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Finding Trends on the Fishery and Abundance of Kitefin Shark, *Dalatias licha* (Bonaterre, 1788), from off Azores, Throughout a GIS Spatial Analysis

(Elasmobranch Fisheries - Oral)

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Abstract

The kitefin shark has been a valuable resource to the fishing community of Azores for the last two decades, representing in 2000, a total income of ca. 12 500 €. This species is targeted by an artisanal gillnet fishery composed of small vessels operating off Azores since late 1970s. The vulnerability of the species to exploitation raised the concern about the impact of the fishery in the resource. The monthly catches of three vessels from the kitefin shark artisanal fishery were analysed geographically for the period between 1986 and 1998 to investigate changes in the fishery and abundance of the species in Azorean waters. A vector-based GIS was constructed to evaluate the changes in the number of individuals captured and squalene oil barrels obtained throughout a spatiotemporal perspective. In order to analyse which areas could be more profitable to one of the vessels in 1997, an optimum pathway for fishing was generated based on a raster GIS. The results indicated a decrease of kitefin shark catches in several areas around Azores archipelago and along the time period analysed. The spatial analysis of the data in a GIS environment permitted to obtain a dynamic and integrated view of the species catches off Azores.

Introduction

The kitefin shark, *Dalatias licha* (Bonaterre, 1788), is a deep-water squaloid species commonly caught in NE Atlantic slope waters. It exhibits a wide distribution 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). In what concerns its bathymetric distribution, the species occurs between 50 and 1800 m depth, however, is more frequently captured from 200 to 500 m depth (Moreno, 1995). Occurs frequently near the bottom, however, can readily move off the substrate (Compagno, 1984).

Due in part to its large liver, rich in squalene oil, the kitefin shark has been exploited since the late 1970s by a gillnet artisanal fishery located in Azores (Gordon *et al*., 2001). However, from early 1990s to the present, captures of this species are considered accidental (Anon., 2000). The vulnerability of this elasmobranch species to fisheries exploitation has been responsible for its inclusion as a case study species in a European research project focused on developing assessments on elasmobranch species – DELASS project, CFP 99/055.

The evaluation of fisheries condition should, whenever possible, be preceded by a comprehensive analysis of different types of information related with the fishery resource exploitation.

Most often, fisheries data share a spatial component (e.g. geodesic coordinates) that allows its identification in a geographic context. This enables the researcher to use visualisation tools that help him 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 and Meaden, 2002) and the possibility to provide the end-user with more and better information resulting from the synergy of different types of data (Wright, 1998). In this sense, several applications have already been used to get some insights and understanding of fisheries and related issues as they enable the scientist to easily create, observe, and interactively manipulate the data as well as the visual presentation of the data (Fortunati et al., 1998; Kemp and Meaden, 2002; Megrey et al., 2002).

The present paper investigates some catch data of the Azorean kitefin shark fishery throughout a spatiotemporal perspective using GIS visualisation and analytical tools. For this purpose, it was used information from three different vessels that are considered to be representative of the kitefin shark commercial fleet. 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.

Data

Samples were obtained from three different fishing vessels (a, b and c) of the Azorean kitefin shark fishery with a total length of 25 m. The data comprised the geographic capture positions of kitefin shark specimens, the date of capture, the number of individuals caught by haul and also the number of squalene oil barrels obtained with 20 l capacity by haul (only for vessel c). The information from vessel relates to the period 1986-1987, vessel b to the period 1988-1989 and vessel c to the period 1992-1998.

Methods

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

After a quick and preliminary observation of the data, it was verified that the capture positions were very scattered around Azores islands. Due to this fact, it was decided to aggregate these points in larger fishing areas to make visualisation and analysis processes easier (Fig. 1). Analytical visualization depends not only on the data available but also on derived data sets generated by applying aggregation and algorithmic functions to the base data (Kemp and Meaden, 2002). So, the GIS database included, besides the capture data, the identification of the fishing area (Fig. 2).

Based on the referred GIS, three different types of thematic layers were generated: 1) Average, maximum and minimum annual values of the number of kitefin shark specimens caught by haul; 2) Difference between average annual values of the number of kitefin shark individuals caught and 3) Maximum annual values of oil barrels obtained and number of kitefin shark specimens caught (only for vessel c). The generation of each theme layer was held by conducting queries to the database with SQL (Structured Query Language) commands. Vector-based GIS operations were conducted in MapInfo 5.5 software.

When analysing the annual trends of fisheries data, it is sometimes interesting to verify how the fleet responds to the spatiotemporal changes of the resource(s) catches along the years. Using the data of vessel c from 1992 to 1996, an optimum pathway for catching kitefin shark specimens 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 grounds with lower depths (< 600 m depth) for fishing and some of the geographic positions with highest capture values. For this purpose it was developed a raster GIS that accounted for bathymetry data, capture data (no. of specimens and oil barrels) and coastlines.

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

a) Weighting of the variables of interest. This is conducted by considering which ones 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 since vessels do not operate on land! Land points received a value of 9999; bathymetry, no. of specimens and oil barrels values remained unchanged.

b) Generation of a friction image. By using a raster overlay operation land values were added to bathymetric values. Using this new raster layer, another overlay operation was conducted where the no. of specimens and oil barrels + 100 were subtracted to the land +bathymetry values.
c) Definition of the source object(s). In this step, a layer containing one or two geographic position(s) where the no. of specimens + no. of oil barrels were higher, was constructed.
d) 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).
e) Definition of a target image. Assuming that vessel c has its departure for fishing at the port of "Ponta Delgada", located at the southern part of the Island of São Miguel (Fig. 1), a target image was generated with only the identification of the geographic position of this fishing port.
f) Generation of a least cost pathway. A distance algorithm is used to find the shortest path between target specified points of capture and the source destination specified as the lowest point on a cost surface. The distance algorithm works by choosing the least cost alternative each time it moves from on 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 on each of the GIS developed it was used data from GEBCO (General Bathymetric Charts of the Oceans) Digital Atlas CD-ROM (1997 Edition) published by the British Oceanographic Data Centre (BODC). In the vector based GIS these data was simply used for visualisation purposes, so a bathymetric layer was generated by a Inverse Distance Weighting (IDW) interpolation in MapInfo 5.5 software, where a distance weighted average of data points is applied to calculate grid cell values. Since bathymetry was an important part of raster operations, it was decided to construct a Thiessen or Voronoi polygons layer using IDRISI 3.2 software. This is generally used 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 (Table 1). From 1986 to 1998 these values have decreased, as well as their variability. The year of 1987 has registered the highest values on the number of specimens caught (ca. 1700 by haul). In what concerns the captures by vessel, vessel a presented the highest values on the number of individuals caught while vessel c, which data is available for a larger time period, has registered the lowest values (Fig. 3).

The total number of specimens caught by month varied with the fishing area (Fig. 4). Fishing areas 1, 2 and 6 registered small values (<1000) and fishing area 3 presented the highest value (≈ 10200). Areas 4 and 5 were the only ones with capture records during all the year. Late spring and summer months accounted for the higher values of the total number of specimens caught. In fact, these months registered captures in the majority of the years analysed (Table 2).

The annual average number of oil barrels by vessel c varied between 5 in 1992 and 9 in 1995 (Table 3). The highest variance of values was observed in 1994 and 1997.

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. 5 a, b). Captures were more frequent in fishing areas 4 and 5. The last area registered captures of kitefin shark in all the years analysed, while area 1 only presented for 1993. The most profitable area, in terms of the number of individuals captured, was area 3 presenting average values of more than

500 specimens by haul. Areas 4 and 5 also registered high capture values, however, and similarly to the other areas exhibited wide range between maximum and minimum values.

In what concerns the bathymetric distribution of the catches in the study area, the majority of the capture positions were located in areas with depths between 200 m and 1000 m. Actually, the catches seem to be associated with seamounts in all the fishing areas analysed.

Three difference theme layers of the annual average number of individuals caught were constructed: 1988-1987, 1992-1989 and 1997-1992 (Fig. 6). From the analysis of the first two, is evident that the catches by vessel experienced a rapid decrease in a short time period (5 years). Despite the catches of vessel c were very low in 1992 in comparison with the ones from vessel a, in 1997 there was a slight increase of the catches in fishing areas 5 and 7.

Another example that can be explored with the vector based GIS is the cartographic visualisation of the maximum annual number of oil barrels by haul and by fishing area. Figure 7 shows the variation of these values from 1992 to 1998 as well as the maximum number of individuals caught. As expected, a large maximum value was also associated with a large maximum number of individuals. Fishing area 3 yielded the most advantageous captures in terms of oil barrels. 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 to where and when the kitefin shark fishery was more profitable around Azores archipelago. Moreover, the underlying data values represented by different colours and symbols can be easily accessed and retrieved in order to conduct 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. 8). The deeper sea grounds were also associated with large friction values, namely areas with more than 3 000 m depth.

For the construction of the cost surface it was chosen as source object the geographic position of fishing area 4 that registered the highest number of specimens plus number of oil barrels obtained during the period 1992-1996. This choice was based on the fact that there were more capture positions within that area with maximum values of the number of specimens and barrels close to the highest values registered in fishing area 3 (number of specimens=357; number of oil barrels=34). The cost surface generated exhibited, as expected, the least costs to movement around fishing area 4 (Fig. 9). Land pixels were associated with the highest costs to movement.

The optimum pathway for vessel c catching kitefin shark in 1997 with departure from the port of “Ponta Delgada” extends along the eastern group of Azores islands to the central group representing a distance of nearly 570 km (Fig. 10). The pathway covered several capture positions and lower depth grounds (< 600 m). Fishing area 3 was not covered by the pathway, nevertheless, it was interesting to notice that 1997 capture values registered in areas 4 and 5 were approximate (Table 4), having higher maximum values either for the number of specimens and number of oil barrels.

Discussion

The kitefin shark catches from Azorean gillnet fishing vessels decreased during the time period analysed (1986 to 1998). The data available was far from being complete with very short time series for two of the vessels analysed. Adding to this, no fishing effort data was analysed, besides the months by year where kitefin shark catches occurred. Despite the deficiencies encountered, the data suggests a reduction on the kitefin shark abundance around Azores from 1986 to 1999.

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

The squalene oil retained by vessel c constitutes a valuable sub-product from the catches and might be a reason for conducting its activity far away from the coastline in fishing area 3.

The visualisation of data on 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 comprehend little more than an import of a data spreadsheet to the GIS software. Maps constitute the main tool for presentation of the information showing distribution of attribute values, for finding spatial clusters and for detecting anomalies and outliers (Kemp and Meaden, 2002). The way the attribute variable is classified also enables the user to visualize the data more flexibly. 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 catching kitefin shark individuals in 1997. This pathway reflected the weights defined in the friction surface as it covered areas with depths below 600 m, where the species could be more frequently found (Moreno, 1995), and also geographic positions, which 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, there could exist prevailing directions to movement (e.g. strategic stops in other islands for fuel refill) that influence the fishing trip of the vessel. In this sense, a future work on this subject should investigate and consider other variables influencing fishing activity as well as directions of preferential movement. If this is the case, an anisotropical cost function should be used instead (Eastman, 1989).

It is worth to emphasise the usefulness of a dynamic visualisation has the one performed with the vector GIS, as it 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 could be an advantageous instrument to researchers and managers in decision support for fisheries resource exploitation sustainability, namely in the identification of the most potential areas for fishing and in the selection of suitable areas for promoting resource conservation measures.

Finally, it is worth to mention that the investigation of the kitefin shark fishery in Azores trough the use of GIS tools could easily accommodate more fishing vessels data and would greatly improve with CPUE (capture per unit effort) and fishing effort data.

Acknowledgements

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Table 1. Annual descriptive statistics of the number of kitefin shark individuals 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

Table 2. Months with catch occurrences of kitefin shark individuals 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 individuals

Table 3. Annual descriptive statistics of the number of squalene oil barrels shark 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

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	58.58	6.32	48.90	6.04
Max	185	32	352	36	318	41
Min	1	1	2	1	1	0.5

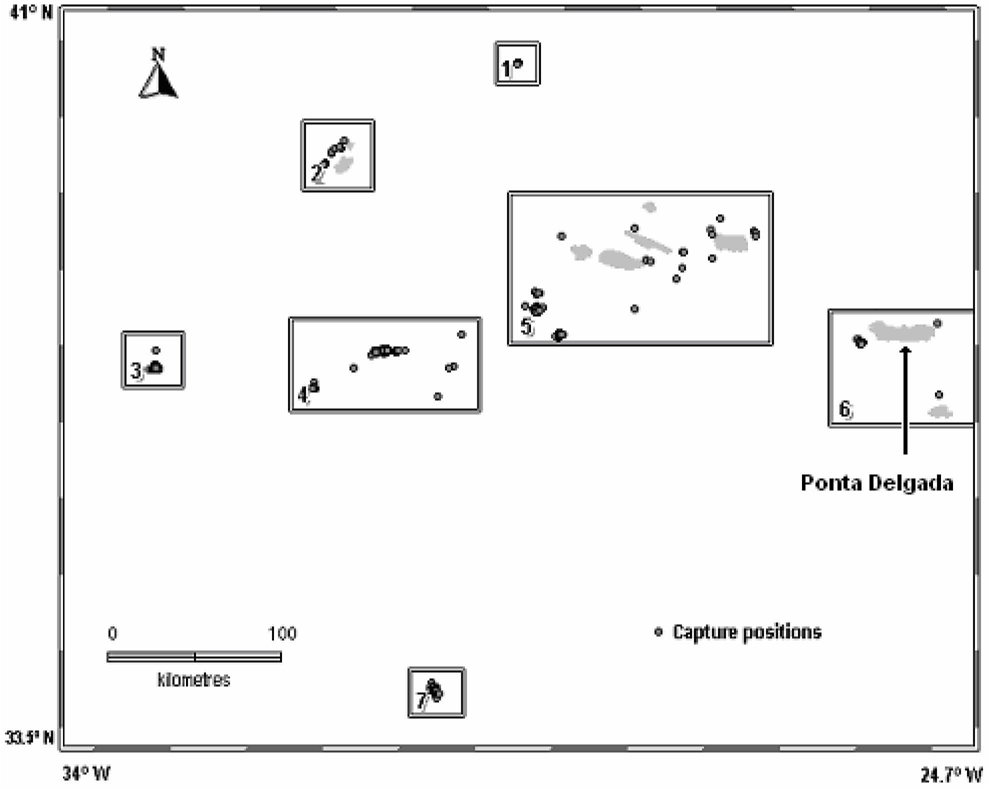


Fig. 1. Study area around Azores archipelago. Fishing areas, kitefin shark capture positions and the port of “Ponta Delgada” are represented.

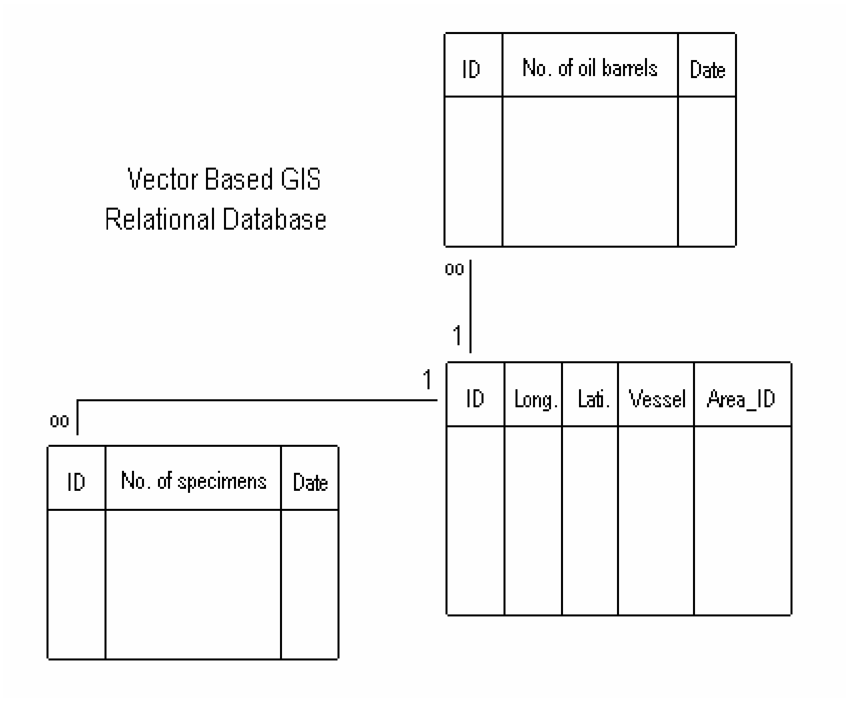


Fig. 2. Schematic representation of the vector GIS database.

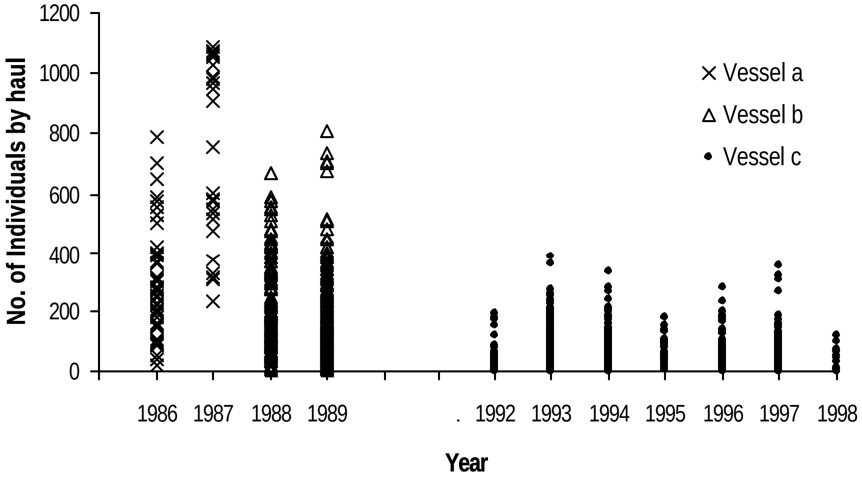


Fig. 3. Kitefin shark catches from each vessel in two time periods: 1986-1989 and 1992-1998.

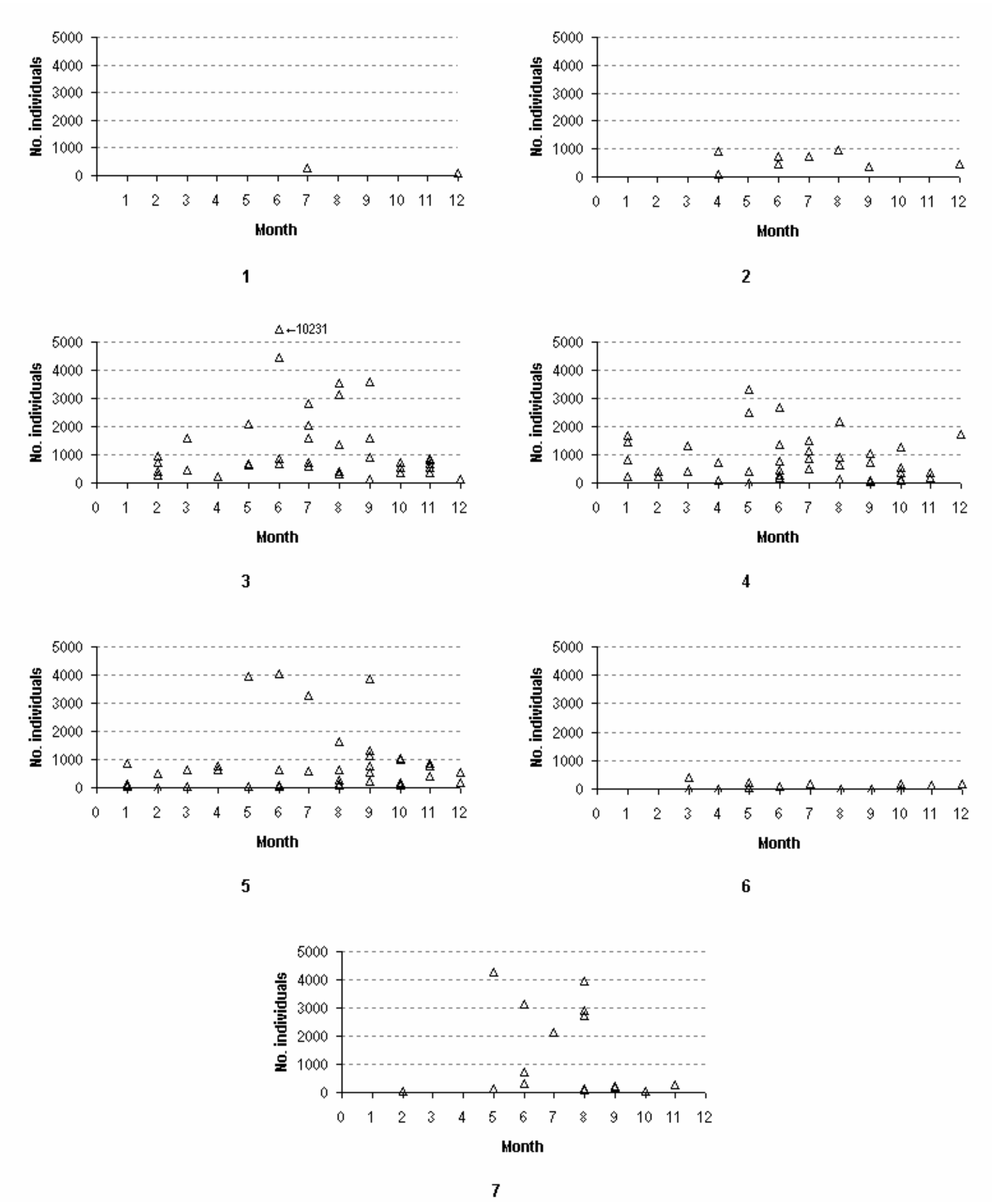
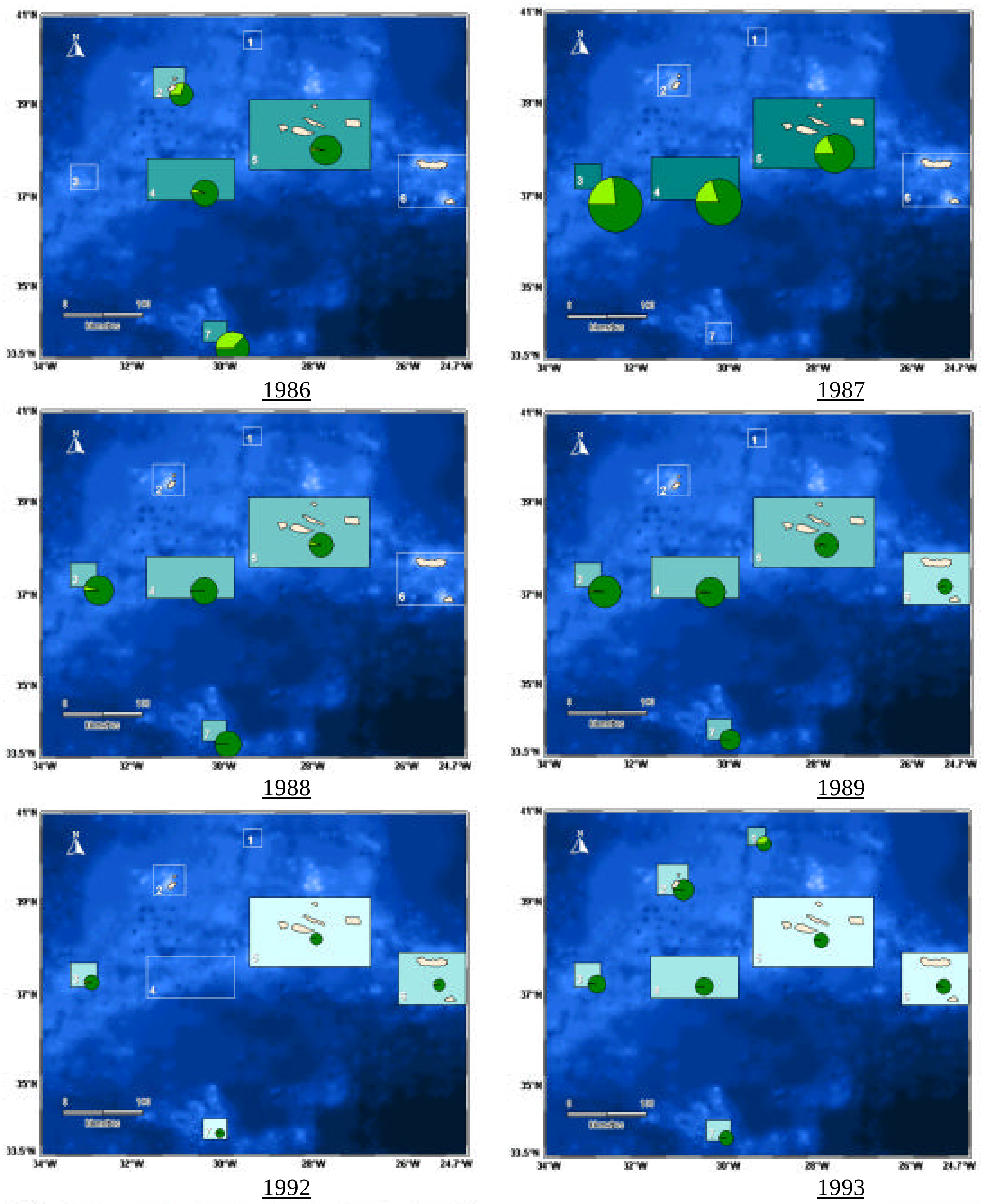


Fig. 4. Variation of the total number of kitefin shark individuals caught by month in each fishing area.



1986

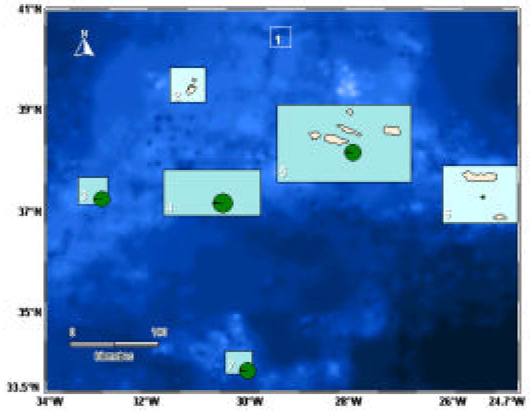
1987

1988

1989

1992

1993



1994

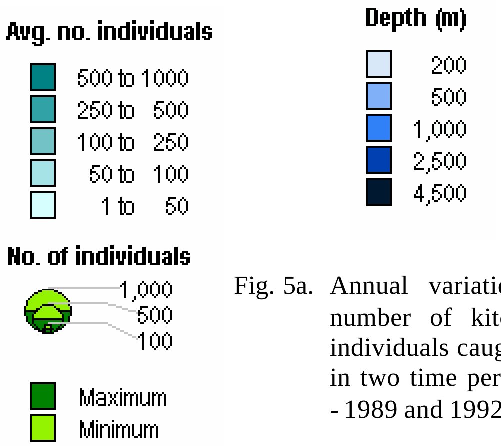


Fig. 5a. Annual variation of the number of kitefin shark individuals caught by haul in two time periods: 1986 - 1989 and 1992-1994.

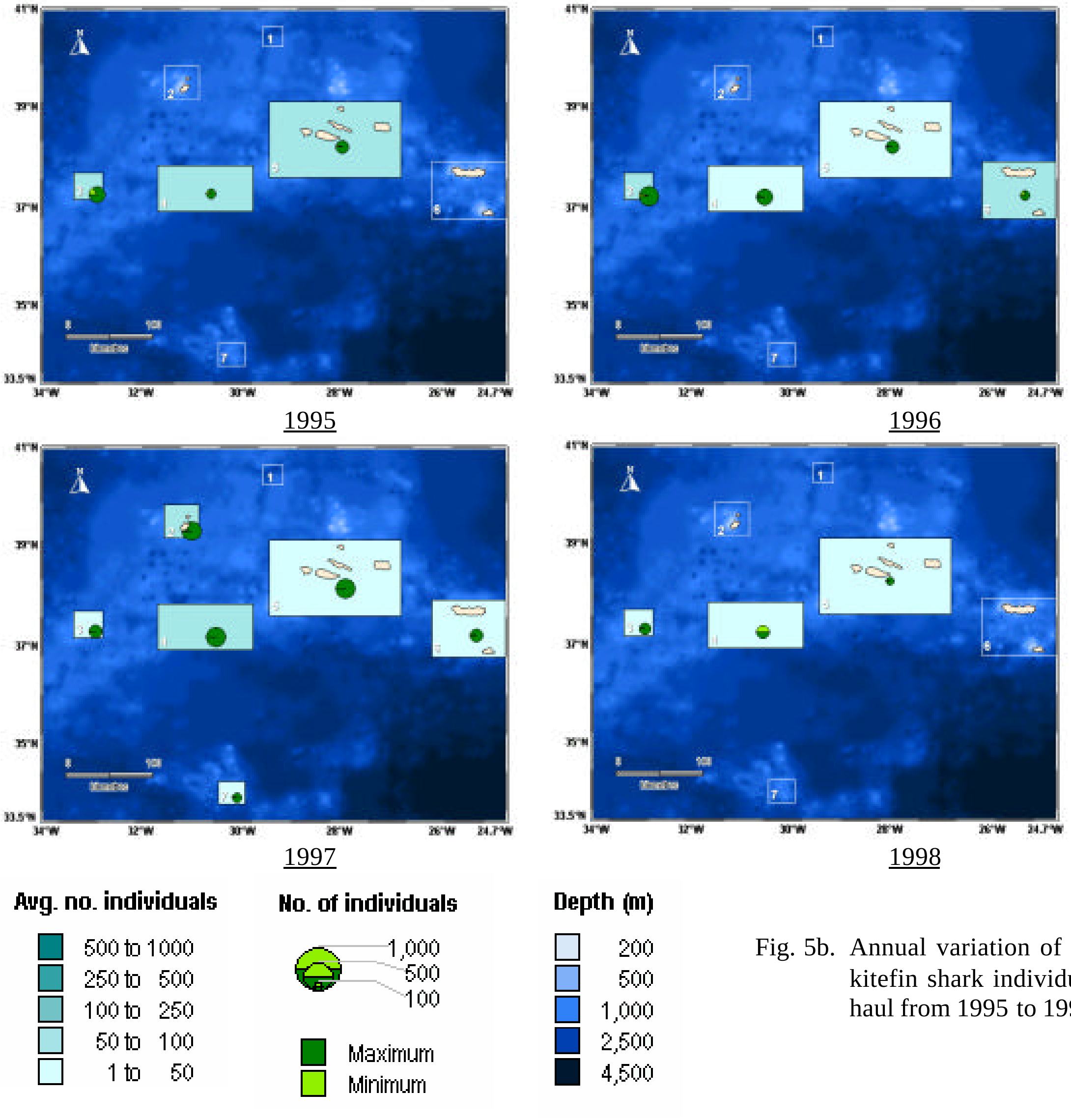
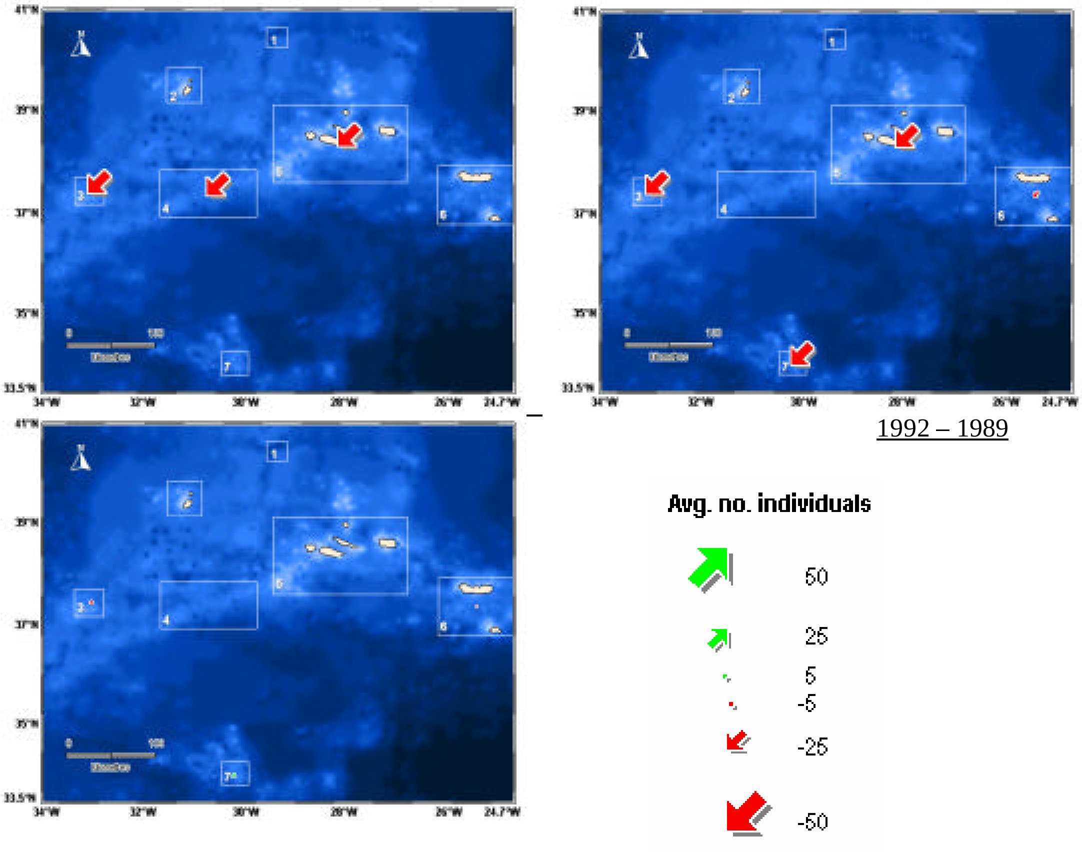


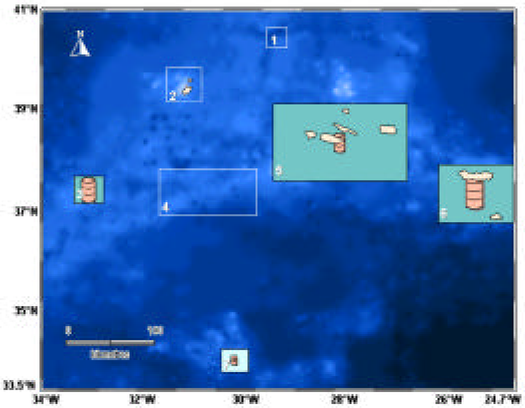
Fig. 5b. Annual variation of the number of kitefin shark individuals caught by haul from 1995 to 1998.



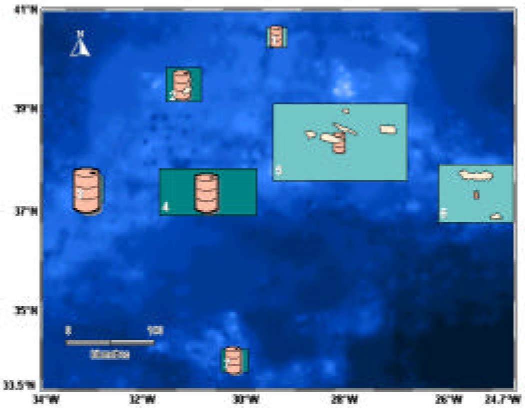
1992 – 1989

1997 - 1992

Fig. 6. Difference theme layers of the annual average number of kitefin shark individuals caught in three time periods 1988-1987, 1992-1989 and 1997-1992.



1992



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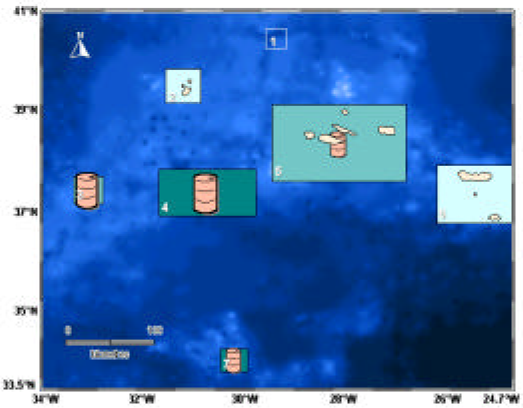

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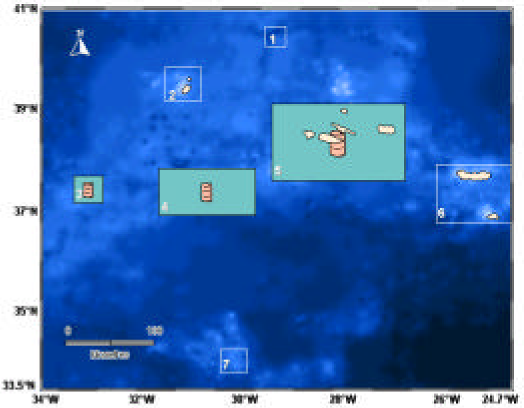
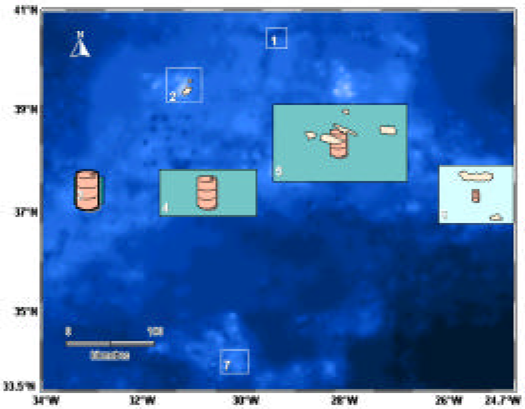
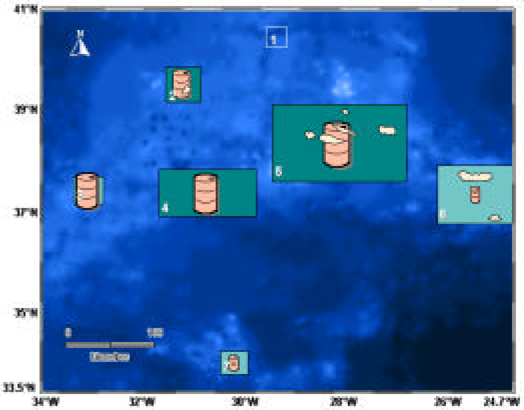


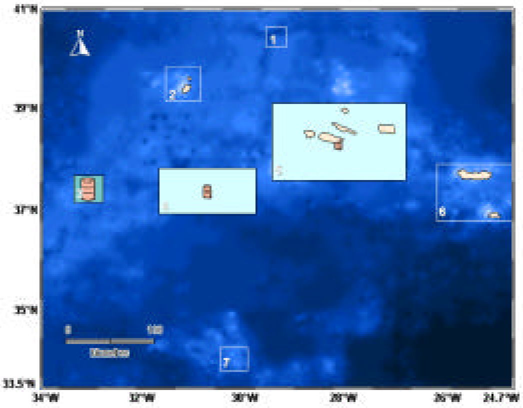
1995



1996



1997



1998

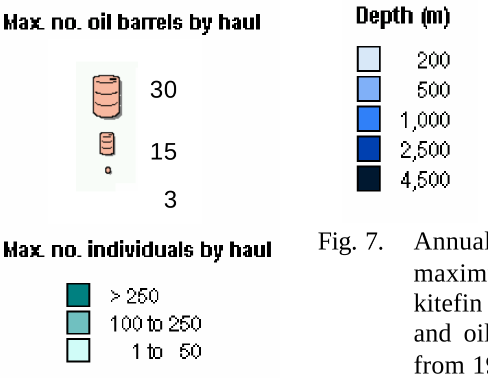


Fig. 7. Annual variation of the maximum number of kitefin shark individuals and oil barrels by haul from 1992 to 1998.

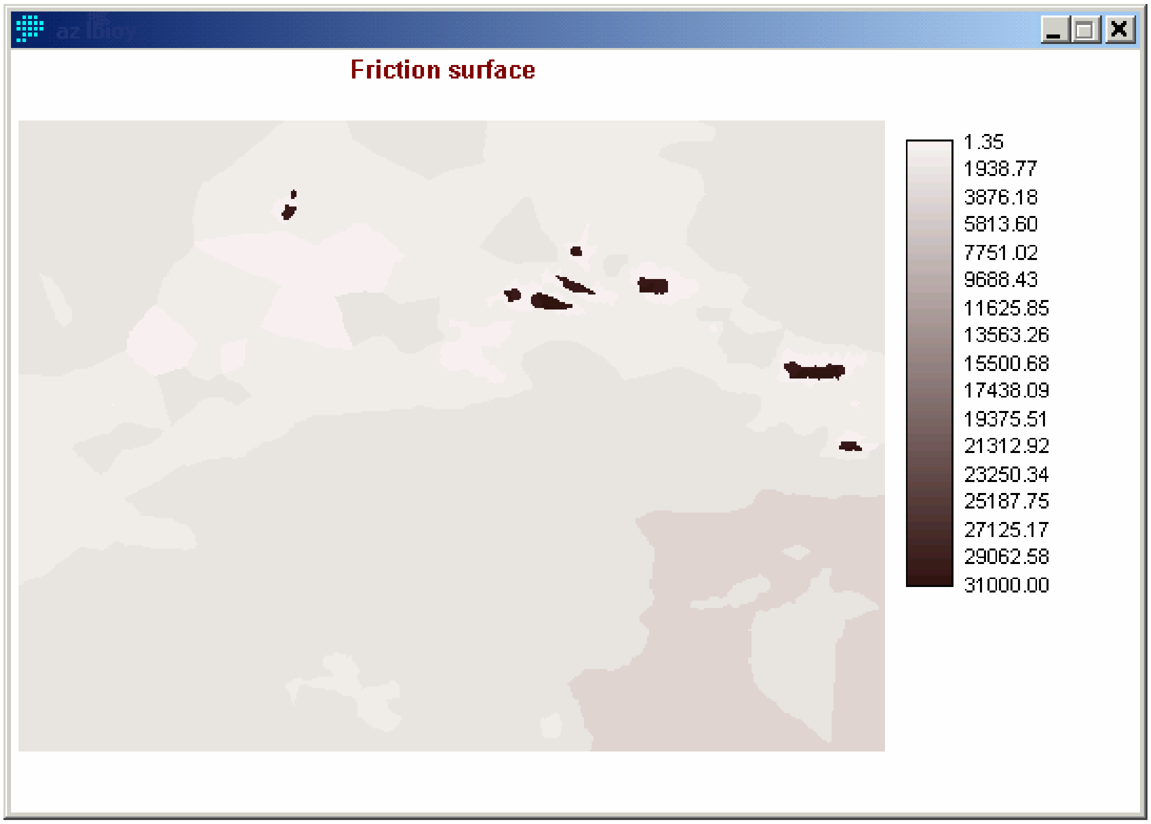


Fig. 8. Friction surface comprising different types of weighted data: bathymetry, land, number of individuals caught and oil barrels obtained. The scale represents pixel weight values.

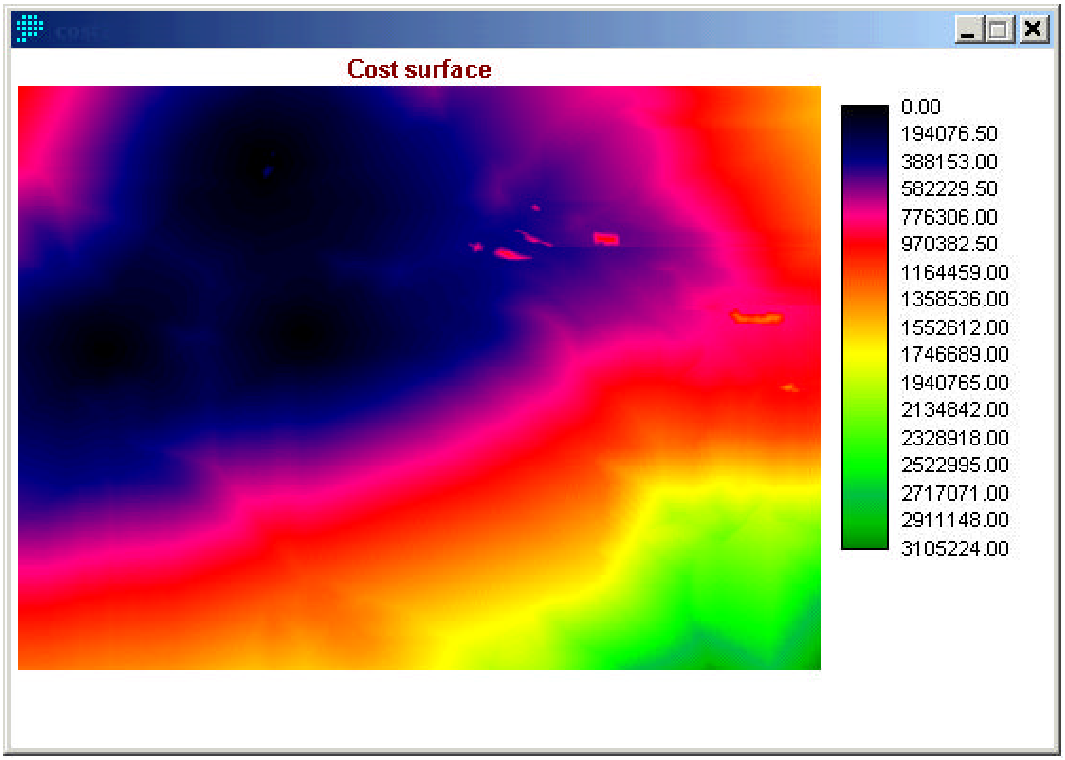


Fig. 9. Cost surface representing the costs of movement between pixels.

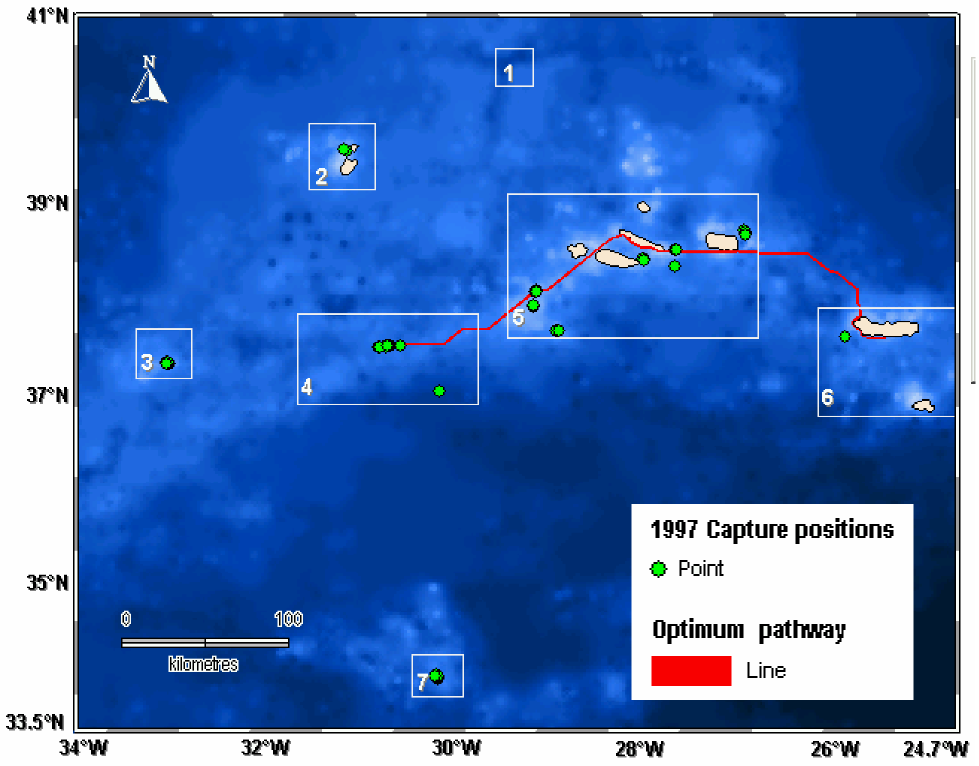


Fig. 10. Least-cost pathway for catching kitefin shark individuals in 1997 from the fishing port of “Ponta Delgada” to the capture positions of fishing area 4.