GIS Categorisation of Commercial Fishes in Dimensions Relevant to Over Harvesting

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ABSTRACT

This study used recent GIS techniques to investigate the sustainability of commercial fishing in northern Australia. The objectives were to explore patterns of fish catch data by using spatial statistics and to merge data sets obtained with different fishing techniques to predict the risk of over-harvesting commercial fishes. Indices, derived from spatial statistics calculated within ArcView GIS, provide the dimensions of the "Over Harvesting Space" (OHS). OHS is a 3D space, created in ArcView, within which similarities between commercial species, based of their response to fishing pressure, are explored. The new, non Linnaean, classification is relevant to the process investigated: sustainable harvesting practice. This categorisation has applications both in terms of management and further research.

Keywords and phrases**:** sustainability, commercial fishing, ArcView GIS, spatial statistics, 3D visualisation.

1.0 INTRODUCTION

Natural resources management relies on field data to provide stakeholders with sustainable practices. Statistics always offered convenient quantitative descriptors of large data sets unfortunately they are often poorly adapted to the analysis of environmental monitoring records as they ignore that spatial data are generally autocorrelated. Geostatistics (Isaaks and Mohan Srivastava, 1989) address this issue and are extensively used in mining exploration, for instance, where valuable resources justify sophisticated analysis and modeling. Other domains of natural resources management deal which problems so poorly defined that improved statistics do not necessarily lead to better quantitative answers. Fisheries endeavour to understand fish populations with limited success. Failures are famous. The history of sardines and cod fisheries in Europe (Smith, 1994) is a constant reminder of the consequences of failing to abandon unsustainable fishing practices. Owing to the large number of variables, modeling fisheries sustainability is a challenge. Modeling, however, is no longer the only issue that policy makers have to contend with. The vulgarisation of researchers' findings to win the support of stakeholders has become increasingly important. Interested parties often are influential lobby groups whose political support is sought by governments through the policies drafted by their representatives. Researchers themselves try hard to convince industry and local associations of the value of their work. In the new landscape of research at the regional level, at least, traditional analytical methods seem to be loosing their appeal.

Fisheries in the Northern Territory, in tropical northern Australia, have used statistics to analyse fish catch data, and assess the sustainability of current fishing practices, with limited success, particularly when it comes to communicating with stakeholders. Geostatistical analysis suffers from similar limitations as it requires a substantial effort to produce results which, owing to the complexity of the underlying theory and the limited mathematical background of interested parties, are unlikely to win much support. Geographic Information Systems (GIS) are well known for the effectiveness of their visual component when it comes to communication. In Australia, however, Fisheries do not seem to appreciate the analytical and modeling potential of GIS and are unaware of the current revolution in quantitative geography (Fotheringham, 2000) and its possible contribution to natural resources management.

The Northern Territory, with its low population density and large surface area, is a comparatively strong consumer of spatial technology. Northern Territory Fisheries decided to assess how GIS could contribute to their present strategy of management of commercial fishes. Specific objectives were:

1/ assess the risk of over harvesting specific commercial fishes (Gold Band Snapper being of particular interest);

2/ effectively communicate results and information between researchers on the one hand and policy makers and professional fishermen on the other, as evaluated through frequent presentations (four in total) to stakeholders;

3/ merge sets of fish catch data obtained by using two (at this stage) different fishing techniques

Figure 1 shows the area selected for the pilot project: the Timor Reef fishing grounds. North West of Darwin and close to the waters of East Timor and Indonesia this area has been subjected to an increasing fishing pressure documented by data recorded by professional fishermen since the early 90s.

Figure 1: The black (drop line) and grey (fish trap) dots show the locations of catch records analysed in this paper

The Timor Reef Fishery (concentration of black and grey points in *Figure 1*) is a good source of commercial fishes. Some of the most important species caught include Gold Band Snapper and Sharp Tooth Snapper (these two species, often confused are grouped under the former), Cod, Red Snapper, Saddle Tail Snapper and Red Emperor. Fish catch data recorded by fishermen include coordinates, number of fish caught per species, number of gear units and fishing method (drop line or fish trap). *Figure 2* shows the extent of the study area.

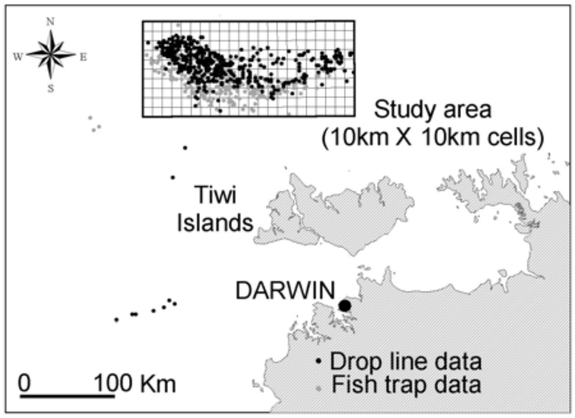


Figure 2: Study area

Spreadsheets, statistics and purely numerical methods make it difficult to develop a mental image of the interactions between all pieces information embedded in *Figure 1* and *Figure 2*. Visual patterns play an important role in human cognitive processes and GIS visualisation can be seen as a very effective primer of abstract concepts. This conceptualisation guides the investigation of large data sets, the formulation of clear working hypotheses and ultimately the modeling of complex processes. Having said that the choice of GIS software turns out to be an important issue it often sets the limits of the analysis and modeling that can be performed. At present there are a large number of GIS commercially available. ArcView is arguably the most popular desktop GIS with out of the box analytical/modeling capability. Additional extensions such as Spatial Analyst and 3D Analyst (both used in the project) provide much needed extra functionality. ArcView benefits as well from a large library of users' scripts ("3D Weighted Means" used in this study is one of them), freely available at http://www.esri.com, which complement existing extensions. Owing to its popularity and Avenue, its powerful programming language, ArcView is often used as a platform for the development of new analytical tools and their vulgarisation by researchers. Lee and Wong (2001) report on Point Descriptors is the source of the Standard Deviational Ellipses calculations used in this study.

2.0 SPATIAL STATISTICS AND GIS VISUALISATION

2.1 Data

Fish catch data recorded by professional fishermen contain sensitive information that need to be kept confidential and are only preserved in the original database. Such fields (latitude and longitude of records for instance) are used in calculations but never appear in interpretations.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	RETURI	EFFOR	BEGIN_D	ENDING_	LICE	CATCI	GEAR_	GEAR_	LAT_I	LAT_	LAT_	LON	LON	LON	DEPT	HRS_	GOLI	SADI	RED_	RED_	SHAI	COD	OTHI	MEAS	Effor	Total
2	300228	281402	03/02/00	03/02/00	5004	DROP	6	40							95		40	0	3	2	0	0	0	NO	1	45
3	300228	282502	08/02/00	08/02/00	5004	DROP	6	40							85		34	0	0	35	0	0	0	NO	1	69
4	300228	282504	09/02/00	09/02/00	5004	DROP	6	40							92		18	4	0	0	0	0	0	NO	1	22
5	300228	282506	10/02/00	10/02/00	5004	DROP	6	40							102		188	22	2	5	0	6	0	NO	1	223
6	300228	281401	02/02/00	02/02/00	5004	MOBIL	12	1							102		8	2	4	0	0	1	1.5	NO	1	16.5
7	300227	281393	29/01/00	29/01/00	5004	MOBIL	18	1							102		62	14	3	5	0	0	0	NO	1	84
8	300227	281397	31/01/00	31/01/00	5004	MOBIL	18	1							108		22	28	16	18	0	4	0	NO	1	88
9	300228	281399	01/02/00	01/02/00	5004	MOBIL	18	1							106		32	0	3	2	0	8	0	NO	1	45
10	300228	281403	03/02/00	03/02/00	5004	MOBIL	20	1							95		188	28	14	8	0	6	6	NO	1	250

Figure 3: Fields of the original fish catch data set used in this study are in light grey.

Columns C and D	→	dates (beginning/ending) of the reported catch
Column E	→	source of information
Column F	→	fishing method (drop line/mobile fish trap)
Column G	→	number of lines/traps used
Columns I to N	→	coordinates of the location of the reported catch
Columns Q, S, T	→	species caught: Gold Band Snapper, Red Emperor, Red Snapper

Some fields are added to the subset of the original data set to create the table (*Figure 4*) which, once imported into ArcView GIS, is the basis of this study.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	BEGIN_[	LICEI	CATCH_METHOD	GEAR	LAT	LONG	DEPTH	GOLDBAND	GOLDBAND	RED_EMPEROR	RED_EMPEROR	RED_SNAPPER	RED_SNAPPER
2	03/02/00	5004	DROPLINE	6			95	40	6.66666667	3	0.5	2	0.333333333
3	08/02/00	5004	DROPLINE	6			85	34	5.66666667	0	0	35	5.833333333
4	09/02/00	5004	DROPLINE	6			92	18	3	0	0	0	0
5	10/02/00	5004	DROPLINE	6			102	188	31.3333333	2	0.333333333	5	0.833333333
6	02/02/00	5004	MOBILE FISH TRAP	12			102	8	0.66666667	4	0.333333333	0	0
7	29/01/00	5004	MOBILE FISH TRAP	18			102	62	3.44444444	3	0.166666667	5	0.277777778
8	31/01/00	5004	MOBILE FISH TRAP	18			108	22	1.22222222	16	0.888888889	18	1
9	01/02/00	5004	MOBILE FISH TRAP	18			106	32	1.77777778	3	0.166666667	2	0.111111111
10	03/02/00	5004	MOBILE FISH TRAP	20			95	188	9.4	14	0.7	8	0.4

Figure 4: Fields added to the subset of the original fish catch data set (Figure 3) are in dark grey.

Columns E and F → latitude and longitude in decimal degrees (erased on Fisheries request)
Columns I, K, M → fish caught divided by number of fishing gear

2.2 Summarising data with spatial statistics

3D Weighted Means (3DWM), downloaded from the ESRI website, was used to calculate for each species the yearly average coordinates of recorded catches weighted by the amount of fish caught in each location. The yearly average was therefore pulled towards the best fishing spots for each species considered.
Standard Deviational Ellipse (SDE), written by J. Lee and W. Wong (2001), is the spatial equivalent of standard deviation. In absence of any trend in the location of best catches the average distance between a yearly 3DWM and the average location of all catches, during that year, would be constant along all directions radiating from the yearly 3DWM. On the contrary, a directional bias in the location of the best catches would distort the circle into a Standard Deviational Ellipse characterised by:

- the ratio of the length of the long axis to the short axis
- the directions of the long and short axis

3DWM and SDE were therefore selected to explore, for the species considered, the migration of the best fishing spots from one year to the next.
Meeting the first two objectives (visualising data and merging drop line and fish trap data) are met by displaying in the same diagram all drop line and fish catch data displayed as 3DWMs.

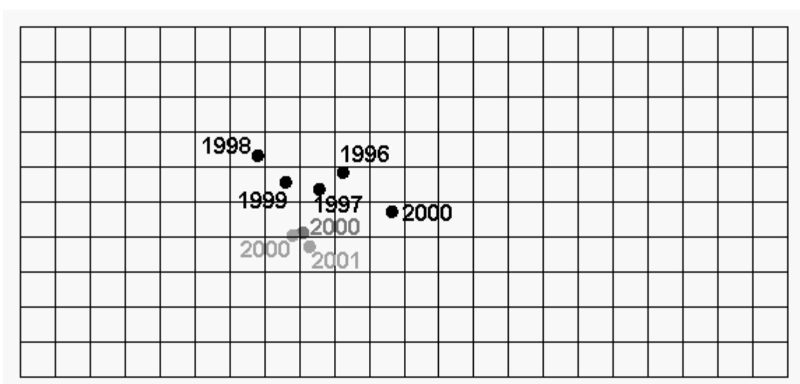


Figure 5: Migration of 3DWMs of Gold Band Snapper catch data recorded by the same professional fisherman on background of the study grid displayed in Figure 2. Black, dark grey (2000 only) and light grey dots respectively correspond to drop line, fish trap and combined drop line/fish trap data.

In *Figure 5*, black and light grey respectively represent drop line and fish trap data 3DWMs derived from one fisherman. Year 2000 was a transition year; both methods were used simultaneously. There are consequently three points for the same year. The darker grey point is the 3DWM obtained from the aggregate of fish trap and drop line data.
Figure 6 shows that the best locations for catching Gold Band Snapper migrated to the West between 1996 and 1998. The black 2000 3DWM is South East of the 1996 3DWM. This suggests a possible decline in catches in areas previously fished so much so that grounds not productive in 1996 became comparatively

better in 2000. Fish trap data, in light grey, show a similar trend (migration to the East between 2000 and 2001) but are located further South, as could be predicted from the spread of all data displayed in *Figure 1*. 3DWMs clearly provide a synoptic view of large data sets and facilitate the identification of possible patterns.

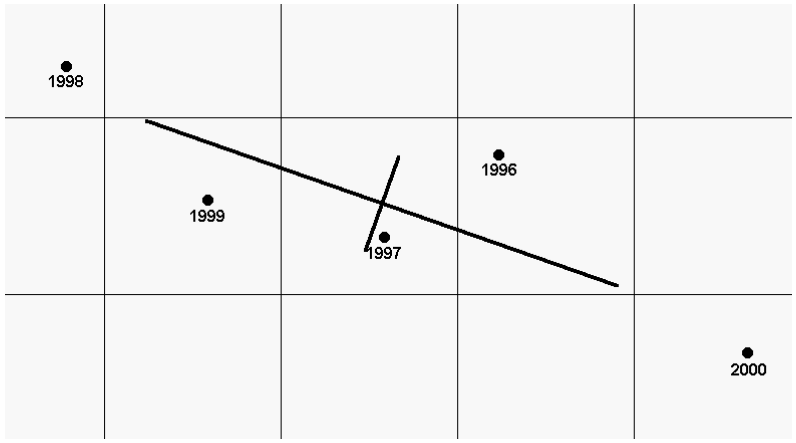


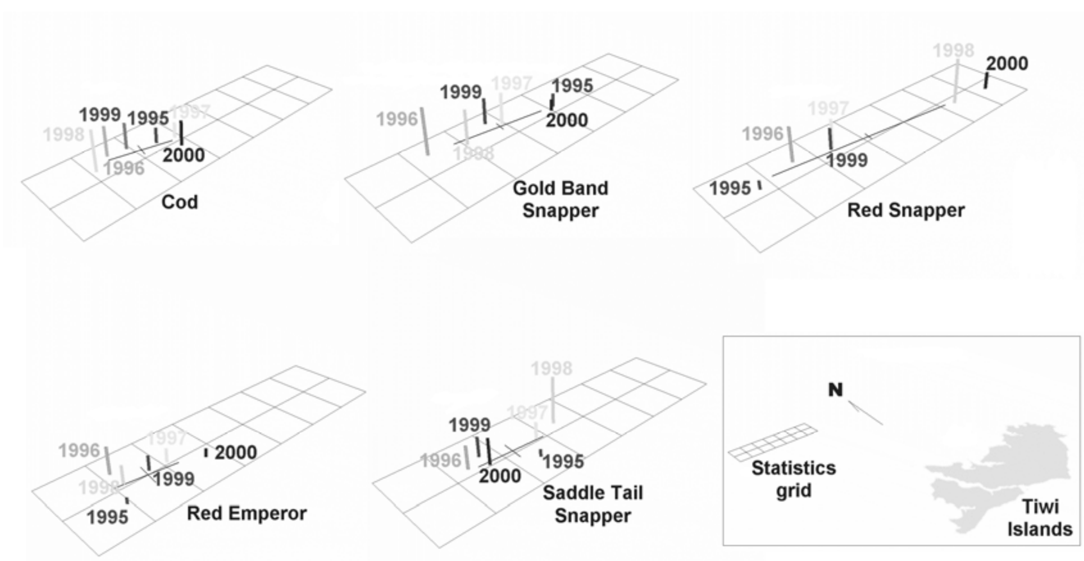
Figure 6: Spread and directional bias of the early 3DWMs of drop line catch data displayed in Figure 5 are visualised by their Standard Deviational Ellipse (SDE). The ratio of the long to short axis of the SDE quantifies the directional bias of the group of points. The bearing of the long axis measures the direction of this bias.

When these results were presented to Fisheries the audience noticed how *Figure 5* improved on their previous strategy which consisted in applying a suitable weighting to fish trap data prior to merging them with drop line data. The reliability of this approach would be dubious at best, as a suitable weighting may be a very elusive parameter.

A number of issues had to be addressed:

- effect of variability in data records
- influence of changing weather patterns

The next phase of the study targeted five species and data was provided by four different fishermen, between 1995 and 2000. SDEs are introduced as they help visualising and comparing trends in a multi



species study.

Figure 7: 3DWMs and SDEs are all within a subset of the original survey grid. The columns are 3DWMs extruded in 3D Analyst by an amount proportional to the catch. Catch scales are not constant across species as the aim is not to compare catches across species but to highlight possible trends.

The five species show different patterns. The best fishing spots associated with Gold Band Snapper, for instance, are less spread out than those for Red Snapper. The latter displays a stronger directional bias. Quantitative comparisons, however, would provide a better framework to compare these five species. Metrics need to be derived from spatial statistics displayed in *Figure 7*.

3.0 3D SPACE OF OVER HARVESTING RISK

3.1 Deriving dimensions of a 3D over harvesting space

The comparison of the five species displayed in *Figure 7*, in terms of the catch data provided by professional fishermen, can be made by reference to:

- the variations in 3DWMs both in amplitude (height of extruded point) and distance between successive values;
- the spread and direction of 3DWMs reflected in the characteristics of the SDE (direction and length of major axis, ratio of major to minor axis)

The Red Emperor and Saddle Tail for instance display similar spreads of 3DWMs, but their patterns of 3DWMs amplitude differ. The Red Snapper displays a more elongated SDE.

Clearly, the above qualitative comparison has limited applications. Subjectivity and inability to rank species with regard to sensitivity to over harvesting are two major weaknesses of the above approach.

A quantitative comparison can be articulated around indices directly derived from 3DWMs and SDEs calculated above. Three indices were created on the basis of what can be logically expected from species at risk of being over harvested. Obviously this logic is largely dictated by one's background. The following indices ought to be considered within the context of a concept feasibility study rather than on the basis of their relevance to marine biological processes.

From 3DWMs two indices could be derived:

- index A (reflects the drop in annual catch)

  $A = (Z_{max} – Z_{latest})/Z_{max}$

  where Z is the amplitude (weighted average catch) of a 3DWM

  Z_{max} = maximum Z value of all 3DWMs for the species considered

  Z_{latest} = most recent Z value of all 3DWMs for the species considered

  $A \cong 0 \Rightarrow$ near constant annual catch (low risk of over harvesting)

  $A \cong 1 \Rightarrow$ very large drop in fish catch

- index B (reflects the magnitude of the latest horizontal displacement of the best fishing zone)

  $B = (D_{Latest} - D_{Min})/ D_{Latest}$

  D_{Latest} = horizontal distance between two latest 3DWMs

  D_{Min} = minimum distance between two consecutive 3DWMs

  $B \cong 1 \Rightarrow$ very large latest migration of best fishing zone

  $B \cong 0 \Rightarrow$ very low latest migration of best fishing zone (low risk of over harvesting)

From SDE:

  Index C (reflects the directional bias of the yearly weighted average location of the best catches)

  C = (Major Axis – Minor Axis)/Major Axis

  $C \cong 0 \Rightarrow$ no directional bias $\Rightarrow$ ubiquitous species (low risk of over harvesting)

  $C \cong 1 \Rightarrow$ strong directional bias $\Rightarrow$ restricted habitat

Indices A, B and C become the three dimensions X, Y, Z (blue, yellow, purple edges) of a cube within which yearly catches of commercial species were visualised using the 3D Analyst extension for ArcView.

Point (0,0,0), the intersection of the three coloured edges below, is the pole of lowest risk (LR) of over harvesting. Point (1,1,1), diagonally opposite to (0,0,0), is the pole of highest risk (HR) of over harvesting. The tree indices A, B and C are normalised (values are always between 0 and 1), therefore all points are always within the cube. Displaying these three indices side by side, below, highlights their common structure:

$A = (Z_{max} – Z_{latest})/Z_{max}$ $B = (D_{Latest} - D_{Min})/ D_{Latest}$ C = (Major Axis – Minor Axis)/Major Axis

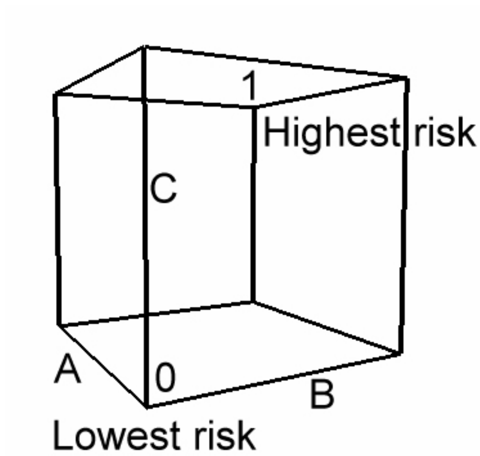


Figure 8: Indices A, B and C are the dimensions of "Over Harvesting Space" (OHS). This framework takes advantage of the 3D visualisation capability provided by the 3D Analyst extension for ArcView.

Variations along the three axes can be interpreted as follows:

- an increase along the A axis reflects a drop in annual catch (represented by the Z coordinate of the 3DWM)
- an increase along the B axis reflects a larger displacement (relatively to the previous year) of the best fishing grounds
- an increase along the C axis reflects catches limited to locations displaying an increasingly marked directional bias (that is a shrinking habitat)

3.2 Indices computation

Deviational ellipses and 3DWMs displayed in *Figure 7* provide the initial data from which indices A, B, C, defined previously, are calculated.

	A	B	C	D	E	F	G	H	I	J
1	SPECIES	POINTS	X_COORD	Y_COORD	Z_COOR	YEAR	Zlatest	Zmin	Zmax	A = (Zmax - Zlatest)/Zmax
2	Gold Band +	2035	597353.1121	8879163.3808	25.7100	2000	25.7100	25.7100	98.3945	0.738704907
3	Gold Band +	2553	584635.5240	8884650.1990	57.7150	1999	57.7150	25.7100	98.3945	0.413432661
4	Gold Band +	8853	577934.4089	8881618.1431	74.9840	1998	74.9840	25.7100	98.3945	0.237924884
5	Gold Band +	4779	586979.0359	8882441.1630	69.4611	1997	69.4611	25.7100	98.3945	0.294055054
6	Gold Band +	2979	570998.9803	8883942.4999	98.3945	1996	98.3945	25.7100	98.3945	0
7	Gold Band +	2237	598722.0806	8880012.4679	31.3751	1995	31.3751	25.7100	98.3945	0.681129535
8	Cod	283	585312.3887	8876413.1868	5.8370	2000	5.8370	3.5923	9.1434	0.361616029
9	Cod	512	576879.7935	8883176.5393	5.9830	1999	5.9830	3.5923	9.1434	0.345648227
10	Cod	1811	568557.1564	8881126.4614	9.1434	1998	9.1434	3.5923	9.1434	0
11	Cod	1701	586290.8079	8879525.9171	3.5923	1997	3.5923	3.5923	9.1434	0.607115515
12	Cod	547	572732.3918	8883739.2130	6.8915	1996	6.8915	3.5923	9.1434	0.246286939
13	Cod	247	582379.0864	8880638.2604	3.6290	1995	3.6290	3.5923	9.1434	0.603101691

a)

	A	B	C	D	E	F
1	SPECIES	YEARS	LENGTH	Dlatest	Dmin	B = (Dlatest - Dmin)/Dlatest
2	GB	1999 to 2000	14329.359	14329.359	6592.368	0.539939784
3	GB	1998 to 1999	6592.368	6592.368	6592.368	0
4	GB	1997 to 1998	9102.642	9102.642	6592.368	0.27577422
5	GB	1996 to 1997	16262.445	16262.445	6592.368	0.594626269
6	GB	1995 to 1996	27998.172	27998.172	6592.368	0.764542914
7	SA	1995 to 1996	12837.282	12837.282	3239.187	0.747673456
8	SA	1999 to 2000	3239.187	3239.187	3239.187	0
9	SA	1998 to 1999	17117.876	17117.876	3239.187	0.810771675
10	SA	1997 to 1998	6333.492	6333.492	3239.187	0.488562234
11	SA	1996 to 1997	14518.453	14518.453	3239.187	0.776891725
12	RE	1999 to 2000	10574.829	10574.829	5501.844	0.479722651
13	RE	1998 to 1999	5501.844	5501.844	5501.844	0
14	RE	1997 to 1998	9188.574	9188.574	5501.844	0.401229832
15	RE	1996 to 1997	10135.484	10135.484	5501.844	0.457170077
16	RE	1995 to 1996	8907.523	8907.523	5501.844	0.382337379

b)

c)

	A	B	C	D	E
1	PO	YEARS	SPECIES	LENGTH	C = (Major Axis - Minor Axis)/Major Axis
2	1	95 to 2000	Sa	14426.751	0.668
3	2	95 to 2000	Sa	4786.814	
4	1	95 to 99	Sa	14890.627	0.653
5	2	95 to 99	Sa	5172.959	
6	1	95 to 98	Sa	5128.710	0.656
7	2	95 to 98	Sa	14926.161	
8	1	95 to 97	Sa	12730.314	0.657
9	2	95 to 97	Sa	4363.885	
10	1	95 to 2000	Re	12450.229	0.564
11	2	95 to 2000	Re	5432.738	
12	1	95 to 99	Re	5258.936	0.390853776
13	2	95 to 99	Re	8633.290	
14	1	95 to 98	Re	5863.438	0.351
15	2	95 to 98	Re	9031.678	
16	1	95 to 97	Re	6723.808	0.342
17	2	95 to 97	Re	10214.037	

Figure 9 (a, b, c): Samples of spreadsheets used to evaluate indices A, B and C from 3DWMs, distances between successive 3DWMs and deviational ellipses.

Indices A, B, C are then assigned to each of the five species studied for each year from 1997 to 2000 as shown in *Figure 10*.

	A	B	C	D	E
1	SPECIES	YEAR	A	B	C
2	Gold Band + Sharp Tooth	2000	0.738705	0.468969	0.870423
3	Gold Band + Sharp Tooth	1999	0.413433	0	0.864379
4	Gold Band + Sharp Tooth	1998	0.237925	0.190139	0.931865
5	Gold Band + Sharp Tooth	1997	0.294055	0.541747	0.969023
6	Gold Band + Sharp Tooth	1996	0	0.737318	
7	Gold Band + Sharp Tooth	1995	0.68113		
8	Cod	2000	0.361616	0.20707	0.744544
9	Cod	1999	0.345648	0	0.804619
10	Cod	1998	0	0.518615	0.83965
11	Cod	1997	0.607116	0.396293	0.992443
12	Cod	1996	0.246287	0.154097	
13	Cod	1995	0.603102		

Figure 10: Sample of spreadsheet assigning A, B, C indices to each of the five species studied for each year from 1997 to 2000.

3.3 Visualisation of species trajectories in Over Harvesting Space

The interpretation of fish catch data is sensitive to fluctuations in fish availability which have a number of possible causes. The robustness of a fish catch analytical method is likely to improve if, instead of focusing on numbers of fish caught, the emphasis is shifted to the comparison of species response to harvesting. Moving away from actual fish catch figures can be achieved by working with indices A, B, C (different definitions could be tried) which, although derived from fish catch data, are less sensitive to fluctuations. Indices A, B, C defined previously are now put to the test and some potential applications are briefly discussed.

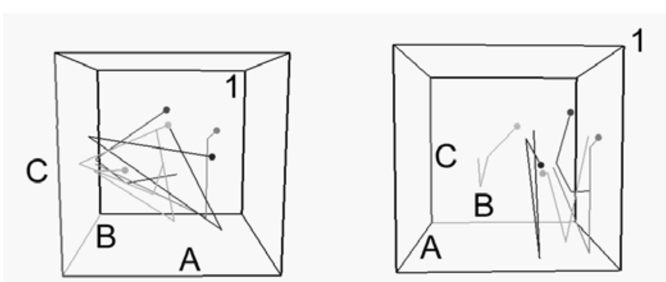


Figure 11: Using the symbology of Figure 7, the two views above show the trajectory of five species under investigation between l997 and 2000 (visualized by a dot). Only 4 points are available for each species as indices based on comparison between successive years reduce the total number of coordinates. In addition, only three distances can be measured between four successive points.

Trajectories in *Figure 11* appear entwined (left) while rotating the cube highlights shared properties in other dimensions. Trajectories appear to be in somewhat parallel planes (right). These trajectories can be separated along the B axis but patterns develop in A C dimensions.

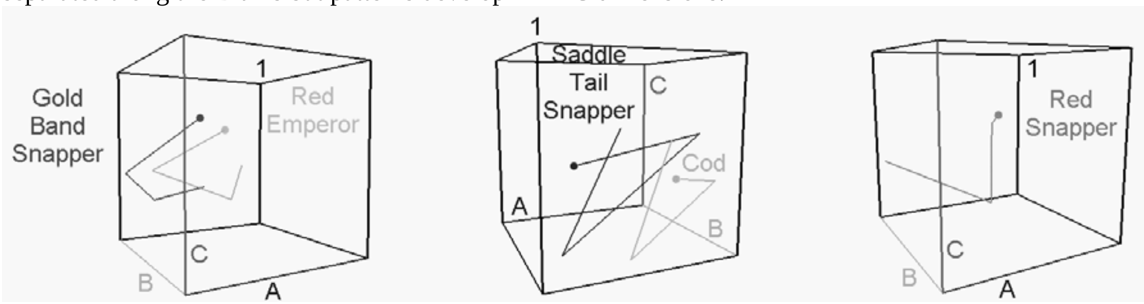


Figure 12: Three dimensional views highlight patterns shared by some species.

Viewing species two at a time in this 3D space highlights common features between species. *Figure 12* shows, on the left, a remarkable similarity between Gold Band Snapper and Red Emperor while the central cube shows how much the trajectory of Cod resembles the one of Saddle Tail. Red Snapper, on the right, is clearly the odd one out as its trajectory does not look like any of those previously displayed.

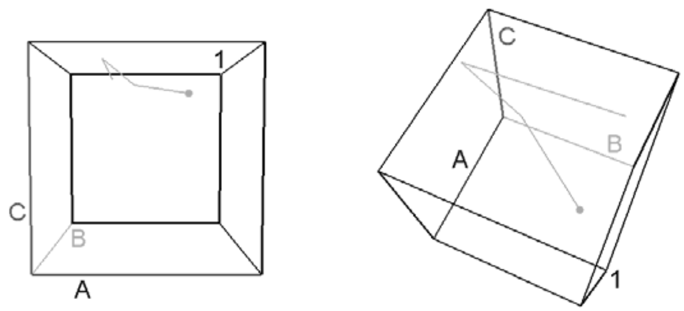


Figure 13: Trajectory of the assemblage of Cod, Saddle Tail, Red Snapper, Red Emperor and Gold Band Snapper.

Finally the trajectory of the whole fishing ground, for the assemblage of five species considered, can be evaluated by calculating each year the 3DWM of the 3DWMs of the five species for the year considered. The calculations displayed in *Figure 9* are then repeated and the trajectory of the whole fishing ground can be plotted in three dimensions as demonstrated in *Figure 13*.

4.0 DISCUSSION

This study deliberately ignores ancillary data (weather patterns, surface temperature …etc) which will be incorporated in further investigations.

Nowadays, professional fishermen use electronic fish finders. For the past seven years, in the Northern Territory, professional fishermen have been required to record, in their logbooks, latitude, longitude and species composition at each fishing spot. This constitutes at present, in absence of independently recorded information, the most useful estimate of fish stocks. Professional fishermen use electronic fish finders, they actively look for fish and therefore selected fishing spots can be seen as snapshots of relative abundance of fish stocks.

3DWMs and SDEs facilitate the visualisation of possible patterns in the fish catch data sets. However it rapidly became obvious that quantifying observed patterns was necessary to compare species and ultimately assess the risk of over harvesting. The use of ratio indices was prompted by their conceptual simplicity. In Remote Sensing, the Normalised Difference Vegetation Index, or NDVI (Schowengerdt, 1997) is one of a collection of vegetation indices which allow quick comparisons of vegetation characteristics between similar satellite images although vegetation reflectance in a single band, on its own, would provide flawed results. A similar reasoning is expected to facilitate comparisons between fishing grounds located in the same biophysical regions of the Northern Territory coast.

The approach adopted here does not seem to have been trialed previously. The comprehensive bibliography by Valavanis (2002) does not mention the use of 3D visualisation nor the calculation of over harvesting indices in GIS anaysis/modeling of fisheries sustainability.

The definition of the three indices A, B and C was arbitrary. The decision was made not to seek input from fisheries stakeholders in order to avoid definitions tainted by preconceived views. The reasoning behind the definition of these indices is subjective but can be modified to incorporate specific assumptions in relation with the risk of over harvesting.

Two of these three indices are derived from spatial statistics: B and C are respectively derived from 3DWM and SDE calculations. The first index, A, only reflects variations in average yearly catch. There is therefore no limitation to the inclusion of indices derived from a variety of non spatial ancillary data. Although deriving more than three dimensions relevant to the risk of over harvesting is attractive, for the purpose of easy visualisation it remains preferable to display a maximum of three dimensions at once. Visual displays, an important function of GIS, are useful, at an exploratory stage, to help formulate working hypotheses. The analysis of 3D trajectories displayed in *Figure 11* and *12* appears to confirm that we are indeed looking at a classification of commercial fishes based on their response to fishing pressure:

- Gold Band Snapper and Red Emperor in *Figure 12* are two most sought after species of this group of five
- Red Snappers tend to be avoided as they take baits that would otherwise attract other species, such as Gold Band Snapper, they often mingle with
- Cod and Saddle Tail are species of intermediate value

The above observations are encouraging as there appears to be, in that instance, a good agreement between the classification of species in OHS and their commercial ranking which can be considered, in first approximation, as a surrogate for fishing pressure.

Observing similar trajectories among commercial species may have applications to the management of fisheries:

- an operational classification of commercial species, on the basis of their response to fishing pressure, could improve the efficiency of research on over harvesting
- one of a group of species that share the same trajectory can be selected as representative of the whole class of species showing comparable patterns

Further analysis would, however, more conveniently be carried out in 2D space, the third dimension providing magnitude/elevation. A GIS is therefore particularly well suited to this multidimensional exploration of fish catch data sets.

The evolution of different fishing grounds can then be explored by comparing simple diagrams which integrate many characteristic variations to reflect the effects of commercial harvesting on a selected number of commercial species used as barometers of over harvesting. Using an assemblage of species is an attractive proposition as it minimizes the impact of fluctuations in one species. This approach could provide a holistic estimate of the health of a fishery. This could help define trigger-points which, being well documented in the better known fisheries, could lead to proactive management practices. These trigger-points could initiate the enforcement of protective measures before the whole fishery shows alarming signs of decline.

Environmental factors are not included in the above discussion as fishing grounds considered here appear to belong to the same homogeneous marine environment. They should however be included in further studies. GIS are particularly well suited to incorporating multiple layers of information and there is no reason to believe that introducing environmental constraints would substantially affect the potential of the methodology promoted in this study.

5.0 CONCLUSION

Despite the short duration of this pilot project, three of the four original objectives are met:

- merging fish catch data and drop line data was achieved easily although in the present study, due to the recent introduction of fish trap and consequently of unsuitable data sets, only drop line data were used
- successive presentations of GIS processed data to an audience including policy makers, researchers and professional fishermen confirmed that GIS facilitated their understanding of large fish catch data sets

- the low cost pilot project lead to original outcomes and clear management recommendations

The need to measure the risk of over harvesting commercial species remains. Promising research directions, however, are now clearly flagged:

- developing one (or more) 3D Over Harvesting Space (OHS) deemed suitable by all stake holders
- assessing the descriptive and predictive ability of models based on OHS
- establishing representative species assemblages
- defining trigger-points in OHS which management can use to initiate measures aimed at avoiding over harvesting

An alternative classification of commercial species based on their response to fishing pressure suggests that there may be more cost-effective ways of allocating fisheries research funding.

Ultimately this pilot project demonstrates the suitability of GIS as an exploratory tool in fisheries research and management.

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