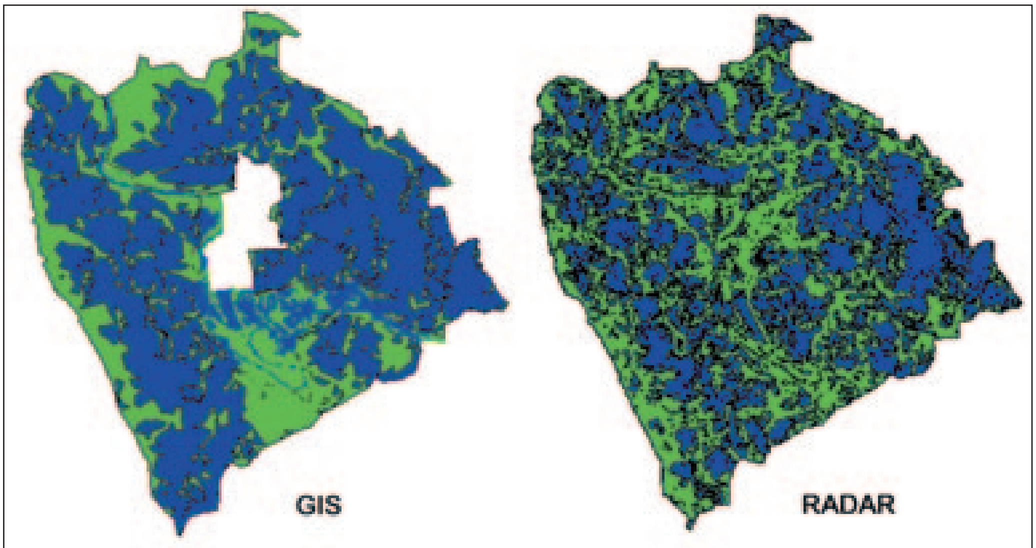
The use of Radar images in floodplain fisheries in Bangladesh

Over the years developments in GIS and remote sensing have been tremendous. One of the most significant developments was radar satellite imaging able to penetrate the clouds. The major advantage is that during the flood season the extend of flooding can be assessed almost realtime from radar images. This is obviously less complicated than the method you have used during the previous exercise (interpolation of water levels over a project area with measured waterlevels at certain points, after which floodmaps need to be made).

A comparison of a flood map calculated with water levels in GIS and a flood map using radar images is presented in Figure 17.40.

FIGURE 17.40
Comparison between calculated flooding and Radar application



Querying radar images

1. Open ArcView, Open a New Project, a New View, check the working directory, and check that the map units and distance units in the View properties are set to meters. Add the Themes (Grid Data Source) 'radarjune', 'radarjuly', 'radaraugust', 'radaroctober', 'radarseptembe', and 'landtype' to the View (from the folder RW_03_Floodplain on your CD). If you want, you can load the legends 'Radar.avl' for the radar Themes, and 'landtype.avl' for the landtype Theme. The radar Themes show you the Radar images[35] for the months June, July, August, September, and October in the year 1998.
2. Query the radar Themes with the landtype Theme and calculate the flooded areas for F3 and F2 landtypes (as you have done in the previous exercise). You can do this either with Map Query (menu bar: **Analysis/Map Query...**) or with Tabulate areas (menu bar: **Analysis/Tabulate Areas...**).
3. Fill in Table 17.8 and compare the results between the calculated catches with radar images and with the generated floodmaps (GIS).

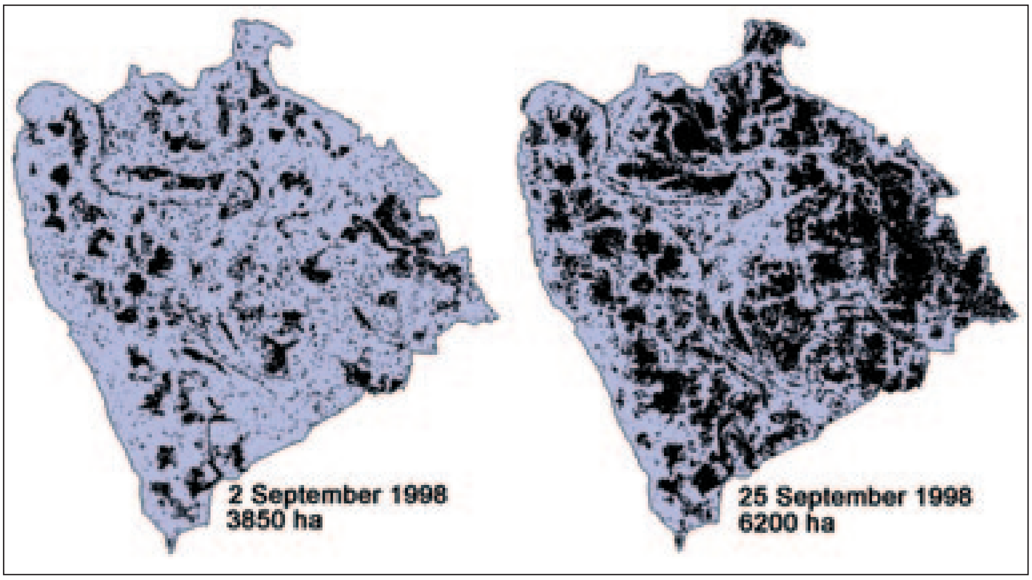
[35] The Images were processed and classified by the Centre for Environment and Geographical Information Systems (CEGIS), Dhaka, Bangladesh and provided by RADARSAT-1 images (c) Canadian Space Agency/Agence spatiale Canadienne 1998. Processed and distributed under licence by RADARSAT International.

TABLE 17.8
Comparison of fisheries analysis using radar or GIS data36

Month	F3 (ha)		F2 (ha)		CPUA (kg/ha/month)		Total Catch Radar (metric tonnes)	Total Catch GIS (metric tonnes)
	Radar	Interpolated	Radar	Interpolated	F3	F2		
June		172	1 404	1 042	22	19		24
July		285	2 300	2 440	16	38		97
August		306	2 428	2 541	13	44		116
September		305	2 419	2 535	14	85		220
October		172	1 280	1 182	220	99		155
Total catch							**632**	**612**

The differences between the two methods are small. The use of radar images could facilitate your work. However you have to realize one thing: Radar images give a flooded area on a given day of the month and not the average flooded area over the month as calculated by using GIS and water levels. The flooded area can be highly variable within one month, which means that the use of radar will only be accurate if more images are available per month. an illustration of different waterlevels in one month can be the radar images of the CPP area of 2 and 25 September 1998 (Figure 17.41).

FIGURE 17.41
Comparison of Radar images for two days in September 1998



[36] The GIS data and the CPUA for 1998 are from de Graaf *et al.*, 2001.

17.2 SURPLUS PRODUCTION MODELS AND GIS

Introduction

For the development of a fisheries management strategy, fisheries scientists and policy makers want to know what the present status of fish stocks is, and what the impact of fishing on these will be. Over the last decades a number of tools, or fish stock assessment models, have been developed that can visualize the interactive processes between fishing and fish stocks. One of these is the Surplus Production model.

The traditional surplus production models are those of Schaefer (1954) and Fox (1970). Surplus production models determine the optimum level of effort that produces the maximum yield that can be sustained without affecting long term productivity of the stock, also called Maximum Sustainable Yield (MSY). Further, surplus production models regard catch per unit of effort (CPUE) in relation to the fishing effort as basic input and assumes that biomass is proportional to the catch per unit of effort (f).

The surplus production models can be applied when reasonable estimates are available of total catch (by species), the catch per unit of effort (CPUE), and the related fishing effort (f) over a number of years. A prerequisite is that the effort must have undergone substantial changes over the period covered. Detailed information on surplus production models can be found in Sparre and Venema (1992) of which the basics are summarized below.

The Schaefer model plots CPUE as a function of the fishing effort (f) on a linear model with the form:

Y= a+bX, or, **CPUE = a + b* (fishing effort).**

Calculated Yield, Maximum Sustainable Yield (MSY) and the fishing effort for MSY (F**msy**) can then be expressed as:

Calculated Yield = a*(fishing effort)+b*(fishing effort)^2

Fmsy = - 0.5*a/b

MSY = - 0.25*a^2/b.

An example of a Schaefer curve, made for shrimp trawling in the Bay of Bengal (Table 17.9, [Mustafa and Khan, 1993]), is given in Figure 17.42.

TABLE 17.9
Shrimp trawling data from the Bay of Bengal

Year	Number of Trawels	Shrimp catch *(metric tonnes)*	CPUE *(metric tonnes/ trawler)*
1984	31	3 716	120
1985	31	4 178	135
1986	33	4 239	128
1987	33	3 338	101
1988	35	4 661	133
1989	37	2 621	71
1990	37	3 903	105
1991	40	3 116	78
1992	41	3 650	89
1993	41	3 237	79

FIGURE 17.42
Schaefer curve shrimp trawling in the Bay of Bengal

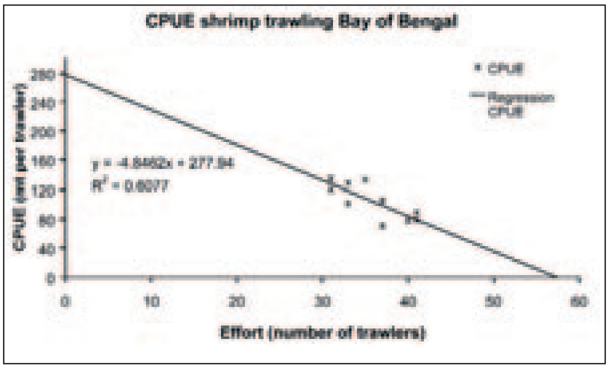
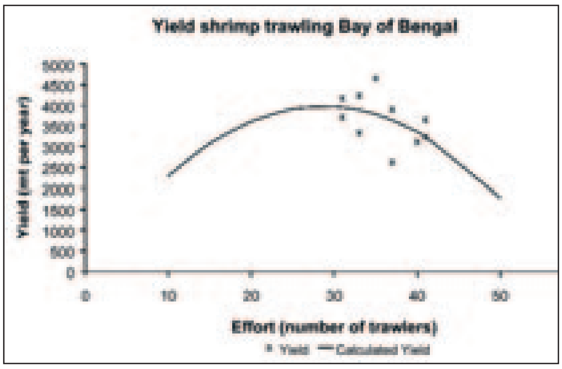


FIGURE 17.43
Yield curve shrimp trawling in the Bay of Bengal



Analysis gives:
CPUE = -4.85 * (Fishing effort) + 278 → **a = 278, b = -4.85**
Calculated Yield = a*(fishing effort)+b*(fishing effort)^2 → 278 * f + (-4.85) * f^2
F**msy** = -0.5*a/b → -0.5 * (278/(-4.85)) = **33 trawlers**
MSY = -0.25*a^2/b → -0.25 * (278*278)/(-4.85) = **3960 metric tonnes/year.**

The Munro and Thompson adaptation of Surplus Production models

Surplus production models are usually applied to long time series of CPUE and Effort. Munro and Thompson (1983a and 1983b), however, applied the surplus production models to a set of data from the Jamaican coral reef fisheries, all collected in the same year but representing different fishing grounds fished at different levels of effort. The basic assumptions for this adaptation of the Surplus production models are:

- The studied species are not very mobile, so each area has its own stock not mixing with the neighbouring stocks.
- The ecological regimes of different fishing grounds do not differ substantially, so the only differing impact on the stocks is the difference in fishing effort among the fishing grounds.

The fishery studied by Munro and Thompson (1983b) is a local trap fishery operated from canoes. Coral reef fish are not considered to be very mobile and it was assumed that each area has its own stocks which are independent of the neighbouring stocks (little mixing). The data used by Munro and Thompson and the resulting Schaefer curves are presented in Table 17.10 (Munro and Thompson, 1983a), Figure 17.44, and Figure 17.45.

TABLE 17.10
Jamaican reef fisheries data

Fishing ground	Effort (canoes/km^2)	CPUE (kg/canoe per year)	Exploitation
A	1.63	2 367	Under exploited
B	0.38	3 279	Under exploited
C	3.09	1 407	Under exploited
D	5.63	556	Over exploited
E	4.43	974	Over exploited
F	5.51	1 306	Over exploited
G	4.58	564	Over exploited
H	4.20	767	Over exploited
I	1.49	1 875	Under exploited

FIGURE 17.44
Schaefer curve reef fisheries Jamaica

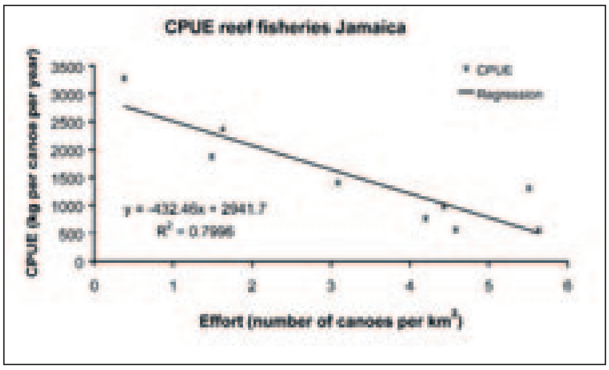
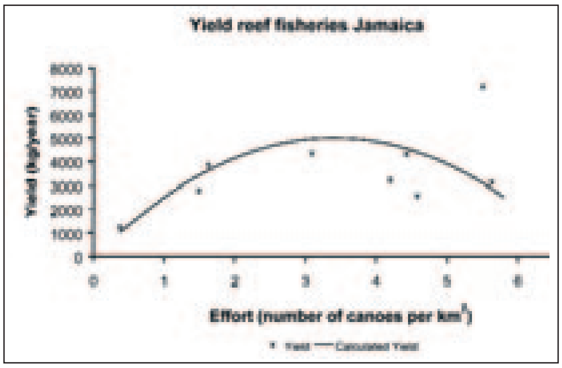


FIGURE 17.45
Yield of reef fisheries Jamaica



From the data and the Schaefer plot the following data can be deducted:
CPUE = 2 941.7 + [(-432.46) * (fishing effort)] → **a = 2 941.7, b = -432.46**
Calculated Yield = a*(fishing effort)+b*(fishing effort)^2 → 2941.7 * f + (-432.46) * f^2
F**msy** = -0.5*a/b → -0.5 * (2 941.7/(-432.46)) = **3.4 canoes per km^2**
MSY = -0.25*a^2/b → -0.25 * [(2 941.7*2641.7)/(-432.46)] = **5 002.5 kg per year.**

The Munro and Thompson adaptation of the Surplus Production models are not commonly known and used. However, it is clear that with the present development of GIS, they offer an opportunity to get some insight of the status of stocks within a relatively short time span (keeping in mind that the basic assumptions mentioned earlier should apply).

Therefore, two examples of this application will follow, one with Pais Pesca data and one using Mediterrenean fisheries data.

17.2.1 Fisheries on the Pescan lobster (*Cherax grafiensis*) in Lake Kadim

Apart from fisheries on carps and clupeids there is a small but highly valuable fishery on the Pescan lobster *Cherax grafiensis* in Lake Kadim. This fishery has the following characteristics:

- *Cherax grafiensis* is rather immobile. Tagging experiments have revealed that the lobsters remain in an area of about 3 km^2 during their whole life.
- *Cherax grafiensis* lives in water up to six metres deep, and its distribution is not related to other ecological factors such as phytoplankton, secchi disk, etc.
- The lobsters are caught by stationary traps placed on the bottom of the lake.

During the survey of the Department of Fisheries in 1999 (see page 70), the number of lobster traps were counted (Number of traps per ha) at the sampling areas and the owners of the traps were interviewed to get information on their annual catch (kg/year).

The spatial characteristics of the fishery allow analysing the data in GIS with an adapted Schaefer curve. For this the data were distributed over nine fishing zones, which are determined by the boundaries of the fishing areas of fishers from the villages located at the shore line of each zone.

There are two ways to carry out the analysis:

- Calculate the average values of fishing effort and CPUE per fishing zone with the data of the sample stations[37]. Construct a Schaefer curve and use the calculated values of **a** and **b** to calculate the F_{msy} (= -0.5*a/b). Interpolate a grid of the number of traps per ha (within the boundaries of the fishing zones) and find the over-exploited areas with the query: **[Number of traps per ha] > [F_{msy}]**.
- The second way is to generate the grids for **CPUE** and **Number of traps per ha**. Then carry out a grid regression between the two and use the obtained values of **a** and **b** to calculate **F_{msy}**. The last step is to query the effort grid to find the over- and under-exploited areas (under-exploited: **[Number of traps per ha] < [F_{msy}]**).

This second method is demonstrated below:

1. Start ArcView, Open a New Project, New View. Add the following Themes from the '18_Lake_Kadim_Lobster' folder: 'Lobster data.shp' (containing all lobster data from the different sampling sites in Lake Kadim), 'depth.shp', 'fishing zones.shp', 'fishing villages.shp', 'Lake Kadim boundary.shp', and 'Pais pesca country.shp'.
2. Check the working directory, the projection (Equal area cylindrical), and properties settings.
3. Make the 'Fishing zones.shp' Theme active, and use the 'Zoom to active Theme(s)' button in the buttonbar to zoom to this Theme.
4. As you are going to work within the fishing zones only, you will first need to make a grid of the 'Fishing zones.shp' Theme[38] (output grid size 100 metres, so each pixel equals 1 hectare). Save this grid as 'Zones'.
5. Set the grid 'Zones' as mask. (Analysis/Properties...).
6. Make the Theme 'Lobster data.shp' active, and make a surface grid[39] of the 'CPUE' with 'IDW' and a 100 metres grid cell size, with the Output Grid Extent: Same As Display. Rename the new grid (Theme/Properties...) and save and rename the Theme as 'CPUE' (Theme/Save Data Set...).
7. Make another grid for fishing effort ('Number of traps per ha', you will see only 'Number_of_' in the drop-down field) and save and rename the grid as 'Effort'.
8. Activate the Grid Regression extension (File/Extensions...).

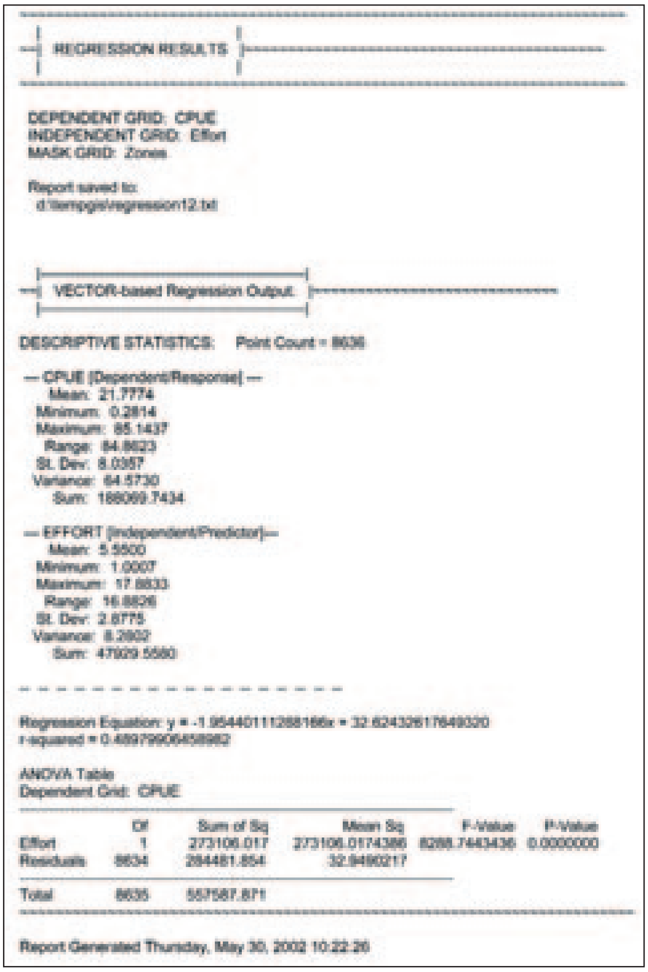
[37] See Calculating Averages in a Theme table at page 127.

[38] Make the Theme 'Fishing zones.shp' active, go to Theme/Convert to Grid... in the menu Bar, name your file ('Zones'), Output Grid Extent: Same As Display, Output Grid Cell Size: 100 m, Conversion Field: 'Zone_code', Join feature attributes to Grid, Add Grid as Theme to the View.

[39] Also create this grid with Kriging, see Annex C.

9. Click on the regression button and make a regression with CPUE as dependent and effort as independent. (see the chapter: Regression analysis of Lake Kadim data using an avenue script, page 84). The results should be like Figure 17.46 and Figure 17.47.

FIGURE 17.46
Regression result outcome

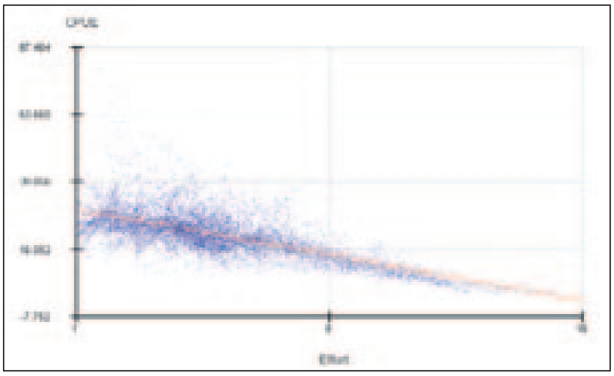


```
REGRESSION RESULTS

DEPENDENT GRID: CPUE
INDEPENDENT GRID: Effort
MASK GRID: Zones

Report saved to:
  d:\tempgis\regression12.txt

VECTOR-based Regression Output:

DESCRIPTIVE STATISTICS:    Point Count = 8636

 — CPUE [Dependent/Response] —
     Mean: 21.7774
  Minimum: 0.2814
  Maximum: 85.1437
    Range: 84.8623
  St. Dev: 8.0357
 Variance: 64.5730
      Sum: 188069.7434

 — EFFORT [Independent/Predictor]—
     Mean: 5.5500
  Minimum: 1.0007
  Maximum: 17.8833
    Range: 16.8826
  St. Dev: 2.8775
 Variance: 8.2802
      Sum: 47929.5580

- - - - - - - - - - - - - - - - - -

Regression Equation: y = -1.95440111288166x + 32.62432617649320
r-squared = 0.48979906458982

ANOVA Table
Dependent Grid: CPUE
```

	Df	Sum of Sq	Mean Sq	F-Value	P-Value
Effort	1	273106.017	273106.0174386	8288.7443436	0.0000000
Residuals	8634	284481.854	32.9490217		
Total	8635	557587.871			

Report Generated Thursday, May 30, 2002 10:22:26

FIGURE 17.47
Scatterplot regression

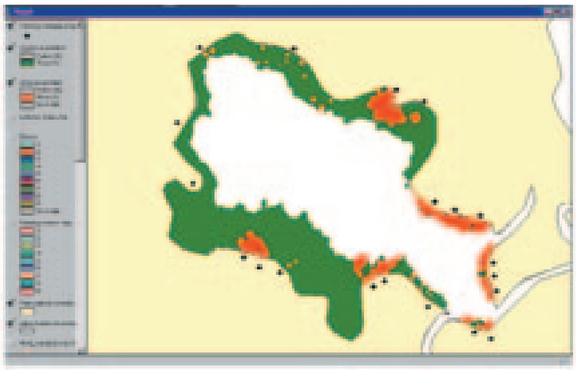


10. Use the obtained values of **a** and **b** to calculate F_{msy}, and MSY[40].
11. Find over- and under-exploited areas, using the Map Query function (**<u>A</u>nalysis/Map <u>Q</u>uery...**) (over-exploited: effort > F_{msy}, under-exploited: effort < F_{msy}. (Figure 17.48)).

[40] If you did the analysis correct, you have found the F_{msy} = 8.35, MSY = 136.1.

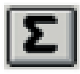
This example has given clear results. However, in the real world, cases with such nice results are not easy to find. Regressions between grids often provides a cloud of points, and zonation is often not that easy and clear-cut. But even in those cases there are some new developments which can be applied on Surplus production models in GIS. Therefore a more complex example of fisheries in the Mediterranean Sea is provided.

FIGURE 17.48
Exploitation status of lake Kadim, areas in green underexploited, areas in red over-exploited.



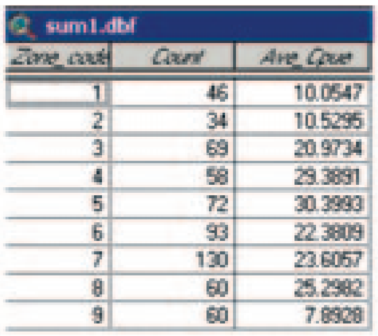
Note: Calculating averages in a Theme table

ArcView has a very neat function to calculate averages within a Theme table. This is best explained through an example:

1. Start ArcView, Open a New Project, New View. **Add** the following Theme from the '18_Lake_Kadim_Lobster' folder: 'Lobster data.shp' (containing all lobster data from the different sampling sites in Lake Kadim). You will see the fieldheaders: 'Shape', 'Id', 'Zone_code', 'Cpue', 'Attractor', and 'Number_of_'. Check the working directory.
2. Press the header of the field 'Zone_code', so that it appears pressed. Go to the summarize function (menu bar: **Field/Summarize...**, or the summarize button in the button bar next to the calculator). The Summary Table Definition window will pop up.

3. Select the field in the dropdown list next to 'Field:' of which you want to know the average per 'Zone_code'. Select 'Cpue'. Then you need to select the function in the dropdown list next to 'Summarized by:' by which the field needs to be summarized, in this case 'Average'. then press **Add**, and you will see the term 'Ave_Cpue' appear. Press **OK**.

The screen of sum1.dbf appears with the average values of CPUE per zone (Figure 17.49).

FIGURE 17.49
Summary of 'Lobster data.shp' per fishing zone

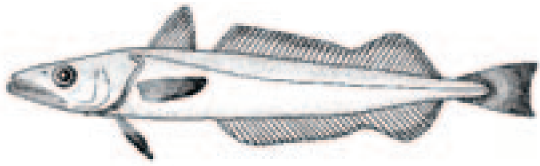

sum1.dbf

Zone_code	Count	Ave_Cpue
1	46	10.0547
2	34	10.5295
3	69	20.9734
4	58	29.3891
5	72	30.3993
6	93	22.3809
7	130	23.6057
8	60	25.2982
9	60	7.8928

17.2.2 Fisheries on the European hake (*Merluccius merluccius*) in the Mediterranean Sea

The European Hake (*Merluccius merluccius*) is a highly valuable demersal fish in the Mediterranean Sea. It lives close to the bottom, usually between 70 and 370 metres at daytime but moves off bottom at night.

FIGURE 17.50
The European hake (*Merluccius merluccius*)



European hake has been an important food for the western Europe population throughout history. It is primarily caught by bottom and pelagic trawls, but also with longlines, bottom-set gillnets and Danish seines. The total reported catch for this species was 71 627 metric tonnes for the year 2000. The countries with the largest catches in this period were Spain (24 853 metric tonnes) and Italy (9 291 metric tonnes) (FAO, 2000). During the mid-1990s several experimental surveys were carried out near the Tyrrenian coast of Italy. With this data Corsi, Agnesi and Ardizzone (2001) developed another approach to surplus production models in GIS.

A Munro and Thompson plot for Hake data in the Mediteranean

Corsi (2000a) carried out an analysis in GIS on catch and effort data obtained over the period 1994-1996. The following data were used:

- Port (being the main landing sites of the different fishing zones) statistics. The data encompass fishing effort expressed in gross tonnage of the trawling fleet per km^2, and CPUE expressed in kg per hour of trawling.
- Data of three experimental trawl surveys carried out at 130 georeferenced randomly selected sampling stations. The mean yields per hour were interpolated by means of Universal Kriging over the entire study area to derive a CPUE surface over the entire area.
- A grid representing the fishing effort over the entire study area, made with deductive modeling which allocates the port's nominal fishing effort throughout the port's fishing ground, based on a combined function of depth and distance from the port (Corsi, 2000b).
- Major fishing zones in the area.
- Data of a bathymetric survey, providing the bottom depth over the study area

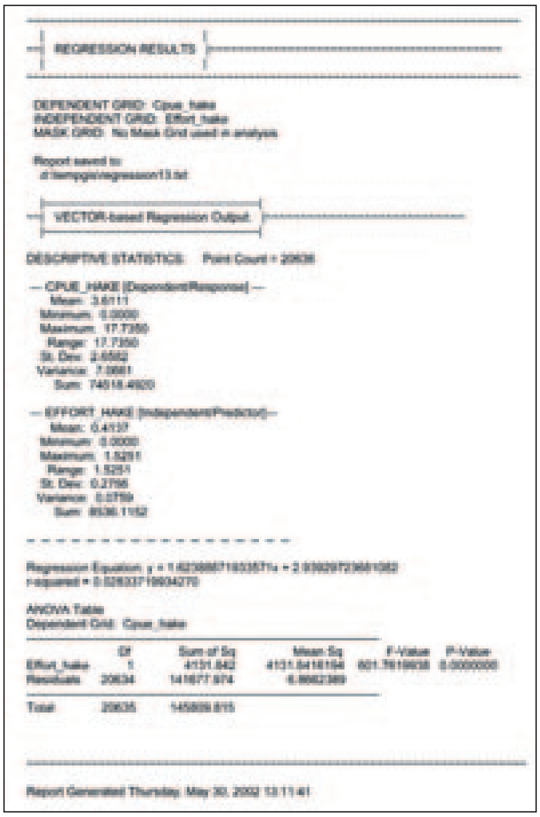
With the available data, i.e. spatial distribution of Fishing effort and CPUE, the Munro and Thompson approach could be used to estimate F_{msy}, and to locate over-exploited areas.

1. Start ArcView, Open a New Project, New View. **Add** the following Themes from the '19_Hake_analysis' folder: 'Fishing zones.shp', 'Ports.shp', 'Coastline.shp' and 'Hake data.shp'.
2. Check the working directory, the projection and activate the Grid Regression extension[41]. While checking the projection you will get an information screen telling you: 'It appears that your data is not in decimal degrees. Do you want to attempt to project anyway?'. Click **No**. This message will appear whenever your data is not in decimal degrees. For this exercise you do not need to project the data. For more information on projections, please see the chapter: Projection, on page 40.
3. The Theme 'Hake data.shp' contains data on the spatial distribution of fishing effort and CPUE. Make two grids from this Theme, one for effort (**Theme/Convert to Grid...**, Gridname: 'Effort_Hake', Output Gird Extent: Same

[41] **File/Extensions...**

As Display, Output Grid Cell Size: 1 000 Map Units, field for cell values: 'Effort'), and the second on CPUE (same parameters, except for the name: 'CPUE_Hake' and the field for cell values: 'CPUE').

FIGURE 17.51
Regression results



REGRESSION RESULTS

DEPENDENT GRID: Cpue_hake
INDEPENDENT GRID: Effort_hake
MASK GRID: No Mask Grid used in analysis

Report saved to:
[illegible]

VECTOR-based Regression Output

DESCRIPTIVE STATISTICS: Point Count = 20636

— CPUE_HAKE (Dependent/Response) —
Mean: 3.6111
Minimum: 0.0000
Maximum: 17.7350
Range: 17.7350
St. Dev: 2.6562
Variance: 7.0561
Sum: 74518.4920

— EFFORT_HAKE (Independent/Predictor) —
Mean: 0.4137
Minimum: 0.0000
Maximum: 1.5251
Range: 1.5251
St. Dev: 0.2756
Variance: 0.0759
Sum: 8536.1152

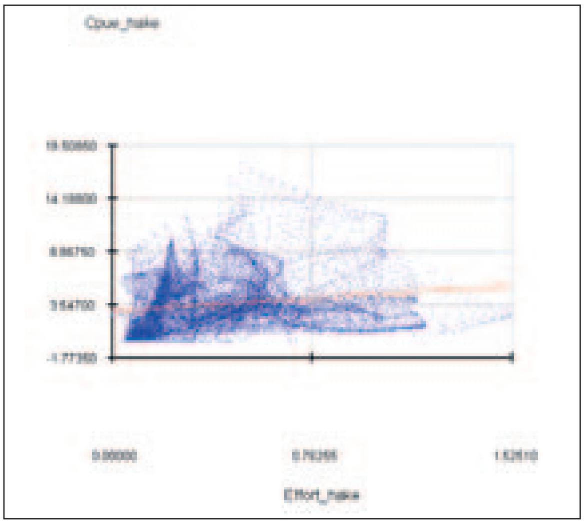
Regression Equation: [illegible]
r-squared = [illegible]

ANOVA Table
Dependent Grid: Cpue_hake

	Df	Sum of Sq	Mean Sq	F-Value	P-Value
Effort_hake	1	4131.842	4131.8416194	601.7619938	0.0000000
Residuals	20634	141677.974	6.8662389		
Total	20635	145809.815			

Report Generated Thursday, May 30, 2002 13:11:41

FIGURE 17.52
Scatterplot regression of 'CPUE_Hake' vs 'Effort_Hake'

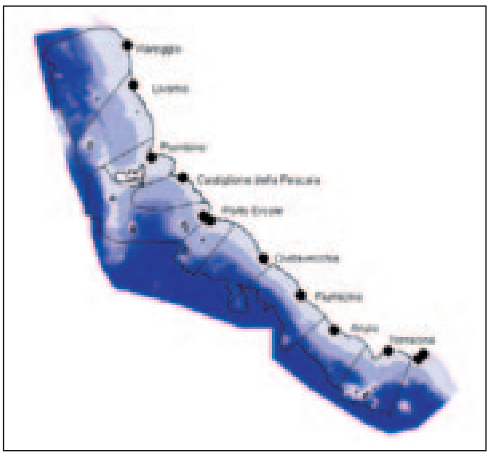


4. Click on the regression button and make a regression with 'CPUE_Hake' as dependent and 'Effort_Hake' as independent.

From the regression analysis (Figure 17.51 and Figure 17.52) you see that the results are not valid for our purpose; the regression has a positive slope (b = 1.62).

5. Add from the '19_Hake_analysis' folder the Theme 'Depth.shp', and make it visible (Figure 17.53). You can see that the fishing zones have a large variation in depth. Hake is a bottom dweller, which means that, for this species, the Fishing Zones are not homogenous ecologically, and thus one of the basic assumptions of the Munro and Tompson model is violated.

FIGURE 17.53
Depths at the Tyrrenean coast



6. Save your project as 'Hake.apr' or another name of your choice.

Developments continue and Corsi (2000a) developed a model to overcome the problem of different ecological fishing zones or varying stock densities. The model is still in its theoretical stage and its merits have to be further studied. However, its simplicity makes it of interest to include it in this manual.

A Corsi type analysis of Hake data in the Mediterranean

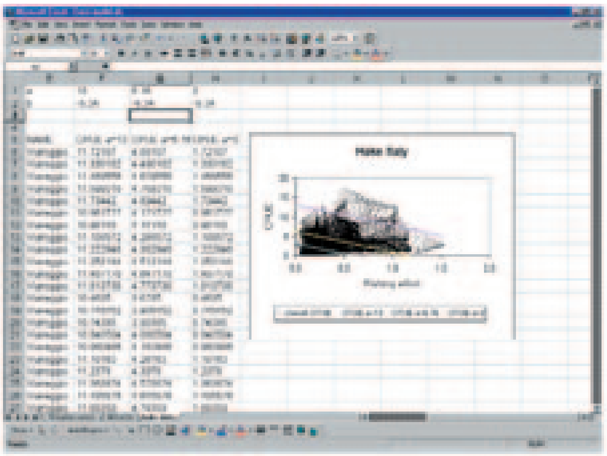
The basic assumption behind the analysis developed by Corsi is that the slope (b) of a Schaefer curve remains constant with different ecological zones while the intercept (a) changes with these zones.

This can be explained with the data in the spreadsheet 'Corsi model.xls'. Open this spreadsheet 'Corsi model.xls' (using Microsoft Excel) from the folder '20_Corsi_model' and open the worksheet 'Schaefer curves'.

In the worksheet, you see the average fishing effort and CPUE per different fishing zones, as obtained from port statistics. Make the Schaefer curve (effort vs CPUE) for the data. Do a lineair regression on the data, of which the result should be Y = 6.16 – 5.34*X (**a = 6.16** and **b = 5.34**), or **CPUE = 5.34 * effort + 6.16**.

Open the worksheet 'hake data'. In this worksheet you see a graph (Figure 16.54) with a cloud of dots, which are the data points of 'Effort vs CPUE' from the Effort and CPUE grid, and three straight lines, three Schaefer curves with the estimated value of the slope; **b = 5.34** and three different values of **a**.

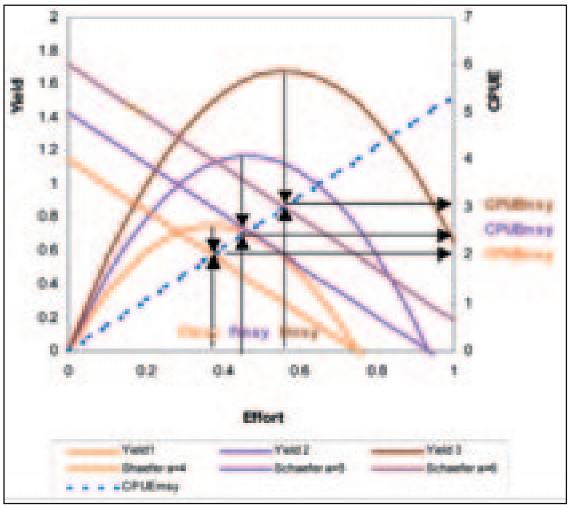
FIGURE 17.54
The worksheet of hake data



For each Schaefer curve F_{msy} and its related CPUE at F_{msy} ($CPUE_{msy}$) can be calculated. This basic function for the Corsi model is described by **$CPUE_{msy}$ = -b * Fishing effort**. This function is called the **attractor**.

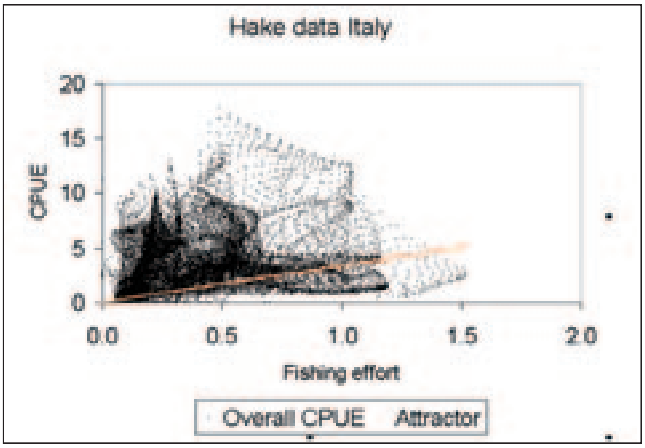
Open another spreadsheet: 'The attractor function.xls'. Yields and CPUE are calculated for three Schaefer curves with the same slope (b) in this spreadsheet. For each curve you see (Figure 17.55) that the relation between F_{msy} and $CPUE_{msy}$ is lying on the straight blue line; **$CPUE_{msy}$ = 5.34 * Fishing effort.**

FIGURE 17.55
The attractor function



If assumed that the cloud of data points for effort vs CPUE for the Hake data is made up of an infinite number of parallel running Schaefer curves for an infinite number of fishing zones then the attractor function can be used to divide the cloud in points below the attractor line, with a CPUE below $CPUE_{msy}$ (or over-exploited points) and above the attractor lines with a CPUE above $CPUE_{msy}$ (or under-exploited points) (Figure 17.56).

FIGURE 17.56
Schaefer curve hake fisheries Thyrrenean coast

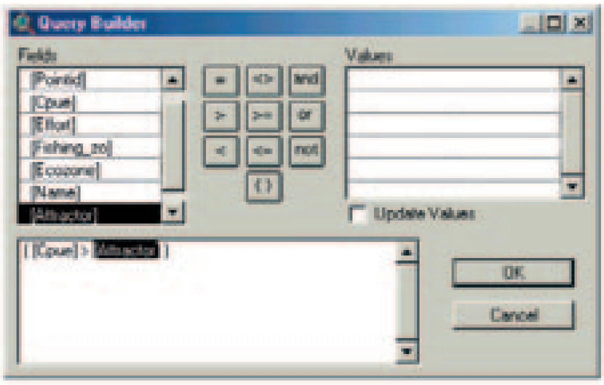


Try to apply the model in ArcView:

1. Open ArcView, open the previously saved project 'Hake.apr'. Add the Theme 'Attractor.shp' from the '20_Corsi_model' folder to the View. Open the Theme Table.
2. Start editing the table. Add the numeric Field 'Attractor' with 4 decimal places.
3. Calculate the field (**Field/Calculate...**) by entering '**[effort] * 5.34**'. Stop editing of the table and save the edits.

FIGURE 17.57

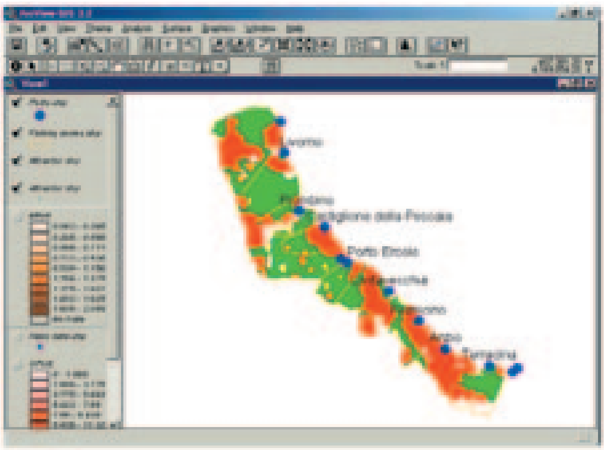
The query for under-exploited areas in the Thyrrenaen Sea



4. Open the Theme properties and make the query '**[CPUE] > [Attractor]**', which gives you the under-exploited data points. Change the color of the data points in green.
5. Copy and paste the Theme into the same view, make only the newly pasted Theme active, open the Theme properties again and make the query '**[CPUE] < [Attractor]**', which gives the over-exploited data points. Change the color of this Theme in red. Now you have the distribution of over- and under-exploited areas in the Thyrrenean Sea according to the Corsi model (Figure 17.58).

FIGURE 17.58

Over- and under-exploited areas in the Thyrrenean Sea according to the Corsi model



Note on the use of this model in general

For the application of surplus production models in GIS of course the same cautious approach as used in traditional applications of surplus production models should be adhered to, as they tend to give falsely optimistic answers. Please refer the handbooks on this subject; Gulland (1985), Pitcher and Hart (1982), Quin and Deriso (1999), Hilborn and Walters (1992).