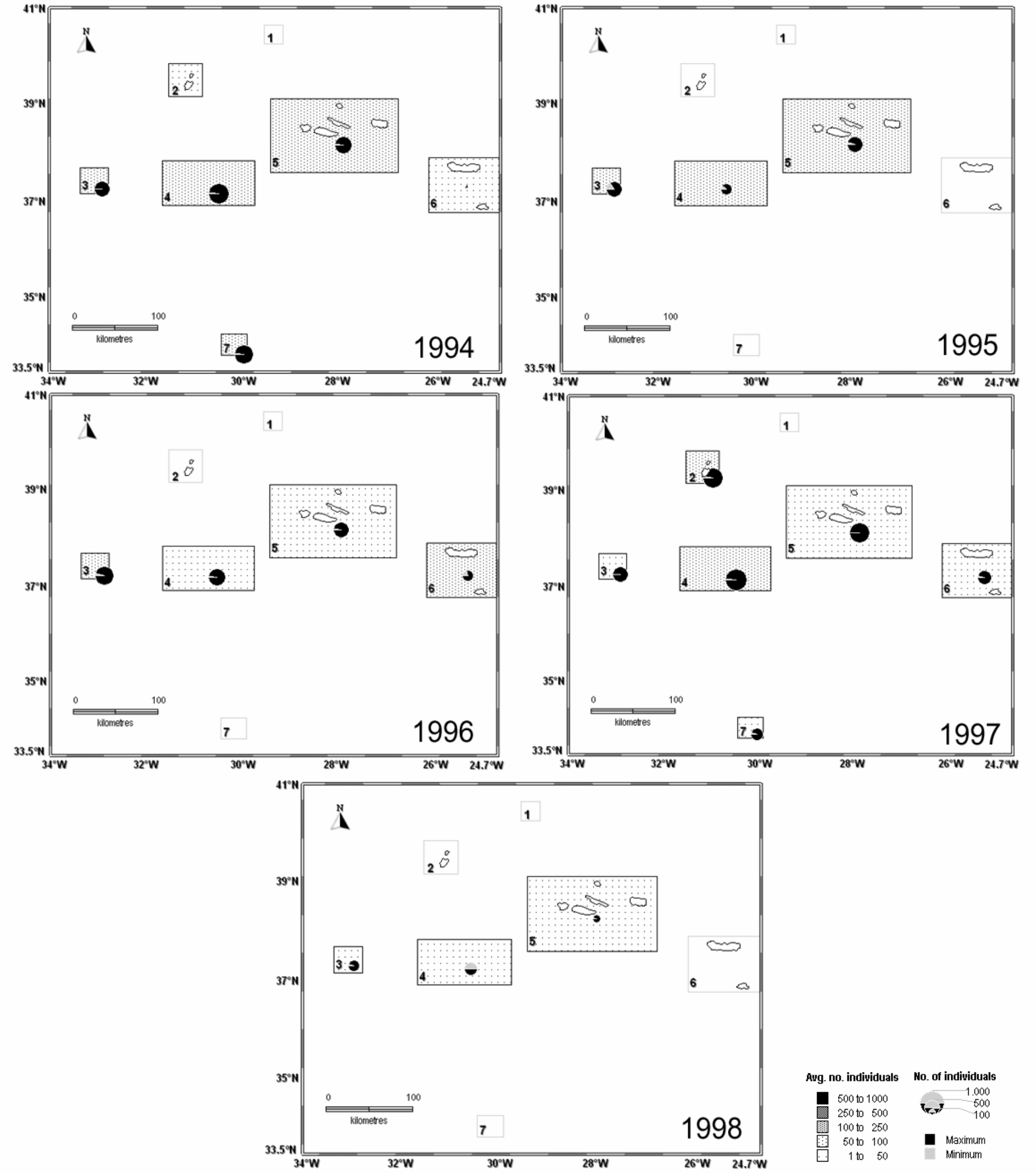


Fig. 5b. Annual variation of the number of kitefin shark individuals caught by haul in two time periods: 1994 - 1998.

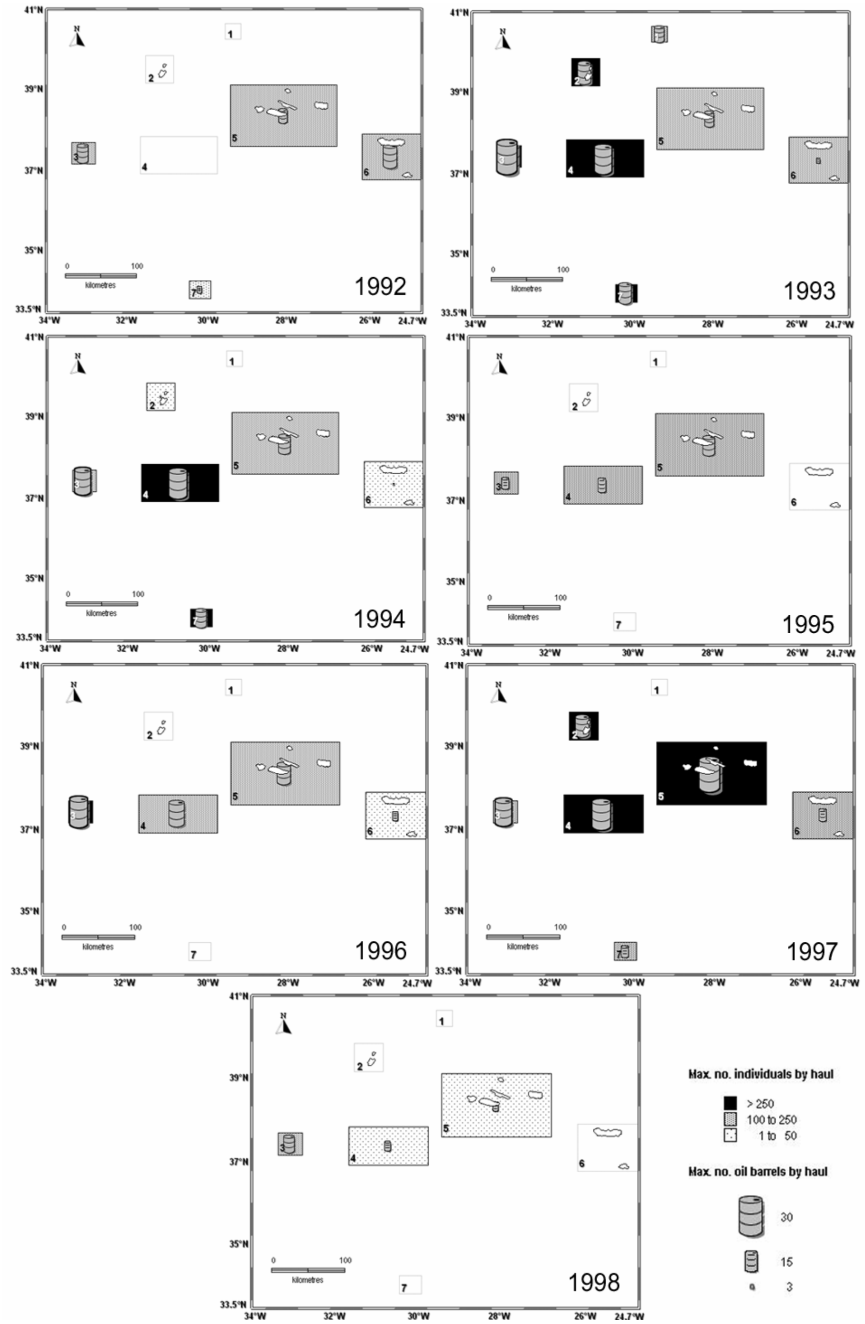


Fig. 6. Annual variation of the maximum number of kitefin shark individuals and oil barrels by haul from 1992 to 1998.

Fig. 7. Friction surface comprising different types of weighted data: bathymetry, land, number of individuals caught and oil barrels obtained. The scale represents pixel weight values.

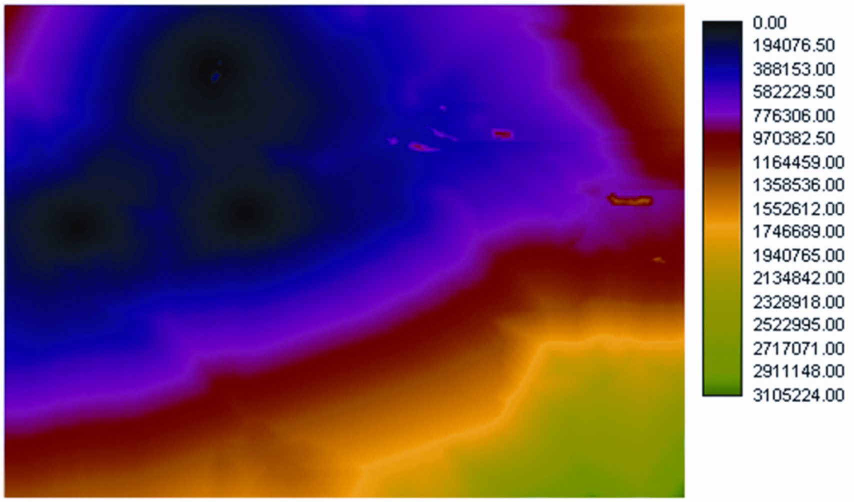


Fig. 8. Cost surface representing the costs of movement between pixels.

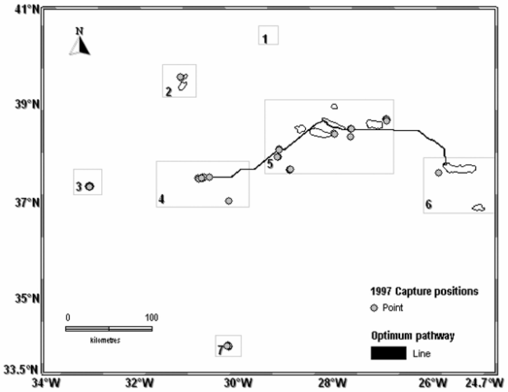


Fig. 9. Least-cost pathway for catching kitefin shark in 1997 from the Northwest region of São Miguel Island to the capture positions of fishing area 4.

Table 4

Descriptive statistics of the number of kitefin shark individuals caught by haul in 1997 for fishing areas 3, 4 and 5.

	3		4		5	
	No. Ind.	Oil Barrels	No. Ind.	Oil Barrels	No. Ind.	Oil Barrels
Average	42.3	6.2	52.4	6.5	41.9	6.0
Std. Deviation	36.73	5.30	59.58	6.32	48.90	6.04
Max.	185	32	352	36	318	41
Min.	1	1	2	1	1	0.5

DISCUSSION

The kitefin shark catches from Azorean gillnet fishing vessels decreased during the period of time analysed (1986 to 1998). The available data was far from being complete, representing a very short time series for two of the vessels analysed. Adding to this, no fishing effort data was analysed in detail beyond the months by year where kitefin shark catches occurred.

Late spring and summer months yielded higher catches of kitefin shark. The present results also suggest that the species is more abundant in fishing areas 3, 4 and 5.

The squalene oil obtained by vessel C constitutes a valuable by-product from the catches and may be a reason for the fishermen conducting their activity away from the coastline in fishing area 3.

The visualisation of the data in a GIS environment allowed the extraction of spatial and temporal patterns from the underlying data. The data analysed has been structured and linked by a relational database, allowing the user to establish relationships between the different types of data and easily perform updates to the maps constructed. For instance, the operation of generating a thematic layer of type 1 with data from 2001 could entail little more than importing a spreadsheet into the GIS software. Maps are primary tools tool for presenting the distribution of attribute values, for finding spatial clusters and for detecting anomalies and outliers (KEMP & MEADEN 2002). The way the attribute variable is classified also enables the user to visualize the data with more flexibility. Classification processes can summarize a variable, and different groupings may expose different spatial patterns. In the present work, several data aggregations and selections (average, maximum, etc.) were attempted in order to identify differences of kitefin shark catches on both spatial and temporal scales. However, other approaches could be attempted. In fact, the limit of the type of data aggregation methods relies only with the software used.

The raster GIS developed allowed the generation of a least cost pathway for vessel C catching kitefin shark in 1997. This pathway reflected the weights defined in the friction surface as it covered areas with depths <600 m, where the species could be more frequently found (MORENO 1995), as well as geographic positions that yielded high catch values in fishing area 5. The cost algorithm used considered that friction to movement is independent of the direction used. However, this is not always the case, as there may be prevailing directions to movement (e.g. strategic stops in other islands for fuel refill) that would inevitably influence the fishing trip of each vessel. As such, further work into this subject is needed and should explore the use of other variables influencing fishing activity as well as directions of preferential movement. Should this investigation be carried out, the possibility of using an anisotropic cost function ought to be considered (EASTMAN 1989).

It is worth emphasising the usefulness of a dynamic visualisation such as the one performed with the vector GIS. Its use allows scientists to easily produce periodic maps that help to carry out integrated analysis of different variables and supply interested end-users with comprehensible and summarised information.

Least cost pathways analysis can be a valuable analytical tool to aid researchers and managers alike in the decision-making process by providing further scientific-based arguments, namely the identification of the potentially productive fishing grounds and the identification of suitable areas for promoting resource conservation measures. Managers are thus provided with supplementary advice facilitating their task of guaranteeing that resource exploitation is maintained within sustainable levels.

Finally, it is worth mentioning that the investigation of the kitefin shark fishery in Azores using GIS tools could easily accommodate data from more fishing vessels and would greatly improve should more detailed information into the CPUE (capture per unit effort) and fishing effort data be considered.

ACKNOWLEDGEMENTS

The authors would like to thank the anonymous reviewers comments and suggestions, which improved the quality of this manuscript. The authors are also grateful to Francisco Leotte (INIAP-IPIMAR) for the English revision of the text. This study was supported by DG XIV of the European Commission through Study project 99/0055 entitled ‘Development of Elasmobranch Assessments’ (DELASS).

REFERENCES

ANDERSON, E.D. 1990. Fishery models as applied to elasmobranch fisheries. Pp. 473-484 *in* H.L. PRATT Jr., S.H. GRUBER & T. TANIUCHI (Eds) *Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries*. U.S. Department of Commerce, NOAA Technical Report NMFS 90. 517 pp.

COMPAGNO, L.J.V. 1984. *Sharks of the World. An Annotated and Illustrated Catalogue of Shark Species Known to Date. Part 1 - Hexanchiformes to Lamniformes.* FAO Fisheries Synopsis 125: 249 pp.

DRYSDALE, S. 1993. *Voronoi diagrams: Applications from Archaeology to Zoology*. Technical Report, Regional Geometry Institute, Smith College, July 19, 1993. Available from: http://www.ics.uci.edu/~eppstein/gina/scot.drysdale.html Last accessed September, 2002.

EASTMAN, J.R. 1989. Pushbroom Algorithms for calculating distances in raster grids. *Proceedings Autocarto* 9: 288-297.

EASTMAN, J.R. 1995. *IDRISI for Windows, User’s guide Version 1.0*. IDRISI production, Clark University, 13: 68-73.

FORTUNATI, L., G. GAROFALO & R. DEMONTIS 2002. TSDV: A GIS tool for inspecting trawl survey data. *ICES Journal of Marine Science* 59:1 168-178.

GORDON, J.D.M., O.A. BERGSTAD, I. FIGUEIREDO & G. MENEZES 2001. The Deep-water Fisheries of the ICES Area. Deep-sea fisheries symposium, *NAFO SCR Doc*. 01/92, 16 pp.

KEMP, Z. & G. MEADEN 2002. Visualization for fisheries management from a spatiotemporal perspective. *ICES Journal of Marine Science* 59:1 190-202.

MEGREY, B.A., S. HINCKLEY & E.L. DOBBINS 2002. Using scientific visualization tools to facilitate analysis of multi-dimensional data from a spatially explicit, biophysical, individual-based model of marine fish early life history. *ICES Journal of Marine Science* 59:1 203-125.

MORENO, J.A. 1995. *Guía de los tiburones de águas ibéricas, Atlántico Nororiental y Mediterráneo*. Pirámide. 310 pp.

SILVA, H.M. 1983. Preliminary studies of the exploited stock of kitefin shark Scymnorhinus licha (Bonnaterre, 1788) in the Azores. *International Council for the Exploration of the Sea*, CM1983/G:18, 13 pp.

SILVA, H. 1987. An assessment of the Azorean stock of kitefin shark, *Dalatias licha* (Bonn., 1788). *International Council for the Exploration of the Sea*, C.M. 1987/G:66, 10 pp.

SILVA, H. 1988. Growth and reproduction of kitefin shark *Dalatias licha* (Bonn., 1788) in Azorean waters. *International Council for the Exploration of the Sea*, C.M. 1988/G:21, 15 pp.

WRIGHT, D.J. 1998. Marine GIS in the Eastern Pacific. Nested Sampling Strategies and a Scientific Information Management Schema for Deepsea Environments. *GIS PLANET 1998 Annual Conference Proceedings*, Lisbon, Portugal, September 1998.

Accepted 4 September 2004.