Spatial Data Integration for Marine Fisheries Management of Oman

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By

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Abstract

Previous research has indicated an increasing need for the use of GIS to assist the management of environmental and natural resources. Forestry, land use, agriculture, and the coastal zone are among those areas where GIS have played a major part in planning and management. Marine fisheries on the other hand, are an area of the natural resource exploitation where GIS is not yet being fully utilized. In this study, the application of GIS techniques to marine fisheries is explored.

The work described in this research uses the commercial data of catch to illustrate the facilities that GIS may offer to fisheries management. Three different types of fisheries data (different in terms of original format, method of collection and geographical footprints) for Oman are presented and discussed. Data collection, manipulation, filtering and preparation for input to a relational database are discussed. The spatial integration of the data is problematic but essential. Two methods of data integration, the point and the area are used to solve this problem. Point and area data are used to display data at different levels of management and decision making.

Alternative visualisations from the GIS are used including total catch distribution, catch per unit effort per unit area, fishing density, and spatio-temporal analysis. The analytical ability of the GIS is used to display the following results: preferred areas of catch, expected catch per area, areas of fish high quality habitat, unexploited areas, and areas suspected of overfishing. Hydro-biological data (marine-related data) such as sea surface temperature, dissolved oxygen, salinity, and zooplankton biomass for the year 1995 with relation to catch are presented and discussed too.

The concentration of catch is found to be more within the area of the continental shelf than in the deep waters, being areas of large fish productivity as well as high zooplankton biomass. Pelagic fish occur in greater density in the northern part of the Omani waters (Gulf of Oman), and in contrast, demersal fish aggregated more at the southern part of the country (Arabian Sea). Different areas are found to have a consistently high catch throughout the years, and the catch, in general, shows no evidence of overfishing. Some areas of Omani water have not been fully utilized although this study shows them high potential catch areas.

Acknowledgement

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1

INTRODUCTION

"All around the world, fish are vanishing. The once ubiquitous cod has virtually disappeared from some parts of the North Atlantic. It's a disaster that threatens to destroy the livelihood and way of life of coastal communities and irrevocably tilt the ecological balance of the oceans. It's generally acknowledged that many of the problems could have been avoided with better management of fish stocks."

(Meaden, 1994, p. 20)

1. Introduction

The problem of the collapse of stock and disappearance of fish from some parts of the World's seas has been noted with much concern. The lack of appropriate fisheries management systems is considered to be one cause of these problems (Meaden and Do Chi, 1996; Kemp and Lee, 1998). Although, the knowledge of fish location and the period of maximum catch were realised, the information systems in use to support management were far from providing the required management tool for such a complex area. The search for an improved system for the management of fishing activities was the main reason behind the introduction of Geographical Information Systems (GIS) into marine fisheries.

The recent growth in Geographical Information Systems (GIS) and their environmental applications have greatly increased the potential of using GIS for managing almost all natural resources. GIS are increasingly being used for inventory, analysis, understanding, modelling and management of natural resources (Burrough, 1986; Aronoff, 1989; Heywood, 1991; Goodchild et al. 1993), and although GIS is well known as a suitable management tool for natural resources, little work has been done to implement such technology in the marine fisheries sector. The basic premise underlying this research is that GIS applied to marine fisheries could lead to a better management system for fisheries resources.

This chapter introduces the research reported in this study. Section 2 provides a general overview of the fisheries sector in Oman. The data complexity in marine fisheries is discussed in section 3. Section 4 introduces Geographical Information Systems (GIS). Section 5 discusses the needs for GIS as a fisheries management tool. The aims and objectives of this study are explained in section 6. Section 7 gives a quick summary and conclusion of the chapter and finally section 8, highlights the contents of the remaining chapters of this thesis.

2. General Overview

In Oman, fish are a very important natural resource. Managing such a resource while maintaining the level of catch and protecting fish stocks from overfishing is the main concern of the Government represented by the Ministry of Agriculture and Fisheries (MAF). Better management can exist when an improved information system with tools capable of storing, organizing, analyzing, and displaying the variety of data is used. It has been argued that the only information systems with such are Geographical Information System (Caddy, 1986; Ricketts, 1986; Charles, 1992; Caddy et al, 1995; Meaden, 1993; 1994; Meaden et al., 1995; Meaden and Do Chi, 1996), which have the added of which for managing marine fisheries have been noticed (Symes, 1991; Hinds, 1992; the World Bank 1992).

The fisheries sector in Oman has played a major role in the national income since late 1989 when commercial fishing first began. Since then, fishing activity has increased rapidly from just a few vessels, to over one hundred in 1993. At the same time, the statistical data of fish catch has shown an increase and then a decrease in the amount. This has been attributed to stock damage (Oman Fisheries Report, 1995), which has occurred at different times and the government's attention has now been drawn to this problem in order to find a solution.

In the early stages the MAF was aware of the problem of commercial fishing. The government has spent an enormous amount of money to develop the fisheries sector, and is investigating new technologies that can resolve the problem concerned with fisheries management.

There are two major fishing sectors in the marine fisheries of Oman, the Traditional and the Commercial sectors. The MAF has established rules for commercial fishing by giving each vessel a specific location in which to fish and for a limited duration each year. The commercial longlines fishery only occurs in a zone more than 20 nautical miles away from the shoreline. Traditional fisheries occur within the 20 nautical miles zone.

There are two types of commercial fisheries, the longlines (catching Pelagic fish such as yellowfin tuna (*Thunnus albacares*) and shark (*Carcharhindae*)), and the trawlers (catching Demersal fish such as ribbonfish (*Trichiurus lepturus*) and grouper (*Serranidae*)). For the longlines, the fishing areas have been referenced by a latitude and longitude coordinate system. Each vessel has to fill in a form with multiple columns showing the coordinates fished and the amount of catch for each species. For the trawlers, on the other hand, an area code is used to identify the fishing areas. The trawler fishing areas have been divided into areas 10 miles square; each trawler vessel is required to fish in defined square. The amount of catch (quota) for each vessel is determined for each year. For both types of fishery, each vessel has to return to the port with a copy of the fishing detail form and hand it in to the Ministry. The commercial vessels make trips on a weekly and monthly basis. For traditional fisheries, the data are gathered for the landing port. The amount of catch is estimated by measuring the catch on sample days (see section 5 of chapter 4).

The decline in the amount of catch directly affects the yearly national income. Recent statistical reports have shown a major decline in the catch of some species. It is considered that management is needed, especially for the commercial fisheries to maintain the level of catch, and to reduce the risk of overfishing, and damage or collapse of the stock.

Although the fisheries data for Oman are available in analog form, to date nobody has considered to integration of these data and linkage to a GIS. In Oman, almost all fishery regulations are set with regards to the location of fishing areas. However, the analysis and evaluation system used has never made use of these spatial data in any form. Much information can be gained by analysing these fisheries data spatially, and since regulations are based in areas of fishing, it is likely that the use of these data will assist the fisheries regulation authorities. The current research is concerned with developing a tool to assist fisheries management by applying GIS to the Oman marine fisheries.

3. Data Complexity in Marine Fisheries

> "The late 20th century has witnessed increasing crises in the world's marine fisheries. A causal analysis of these reveals that a common element are various manifestations of spatial inequity. This most frequently includes the inequity of access rights to the resources, but factors such as variations in resource depletion, spatiotemporal variations in stock recruitment, the imposition of regulatory zoning, destruction of marine ecosystems and siting of mariculture facilities are other examples."
>
> (Meaden and Do Chi, 1996. p. iv)

Fisheries around the world are reported to be in a crisis (FAO, 1993; Brown, 1994; Buckworth, 1998), and a large part of fish stocks are fully or overexploited (Garcia and Newton, 1997). Despite the fact that fish species have virtually disappeared from some parts of the world's seas, no one has yet developed a system that can assist in the management of marine fisheries. The problem of overfishing around the world has been strongly related to the uncontrolled commercial fishing activities (Gwyer, 1991). Some of the fish stocks of some of the world's fishing areas have collapsed as a result of commercial fishing. This problem has been recognized in Europe, and has occurred due to the poor management systems that have been used in fisheries. The problem of stock collapse has forced fisheries authorities in different parts of the world to consider about GIS. Although the basic idea has been proposed, however, very little progress seems to have been made to date (Meaden, 1994).

Many difficulties arise, when fisheries management systems are to be implemented in general (Sumalia, 1998), and for GIS in particular, due to uncertainty. Fish stocks, for instance, are always changeable and uncertainty should be explicitly considered. Estimating the size of fish stock, for example, is said to be usually within one third to one half of its actual value. In fisheries, however, and because of the uncertainty, this is considered acceptable (Wilson et al., 1994). Part of the uncertainty is the difficulty in determining, using the ordinary fisheries systems, where the fish were caught, and so the catch per unit area is always in doubt. Due to the uncertainty, spatial data of the catch must be considered when managing fish and by taking a periodic catch per unit area, for example, the level of uncertainty can be reduced so improving fisheries management procedures.

Part of the difficulty in establishing a GIS for fisheries management is that the fisheries environment involves more than one element from a traditional fisherman, who uses a small boat, to a large commercial vessel. In addition to that, a marine fishery is a mobile sector, which makes it difficult to target and capture. There are other difficulties to overcome when building a GIS for marine fisheries management as is discussed throughout this research.

Buckworth (1998) argued that world fisheries are at risk, and that there are two main components to the problem. The first is that the catch of fish from all over the world are near to the limit for sustainable yields where more catch can damage the stocks, and second that many fish stocks are already overfished. This raises the question of the abilities of the current management systems. Charles (1998) emphasizes the idea that the key challenge in recent fisheries management systems lies in developing new techniques or obtaining better data for managing the level of sustainability in each of the fishing areas. In summary, one of the current problem facing fisheries management is to find a better system to deal with locational data of catch, and GIS could be a tool to solve such problem.

For fisheries researchers and managers, although the idea of improving the current management systems have been widely proposed and numerous suggestions made, the possible use of spatial data in fisheries were rarely mentioned as one of the key factors for better management systems. The point here is that fisheries management could benefit from the available fisheries spatial data of catch in helping to understand the spatial fluctuation of catch during five consecutive years (1991-1995) and the information gained from such analysis will help fisheries managers to evaluate the states of fisheries and applying the necessary responses.

4. Geographical Information Systems

Almost all living creatures on the Earth exist within a determined space or area, and Geographical Information Systems (GIS) can be applied in any context where spatial location is important. The basic concept of GIS that makes it different from other information systems is one of location, of spatial distribution, and relationships (Fedra, 1993).

There are many definitions of GIS in the literature, vary with the subject being discussed. However, the basic components of GIS are almost the same. For example:

> "GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information" [Environmental System Research Institute (ESRI), 1990].

In relation to marine fisheries, GIS can be defined as an integrated computer-based system which can handle both the spatial data (e.g. maps of fish location/catch, maps of landing ports/site), and associated attribute data (e.g. amount of catch, type of catch, duration, and sea surface temperature), and produce maps with all related data in graphics, text, and tables. The use of GIS for management lies with ability to facilitate work in a multi-data environment and to organize and integrate these data for analysis. Visualization is also embedded, so as to facilitate decision making. The multiple roles that GIS can perform in terms of visual output can positively help the decision makers. The other advantage of using GIS is the speed with which it handles the large variety of different types of source data (Isaak and Hubert, 1997).

5. The needs for GIS as a fisheries management tool

As discussed above, GIS have been widely used to manage different environmental resources. Forest, wildlife, land use, and agriculture are some examples of such areas in which GIS is playing a major part as a management tool. Despite the huge potential of GIS technology for environmental applications, its full penetration into the marine fisheries field is still undetermined.

In a country like Oman, there are enormous amounts of marine fisheries data, but there has always been a lack of awareness of the value of these data. It is time for this data to be more effectively used to support fisheries management, because fish stocks are under great pressure that increases on a daily basis.

Commercial fisheries have left few unexploited stocks anywhere in the World. In some parts of the World sea there are records showing fish disappearing and stock collapsing (McGoodwin, 1990; Meaden 1994). Obviously, part of the reason underlying such problems is the ongoing unlimited fishing activities, but the main reason is the current system in use for fisheries management.

In Oman, the current system used to support fisheries management lacks the ability to analyze locational distributions of species in which the regulations are originally based. The initial idea behind setting these regulations is to avoid fishing the same area for continuous periods of time as a way to avoid the problems of overfishing and stock damage. Whether these areas have been damaged or not remains unknown since spatial data are neglected when fisheries data are stored and analyzed.

Although the problem of stock collapse has been recognised in some developed countries, in a developing country like Oman the problem is probably still in its early stages and for that reason the best systems to support management should be applied before it is too late, and so there is a need to explore the use of GIS.

The major values of the concept of GIS is that it can display output at any stage in the processing of the data. GIS provides the facility for maps to be incrementally built up, with desired modifications being possible at any stage. Modifications might be in terms of changes to the data input to the map, or in terms of the visual representation of the map. So the GIS user can control, review or experiment at any stage in order to achieve a meaningful final output. These, however, are all depends on the amount of available fisheries data and the capabilities of GIS analysis functions to date.

One of the main reasons for replacing the traditional cartographic mapping techniques or mapping software by GIS packages is the realisation that this will allow for a greater variety of analyses and output. GIS have the ability to display and to re-express the spatially and temporally distributed database and to analyse whatever subset of the data that might be desired. Another reason is that the creation of maps or analyses is not costly and time consuming as is the case using the tools of traditional cartography. Furthermore, it is relatively easy to introduce new data as they become available, and so rapidly generate new views and analysis, adding any new spatial data types as hypotheses and ideas change and develop

One of the significant advances in the application of GIS to fisheries management, is the mapping of catch or fishing effort distributions, and matching of these to basic environmental or habitat parameters (Meaden, 1999). These allow for better understanding of areas suitable for certain types of fish species. Data of commercial catch per unit area can be used as a basis of measuring stock assessment, and once data are available to measure the catch per unit effort (CPUE), it is easy to estimate the stock size at any location rather than relying wholly on other methods of stock assessment such as cruise survey.

6. Aims and Objectives

The main objective of the work described in this research is to use the visual and analytical capabilities of GIS to assist the fisheries management authorities in Oman dealing with spatial fisheries data. That is, to explore the use of GIS technology in the marine fisheries arena using GIS techniques and functionality to organise, analyse and display marine fisheries data. To explore such a use would benefit fisheries management in finding several important areas such as areas of high and low catches, high fish density, effort concentration, under-exploitation, and overexploitation.

In detail, the objectives can be described as:

1. To integrate the data types and to subset then by species by time and by location for the purposes of deriving data and map products which might be useful in management using the national catch data for Oman (Chapter 6), which are a systematic five year record (1991-1995).
2. To illustrate how any supplementary environmental variables that might be added will enhance the analyses (Chapter 7). For Omani waters such data, however, are becoming widely available since 1995.

The specific aims of this project are concerned with two main tasks that must be established before the implementation of the GIS can take place. These are:

- Building an integrated database system that holds the three types of fisheries data (traditional, trawlers, and longlines).
- Integrating the different geographical footprints of the three types of data, i.e., finding a uniform method/methods of representing the spatial fisheries data.

Once that is achieved, several map types (outputs) can be expected such as:

- Mapping total catch distribution of different fish species and the catch per effort per area.
- Mapping fishing densities.
- Understanding the spatiotemporal changes of species.
- Mapping historical catch and areas of catch for different fish species.

In summary, catch per unit effort is a key method used in the process of stock assessment. The commercial data of catch can be used, together with the fishing effort data, to measure fish abundance in certain areas. By determining catch per unit effort, the increase or decrease in catch per unit area can be analysed.

7. Summary and Conclusion

Omani fisheries management authorities need a better management tool with the capability to organize, analyze, and display spatially related datasets. These tasks can perhaps be performed only by GIS. All current regulations are based on the location of catch. However, the management system has not used these spatial data to assist the management procedure until now. GIS are basically integrated computer-based systems that can store both attributes and spatial data, that is, information describing the properties of geometrical objects such as points, lines, and areas. The main strength of GIS lies in its ability to manipulate data in a large number of ways and consequently to perform different analytical functions so as to produce output. It is a technology, which can be integrated with fisheries data. Understanding catch per unit area, total catch distribution, historical catch, and spatio-temporal catch, areas of under-exploitation, over-exploitation or damaged fish stocks, and areas of high fish production can be visualized within the GIS. This helps to improve the management and decision making systems.

8. Thesis Structure

Chapter 2 provides an overview of the work that has been done in the area of GIS and marine fisheries. It highlights the reasons why GIS has been slow to be applied to marine fisheries. The three different types of acquired data (traditional, trawlers, and longlines) used in the research and their formats are presented in **Chapter 3**. The preparation of these data and the investigation of the method used in constructing the spatial marine fisheries database that leads to defining the database model are explored in **Chapter 4**. The proposed integrated relational database has not been constructed in any previous work, and has been used for the first time in this research. GIS Implementation (the visual views) of the three fisheries types is discussed too. **Chapter 5** focuses on the methods used to integrate the different marine fisheries data, and a standardized output for the three fisheries types is produced. **Chapter 6** concerns the use of the GIS as a management and decision making tool in marine fisheries. The chapter uses the catch data to highlight the use of the GIS functions to assist the fisheries managers and decision makers mainly from the government point of view but also from the commercial one. A general introduction to applying hydro-biological marine data and their relationship with the catch data will be the issues discussed in **Chapter 7**. The last chapter, **Chapter 8**, synthesizes the research findings and includes suggestions for the refinement and further development of the approach.

2

GIS APPLICATIONS IN MARINE FISHERIES

"Mapping the fishery and the resources should be among the priority tasks when planning for fisheries management and should not be postponed until "complete" information is available, since redundancies or blanks in the information base will more readily appear in the process of elaboration."

(Caddy and Garcia, 1986. p. 32)

1. Introduction

The potential for GIS applications in the area of environmental management are many: from monitoring bird populations to modelling the impacts of new developments, or analysing the effects of changes in management practices. On the other hand, GIS and marine fisheries is a subject that seems to have received little attention from researchers. Since GIS have been widely used in other natural resource fields where spatially related problems are evident, it is likely that GIS can contribute to the problems of managing marine fisheries. Researchers and managers, however, have yet to take maximum benefit from the facilities that GIS can offer in the area of fisheries specifically (Aspinall, 1994).

This chapter highlights the previous work that has been done in the area of GIS and marine fisheries in particular. Section 2 discusses in details the use of GIS in marine fisheries. Section 3 highlights the areas where fisheries management can be improved by the use of the GIS. The limited use of the GIS in the marine fisheries sector is highlighted in section 4 with the discussion on the main reasons why use is not widespread.

2. GIS and Marine Fisheries

Very limited studies have been published which directly links GIS techniques in marine fisheries applications (see e.g., Meaden and Do Chi, 1996). From the previous discussion in Chapter 1, GIS has been shown to have been used for management, and decision support in many areas where data is or can be georeferenced. However, marine fisheries are one of only a few (and possibly the only) natural resource fields in which the advantage of GIS has not yet been completely realised. Nowadays, there is a noticeable increase in work related to marine fisheries; coastal zone management (as noted above) and mariculture[1] location (Meaden and Do Chi, 1996) are two areas which GIS has been used.

[1] Mariculture is another word for 'aquaculture' or 'fish farming'.

The earliest geographical fisheries models were simple conceptual as a result of models created mainly for the purpose of explaining the movement of fish changes in temperature (Hunsaker et al. 1993). However, recent developments in some related areas such as landscape ecology have created a promising foundation for the area of ecological modeling which could include marine fisheries (Goodchild, 1993).

Although limited, examples of GIS use in fisheries do exist, and the main works that are related to the subject of this study are highlighted in the following sections. However, one major problem related to most of the work that has been done in the area of GIS and fisheries, is the lack of enough information on the system in use. There are very rare explanations of the types of software, hardware, and methods of data integration and analysis.

2.1 Inland Fisheries

> GIS technology provides new opportunities for fisheries scientists. Predictions of standing stocks, species distributions, year-class strength, etc., can now be made at virtually any spatial scale, depending only on the resolution and extent of the data used to construct the GIS
>
> (Isaak and Hubert, 1997, p. 6)

Ehrhardt and Ault (1992) used a GIS to produce original maps of geologic districts and land-type associations that were related to the distribution of trout species and physical habitat characters. In addition, using a modelling approach, Keleher and Rahel (1996) simulated the effect of global climate changes on trout (freshwater fish) distributions for the state of Wyoming and the Rocky Mountain. The objective was to study the distribution of trout with regards to the climate changes. However, Ehrhardt and Ault (1992) did not give any details on how their system works and the analysis of data.

2.2 Mapping Marine Fisheries

The importance of mapping marine fisheries has largely arisen since the beginning of the 1980s. Mapping the demersal resources of the Persian Gulf and the Gulf of Oman, as an example, was done manually in 1981 by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1981) (see Figure 2.1). However, the method of mapping the catch (in kilograms) per hour of fishing was based on a survey of estimated catch rather than the real catch data.

Thematic mapping of marine fisheries is critical for fisheries managers and decision makers and can be used to highlight the importance of certain parts of a marine area for other human activities such as coastal development and navigation (Caddy and Garcia, 1986).

Butler et al., (1987) studied methods used in mapping marine resources. The study was generally aimed at those involved in the fisheries and marine services of government, and those concerned with coastal planning. The overall intention was to provide the necessary details of the basic concepts underlying preparation of both maps and charts as well as investigating the methods of fisheries data collection and the graphic techniques that improve information transfer from cartographic representation to the end user. They found that the greatest benefit from these resources is the map which has proved to be the most efficient method of displaying the necessary resource information. A poor understanding of the country's wealthy resources often results in resources being over-exploited or even destroyed before they are fully determined.

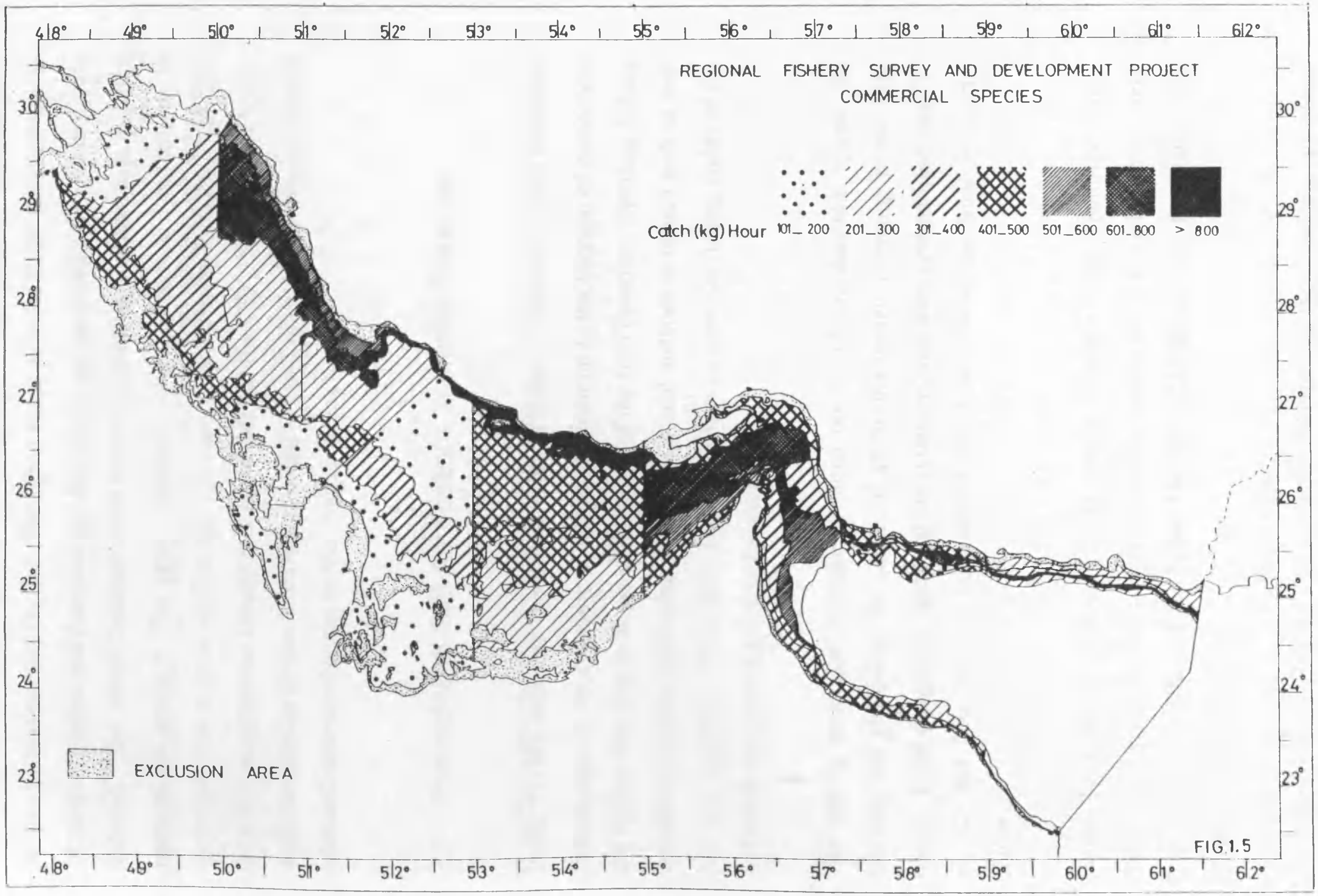


Figure 2.1. Commercial species catch in the Gulf and Gulf of Oman of 1981 (from FAO, 1981)

In 1996, the United Nations Food and Agricultural Organization published a report of more than 300 pages on the applications of GIS to fisheries management written by Meaden and Do Chi. The report raises different issues about using GIS in marine fisheries and discusses the difficulties and capabilities for GIS in marine fisheries. The report discusses some case studies being undertaken in different parts of the world. The report, however, failed to address the methods or techniques that must be used in order to convert the different formats of fisheries data into an integrated dataset that is suitable for the GIS. There is also no in-depth description of how to covert a normally 3 to 4 dimensional data into usable relational database that can be then linked to the GIS.

2.3 Examples of GIS Applications in Marine Fisheries

Pollitt (1994) discussed the use of GIS for fishery protection in the exclusive fishing zone of the Republic of Ireland. In addition to the purpose of protection, the system was used to zoom-in on details of the Irish coastline, reporting fishing activity at a glance, displaying fishing vessels and methods of fishing such as drift nets and longlines. The system enables the user to view the fishing rights of the individual neighbouring European countries.

The fishery protection database is based on the Oracle database system for handling and processing the details of all fishing vessels operating in the Irish waters. Basic geographic details of the system include Irish straight baselines, 3-, 6-, 12- and 200- nautical mile fishing limits as well as the limit of nearby countries.

Figure 2.2 gives an example of GIS output, showing which countries (color-coded) have rights to fish for certain species within the 6-12 mile fishery zone. (e.g. yellow for UK, red for Spain, Orange for Belgium, blue for France, and purple for Germany).

The benefits from using the GIS in marine fisheries and the consequent problems have been highlighted by Meaden (1994). According to him, the value of GIS in supporting the overall management strategy can be easily seen in some areas. For example the FAO is already setting up an integrated marine fisheries GIS for the West Africa coastal states. This project is still in development procedure.

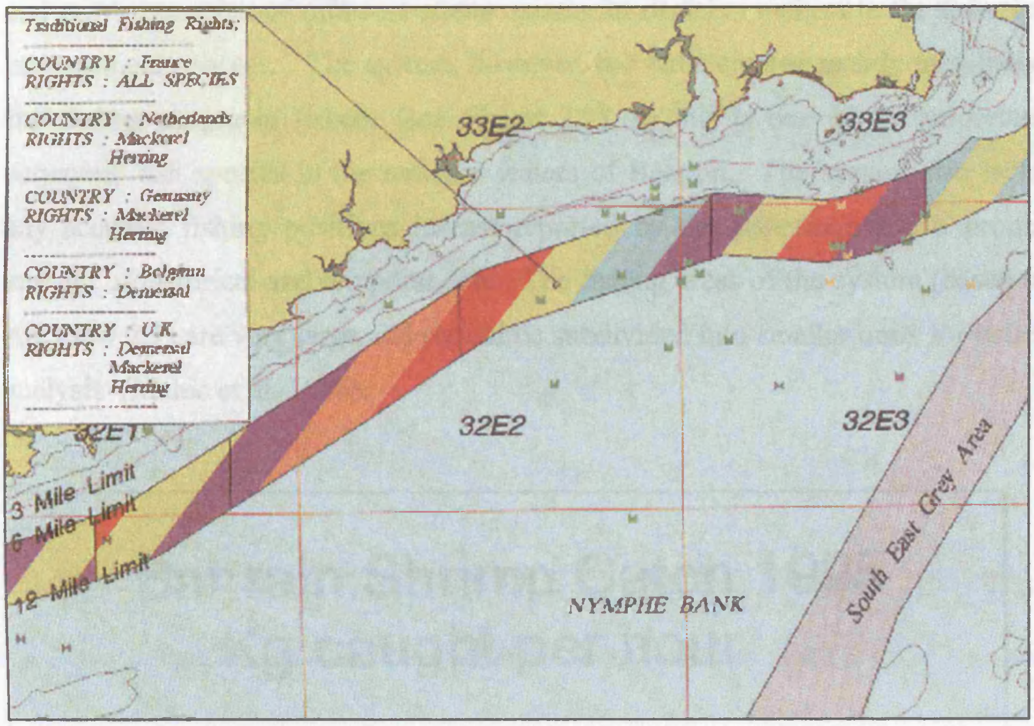


Figure 2.2. Traditional fishing rights zone broken down into colour-coded segments indicating the fishing rights of individual countries (from Pollitt, 1994)

Caddy and Do Chi (1995) examine recent trends in fish landing in the Mediterranean and Black Sea basins separately for each statistical area of the General Fisheries Council for the Mediterranean (GFCM) and compare estimates of production in different basins. Comparisons were based on GIS databases, and maps of catches were created per type of fishery per statistical and continental shelf area. The GIS was used for two main purposes:

1. To overlay the shelf areas with GFCM statistical areas in order to define the shelf areas within each statistical division.

2. To elaborate maps of catches per type of fishery per statistical and per shelf area.

However, the use of the GIS has concentrated on the area of continental shelf where basins have been identified. Applying GIS to a rather wide area such as the 200 mile zone is more sophisticated and requires large operations of analysis.

A GIS has been used for Bahrain fisheries in order to provide rational management, fisheries statistics, fishing vessels utilization, economical forecasts, information on the location of threatened and endangered species, and fast access and easy generation of different status reports for decision makers in the fisheries management process. The system, however, has been created mainly to manage the shrimp or prawn fishery (see Figure 2.3), as this is one of the important economic fish species in the national waters of Bahrain. The system also lacks any accurate fishing positions (areas) reported by the fishermen and a proper amount of historical and temporal data. The fishing areas of the system (based in ArcView 2.1) are very large and should be subdivided into smaller units for better analysis (Mehic et al. 1986).

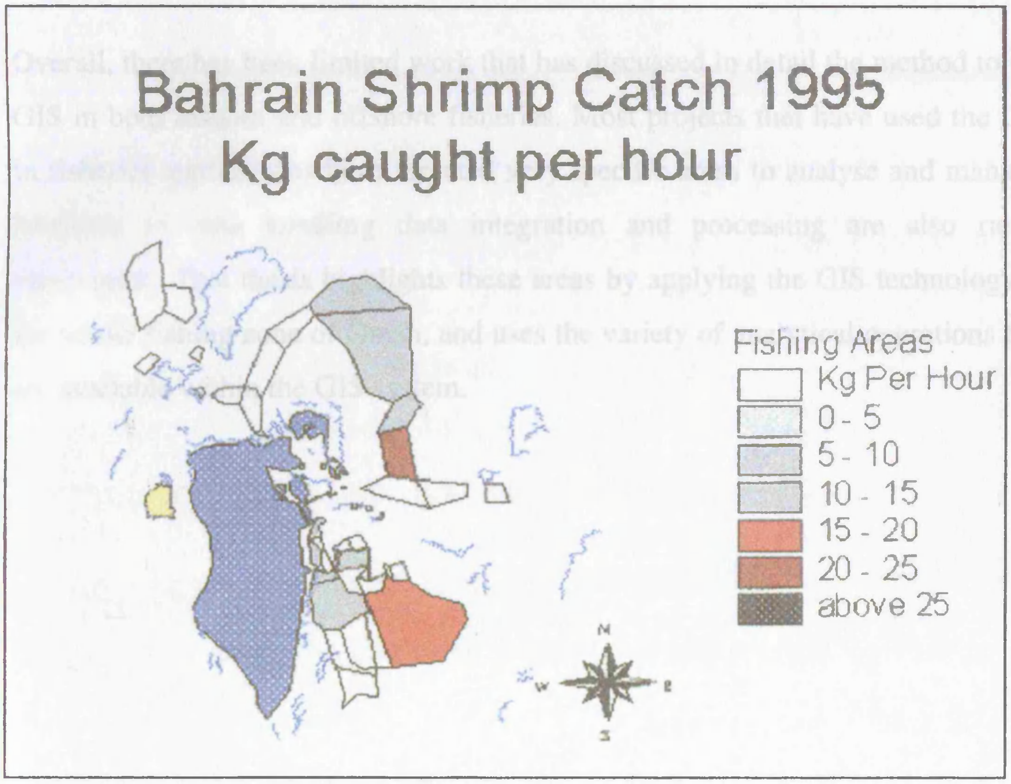


Figure 2.3. Bahrain Shrimp Catch (kg) per hour for the 1995 (from Mehic et al. 1996)

Kraak and Ormeling (1996) used the visual ability of the GIS in mapping statistics of fish catch in Africans countries (Figure 2.4). Their main goal was to visually illustrate the amount of catch per area using the proportional mapping method (the larger the circle the higher the catch) as this would help in better understanding of status of fish catch participation of the African nations.

The exploration of analytical abilities of the GIS have not been considered by Kraak and Ormeling (1996). The main objective of using any GIS system is not only its visual ability of displaying data, but also its power to analyse multiple layers of data.

In France, where shellfish cultivation is important and where some 3,500 people depend directly on oyster production for their living with 35,000 tons harvested every year, GIS technology is being used to bring together a variety of geo-referenced data at a number of different levels, covering the local environment and cultivated areas. The overall aim is to maintain the ecological balance of the environment and to encourage sustainable methods of oyster farming (Marshall, 1998).

Overall, there has been limited work that has discussed in detail the method to use GIS in both inshore and offshore fisheries. Most projects that have used the GIS in fisheries applications have targeted very specific areas to analyse and manage. Methods of data handling data integration and processing are also rarely mentioned. This thesis highlights these areas by applying the GIS technology to the whole fishing zone of Oman, and uses the variety of analytical operations that are available within the GIS system.

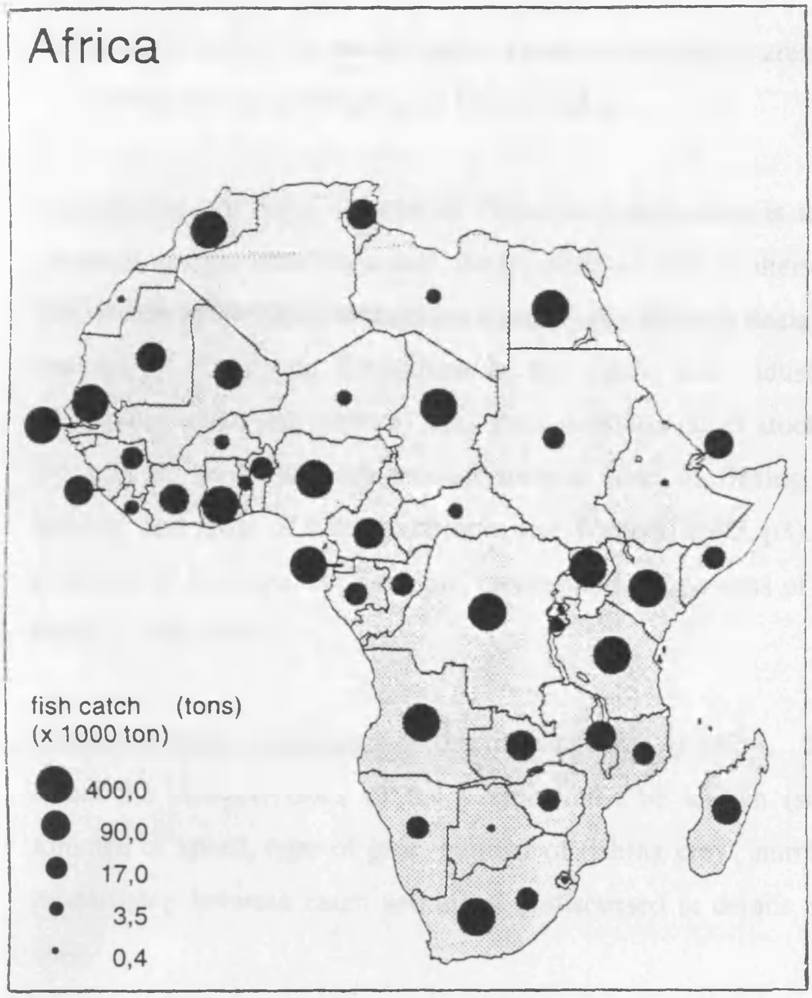


Figure 2.4. Mapping statistics of fish catches in Africa (from Kraak and Ormeling, 1996)

3. Improving Fisheries Management

> The aim of fisheries management is to establish the status of a resource and to determine the levels at which it may be sustainably exploited
>
> Michael King, 1995, p. 236

In fisheries there are two main parties with interests in fisheries management: government and industry. The former's objective is to insure the sustainabilty of the catch as well as to increase the employment and the national income, whereas the latter are more concerned with maximizing their catch while minimizing the effort. It is rather difficult for the government to control the activity of the commercial vessels (Fabrizio and Richards, 1996) and so the stock is always in danger of overexploited. However, the best method to control these activities from the government point of view is probably to control the amount of applied effort and monitor the rate of catch in each of the fishing areas as that the amount of catch from any given area can be controlled.

Specifically, the main concern of fisheries management is to ensure sustainable production over time from fish stocks (Hilborn and Walters, 1992, p3). Using knowledge of the stock authorities usually take difficult decisions of management mainly by specifying limitations to the catch, and industry can then target effectively where and when to fish. Important aspects of stock assessment, which are part of the regulatory process include time of fishing, size of fish, total landing, and areas of fishing (Hilborn and Walters, 1992, p3). The data from the commercial fisheries, for example, can support the process of stock assessment if effort is well known.

Crucial to stock assessment is the measurement of effort. To calculate fishing effort the characteristics of the vessels must be known (such as vessel size, tonnage or speed, type of gear, number of fishing crew, number of hooks). The relationship between catch and effort is discussed in details in Chapter 6 of this study.

The role of GIS in fisheries management can be summarized as the follows:

1. Fisheries authorities are in need of a GIS to help in monitoring the fluctuation of catch in fishing areas (Meaden, 1999) from the knowledge of the stock size in that area. The level of fishing effort applied also depends on the size of stock. When dealing with a large area of fishing, such as of Oman, it can be hard to appreciate the states of fish stocks in all different areas. With the use of GIS the process of tracking the changes in effort and catch in different areas can be improved. King (1995) has indicated that a monitoring program of fisheries must be used in order for better estimation of stock. King's (1995) idea was that if the source of data of catch and effort is available, this then could assist the effectiveness of management strategies as well as studying the process of exploitation. For example, by monitoring fishing activity, the level of effort per area can be observed and controlled especially when it reaches the level where further increase in effort will no longer produce an increase in yield.

2. GIS can help in understanding the areas of multiple fish concentration. This determination would help in understanding the areas of fish habitat throughout the total fishing area (Freon and Misund, 1999). Applying certain levels of effort as well as specifying the type of fishing gear and fishing quota depends on the types of available species in different areas.

3. Mapping the movement of commercial vessels may help in understanding the locations of different type of species, because commercial vessels tend to use advance technology in their search for fish such as fisheries acoustics (MacLennan and Simmonds, 1992). Many commercial fisheries also use their historical data of catch to concentrate their effort in the same place and time (Fabrizio and Richards, 1996). As a result, mapping the areas of commercial fisheries can give a good indication of where the stocks are located. For example, the spatial distribution of effort was used in understanding the stock distribution of the cod and haddock in the northwest Atlantic (Fabrizio and Richards, 1996). Any changes in the distribution of fishing effort may indicate a decline in stock abundance as fisheries move to a new (less depleted) area. The changes in the spatial distribution of effort maybe associated with changes in stock abundance (Dickie and Paloheimo 1965).

4. Mapping spatio-temporal distributions can also help in understanding the unexploited areas of catch. These are the areas where catch per unit effort has been high but with, in total, low amounts of effort applied. It can also be used to show these areas where no commercial catch has been taken and where research fishing trips may be desirable.

4. Problems of GIS in Marine Fisheries

> "Although marine fishing is the world's most extensive economic activity, and marine resources are presently exploited in a near "free-for-all" manner, there have been no national attempts to utilize Geographical Information Systems (GIS) as an aid to monitoring or controlling the industry"
>
> (Meaden, 1993, p.1)

Although GIS have been partially used in fisheries it is clear that it is still restricted when compared with what has been done in other areas of natural environmental management. There has been some debate attempting to highlight the main problems of that. Meaden (1994) has argued that fish are on the move and mapping a constantly mobile phenomenon brings with it obvious challenges and that a lot of factors should be included such as speed of fish and the seasonal controls on their activity. Fish catch, due to fish movement, also have a poor temporal scale and this can make it difficult to map, although, this difficulty can be resolved by having historical and temporal quality and quantity data (Kemp and Lee, 1998). The amount of temporal data for total catch can help the user (e.g., fisheries manager) to understand the patterns that can be extracted from such data. This includes determining what type of species exist at specific times of the year in specific areas of the sea. GIS itself is a relatively new technology and many people are unaware of its capabilities and/or aware that the cost of applying such technology is high when compared to any other computer-based information system. Meaden and Do Chi (1996) have discussed in detail the main reasons why marine applications of GIS have been slow to be applied in the marine fisheries sector. These reasons are shown in table 2.1.

5. Summary and Discussion

Fish are an important natural resource but recently the fishing areas and fish stocks have been under a great deal of pressure especially from the large commercial vessels. Fisheries authorities, like other natural resources managers, are looking to GIS to provide part of the solution for better management. Although the idea is there, little work has been done in this regard. Marine fisheries are a complicated environment that has a strong relation with other influencing factors and facts. It is mobile, fuzzy, and changeable. GIS with its capabilities of storing, organizing, and displaying the data in a way that is unique and impressive, makes it the most efficient system in the area of information technology. There is a growing interest in the field of GIS and marine fisheries. However, it is understood that the examples cited are still far from creating a general and useful system. One general limitation found in the literature is the method of data handling of different types of fisheries sector (traditional and commercial) data, which has not been well explored

- The difficulties in mapping many marine species distributions, especially in a 3-D environment.
- The fact that the marine environment is constantly changing i.e. exhibits high time/space variability.
- The high costs of obtaining marine related data.
- The large spatial units which need to be covered.
- The lack of recognition of the spatial aspects of fisheries management.
- The cooperation problems which need to be overcome in data collection.
- The difficulty of defining boundaries around "fuzzy" marine resource distributions.
- The problems of storing the huge amounts of data which are necessary for a reliable marine GIS.
- The lack of suitable databases in many areas of fishery resources.
- The lack of integration and/or the fragmentation of decision making amongst those responsible for fisheries management.

Table 2.1. Reasons why marine applications of GIS have been slow to be implemented (From Meaden and Do Chi, 1996)

Fisheries data have been collected and stored using different methods. Understandably, it is difficult to handle both traditional fisheries, which exist near the shoreline, and commercial that occur in offshore (in deep-sea) areas using the same implementation. These data should be integrated first. The method of handling these data is rarely mentioned, and the method of identifying fishing area (geo-referenced area for GIS) is never discussed.

Spatial data integration is crucial to any geo-referenced natural resource management system, but research in GIS and fisheries has rarely discussed the issue. For example, traditional and commercial areas need to be integrated as well as catch data. This basically leads to a better understanding of the total view image of fishing activities both close to the shoreline and far away. Since fish are mobile and the chance of all types of fisheries to catch the same type of species is high, integration will help understanding of the distribution of fish stocks throughout the marine area and may lead to a better understanding of the movement of some species.

The purpose of this research is therefore to develop a prototype system that can used as a tool to those concerned with making decisions related to the fisheries environment.

3

CHARACTERISTICS OF THE SOURCE DATA

"Conflict of interest among fishers characterizes most fisheries and leads to competition for the resource. This puts a premium on present actions and discounts the future. As a result, most common-property fisheries inexorably move toward overexploitation."

(Paul J.B Hart, 1998. p.227)

1. Introduction

Most GIS applications in environmental management require huge amounts of data from a myriad of sources. Fisheries management is one of those areas (Meaden and Do Chi, 1996). It is believed that there is a lack of data (in both quality and quantity) to be used in a fisheries management system (Kemp and Lee, 1998). The main concerns when gathering fisheries data for this research was to collect the maximum (quantity) reliable (quality) data for both traditional and commercial fisheries to provide optimum outputs. For that reason, the national catch data for Oman for the period of 1991-1995 were obtained for this research from all the different sources and participants involved in the fisheries industry. Although, all the data were collected successfully there is no assurance or guarantee that these data are complete or accurate especially when derived from commercial fisheries.

The intent of this chapter is to explore the process of data gathering: what are these data, where they came from, and what are their characteristics. Section 2 gives a brief introduction to the location of the Sultanate of Oman and the history of its fisheries activities. Section 3 explains the components of the fisheries sector in Oman and both types of fisheries (the traditional and the commercial fisheries) are discussed in detail as well as the Governmental regulations applied to them. Section 4 provides details of the characteristics of the data gathered. The use of Global Positioning Systems (GPS) by commercial fisheries is explained in section 5. Finally, the characteristics of spatial data collected for this research are discussed in section 6.

2. Background

2.1 Location of Oman

The Sultanate of Oman occupies the south eastern corner of the Arabian Peninsula and is located between latitudes 16° 40' 00" and 26° 20' 00" North (N) and longitudes 51° 50' 00" and 59° 40' 00" East (E). The coastline extends 1,700 kilometres from the Strait of Hormuz in the north to the borders of the Republic of Yemen and overlooks three seas: the Arabian Gulf, the Gulf of Oman and the

Arabian Sea. The Sultanate of Oman borders Saudi Arabia and the United Arab Emirates in the West; and the Republic of Yemen in the South. The total land area is approximately 309,500 square km. Figure 3.1 shows the map of Oman and the three seas along its coastline.

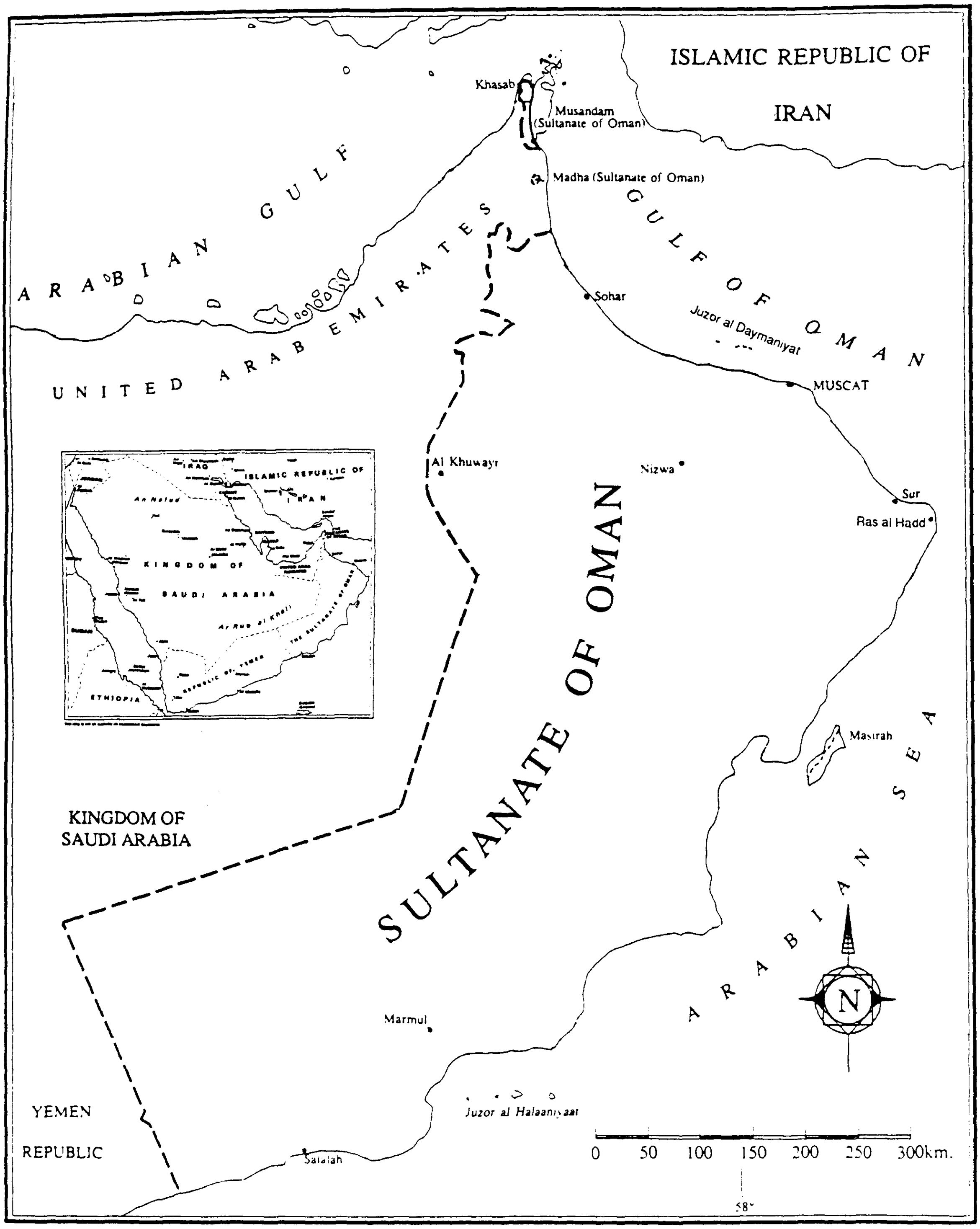


Figure 3.1 The map of the Sultanate of Oman (Oman '96, 1996)

2.2 History and development of Oman Fisheries

For centuries the coastal waters of Oman have been exploited by small and often isolated fishing communities. In recent years much has been done to expand and modernise this traditional industry.

More than 150 species of fish and crustaceans have been identified in Omani waters, ranging from shrimp to sardine to tuna. A wide variety of fish are eaten locally - yellowfin tuna (*Thunnus albacares*), kingfish (*Scomberomorus lepturus*) and grouper (*Serranidae*) being very popular - while shoals of tiny sardines (*Clupeidae*) are netted for use as fertiliser and animal fodder. Sharks' (*Carcharhindae*) fins are exported and lobsters (*Palinuridae*), which used to be avoided by fishermen, are now caught for the lucrative hotel and restaurant trade. The quantity of the total catch landed rose rapidly during the 1980s, reaching the peak in 1988 after which there has been a decline. Research carried out by the Marine and Science Fisheries Centre (MSFC), set up in 1986 at 'Sidab' area with the help of FAO and UNESCO, has indicated that overfishing had played a part in this decline. It is suspected that the approach to fisheries management is the main problem. The last fish stock estimation was done many years ago. The total fish stocks at that time were estimated at over 5 million tons, yielding a potential annual catch of about 4 million tons. These stocks include between 15,000 and 27,000 tonnes of kingfish, 50,000 tonnes of tuna and 2,000 tonnes of shellfish.

The Ministry of Agriculture and Fisheries (MAF) has taken a number of steps to conserve fish stocks while at the same time developing commercial fishing and preserving the livelihood of traditional fishermen. These include restricting the fishing for lobsters and abalone to two months in the year (January and December), regulating the size of nets and equipment used for fishing, as well as defining the areas, depths, quantities and kinds of fish that may be caught commercially. These regulations are designed to protect the traditional fishing industry. Inspectors, assisted by the Royal Air Force of Oman and Royal Police coastal patrols, monitor commercial fishing vessels. Commercial fishing is limited to 15% of the total catch, within Oman's territorial waters; foreign vessels may not fish without a licence to do so. However, with all these restrictions and regulations, a continuing decline in the amount of landed catch has still been recorded (Annual Statistical Report of 1994 and 1995). The MAF believes that the use of GIS in the fisheries sector can provide a tool for better management.

2.3 Principles of Fisheries Development in Oman

The fishery sector is considered to be one of the most important economic sectors of the economy as it provides employment opportunities for more than 25,000 people, revenue and nutrition for the whole population and around 30 to 35% of the total landing is exported. To manage fish resources the MAF has specified the four following principles of fisheries development in Oman (Marine and Living Aquatic Resources Protection Law, 1981):

1. The resources within the Exclusive Economic Zone (EEZ) are reserved for the benefit of the country;
2. Fisheries development has priority in the economic diversification of the country;
3. The traditional fishermen are and will continue to form the foundation of the fisheries sector;
4. Fisheries development policy is guided by conservation based on optimum utilization of resources.

2.4 Marine Fishing and Living-Aquatic-resources Protection Law

The protection law called the 'Marine Fishing and Living-Aquatic-resources Protection Law' contains articles and regulations that are set by the Government in order to protect the living marine organisms. The regulations were set by the MAF mainly to control both the traditional and commercial fishing activity in the national waters of Oman.

Living-aquatic-resources means animals and plants that live in fishing waters or interior waters or in the depths of the sea, or sediments, or substances that form inside the bodies of those living creatures (pearls), or after their death (coral reefs). The law explains the regulation in seven chapters that are summarized as the following:

1. **Licenses for marine fishing** which, states that fishing and related activities is not to be practiced without the required license.
2. **Fishing license fees.**
3. **Protection and development of living aquatic resources** which indicates that, all fishermen shall immediately return to the sea, all live juveniles if found among shrimps and fish catch.
4. **Regulation of fishing** which controls the types of fishing gear, fishing vessel and the areas of fishing.
5. **Preservation, transport and marketing of living aquatic resources** which regulates the activities of fish exploitation, handling, marketing, transportation, and preservation.
6. **General provision** which specifies the management of the process for buying, selling and renting fishing vessels.
7. **Penalties** issued to those violating any of the protection laws.

The regulations discussed throughout this research were formed by the MAF on 1981 and evaluated and renewed on 1991. Each type of fishery has its own restrictions and regulations.

In general, fishing is not allowed without the authorization of the MAF, and for both traditional and commercial fisheries, a fishing license is required for both the person (fisherman/captain) and the fishing boat or vessel. The restrictions applied to commercial fisheries in particular will be discussed throughout this chapter.

3. Types of fishing industry

The fishing activity in Oman is divided into two major sectors, the traditional and the commercial sector. The latter is categorised into two main types according to the method of fishing used and the species caught: (a) trawlers which use trawl nets to catch demersal fish and (b) longlines which catch large pelagic fish found in open seas such as yellowfin tuna. For the purpose of this research, and the way the data is gathered and later organised within the database, the fishing sector will be divided into three types according to the fishing method: (a) Traditional, (b) Trawlers and (c) Longlines.

Traditional fishery refers to the small boats operated near the coast at a distance of approximately 20 km from the shoreline. These catch all types of fish. Commercial fishing, trawlers and longlines, on the other hand, refers to large fishing vessels that operate on the high seas at specified places and catch demersal and pelagic fish respectively.

3.1 Traditional Fisheries

Traditional fishery occurs along the coastline of the country. There are six main fishing regions in Oman each containing several villages or sites where traditional fisheries are based. Table 3.1 shows the six main regions with their landing sites (villages). The traditional fishermen use small fiberglass[1] fishing boats and make on average, one trip per day. Figure 3.3 shows the main landing sites over the coastline of the country.

Most of the fishermen use two or three fishing methods such as hand line, traps, trolling, and gillnets (drift gillnet and pen gillnet). Various fishing gear are used to catch the same species; for example drift gillnets, pen gillnets and hand line are used to catch kingfish; Drift gillnets and trolling are used to catch yellowfin tuna; and Traps, pen gillnet and hand line to catch demersal species.

ID	Villages/Sites	Region
1	KHASAB	MUSANDAM
2	BUKHA	
3	DABBA	
4	SHINAS	BATINAH
5	LIWA	
6	KHABURA	
7	SOHAR	
8	SAHAM	
9	WIDAM	
10	MUSANAA	
11	SUWEQ	
12	BARKA	
13	ALSWADI	
14	SEEB	MUSCAT
15	CAPITAL	
16	SIDAB	
17	QARYAT	
18	DAGMAR	
19	FINS	SHARKIA
20	TIWI	
21	KALHAT	
22	SUWEH	
23	SUR	
24	RUWES	
25	DAFFAH	
26	ASHKARA	
27	RASRUWE	
28	MASIRAH	
29	MAHUT	WUSTAH
30	KHLOUF	
31	SEDRAH	
32	SERAB	
33	NAFUN	
34	DUQM	
35	SHUAIR	
36	RASMADR	
37	HAITEM	
38	LAKBI	
39	SOQRAH	
40	SHUWAIM	DHUFHAR
41	SHARBIT	
42	SADAH	
43	HADBEEN	
44	RAYSUT	
45	MIRBAT	
46	MAGHSAI	
47	RAKHIUT	
48	DHALKUT	

Table 3.1 Traditional landing sites

[1] Fiberglass has been widely used for the last decade, although there are other types of fishing boats like aluminum and houri they are rarely used nowadays.

3.2 Trawler Fisheries

Trawlers are allowed to catch all demersal types of fish, which means a large number of different species. Both groups of species found on the ground of the continental shelf and species, which come near to the sea bottom searching for food, can be trawled. These nets can also be use to catch species which are far from the seabed by increasing the speed of the vessel.

Although these vessels catch mainly demersal species, the records shows that other type of fish have been caught by trawlers, such as mullet, all small pelagic fish and lobster which are crustaceans. The production of all type of fisheries in general and trawlers in particular can be classified into demersals, large pelagic, small pelagic and crustaceans. Table 3.2 shows the groups to which individual species in Omani fisheries belong (this is very similar to the standard fish classification).

Demersal	**Large Pelagic**	**Small Pelagic**	**Crustaceans (Shellfish)**
Emperor	Yellowfin tuna	Indian mackerel	Lobster
Seabreams	Longtail tuna	Sardine	Shrimp (prawns)
Grouper	Striped bonito	Small jacks	Cuttlefish
Croaker	Frigate tuna	Mullet	Abalone
Grunt	Kingfish	Baby shark	Crabs
Snapper	Barracuda		
Jobfish	Cobia		
Rabbitfish	Large jacks		
Catfish	Large shark		
Trevally	B.Marlin		
Salmon bass	Mahimahi		
Puffer	Sailfish		
European squid	Sword fish		
Ribbon fish			
Others			

Table 3.2. Classifications of fish species (see Appendix A for the Scientific (latin) names of all types of species discussed in this research) used in Omani fisheries (not all species are included)

3.2.1 Trawler Fisheries restrictions

The following are the restrictions imposed on trawlers fishery:

1. These vessels are allowed to fish on the continental shelf between latitude 21° 00' 00" North, which passes south of Masira Island and Longitude 55° 45' 00" East, which passes by the Halaniyat Island, and at a distance of more then 10 nautical miles from the coast and depths grater than 50 meters.
2. No vessels of this type are allowed to fish the same area for more than three consecutive days.

For trawlers to make a fishing trip a copy of the 'one voyage/trip fishing vessel license' (Figure 3.2a) issued by the MAF must be approved and signed by authorized personnel at the Ministry prior to the trip. On the form, the area of fishing, the sea depth, the distance from the shoreline, and the trawler's mesh size are all specified.

3.3 Longline Fisheries

These vessels are allowed to use longlines to fish tuna in accordance with fishing quotas allowed by the Ministry of Agriculture and Fisheries to companies that own these vessels. The longlines can fish on the high seas at distances of more than 20 nautical miles offshore (see Figure 3.3).

The species fished by the longlines are mainly large pelagic fish. Although tuna is the main product of these vessels, longline is involved in catching other species such as shark

3.3.1 Longline Fisheries Restrictions

1. Longlines fishing is forbidden within the area of 20 nautical miles of the coast as this is dedicated to traditional fisheries and its future developments, and allowed only in the area from latitude 24° 45' 00"N

offshore Shinas[2] to the Gulf of Oman down to longitude 54° 00' 00"E offshore Raysut[3] in the south.

2. No fishing is allowed north of 24° 45' 00"N and west of longitude 54° 00' 00"E.

3. With regard to Islands in general, the nautical mile is measured from the Island shore (see figure 3.3 for the 20 nautical mile zone).

SULTANATE OF OMAN
MINISTRY OF AGRICULTURE & FISHERIES
DIRECTORATE GENERAL OF FISHERIES RESOURCES

Reference:--------------
Date:-----------------
Onevoyage Fishing Vessel Licence

Voyage No: /

Voyage Commencement Date

From: - - 199 To: - - 199

Vessel Name:----------------

Company Name: Oman Fisheries Co

Call Sign:-------------------

Licence No:------------ muscat

Obsserver Name:--------------

Captain Name:----------------

Cap. Licence No:------------

Fishing is permitted in areas between latitud (21 00)N and longitude (55 45)E along the southern coast of oman provided that the following are complied with :-
1- Fishing should be practised in depths not less than (50m) or at adistance not less than (10 nautical mile wichever is further.
2- Fishing is prohibited in all areas located at the eastern side of masirah island and in areas around ras basik between longitude (55 45 55)E
The fishing vessel is allowed To fish
Fishing methods:Trawling(the outside mesh size should not be less then) (210mm)and the cod end not less(110mm)
Demarsal fish only .
Nuber Crew: ( ) Prs.
The captain shall maintain this licenc onboard the vessel throughout the voyage and present it to whoever it may concern on request.

SALIH KHAMIS AL-MUKHAINI
Act.DIRECTOR OF FISHERIES AFFAR DEPT.

C.C .Office of A.COSSAF.
.R.O.A.F.
.R.O.N.
.COASTAL GUARD.
.Director of F.R.D.
.Vessel File.

a)

SULTANATE OF OMAN
MINISTRY OF AGRICULTURE & FISHERIES
DIRECTORATE GENERAL OF FISHERIES RESOURCES
DEPARMENT OF FISHERIES AFFAIRS

سلطنة عمان
وزارة الزراعة والثروة السمكية
المديرية العامة للثروة السمكية
دائرة الشئون السمكية

REFERENCE:-------------------
DATE :-------------------
TUNA FISHING VESSEL LICENCE
(FOR ONE VOYAGE LICENCE)

رقم الصادر:-------------------
التاريخ :-------------------
تصريح ابحار سفينة صيد التونه .
(رحلة واحده)

VOYAGE NUMBER : /
VOYAGE COMMENCEMENT DATE :

FROM: - - 199 TO: - - 199

VESSEL NAME :----------------

COMPANY NAME :----------------

CALL SIGN :----------------

LICENCE NUMBER :--------- MUSCAT

OBSERVER NAME :----------------

CAPTAIN NAME :----------------

CAPTAIN LICENCE NUMBER :----------

Permitted Fishing area located between longitude(54 00)and latitude(24 45)
Fishing operations should be practised at a distance not less than(20 nm) from the coast.

-Permitted Fishing gears :long lines
-Harvesting of large Pelagics is permitted .

-Number of crew:( ) persons.
The captain shall maintain this licence onboard the vessel and present it to whoever is concerned upon request .

2- This licence is valid for two months from the date of issue.

SALEH KHAMIS AL-MAKHANI
ACT DIRECTOR OF FISHERIES AFFARIS DEPT.

C.C . OFFICE OF A. COSSAF .
. R.A.F.O.
. R.N.O .
. COASTAL GUARD .
. DIRECTOR OF F.R.D .
. VESSEL FILE .

b)

Figure 3.2 a) Fishing vessel license for trawlers fishery and b) Fishing vessel license for longlines fishery.

[2] City and fishing site at the north of Oman (see figure 3.1)

[3] Port and fishing site at the south part of the country (see figure 3.1)

Similarly to trawlers, a copy of the 'Tuna fishing vessel license' (Figure 3.2b) for a single fishing voyage or trip must be approved and signed by authorized personnel at the MAF before making the fishing trip. However, the longline fisheries license is only valid for a maximum of two months from the data of issue. It is issued in order to control the fishing activity of longlines in general and maintain the tuna stock in particular. In the longlines fishing licenses' form, the area of fishing, the 20 nautical miles distance from the shoreline, and the use of only the longlines fishing method are all specified

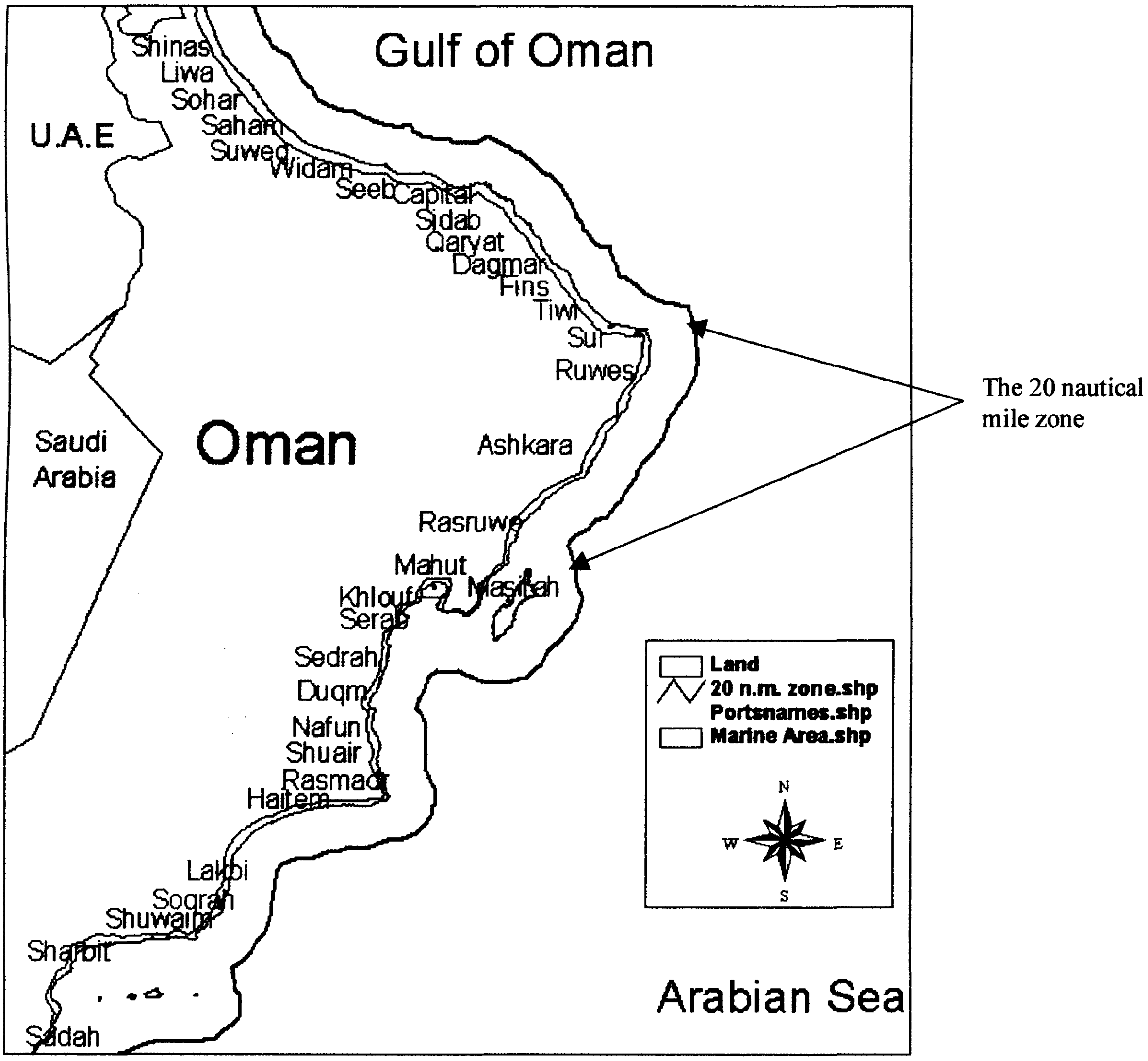


Figure 3.3 The 20 nautical mile zone where longlines vessels are forbidden to access and fish.

4. Types of collected Data

Different methods of data collection are used by the MAF in collecting fisheries data. The three types of fisheries data, traditional, trawlers and longlines are collected from multiple sources. These data are of different formats and treated separately. This section discusses in details the methods used to gather the different types of fisheries data and their characteristics.

4.1 Traditional Fisheries Data

Traditional fisheries data are collected for the catches of small boats operating near the coast and collected at each landing port. The basis of the data collection system is a large-scale continuous sample survey of selected traditional fisheries landing sites in the administrative regions.

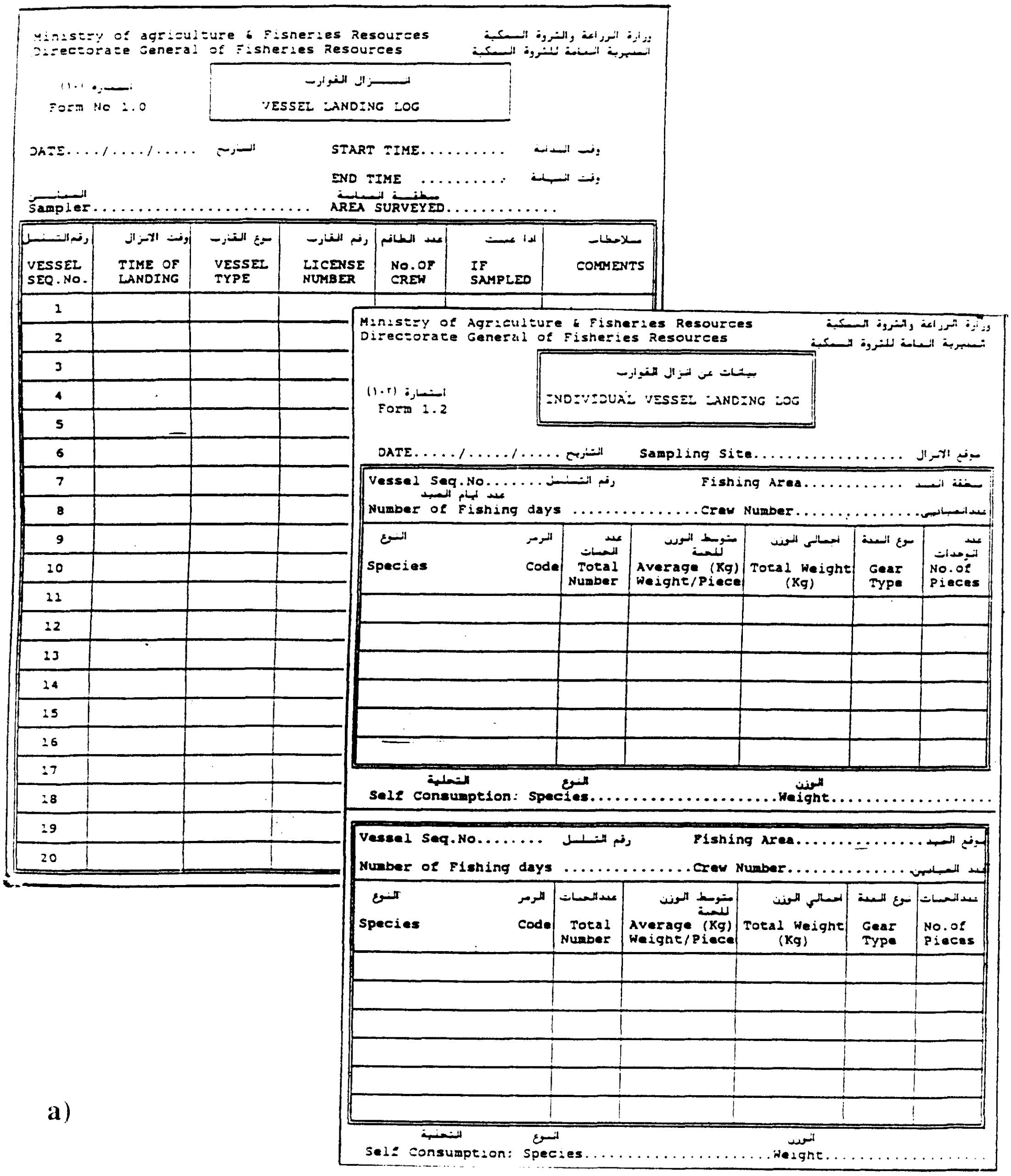
The selection of sample days during a month at a landing site is done at random. The sample size set for a landing site, that is the number of days in the month to be sampled, is determined by the expected total catch during the month.

Data has been collected by field staff using the vessels landing sheet (Figure 3.4a and b). The number of days on which samples are taken at the major landing sites during each month are diverse (e.g. Sur 23 days, Masira 22 days, Shinas 16 days). On the selected sampling days landing data are recorded by a single data collector, generally during a specific period of five hours. On some days the period is in the morning (05:30-10:30), on others it is in the afternoon (10:30-15:30), and occasionally it is in the evening (14:00-19:00), as different fishing methods have different times of landing.

The enumeration units are the small boats landing fish. Data are recorded for each boat separately on the landing log sheet. This data has been computed and stored within the MAF using dBase IV. This research gathered those data for the period 1991-1995. The data has been imported to Microsoft Access, and will be discussed further in the following chapter.

4.1.1 Characteristics of Traditional Fisheries Data

The primary data collected from the MAF are of multiple columns. Figure 3.4a) and b) represents the original boats/vessel landing log sheets used to collect the data.



Ministry of Agriculture & Fisheries Resources
Directorate General of Fisheries Resources

Form No 1.0

VESSEL LANDING LOG

DATE..../..../..... START TIME..........
END TIME ....
Sampler........................ AREA SURVEYED............

VESSEL SEQ.No.	TIME OF LANDING	VESSEL TYPE	LICENSE NUMBER	No.OF CREW	IF SAMPLED	COMMENTS
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Ministry of Agriculture & Fisheries Resources
Directorate General of Fisheries Resources

Form 1.2

INDIVIDUAL VESSEL LANDING LOG

DATE...../...../..... Sampling Site..................

Vessel Seq.No........ Fishing Area............
Number of Fishing days ....Crew Number...............

Species	Code	Total Number	Average (Kg) Weight/Piece	Total Weight (Kg)	Gear Type	No.of Pieces

Self Consumption: Species......................Weight..................

Vessel Seq.No........ Fishing Area...............
Number of Fishing days ....Crew Number..............

Species	Code	Total Number	Average (Kg) Weight/Piece	Total Weight (Kg)	Gear Type	No.of Pieces

Self Consumption: Species......................Weight..................

a) b)

Figure 3.4a) Boat/Vessel landing logsheet and b) catch description of each boat/vessel.

Form 3.4a records the following data: each landing boat/landing time, boat type, license number and crew number. Form 3.4b records the following information: each sampled boat, trip duration, number of fishermen, and for each landed species; name, number of fish and average weight, fishing methods, number of fishing units and price. These data are collected by a number of samplers employed by the MAF, covering most of landing sites along the Oman coastline.

The catch by species is expressed as the number of fish in each sampled boat and the average individual weight. The total weight is the product of the number of fish by the average weight. Concerning such species as sardine, and bottom fish which are landed by truck or basket, the number of fish is difficult to obtain, and the total weight is estimated and recorded. Other data recorded, concern fishing effort as type of boat, number of fishermen, fishing methods, number of gear units and fish average price at the landing site.

There are two different database files stored in dBase IV. The schema diagrams of those files and their data contents are shown in Figure 3.5a and b. The schema in Figure 3.5a is a direct output from the original data sheet shown in Figure 3.4a. Figure 3.5b is basically one single schema and it has been divided into four layers of schemas to fit within the page space. It should be noticed that these tables have not been normalized (Elmasri and Navathe, 1994), and the primary data contains a lot of redundant information and many empty columns. The issues of redundancy and database design in general are discussed in chapter four

Since the traditional fisheries data has been collected using sample survey and landing port selection is done at random, the selection of boats to sample within a landing port is also done at random. One in five boats landing fish is selected and the catch data is recorded. The sampled boat is given a value of 'TRUE' under the field 'SAMPLED' in Figure 3.5a.

SAMPLEDATE	SEQUENCE	TYPE	LICENSE	CREW	SAMPLED
1/1/94	1	FG		2	TRUE
1/1/94	2	FG		2	FALSE
1/1/94	3	FG		2	TRUE
1/1/94	4	FG		2	TRUE

3.5a

SPECIES	PIECES	AVWT	TOTALWT	AREA	TIME	SAMPLER	CONDITION
MUG	3	1.60		SOHAR	725		
TA	4	8.00		BARKA	725		
SCK	5	0.75		SEEB	725		

GEAR	GEAR_SIZE	GEARUNITS	VESSEXPAN

GEAREXPAN	CALCWT	REC_NO	FLAG	DEPARTED	BOAT_HOURS	GEAR_HOURS
		1				
		1				

PRICE_UNIT	KILO_PRICE	SELF_CONS	SELF_WT	USERID
				HUS

3.5b

Figure 3.5 a) Boat landed data, b) catch information

Where:

SAMPLEDATE: Date sampled

SEQUENCE: Sequence number

TYPE: Boat type

LICENSE: Boat license number

CREW: Number of crew on board

SAMPLED: Whether the boat has been sampled (value: 'Y') or not (value: 'N')

SPECIES: Type of landed species

PIECES: Number of pieces of the same species

AVWT: Average weight of each species

TOTALWT: Total weight of total number of pieces per species

AREA: Landing site

TIME: Landing Time (24 hours system)

SAMPLER: Name of the sampler (data collector)

CONDITION: Condition of landed fish (fresh, not fresh, iced)

GEAR: Type of fishing gear (net)

GEAR_SIZE: Size of fishing gear

GEARUNITS: Number of gear units used

VESSEXPAN: Any vessel explanation

GEAREXPAN: Any gear explanation

CALCWT: The total weight of all species per boat

REC_NO: Sequence number for the sampled boats
FLAG: Boat flag (if any)
DEPARTED: Time of boat departure from the port
BOAT_HOURS: Number of hours the boat was at sea
GEAR_HOURS: Number of fishing hours
PRICE_UNIT: In O.R (Omani Rials). To the north of the country near the United Arab Emirates (U.A.E) some are sold fish in Emirates Dirham (E.D.)
KILO_PRICE: Species kilo price
SELF_CONS: Fisherman self consumption ('Y' is fisherman kept some species for self consumption, otherwise 'N')
SELF_WT: The weight of fish kept for self-consumption
USERID: ID of data collector/sampler

4.2 Trawler Fisheries Data

Figure 3.6 shows the map representing fishing areas that are specified for the trawlers. The trawler fishing areas are divided into squares of 30 * 30 miles which are divided into nine smaller squares of 10 * 10 miles. To indicate the fishing area, the Captain of each fishing vessel indicates the number of the large square and of the small one. For example, 755-8 indicates the small square 8 that exists within the large square of 755.

The Captain of each vessel has the responsibility of filling an activity report that should be submitted to MAF at the end of each trip (Figure 3.7 gives an example an actual form submitted by a trawler). Each trawler makes a weekly to monthly trip to the specified area. The report submitted to the MAF includes information about fishing location, fishing area, date of fish, type of species caught, and amount of catch, in number and total weight in kilograms for each type of species. The total annual catch by each vessel must not exceed the specified quota.

The data collected for the period of five years (1991-1995) incorporate many problems to be solved before it can be useful. The main problem is that the data were in their original format: the vessel log sheets. These data have not been stored or processed by any computer system. Only the total amount of catch has been computed. The process has excluded the information concerning locations, even though the system for fisheries management was built on the basis of locational information.

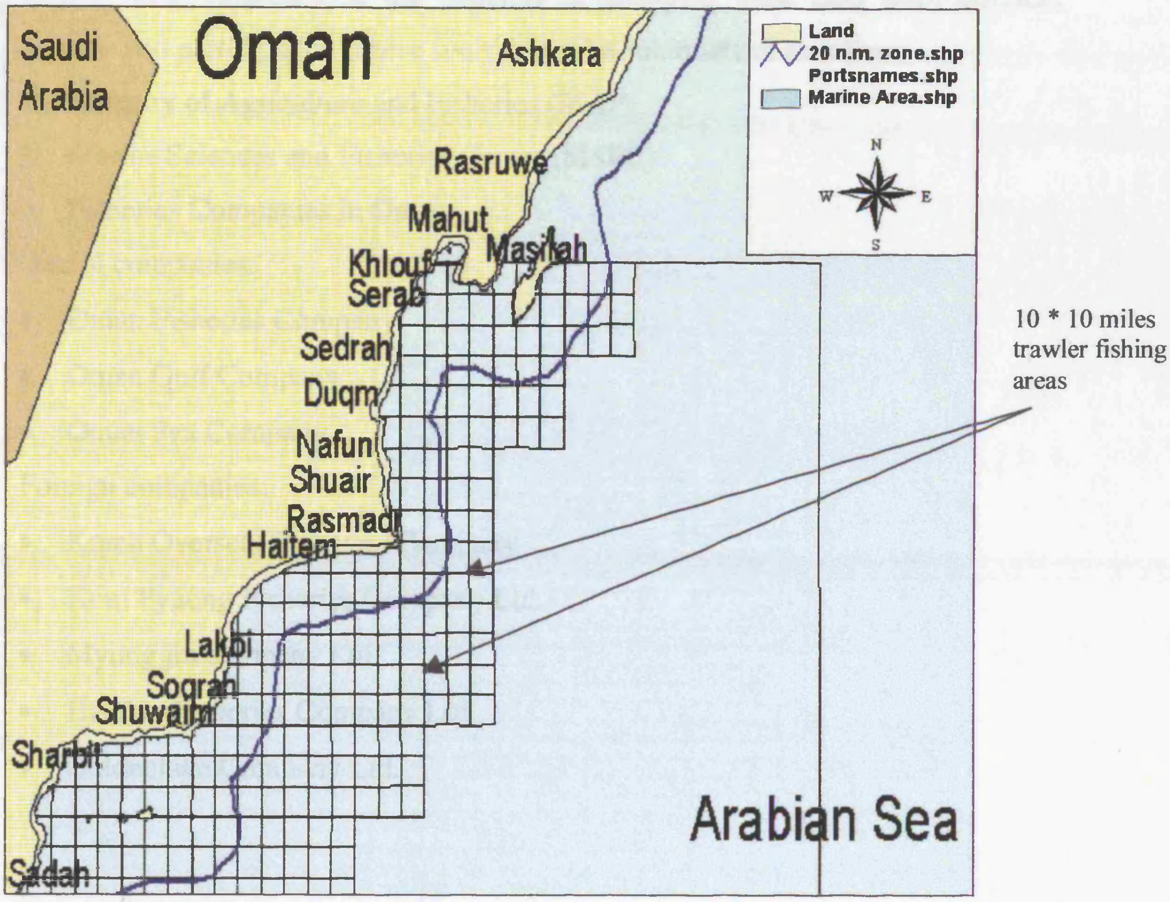


Figure 3.6 Trawlers fishing areas located at the southern part of the country within the Arabia Sea territories.

Direct entry of these data using the keyboard was the only available solution to this problem. The total number of collected and saved records per year from trawlers is summarized in Table 3.3.

Year	1991	1992	1993	1994	1995
Number of collected fishing reports /fishing trips	52	48	45	50	52
Total number of fishing days	690	701	698	700	705

Table 3.3. Number of collected fishing reports and fishing days from trawler fisheries.

The second problem is concerned with the availability of the data within the Ministry of Agriculture and Fisheries. Many of these data have been lost or moved to somewhere else especially for the period of the first two years (1991-1992). The research took the initiative of gathering these data from different sources and participants. These sources can be summarized as follow:

1. Ministry of Agriculture and Fisheries (MAF)
2. Marine Sciences and Fisheries Center (MSFC)
3. Fisheries Companies in Oman:

Omani companies:

- Oman Fisheries Company
- Oman Gulf Company
- Oman Sea Company

Foreign companies:

- Korea Overseas Fisheries Company
- Kum Pyuong Fisheries Company Ltd.
- Myung jin company Ltd.
- Handdo Fisheries Company Ltd.
- Goldenlake Company Ltd.

MINISTRY OF AGRICULTURE & FISHERIES RESOURCES
Directorate General of Fisheries Resources
inspection Section

CATCH REPORT OF: MYUNGJIN 55 VOYAGE NO.: 3 DATE: 25-JAN-1995

		DATE. AREA.	1/22 758-8		1/23 758-8		1/24 758-8		1/25 750-5		TOTAL	
No.	CODE	FISH SPECIES	C/S	KGS	C/S	KGS	C/S	KGS	C/S	KGS		
1	A1	Blood Snapper										
2	A3	Rosy Sea Perch										
3	B	Barracuda	3	60	1	20	1	20			5	100
4	B1	Grey Mullet										
5	B3	King Fish										
6	C	Trevally	1	20	3	60	3	60	1	20	8	160
7	C1	Yellow Fin			1	20					1	20
8	C2	Rudder Fish										
9	C	Tailor										
10	D	Bream / Sea Bream										
11	D1	Brasse										
12	D2	Bream										
13	D3	Sea Bream			1	22					1	22
14	DR	Barred Spade Fish										
15	DS	Porgy										
16	E	Rock Cod / Bass			1	22					1	22
17	G1	Gilt Head / Gold Fish										
18	GR	Mojarra										
19	H	Scavenger			1	20					1	20
20	I2	Cuttle Fish										
21	J	Butterfly Bream										
22	K1	Croaker										
23	K2	Salmon Bass										
24	K3	Silvery Croaker										
25	KF	Puller			1	22					1	22
26	L	European Squid										
27	M	Grunt										
28	M1	Smooth Dog Fish	1	22							1	22
29	MU	Goat Fish										
30	NG	Blotched Grunt	4	80							4	80
31	NG1	Spotted Grunt										
32	O	Octopus										
33	P	Porgy			1	20					1	20
34	Q1	Rabbit Fish										
35	R	Jack Mackerel										
36	RR	Indian Mackerel										
37	RC	Trevally	1	20							1	20
38	S	Cuttle Fish										
39	SM	Bonito										
40	ST	Butter Fish										
41	U	Large Tooth Flounder										
42	U1	Left Eye Flounder										
43	V	Indian Halibut										
44	W	Ribbon Fish	252	6048	718	17232	319	7656	219	5256	1508	36192
45	X	Flat Head										
46		Loose										
47	CB		3	60	1	20					4	30
48												
49												
50												
TOTAL			265	6310	729	17458	323	7736	220	5276	1537	36780

Captain's Signature: Inspector's Signature:

Figure 3.7 Fishing operation logsheet for trawlers

Gathering these data from different sources meant that there is a chance of having both duplicate data within the database, and loss of data. Duplication has been avoided by cross-checking since each vessel log sheet shows the name of the vessel, voyage or trip number and the data of departure and arrival. Loss of data, however, cannot be avoided so easily and is a continuing source of possible inaccuracy, although all available data have been collected.

The third and final problem is a concern with the fishing area. The square that indicates the fishing area represents a large area (10 square miles). No data is available or required by the Ministry on the exact location within the square, although these vessels use a Global Positioning System (GPS) to determine their location at sea. These vessels are allowed to fish at any point within the square.

It is essential to mention, again, that these data have no guarantee of completeness and accuracy, and for that reason mainly, the purpose was to gather the maximum data that will assist the final output of the study. The 5 years data will help in determining the patterns of fish catch by vessels and so better understanding of the areas where fishing is concentrating. These areas of all years high fishing activity and high catch could be used as an indication of the fish biomass areas.

4.2.1 Characteristics of Trawler Fisheries Data

As mentioned, trawlers catch the species existing on the seabed of the continental shelf and species that search for food near the sea bottom. Different features can be observed from the trawlers primary data. Referring to Figure 3.7 these features are:

- There are over 40 different species in the trawlers fishing report including kingfish, tuna, squid, salmon, and shellfish (crustaceans) such as lobster.

- Fisheries data in general and trawler data in particular are of four-dimensional format. The 4-D data can be discussed with regards to the contents (data) of Figure 3.7. The log sheet presents the amount of catch of one vessel (Myunjin 55) for any particular species (kingfish (*Scomberomorus commerson*)) in kilograms caught from a specific area (755-8) at a specific date (25/1/1995). The 4-D data are difficult to be represented in a single database file with all required information on it. This has been converted to a suitable 2-D database by creating multiple relational tables. The representation of this data is discussed in the following chapter.

- Some types of fish have the same species name but different codes. The species names represent the species English (common) name of the species that can be the same for more than one species but represents different scientific names. For that reason some species appear to have the same name but different codes.

4.3 Longline Fisheries Data

Similar to trawlers, longlines data are captured by the MAF through the activity reports submitted by the Captain of each fishing vessel. The Activity reports include data about the duration of the fishing trip, vessel name, registration number, fishing master/company, location in longitude and latitude, amount of catch per day per species (yellowfin (*Thunnus albacares*), b.marlin (*Makaira indica*), mahi-mahi (*Coryphaena hippurus*), sailfish (*Istiophoridae*), shark (*Carcharhinidae*), and swordfish (*Xiphiidae*)) in kilograms, and a total of all catch per day and per trip. An example of the logsheet filled by the vessel Captain is shown in Figure 3.8.

However, these data have the same problems as for trawlers, in terms of their availability in digital form or even the existence of all required data for the five years period in analog format within the MAF.

Although the total catch per species per month has been recorded and stored using Excel, none of these data has been recorded with regards to fish location. Again entering and storing these data using the keyboard was the only solution to solve this problem. The number of collected and saved records per year from longlines fisheries is summarized in Table 3.4.

Year	1991	1992	1993	1994	1995
Numbers of fishing reports/trips	60	60	65	62	70
Numbers of fishing days	2934	2855	3014	2993	3048

Table 3.4. Number of records gathered and computed from longlines fisheries

Longlines data have been collected from different sources and participants. The data have been checked before entering, and any duplicated data has been removed throughout the process. The main data sources for longliners are:

- The MAF
- The MSFC

Fisheries companies:

- Oman Fisheries Company
- Oman Sea Company
- Oman Gulf Company

FISHING OPERATION LOGSHEET 捕魚記錄

TUNA VESSELS: LONGLINE ✓ NET — TROLLER — OTHER — LOGSHEET NO. 頁次 1 — TRIP NO. 航次 2

VESSEL NAME 船名: 建輝221號 CHIEN HUEI NO.221 — REGISTRATION NO. 編號: 626

	DATE 日期	PORT 港口
DEPARTURE 離開	29.1.93	MUSCAT
~~ARRIVAL~~ 到達	29.3.93	MUSCAT

FISHING MASTER: NAME 船主名稱: 建輝漁業股份有限公司 CHIEN HUEI FISHERY CO..LTD

SIGNATURE 簽名: NO. 221, CHIEN HUEI 船長:何添財

CATCH IN NUMBER AND WEIGHT BY SPECIES 漁獲量

Date 日期	Latitude N 北緯	Longitude E 東經	Yellowfin 黃鰭 NO數量	WT重量	B. Marlin 黑旗魚 NO數量	WT重量	Mahi-Mahi 鬼頭刀 NO數量	WT重量	Sailfish 雨傘旗魚 NO數量	WT重量	Shark 鯊魚 NO數量	WT重量	Swordfish 紅肉旗魚 NO數量	WT重量	TOTAL 總計 NO數量	WT重量
1/11	2111	5905	23	480											23	480
1/12	2020	6115	17	510											17	510
1/13	2131	5950	22	750											22	750
1/14	2121	5950	16	400											16	400
1/15	2015	6015	12	350											12	350
1/16	2010	6010	35	1000							5	200			40	1200
1/17	2005	6005	28	1000							1	50			29	1050
1/18	2133	6040	32	900											32	900
1/19	2155	6059	31	800							4	200			35	1000
1/20	2145	6105	19	600							4	250			23	850
1/21	2141	6045	74	2000							2	100			76	2100
1/22	2140	6041	31	800											31	800
1/23	2142	6045	22	470											22	470
1/24	2145	6046	15	380											15	380
1/25	2139	6040	16	440											16	440
1/26	2138	6042	16	470											16	470
			409	11350							16	800			425	12150

Figure 3.8 Fishing operation logsheet for longliners

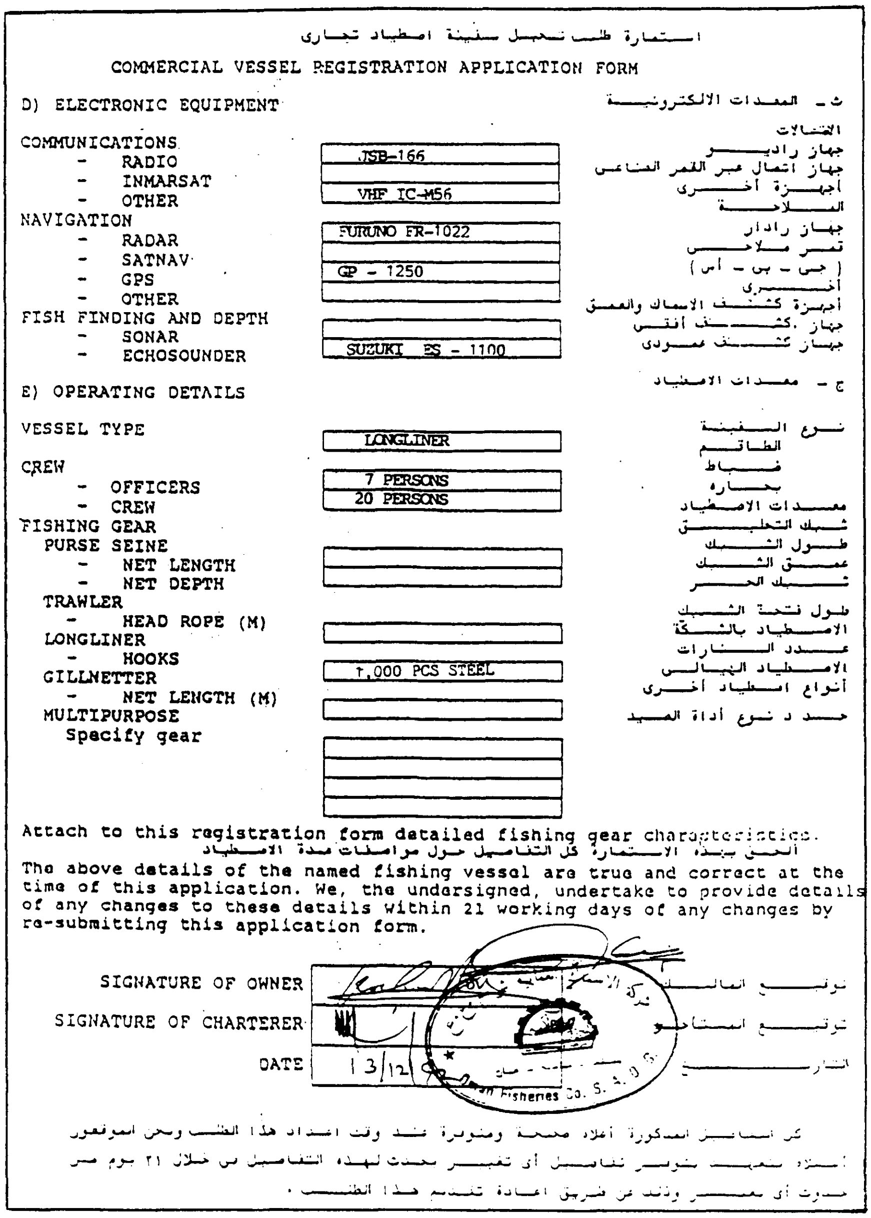
4.3.1 Characteristics of Longline Fisheries Data

Since these vessels use the longitude/latitude system the amount of catch of any fishing vessel at any single day will appear as a point on the sea, and so compared to trawlers, the longlines fishing data more precisely located. Using the

Longitude and Latitude coordinate system to record the fishing area results in more accurate location of catch. The latitude and longitude of longlines are measured in Degrees, Minutes, and the nearest 10 Seconds (DMS).

The characteristics of longlines data can be summarized as follow:

- Data only exist beyond the 20 nautical mile zone.
- Only six different fish species appeared in the longliners fishing report.
- Similar to trawler data, longlines is a four dimensional data type. The amount of catch in kilograms for each vessel is recorded by date of fishing and fish location in longitude and latitude.



استمارة طلب تسجيل سفينة اصطياد تجاري

COMMERCIAL VESSEL REGISTRATION APPLICATION FORM

D) ELECTRONIC EQUIPMENT

COMMUNICATIONS
- RADIO: JSB-166
- INMARSAT
- OTHER: VHF IC-M56

NAVIGATION
- RADAR: FURUNO FR-1022
- SATNAV
- GPS: GP - 1250
- OTHER

FISH FINDING AND DEPTH
- SONAR
- ECHOSOUNDER: SUZUKI ES - 1100

E) OPERATING DETAILS

VESSEL TYPE: LONGLINER

CREW
- OFFICERS: 7 PERSONS
- CREW: 20 PERSONS

FISHING GEAR
PURSE SEINE
- NET LENGTH
- NET DEPTH

TRAWLER
- HEAD ROPE (M)

LONGLINER
- HOOKS: 1,000 PCS STEEL

GILLNETTER
- NET LENGTH (M)

MULTIPURPOSE
Specify gear

Attach to this registration form detailed fishing gear characteristics.

The above details of the named fishing vessel are true and correct at the time of this application. We, the undersigned, undertake to provide details of any changes to these details within 21 working days of any changes by re-submitting this application form.

SIGNATURE OF OWNER

SIGNATURE OF CHARTERER

DATE 13/12

Figure 3.9 Application form for commercial vessel, electronic equipment and operating details.

5. Location Determination (GPS)

Traditional fisheries exist along the coastline of the country and use no navigation systems. In general the traditional fishermen depend on their eyes and experience to determine the distance they have to travel to get to the fishing areas.

For commercial fisheries, both types of vessels (trawlers and longliners) are using GPS to locate their specified areas. Figure 3.9 shows the 'commercial vessel registration application forms' for both types of vessels that must be filled with details about the electronic equipment including the navigation system in use (e.g. radar, satnav, and GPS). Then, it has to be signed by the owner of the vessel (the company) and the charterer to ensure that the details given are correct and according to the regulations. Figure 3.10 shows the GPS devices used in the commercial vessels.

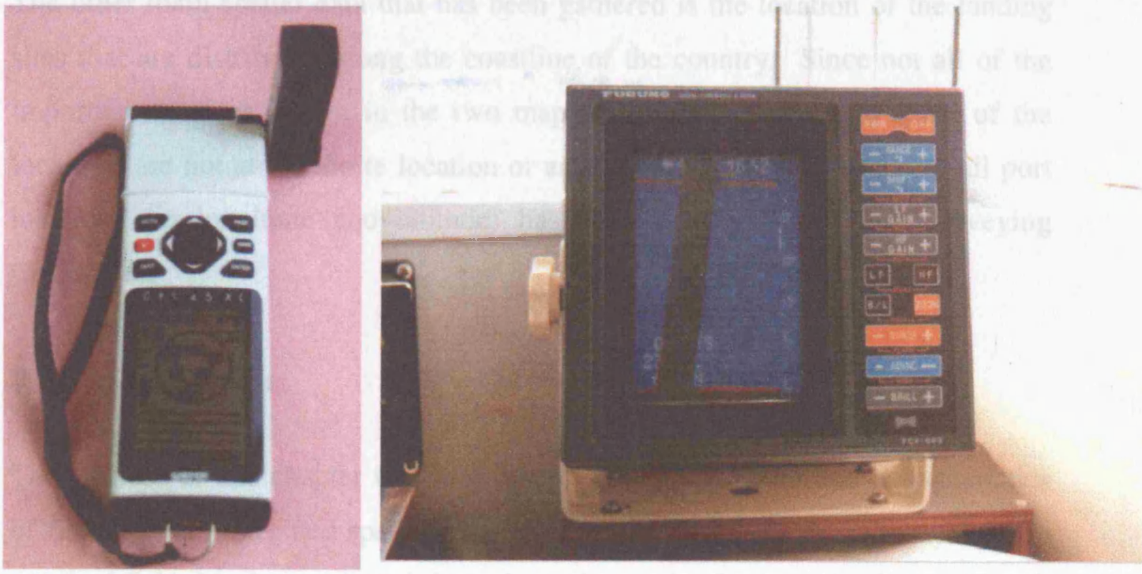


Figure 3.10 Global Positioning System (GPS) used in commercial vessels.

6. Gathering Spatial Data

Two maps (in analog format) have been gathered for the purpose of this research. Those two maps represent the area of Oman with the emphasis on the coastline and the sea areas. The first map represents the north part of the country and is therefore called the 'north map', and the second map represents the south part and is called the 'south map'. Both maps are of the same scale of 1: 750,000 at latitude 20° 00' 00"N. The following is the description of each map:

1. The Northern map covers the area from the 'Strait of Hormus' at longitude 60° 50' 12"E and latitude 26° 39' 00"N at the north to 'Almasirah' at longitude 56° 15' 00"E and latitude 20° 02' 15"N at the south. This map shows the longlines area starting at latitude 24° 45' 00"N.
2. The Southern map covers the area from 'Almasirah' at longitude 60° 50' 12"E and latitude 20° 46' 30"N at the north to "Mina Raysut' at longitude 53° 31' 36"E and latitude 16° 20' 00"N at the south. This map shows the 10 * 10 squares of the trawlers fishing areas that are designed by the MAF.

The two maps have been supplied by the Surveying Committee of the Ministry of Defense in Oman. Both maps were digitized (chapter 4), as the information was not available in digital format when this research commenced.

The other main spatial data that has been gathered is the location of the landing sites that are distributed along the coastline of the country. Since not all of the important sites are shown in the two maps mentioned above, and some of the locations are not at a definite location or are difficult to digitize, a list of all port locations (in longitude and latitude) has been collected from the Surveying Committee.

7. Summary

The purpose of this chapter was to give details on the amount and characteristics of fisheries attributes and spatial data gathered for this research. There are three types of fisheries data gathered throughout the work of this research: traditional, commercial trawlers, and commercial longlines. The data collected represent the fishing data for the period of five years (91-95). For the traditional fisheries the primary data has been stored in the dBase IV program within the Ministry of Agriculture and Fisheries. The trawler and longlines primary data has been collected from different sources, and different method has been used to prepare and adjust them for input into computer programs. The creation of digital data for the commercial fisheries (trawlers and longlines) data has been done throughout this research. The recent system for fisheries management has applied different types of restrictions to fisheries in order to reduce the damage that can be caused by commercial fisheries and protects the fisheries resources from overfishing. Commercial vessels use Global Positioning System (GPS) in order to locate the approved fishing areas.

For spatial data, two maps of scale 1:750,000 showing the north and the south of Oman and designed specially for the purpose of controlling the marine activities, have been collected and later digitized to be used within the GIS, together with the location of traditional landing sites.

4

CONSTRUCTION OF THE SPATIAL MARINE FISHERIES DATABASE

"The design of the database is not the only component of the more encompassing design of an information system, but it is a most important part".

(Laurini and Thompson, 1992, p. 392)

1. Introduction

In designing Geographical Information Systems (GIS) for marine fisheries three types of data input, in digital form, are required:

1. *Attribute data* that describe the phenomenon or object reported such as a physical dimension or class,
2. *Spatial data* that define the spatial location of the phenomenon or object being described, and
3. *Temporal data* that describe the point in time where the phenomenon existed.

Examples of a physical dimension might be the type or the weight of fish species. Spatial location is usually specified with reference to a common coordinate system such as latitude and longitude. The time when the object is recorded is a third fundamental type of data input essential for the GIS, although it is not stated explicitly in the literature (Burrough, 1986; Aronoff, 1989; Frank, 1991; Laurini and Thompson, 1992; Demers, 1997).

Geographic information describes a phenomenon at a location as it existed at a specific point in time. Map coverage of marine fisheries data, for example, describes the location of different fish species at the time of data collection. Since the fish are moving, this information may quickly be out of date. The importance of the time element in GIS is crucial to management and decision making.

In order for the GIS is produce the outputs successfully, data must be fully organized within the database, that is to say, designing the required database is the most important part of building any geographical information systems. This chapter elaborates on much of the methodology used to design a spatial marine fisheries database and it presents the spatial outputs. Section 2 highlights the overall methodology used to create a suitable database system. The main software used to hold and organise the data are discussed in detail as section 3. Section 4 outlines the method used to capture digital coverages of the marine area of Oman. Section 5 discusses the sampling method used to estimate the catch from the traditional fisheries. The Relational Database Management System (RDBMS) forms the contents of section 6. Section 7 explains the use of Structured Query Language (SQL). Finally, section 8 links the attributes (fish description) and spatial data (marine area coverage) within the GIS in an endeavour to produce an integrated visual output.

2. Overall Methodology and System Architecture

This section gives a brief outline of the method used to design the database. The word "design" in this context means the steps or techniques used to build the required spatial marine fisheries databases.

The design method consists of phases, with steps, which guide the techniques appropriate for each construction stage for building the database. Since the design of the database requires three types of data identified above (attributes, spatial and temporal), the process used to build such a database involve two main phases:

a) Spatial data construction, i.e. digitizing of the appropriate maps according to the four steps:
   - Digitization of the two maps of the marine fisheries area,
   - Correction of the digitizing errors,
   - Conversion of the coverages to real world coordinates, and
   - Placement of labels and captions (assigning identities to the digitised marine fishing areas)

More details of the procedure of spatial data construction is described in section 4 of this chapter.

b) Construction of the appropriate relational database for the attributes (fisheries) and temporal data according to five steps:
   - Identification of entity types and relationship types (database schema) using the Entity-Relationship (ER) model (see section 6.2).
   - Identification of attributes associated with entity or relational types (associate attributes),
   - Determination of the primary key attributes (see section 6.5.2) and,
   - Determination of the relational integrity (entity integrity constraint and referential integrity constraint (see section 6.5.3)).

The temporal data are basically treated as an attribute entity that has been constructed together with the other fisheries attribute data.

The steps used to build the database system are outlined through Figure 4.1. The steps and details of building the Relational Database for marine fisheries are discussed further in section 5. The architecture and the contents of the spatial marine fisheries database can be viewed in Figure 4.2.

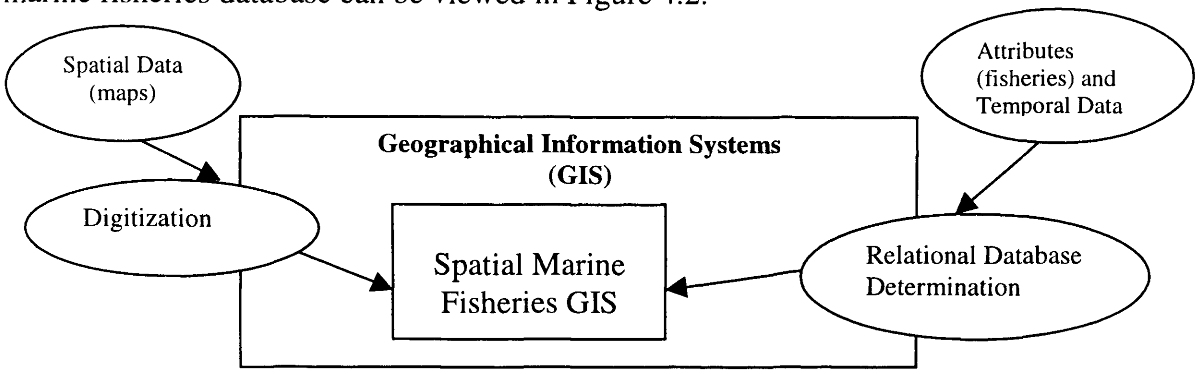


Figure 4.1 Construction process for building a spatial marine fisheries database

The overall expectation from building the database is to enable the GIS, when linked with the attribute data, to produce the required outputs that show the fisheries data displayed within the digitized coverage. The fisheries data should include information about the location of caught fish (points and polygons), data of catch, fishing duration, type of species caught, and amount of the catch from each species.

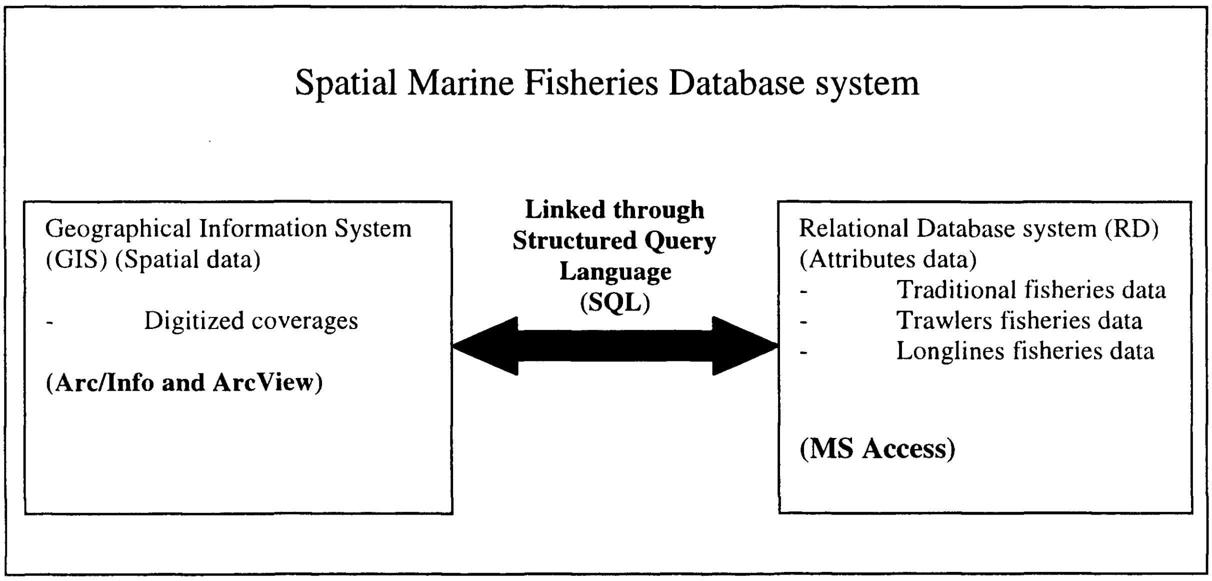


Figure 4.2 Overview of spatial marine fisheries database.

3. Software Used

Before explanation of the construction of the database systems it is essential to cite briefly the software used in this research. The following is a list of these software, with a brief introduction to the purpose of each one:

1. For the spatial data:

   a) **ARC/INFO version 7.2.1** is the commercial geographical information system, which originated about 1980 and was developed by Environmental Systems Research Institute (ESRI) in California (ESRI, 1990). The function of the Arc software components is to manage the geographic data, whereas the Info component holds the attributes data. Throughout this research ARC/INFO has been used to store the main coverages and the ARC sub-modules ARCEDIT and ARCTOOLS have been used for the purposes of correcting digitized errors and joining the two coverages (ARCEDIT is the graphical and database editor that employs 'edit environment' and 'feature-oriented editing' whereas ARCTOOLS is a menu-based interface to ARC/INFO functionality that has been designed to get new users started quickly and to make all users productive at performing common geo-processing tasks).

      Arc Digitizing System (ADS) is and ARC command that has been used to convert the original format map (the hard copy) into a digital format. ADS is used to create a coverage by copying tics from the original map coverage and adding arcs and label points.

   b) **ArcView GIS version 3.1** is the main GIS program used in this research. ArcView is a desktop mapping system that provides geographical information system functionality and supports the analytical tools to create spatial data and define spatial relationships among multiple sets of data (ESRI, 1990). It can be use to organise, maintain, visualise, analyse, and disseminate maps and spatial information. ArcView is fully integrated with the rest of ESRI products such as ARC/INFO.

Arc View is used to produce the visual outputs for the tasks of applying fisheries data to GIS. Although Arc View has query tools built in to allow the spatial relationship to be investigated, the main query building will be performed by Access software (the relational database system).

2. For the attributes data:

a) **Microsoft Excel 97** is the spreadsheet used for storage, analysis, and charting of the data (Microsoft, 1992). Only those data for commercial longline fisheries have been stored initially in Excel worksheets for external operations before being imported to Access.

b) **Microsoft Access 97** is the database management tool used to store, organize, analyse, and query the data (Microsoft, 1994). For the work conducted in this research, Access has been used as a relational database system which holds the attribute data and is used to organize the relations between the files or tables and build the required queries.

4. Map Digitization

The analogue (hardcopy) maps of Oman have been converted into digital form by manual digitizing. The digitizing process has mainly focused on the area of fishing activities (the coastline and the open sea).

The two maps of Oman at a scale of 1:750,000 that were discussed in Chapter 3 were digitized. The first map represents the northern part of the country's coastline and the second map represents the southern part with the grid squares of 10 square miles used as a reference for the demersal fishing areas.

For both coverages (i.e. digitized maps) locational references for each tic were marked on the original map and their latitude and longitude recorded. Before proceeding, these real-world locations were converted from Degree, Minutes and Seconds (DMS) into Decimal Degree (DD). The following equation is used to compute the decimal degree:

Decimal Degree = Degree + Minutes/60 + Seconds/3600

4.1 Fishing Area Identification

For the northern map the coastline and the sea area were digitized as area coverages or polygons. Each land area has been given a unique label or identifier. The longline fisheries data is directly applied to the sea area because the fishing locations of this type of fishery have been data recorded in terms of DMS, which can be converted into DD.

The southern map has been digitized the same way by using polygon features. In addition, the small areas of 10 miles squares of the trawlers fisheries map have each been digitised and given a unique identifier. Each square has been given the same number as that originally found in the primary data.

The two maps have been joined using ARC/INFO and the landing ports for the traditional fisheries have been spatially recorded using the locational data collected by the Ministry of Defence. The general appearance of the output coverage from the two digitized maps is shown in Figure 4.3.

The 20 nautical mile zone dedicated for the fishing activity of the traditional fisheries and separating it from the commercial longline fisheries has been created in Arc Info by generating a buffer zone along the coastline. In case of the islands in general the 20 nautical miles are measured from the island shore.

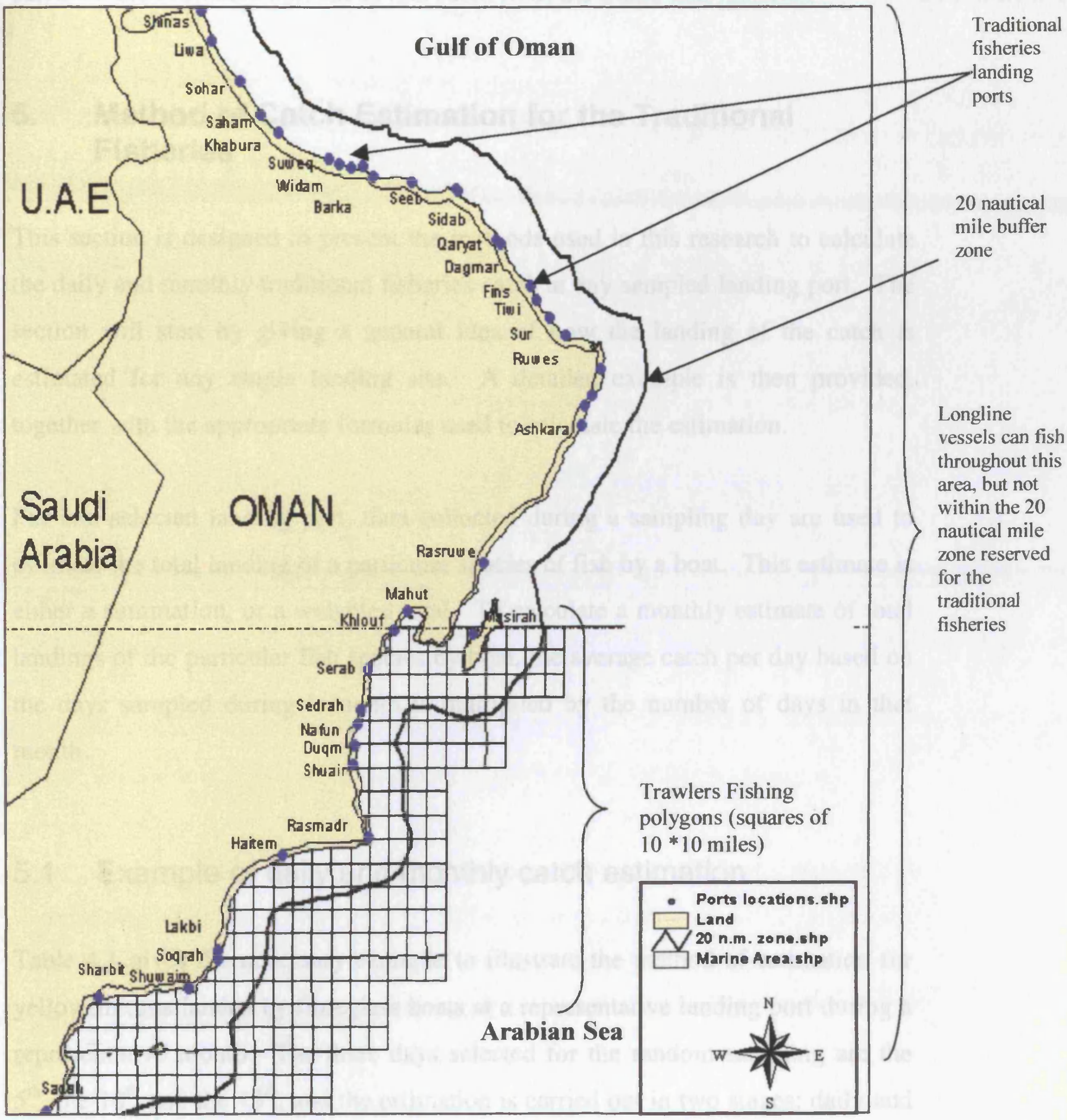


Figure 4.3 Digitized marine fisheries areas for the types of fisheries (Traditional areas/ports occur as points at the landing ports, trawler squares occur off the southern coastline of the country, whereas longline areas are distributed along the coastline.

Before the detailed discussion on the construction of the database system and the use of the ER method it is necessary first to explain the method used in order to calculate the estimated amount of fish catch from the traditional fisheries.

5. Method of Catch Estimation for the Traditional Fisheries

This section is designed to present the methods used in this research to calculate the daily and monthly traditional fisheries catch at any sampled landing port. The section will start by giving a general idea of how the landing of the catch is estimated for any single landing site. A detailed example is then provided, together with the appropriate formulas used to calculate the estimation.

For one selected landing port, data collected during a sampling day are used to estimate the total landing of a particular species of fish by a boat. This estimate is either a summation, or a weighted total. To calculate a monthly estimate of total landings of the particular fish species by boat, the average catch per day based on the days sampled during a month is multiplied by the number of days in that month.

5.1 Example of daily and monthly catch estimation

Table 4.1 gives the necessary example to illustrate the method of estimation for yellowfin tuna landed by fibreglass boats at a representative landing port during a representative month. The three days selected for the random sampling are the 5th, the 10th and the 15th, and the estimation is carried out in two stages: daily and monthly. The total number of boats counted on the beach during the last annual (1995) census was 140. The same method of calculation is used by the Ministry of Agriculture and Fisheries.

Fishing Days	Sampled Boats (s)	No. of boats catching yellowfin tuna (y)	No. of boats landed fish (l)	Census boats (n)	Sampled weight landed (sw)	Estimated total weight landed tw=sw*l/s	Estimated boats catching yellowfin tuna Y_b = l*y/s	Participation rate p= Y_b /n
5^{th}	20	5	60	140	395 kg	1185 kg	15	0.107
10^{th}	24	6	73	140	740 kg	2251 kg	18	0.129
15^{th}	30	8	68	140	970 kg	2199 kg	18	0.129

Table 4.1 Method used to estimate the daily catch of yellowfin tuna by the traditional boats

For a daily estimate of catch from the yellowfin tuna, taking day 5 as an example.

On the 5^{th}, the total number of boats landing fish was 60 (l), whereas the total number of sampled boats = 20 (s). Out of the sample boats, only 5 (y) boats recorded the catch of yellowfin as follows: 35, 60, 80, 120 totalling 395 kg (sw). Then, the estimated total catch of yellowfin (tw) landed by boats for the 5^{th} day is:

$$tw = sw*l/s$$

$$395 * 60 / 20 = 1185 \text{ kg}$$

Where the *catch* is based on the sampled boats of 20 out of 60 boats landing.

Number of boats that are contributing to the catch out of 20 boats sampled, 5 recorded the catch yellowfin tuna. With the assumption that the same proportion contributes to the total catch of yellowfin during the day among the sampled and unsampled boats (60), the number of boats landing yellowfin is:

$$Y_b = l*y/s$$

$$60 * 5 / 20 = 15$$

Thus the fishing effort for this day from this site in the traditional yellowfin tuna fishery would be 15 boat per day. The *Participation Rate* then is equal to:

$$p = Y_b / n$$

$$15 / 140 = 0.107$$

Where 15 boats out of the 140 boats counted on the beach participated in catching yellowfin.

The method used to calculate the monthly catch from each is as follows, assuming that catches in the sampled days were representative of all days in the month of April at that landing port.

Catch based on the data of the total landing of the yellowfin tuna by fibreglass boats on the three sample days as recorded above, the estimation for this month would be:

$$m_c = \Sigma wy * 30/3$$

$$(1185 + 2251 + 2291) * 30 / 3 = 56345 \text{ kg}$$

Where m_c is the monthly catch and Σwy is the summation of the estimated total weighted landed, 30 is the number days of the month of April, and 3 is the number of sampling days.

Number of boats contributing to the catch: based on the three sample days of data the estimated number of boats contributing to the catch would be:

$$t_b = \Sigma Y_b * 30/3$$

$$(15 + 18 + 18) * 30 / 3 = 510$$

Where t_b is the total number of boats participated in catching yellowfin tuna, and ΣY_b is the number of boats estimated to have catch yellowfin tuna at that month of April. Thus, the monthly fishing effort generated by the vessels from this port was 510 boats per day.

Monthly participation rate is calculated as follows:

$$(0.107 + 0.129 + 0.129) / 3 = 0.1217$$

The same method of estimation is applied to the data collected at each selected landing port in the region.

Table 4.2 gives the results of the sampled survey for yellowfin tuna in the representative region during the representative month used in the example above.

Landing Port	Catch (kg)	Number of Boats per Day	Number of boats on Beach	Participation Rate (estimate)
Landing port (a)	12350	190	32	0.198
Landing port (b)	56345	510	140	0.122
Landing port (c)	24300	365	43	0.283
Landing port (d)	11573	215	28	0.256
Landing port (e)	348	78	18	0.144
Total	104916	1358	281	

Table 4.2 Sample survey of yellowfin tuna in a representative region for a representative month

The mean daily participation rate for the region for this month weighted by the number of boats on the beach is calculated as:

(0.198*32 + 0.122 * 140 + 0/0.283 *43 + 0.256 *28 + 0.144 * 18) / 281 = 0.1612

The mean participation rate allows the total indicative effort, 1,358 boats per day, to be adjusted in order to take into account fishing by vessels believed to be fishing in the region but not subject to the sampling program.

The following sections will explain the way traditional data has been structured and organised using the RD method.

6. Database Management Systems for Marine Fisheries Data

This section explores in detail the methods used to construct the database system for the spatial marine fisheries. The discussion includes the method of building the database for each of the three different types of fisheries data as well as linking them to the spatial database within the GIS. The attributes and the spatial data of this research were stored separately.

When creating the spatial database system for natural resources data in general, spatial data is usually held within the GIS and the attribute data are stored externally using software such as Oracle or dBase (Meaden and Do Chi, 1996).

A database is a collection of related data or information about things and their relationship to each other, and a Database Management System (DBMS) can be defined as an operating system for integrating and sharing computer-based data records (Laurini and Thompson, 1992). It can also be defined as a computer programme for creating, manipulating and accessing digital databases (Whittington, 1988; Elmasri and Navathe, 1994; Connolly *et al.* 1996). The use of DBMS generally is to organise, properly order and structure the data.

6.1 The Relational Database Method

The Relational Database (RD) method is used to represent the database as a collection of relations where each relation takes the form of a table in which each row represents a collection of related data values (Elmasri and Navathe, 1994). The use of a RD will be gradually highlighted throughout this chapter.

The advantages of using the relational data model/method in the design of any information system in general and in marine fisheries in particular can be outlined as follows:

1. a RD is currently the most common approach applied by GIS users and researchers (Batty, 1992; Floen et al, 1993; Kemp and Lee, 1998)
2. a RD is the most appropriate data model for fisheries data. All fisheries data employed in this research are logically well related (relationally) to each other and all required operations of data organization and retrieval can be easily performed using a RDMS.
3. a RD can be flexible method to be used in organizing the relational tables as well as establishing and maintaining the database design (Meaden and Do chi, 1996).
4. Using a RD has a significant benefit of storing all data in a single database file. This provides an easy way of linking the data and minimises overheads such as administration and management procedures (Batty, 1992).

5. Almost all relationships can be worked out by use of Boolean operations.
6. With the RD method it is easy to add or subtract data at any time (Healey, 1991).
7. The Structured Query Language (SQL) has been developed as the standard language to be used in RDMS and this can be easily imported and read within ArcView GIS (SQL provides a quite natural way to access data and to perform some operations upon them, including the definition and manipulation of data.

When building a RD for marine fisheries, many concepts and constraints need to be included and explained (e.g., the relation schema, characteristics of relations, the primary keys, candidate key, and entity integrity constraints). Those concepts and constraints of importance to the design of the RD will be discussed in the following three sections which are divided according to the three types of fisheries data.

Generally, the three relational database files of traditional, trawlers and longline fisheries, are built and stored within one main database file called fisheries data. Although, when designing the database the aim is to build a fully integrated RD system in which data can be shared and merged together. However, each type of data has its unique characteristics and so it is necessary to discuss each one individually. It is also important to notice that when it is desirable to link these attribute data to spatial data within the ArcView package, it is preferable to have the three data types located within a single database file, they need to be spatially integrated.

Representing the data as Entity-Relation (ER) diagrams can help in understanding how these data are related to each other and thus supporting the way the RD is constructed. The ER model is a popular high-level conceptual data model (Elmasri and Navathe, 1994). The ER model describes data as entities, relationships, and attributes.

6.2 Data Modelling Using the Entity-Relationship Model

Each entity on ER model represents an object in the world such as person, fishermen, and fish species. Each entity has particular properties, called attributes, that describe it (Elmasri and Navathe, 1994; Connolly et al, 1996). For example a fish entity might be described by the attributes: fish code, English name, and Scientific name. A particular entity has a value for each of the attributes. Figure 4.4 shows one fish entity and the values of the attributes. The species yellowfin tuna has three attributes: Code, English Name, and Scientific Name; their values are "TA", "Yellowfin tuna", "*Thunnus albacares*", respectively.

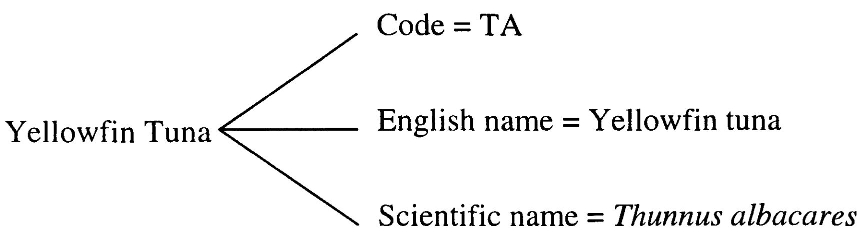


Figure 4.4 Yellowfin tuna (*Thunnus albacares)* entity and its values

6.3 Entity-Relation Model for Traditional Fisheries

Figure 4.5 shows how the schema for the traditional application can be displayed by means of graphical notation in an ER diagram. Referring to figure 4.5, this ER diagram describes a boat making fishing trips and landing catch. Then, the steps of database design can be described as follows:

1. The boat making fishing trips. Each boat has a license number, type (mostly fiberglass), and location (Port).
2. A particular boat makes one or more fishing trips per day. Different data associated with each fishing trip such as date of trip, number of crew on the boat, types and number of fishing gear used to fish.

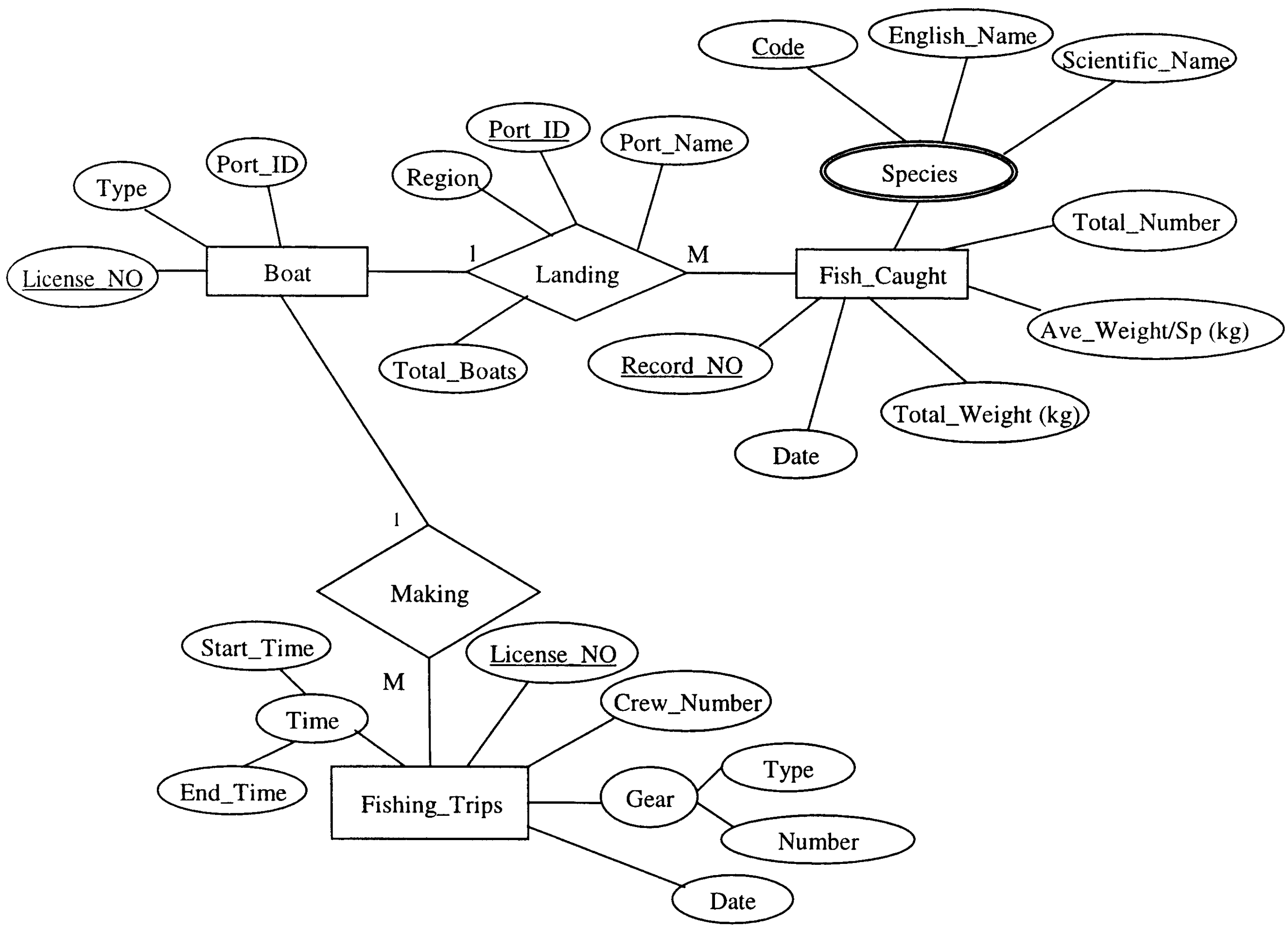


Figure 4.5 ER diagram for the traditional fisheries

3. The boat landed the catch on the port. Each port has a unique Identifier, name, and region where it located.
4. Each boat landing different types of species. The fish description of each species is described in figure 4.4.

From these four points the ER diagram is being drawn in Figure 4.5. The next step is to convert the ER model into a relational database. This is discussed in the next sections.

The notation used in ER diagram is summarized in Figure 4.6.

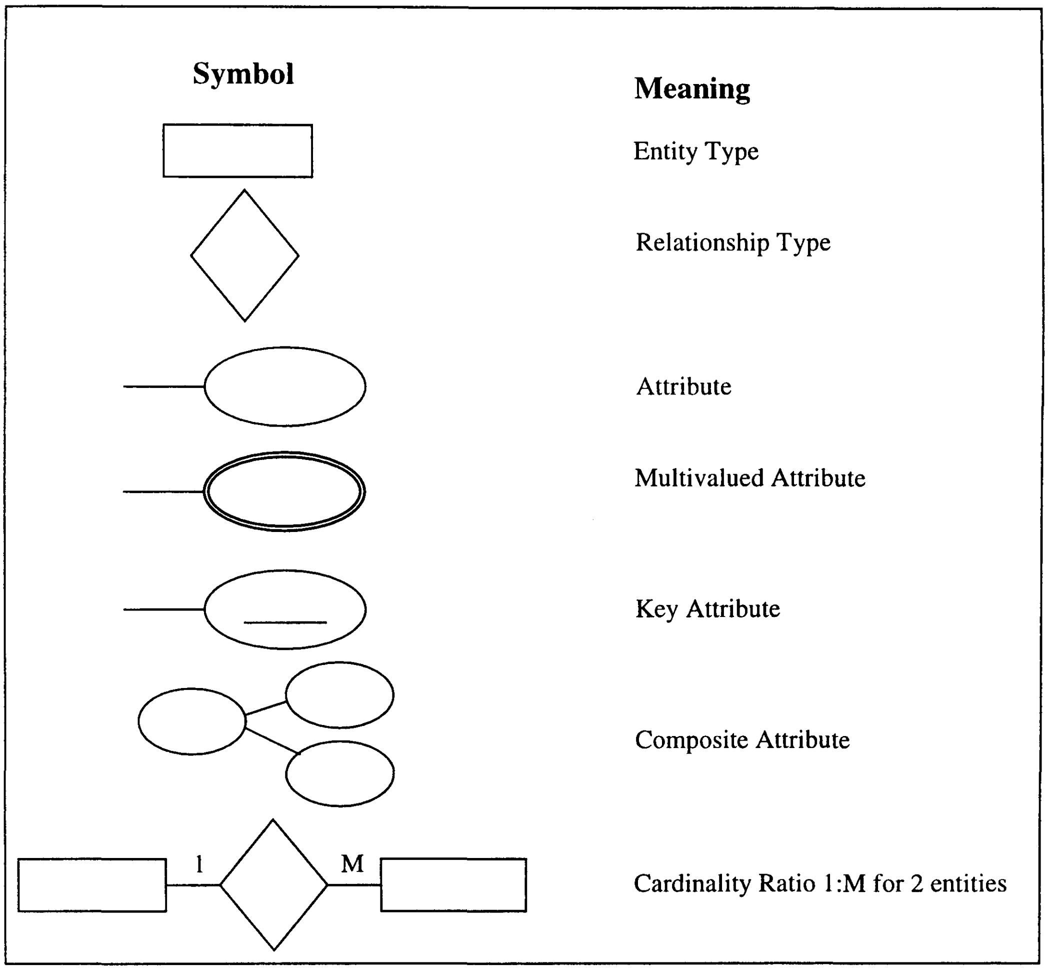


Figure 4.6 Summary of ER diagram notation (after Elmasri and Navathe, 1994)

Where multivalued attribute is the attribute that holds multiple values for a single entity and Composite attribute is the attribute that is composed of a single component with an independent existence.

6.4 Fish Description Table

Although the three types of fisheries catch different types of fish species, ***FISH_DESCRIPTION*** table has been integrated to hold all types of fish species with attributes containing the following data:

- *Species_Code* (each fish species has been given a unique code)
- Species *English_Name* (the given English name of each fish species)
- Species *Scientific_Name* (the given Scientific name of each fish species)

The detailed information of the ***FISH_DESCRIPTION*** table is listed in Appendix A. Traditional fisheries set to catch all different types of species, and their catch record shows that they are indeed catching almost, the ***FISH_DESCRIPTION*** table of the database was created using the *Species_Code* used in the traditional fisheries database. Thus, although the trawler fisheries coded the yellowfin tuna as 'C1' in their original catch reports, this code as well as the rest of the other species codes were integrated (changed for trawlers as well as longlines data so that all integrated with the traditional). The yellowfin tuna, as an example, is coded as 'TA' in the integrated ***FISH_DESCRIPTION*** table of the database.

6.5 The Relational Database System for Traditional Fisheries

As mentioned in the previous chapter, the traditional fisheries were based on the catch of fish landing at ports by boats along the coastline of the country. Reference to Figure 3.5 shows that the primary data for traditional fisheries contains a large amount of information collected as samples from selected landing ports. These data need to be structured and organized, with different calculations applied to each in order to calculate the catch data (mean, average, total, etc.), temporal data of daily, monthly and annually outputs as well as any other required queries.

Since the collection of these data is, geographically based on the landing ports a unique identifier (ID) has been assigned to each port. The port identities are shown in Figure 3.1 of Chapter 3 and form the basis for linking the attribute data to spatial data in the GIS.

6.5.1 Structure of Relations (Tables)

The ER model is transformed into a relational database structure. Five relational database files (tables)[1] have been created to hold the traditional fisheries data. The four relational tables contain data found from primary sources. The relational database schema[2] for traditional fisheries is shown in Figure 4.5.

The first relational table is labelled ***FISH_DESCRIPTION,*** concerns the description of fish species and is discussed above.

[1] Relation and table are synonymous. In general, a relation is a table with columns and rows
[2] A database schema is the description of the database

The second relational table, ***FISHING_BOATS,*** (corresponding to the 'Boat' entity in Figure 4.5) lists the data concerns the information about the fishing boats. This includes:

- *License_NO* (boat license number that are given by the MAF)
- *Type* of the boat (almost all are fiberglass boats)
- *Port_ID* (port identity where the boat is activating)

The third relational table, ***LANDING_PORT,*** (corresponding to the 'Landing' entity in Figure 4.5) lists the data of the landing ports. The contents of this table:

- *Port_ID* (port identity: the unique identity of each landing port)
- *Region* in which each port is located (Oman is divided into seven main regions, six of them are located along the coastline of the country, see Table 3.1)
- *Port_Name* that lists the names of each port.
- *Total_Boats* (number of boats in census of five years (1991-1995)

The number of boats per landing port has been carried out every year by the MAF since 1985. The number of boats is crucial to calculate the catch estimation as well as measuring the efforts. Once the boat has been registered at a specific port, the regulation allows that boat to land the catch only at that port.

The fourth relational table, ***CATCH_REPORT,*** (corresponding to the 'Fish_Caught' entity in Figure 4.5) gives details of the amount of fish caught by the small boats landed in each port. This contains details of:

- *License_NO* (boat license number)
- *Record_NO* (sequence numbers for each fishing record)
- *Date* (date of catch in dd, mm, yy format)
- *Species_Code* (codes of caught species)
- *Total_Number* (number of fish from each type of species)
- *Average_Weight/Sp* (Average weight in kg of each species)
- *Total_Weight* (total landed catch in kilograms). Average weight is used for large species whereas total weight is mainly used for small species like shrimp and sardine.

The column called the *Record_NO* is included in this table to give every fishing record a unique record identity. The record number will form the primary key of the relation, as this is essential for many other operations as well as for linking to other relational files.

The fifth relational database file is ***TRIP_INFORMATION,*** (corresponding to the 'Fishing_Trip' entity in Figure 4.5) which has been designed to hold those data that concern fishing trips made by traditional boats. This file includes the following:

- *License_NO*
- *Date* (date of starting the fishing trip. This could be different from the date of ***CATCH_REPORT*** table, since the boat may start the fishing trip before midnight and return back next morning*)*
- *Start_Time (*time where fishing trip is started*)*
- *End_Time (*time where fishing trip is ended*)*
- *Crew_Vessl* (number of crew per vessel/boat)
- *Gear_Type* (Type of fishing gear)
- *Total_Gear* (Number of used gears)

Since the temporal data employed in this research are for a 5 years period (1991-1995), five relational database files have been created. These are:

- TRADITIONAL_DATA91,
- TRADITIONAL_DATA92,
- TRADITIONAL_DATA93,
- TRADITIONAL_DATA94, and
- TRADITIONAL_DATA95

Although the ***FISH_DESCRIPTION*** table is the same for each of the five years period, the number of boats is changing throughout the years and thus fishing effort and amount of catch are always different from year to year.

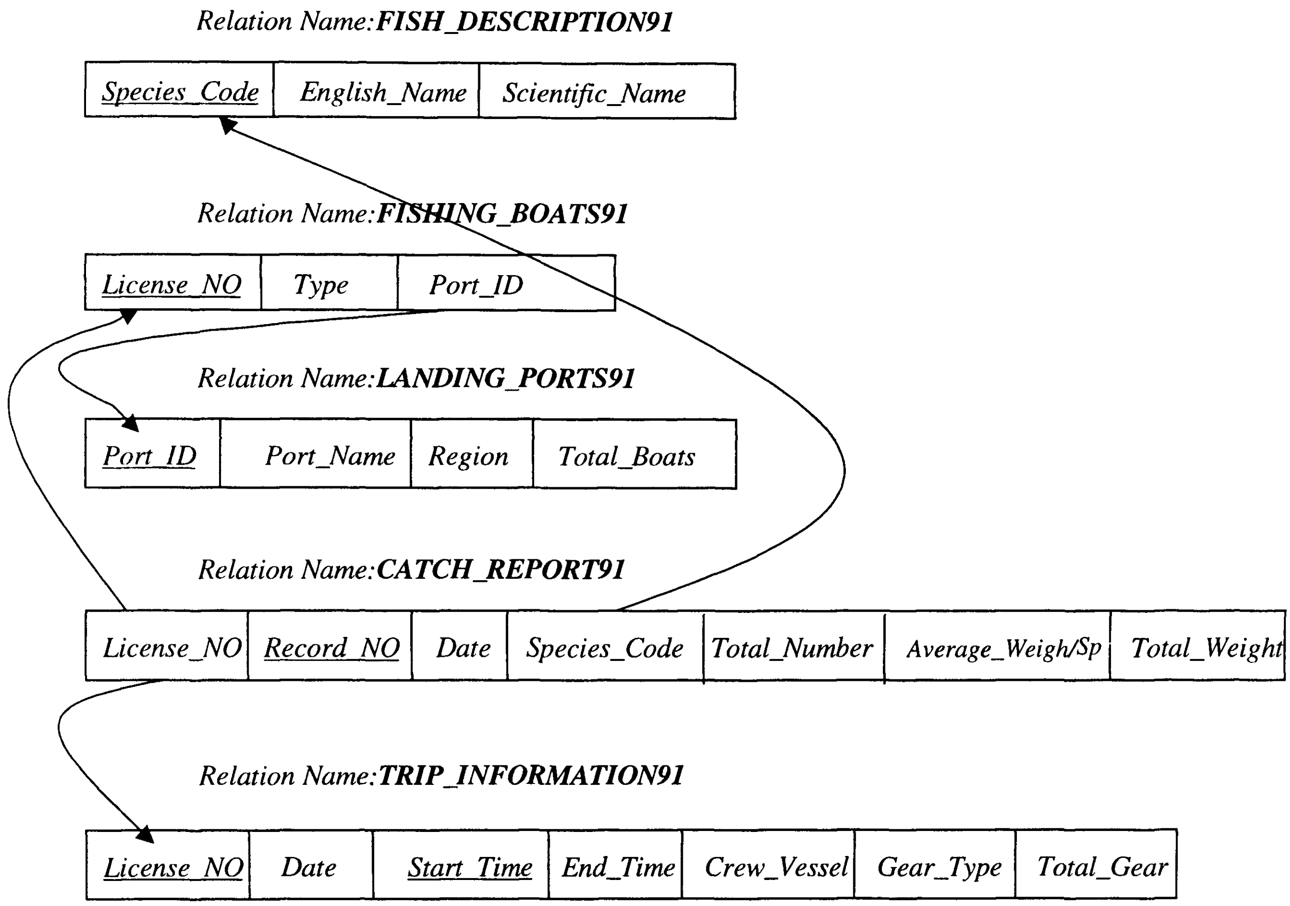


Figure 4.7 Schema diagram for the traditional fisheries database of 1991

6.5.2 Primary keys

A relational database usually contains many relations, with columns linked in various ways. A relation or a table is defined as a set of columns. By definition, all elements of a set are distinct; hence, all columns in a relation must also be distinct. This means that every relation has at least one primary key. A primary key is the candidate key that is selected to identify columns uniquely within the relation (Connolly et al. 1996). Assigning primary keys for the relations is essential because of the constraints for all relational databases that are called "key constraints".

In the Figure 4.7, the primary key is *underlined*. The primary key in the first relation file (***FISH_DESCRIPTION***) is *Species_Code*. Each type of fish species has a unique code. In the second relation file, ***FISHING_BOATS***, each boat has a unique license number that is issued by the MAF. In the relation

LANDING_PORTS, each landing port has been given a unique identity number called *Port_ID,* which is the primary key of the relation. *Record_NO* and landing *Date* have been designated as the primary key for the fourth relation file ***CATCH_REPORT***, as every record (row) within the relation has a unique record number. Both the boat *License_NO* and the fishing *Start_Time* forms the primary key for the fifth relation of ***TRIP_INFORMATION.*** Each boat in the relation can make more than one fishing trip, however, the starting time for each trip is always different. By comparison, one boat or more can start their fishing trips at the same time but each boat has a different license number.

6.5.3 Relational Integrity

When designing RD there are two important integrity rules, which are defined as the constraints or restrictions that apply to all instances of the database. The two principal rules for the relational model are known as the "entity integrity constraint" and the "referential integrity constraint".

6.5.3.1 Entity integrity constraint

Entity integrity means that in a base relation no attribute of a primary key can be null. In reference to the above relational, there is no primary key with a null value. This is because the primary key value is used to identify the individual column in a relation and null values for the primary key imply that some of values cannot be identified. This problem has been avoided by giving each relation a key that cannot contain a null value (Elmasri and Navathe, 1994).

6.5.3.2 Referential integrity constraint

In a RD, the referential integrity constraint states that a column of one relation that refers to another relation must refer to an existing column in that relation (Elmasri and Navathe, 1994). For this reason, many foreign keys have been designated to form the relationships among the entities represented by the relational schemas. The foreign key (between two relations) is a set of attribute values in the first relation that have the same domain as the primary key attribute values of the second relation (Connolly et al, 1994). For example, in the ***LANDING_PORTS*** relation the primary key is the *Port_ID*, which is also the foreign key in the ***FISHING_BOATS*** relation. These two columns of the two relations must match the values of each other so that the column *Port_ID* in one relation is a reference or refers to the similar column in the other relation.

The referential integrity constraint is diagrammatically displayed in Figure 4.7, the directed arc being drawn from each foreign key to the relation it references. The arrowhead points to the primary key of the referenced relation.

6.6 Data Problems

The same problems occurred when building the RD for the traditional fisheries. Generally, the main cause of these problems was the nature of the primary data.

One problem relates to the diversity in the number of the landing ports during the five year period. Some of these ports have very small catches reported only once or twice during the five years. To solve that problem, the amount of fish landed on these ports have been added to the nearest major port.

When designing the RD the problem was to convert the 4-dimensional primary data into a suitable 2-dimentional relational database system that can hold all required data. The way the database has been organised and the use of the SELECT operation (the basic SQL statement that is used to select the required columns from single or multiple relations) within Access has resolved this difficulty.

6.7 Entity-Relation Model for Trawler Fisheries

Figure 4.8 shows the ER schema diagram for the trawlers fishery. Referring to Figure 3.7, the design of the ER model for trawlers can be summarized as follows:

1. The trawler vessel makes fishing trips. Each vessel has a specific name and belongs to a specific fish company. Each vessel records the number of trips it makes during the year.

2. A particular vessel makes trips to a specified area. The specified area is recognized by the area code associated with it.

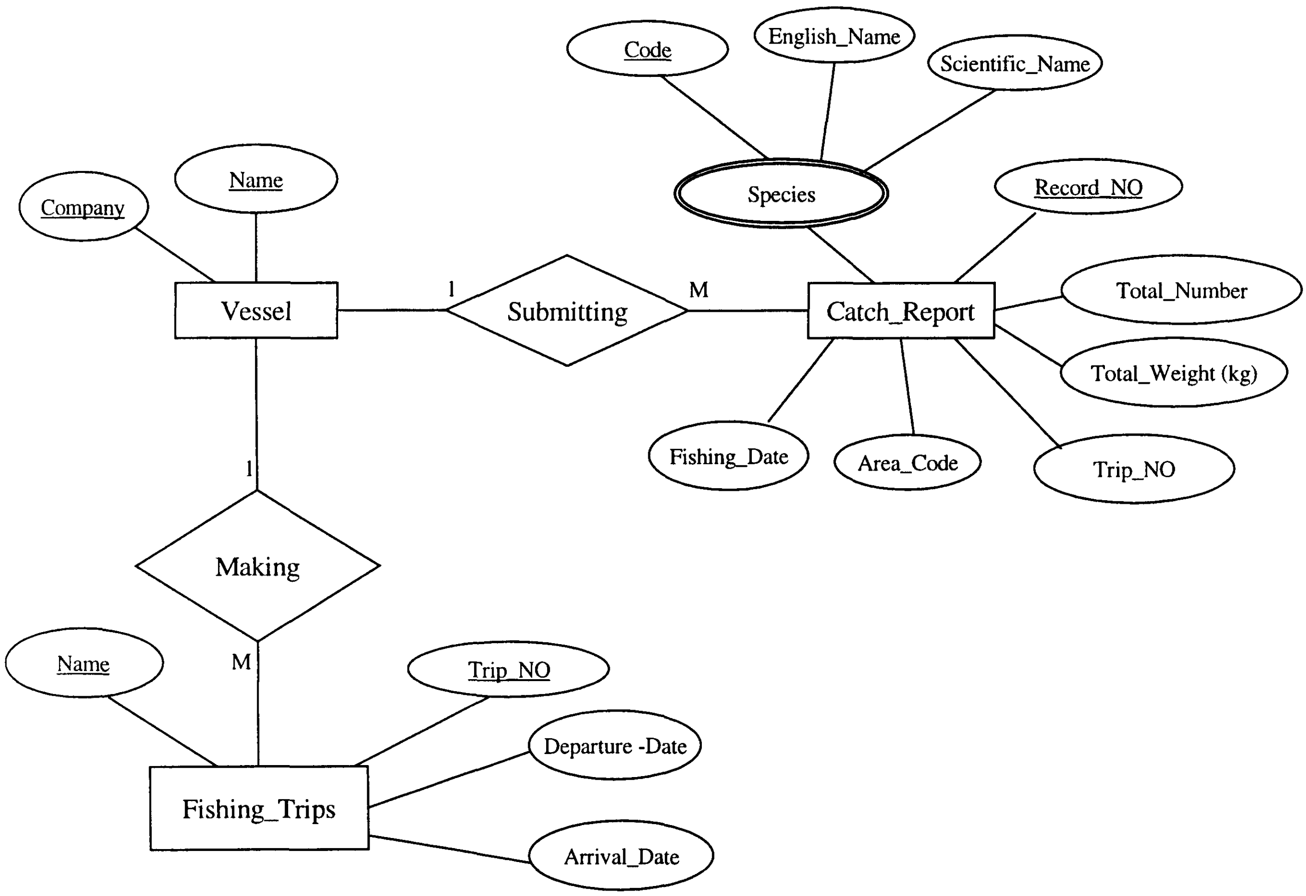


Figure 4.8 ER schema diagram for the trawler fisheries

3. From each area different types of species are caught at different times.
4. The vessel submitting a catch report at the end of each fishing trip. The report including the type and amount of caught fish in kilograms.
5. Each vessel fishing different types of species.

6.8 The Relational Database System for Trawler Fisheries

The main key for constructing the required databases for trawlers was the geographical footprint. Trawler fishing activities occupy the southern part of the country's national water within the specified 10 * 10 miles squares grid. This grid has been used as a key for the construction of the database.

The structure of the database and its characteristics are discussed in the following sections.

6.8.1 Structure of Relations

Four relational database tables (files) have been created for the demersal fisheries. It is important to notice that these data are different than those of traditional fisheries in that these data are not initially gathered using a sample survey. These data reflect the amount of catch by each trawler vessel during any reported fishing trip. The fishing trip itself can be as short as a few days or it can run for about two to three months.

The difference between the actual amount of catch from each area and the potential amount of catch that can be caught from the same area can be calculated. This and several methods of analysis will be explored further in the following two chapters.

The relational database schema for the trawler fisheries can be seen in Figure 4.9. The first table is the ***FISH_DESCRIPTION***. The second relational table, ***VESSELS_INFORMATION***, (corresponding to the 'Vessel' entity in Figure 4.8) contains information about the trawler vessels and includes:

- *Vessel_Name* (the given name of each fishing vessel)
- *Fish_Company* (the fishing company each vessel is belong to)

Compared to vessels of traditional and longlines fleets, the trawler vessels have no license or registration numbers.

The Third table called ***CATCH_REPORT,*** (corresponding to the 'Catch_Report' entity in Figure 4.8) includes the following attributes:

- *Record_NO,* that has been used as the primary key for the relation. The Record_NO consists of the sequence numbers assigned to each fishing record.
- *Trip_NO*, (number of trips per vessel where vessels make more than one trip per year)
- *Fishing_Date* specifies the date in 'dd, mm, yy' format (i.e., day, month, year) in which fish has been caught.
- *Area_Code* specifies the code of the fishing area (in this case the specific grid square of 10 *10 miles) in which fish has been caught,
- *Species_Code* (there are 45 fish species caught by trawlers)
- *Total_Number* (number of pieces from each species)
- *Total_Weight* (total weight from of each type of species)

The fourth table is ***TRIP_INFORMATION,*** (corresponding to the 'Fishing_Trips' entity in Figure 4.8) and contains data about the fishing trips that the trawlers are making. The attributes data of this relation are:

- *Vessel_ Name*
- *Trip_NO*
- *Departure_Date* (starting date of each fishing trip)
- *Arrival_Date* (arriving date of the vessel from the fishing trip)

As for the traditional fisheries, there are five ***TRAWLERS_DATA*** files created for the trawler each represents the catch data of each year from 1991-1995.

6.8.2 Primary Keys

The primary key in the first relation file, ***FISH_DESCRIPTION*** is *Species_Code*, and in the second relation, ***VESSEL_INFORMATION***, is the *Vessel_Name.* Thus, each trawler is said to have a unique name and belongs to one fishing company. *Record_NO* has been designated as the primary key for the third relation file, ***CATCH_REPORT*** as every record within the relation has a unique record number. The primary key for the fourth relation, ***TRIP_INFORMATION*** is *Trip_NO*. Trawlers makes more than one fishing trip per year, each of this trips has a different number.

6.8.3 Relational Integrity

All primary keys within the trawlers RD have no null value. The referential integrity constrain is diagrammatically displayed in Figure 4.9. The directed arc is drawn from each foreign key to the relation it references. The arrowhead points to the primary key of the referenced relation.

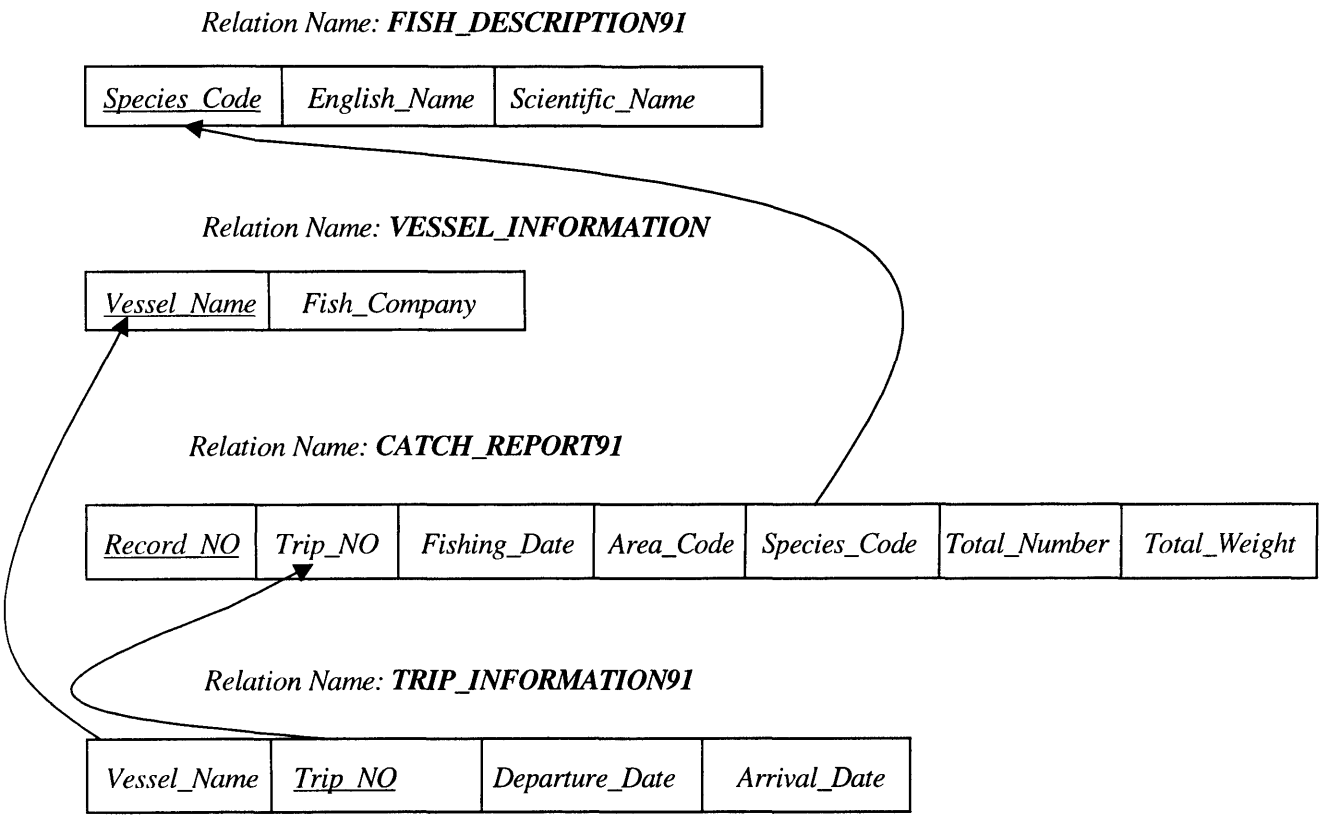


Figure 4.9 Schema diagram for the trawlers fisheries database

6.9 Entity-Relation Model for Longlines Fisheries

The design of the ER model for longlines is very similar to that for trawlers. The only differences are the location of fishing areas and type of fish caught. Longlines have no specified area codes to fish from, but they uses longitude and latitude coordinate to specify their fishing location. While trawlers catch demersal fish, longlines catch only large pelagic species such as yellowfin tuna and shark.

Figure 4.10 shows the ER schema diagram for longlines fishery that contains similar features of trawlers. The design of ER model for longlines is based on the form shown in Figure 3.8.

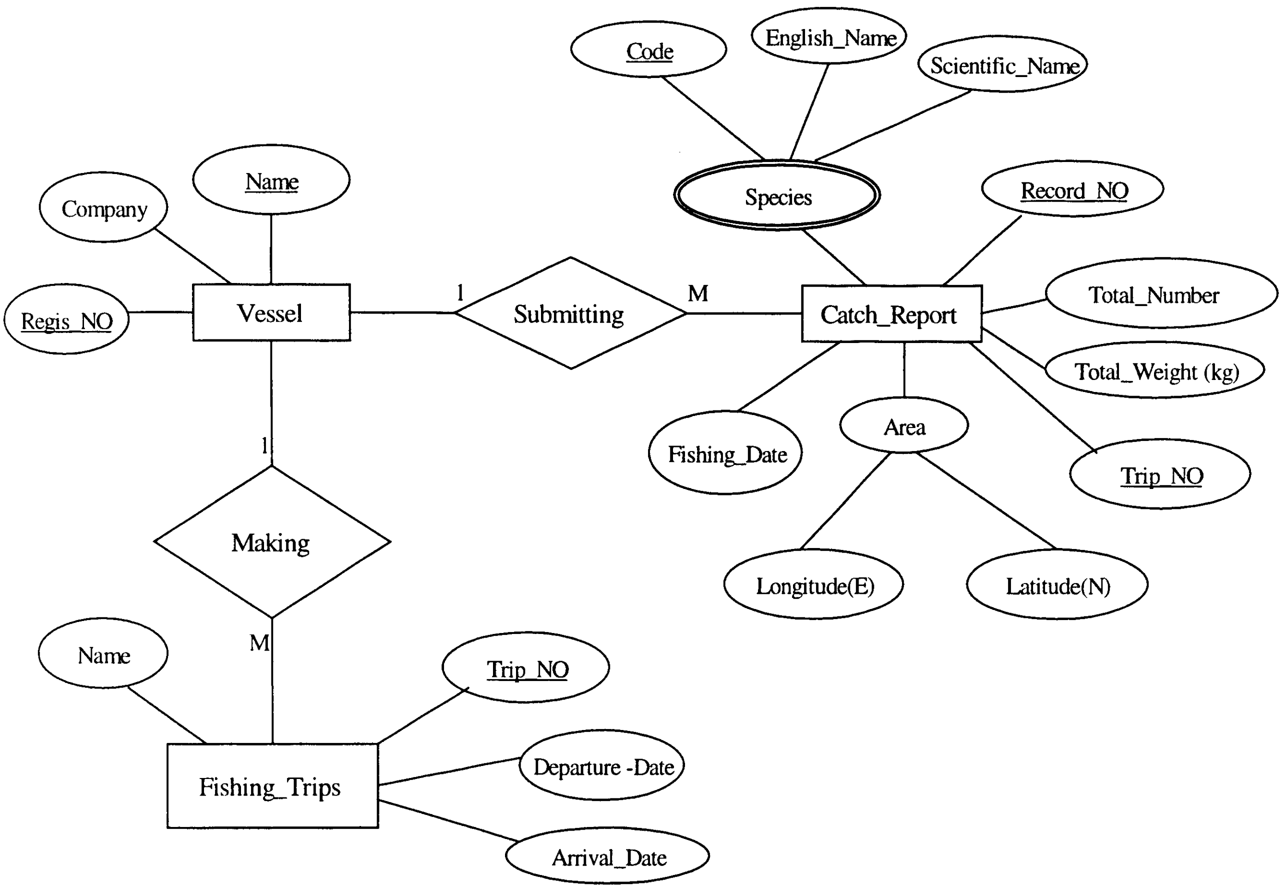


Figure 4.10 ER schema diagram for the longlines fisheries

6.10 The Relational Database System for Longline Fisheries

The primary data for Longline fisheries have similar contents to the data for trawlers but follow a different format (see Figure 3.8). The main two differences lie in the types of fish caught and the areas of fishing. There are only six main pelagic types of species shown in the original longline fishing forms. These are yellowfin tuna (*Thunnus albacares*), B.Marlin (*Istiophoridae*), Mahi-Mahi or Dolphin fish (*Coryphaena hippurus*), Sailfish (*Istiophoridae)*, Shark (*Carcharhinidae, Sphymidae*), and Swordfish (*Xiphiidae*), but the fishing records submitted show mainly the catches of yellowfin tuna and shark.

Since the trawler and longlines methods form the commercial fisheries it was fundamental to create a similar relational database structure for both of them. This is important for any attempt to ease the process of data integration. The whole of Chapter 5 is devoted to the subject of spatial integration of the marine databases.

Construction of the database for longliners was achieved by use of the geographical footprint. Catch is recorded by using the longitude and latitude coordinates. Compared to trawlers, longlines have no specified square/area to fish, but their fishing areas are recorded as reference points where the fish have been caught. The structure of relational database files and their characteristics are discussed in the following section.

6.10.1 Structure of Relations

Four relational database files have been created for the longliners. The longline relational database schema can be seen in Figure 4.11. The first table is ***FISH_DESCRIPTION***. The second table, ***VESSELS_INFORMATION***, (corresponding to the 'Vessel' entity in Figure 4.10) is concerned with the information of the longliner vessels. This information includes:

- *Vessel_Name*
- *Regis_NO* (vessel registration number give by the Ministry of Agriculture and Fisheries)
- *Fish_Company*

The third table called ***CATCH_REPORT***, (corresponding to the 'Catch_Report' entity in Figure 4.10) includes the following attributes:

- *Record_NO*
- *Trip_NO*
- *Fishing_Date* in (dd, mm, yy) format
- *Longitude* which specified the longitude coordinate of the fishing area,
- *Latitude* which specified the latitude coordinate of the fishing area

- *Species_Code.* The codes for the six fish species that are caught by the longliner.
- *Total_Number*
- *Total_Weight*

The fourth table is ***TRIP_INFORMATION,*** (corresponding to the 'Fishing_Trips' entity in Figure 4.10) which contains data about the fishing trips the trawlers are making. The attributes data of this relation are:

- *Regis_NO*
- *Trip_NO*
- *Departure_Date*
- *Arrival_Date*

As for the traditional fisheries and trawlers, there are five ***LONGLINES_DATA*** files created for the longlines. Each represents the catch data of one year from 1991-1995.

6.10.2 Primary Keys

Similar to trawler relations, the primary key in the first relation file (***FISH_DESCRIPTION***) is *Species_Code.* In the second relation file (***VESSEL_INFORMATION***) the *Vessel_Name* is the primary key of the relation. Thus, each trawler vessel is said to have a unique registration number. *Record_NO* has been designated as the primary key for the third relational file (***CATCH_REPORT***), as every record within the relation has a unique record number. The primary key for the fourth relation, ***TRIP_INFORMATION*** is *Trip_NO.*

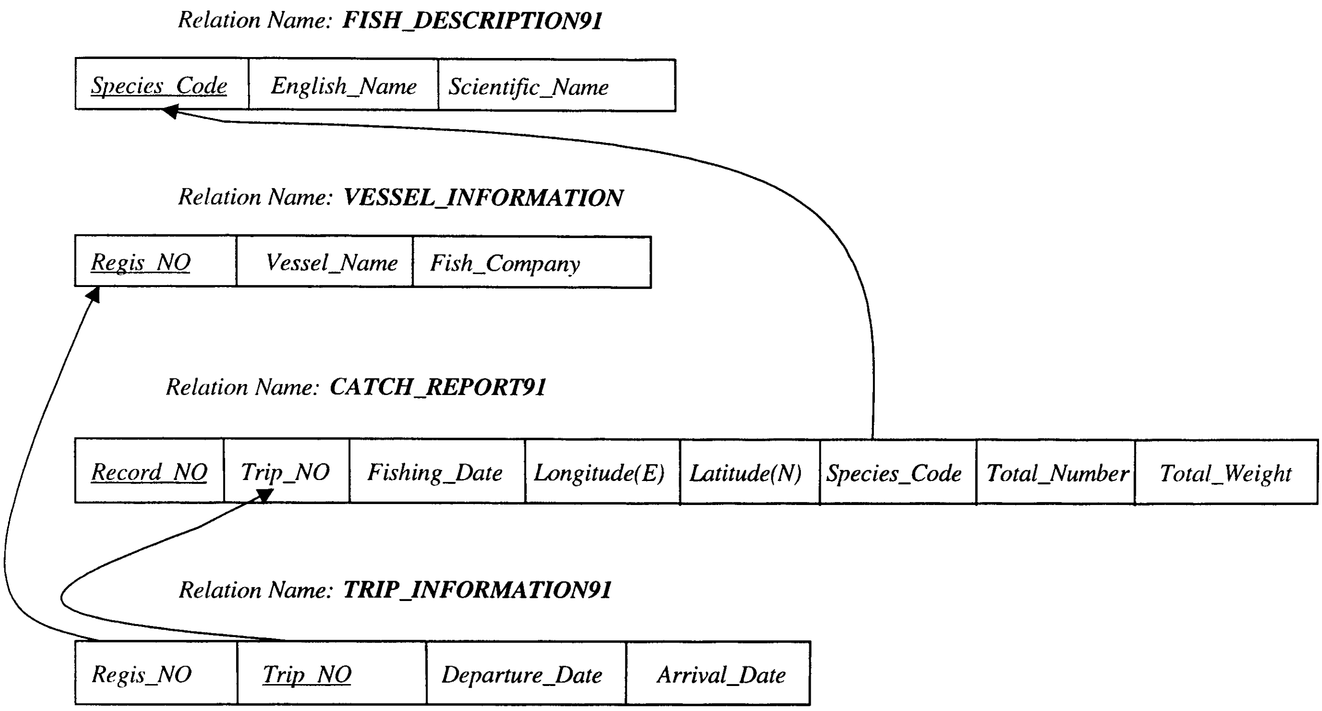


Figure 4.11 Schema diagram for the longlines fisheries database

6.10.3 Relational Integrity

For the integrity constraint, the longline relational model has no primary key with null value associated to it. The referential integrity constrain is diagrammatically displayed in Figure 4.11, the directed arc is drawn from each foreign key to the relation it references. The arrowhead points to the primary key of the referenced relation.

6.11 Data Problems for the Commercial Fisheries

Different problems have been encountered when establishing the commercial fisheries relational database then that for the traditional. As for the traditional fisheries, the main problem was to establish the proper method to store the 4-D data in a way that is suitable not only to the relational database but also accessible for reading it within the GIS using the ArcView package. Different relational database file scenarios were examined and tested before settling for the final form.

The main difficulty occurs at the stage of integrating the two commercial databases, and these are highlighted in Chapters 5.

7. Structured Query Language (SQL)

SQL is the standard relational database language. It is used to create the required queries, which will then be linked to the GIS in ArcView. Generally, the overall objectives of SQL are to allow the users to create the database and relational structures and to perform basic data management tasks such as insertion, deletion, and modification of the relations. The two major SQL components are the Data Definition Language (DDL) used to define the database structure and the Data Manipulation Language (DML) for retrieving and updating the data (Elmasri and Navathe, 1994; Connolly, et al, 1996). Most of the recent database management systems support SQL, running on various hardware platforms from personal computers to mainframes (Robinson, 1991).

The importance of SQL lies in its abilities to retrieve the required data from very complicated datasets. SQL has one basic statement for retrieving information from a database: the SELECT statement.

The select operation is also used to solve the problems of reading the fisheries data within the GIS ArcView. ArcView establishes a one-to-one or many-to-one relation between the tables or fields of spatial and attribute data.

SQL is used to select columns from individual relations and to combine related columns from several relations for the purpose of specifying a query on the database.

The more detailed SELECT statement can be viewed in Figure 4.12.

SELECT	[DISTINCT I ALL] {column_expression}
FROM	table_name [alias]
[WHERE]	condition
[GROUPED BY]	column_list
[HAVING]	condition
[ORDER BY]	column_list

Figure 4.12. Detailed SELECT statement, where:

- <ATTRIBUTE DATA> is a list of attribute names whose values are to be retrieved by the query.
- <TABLE OR RELATION> is a list of the relation names required to process the query.
- <CONDITION> is a conditional (Boolean) search expression to be matched in the columns within the query.
- GROUPED BY forms groups of rows with the same column value.
- HAVING filters the groups subject to some condition.
- ORDER BY specifies the order of the output.

7.1 Retrieving Catch Data from the Database

The purpose of this section is to give very general examples of how SQL retrieves the required data from the main database. The results of these queries will be implemented in the following section.

7.1.1 Example 4.1: Traditional Tuna Catch

Retrieve the total amount of landed (catch) yellowfin tuna (*Thunnus albacares)* on each landing port of the traditional fisheries for 1995.

SELECT [CATCH_REPORT95].Port_ID,
[CATCH_REPORT95].Port_Name,

Sum([CATCH_REPORT95].Total_Weight) AS Sum Of Total_Weight

FROM LANDING_PORTS *INNER JOIN* [CATCH REPORT95] ON LANDING_PORTS.Port_ID = [CATCH_REPORT95].Port_ID

GROUP BY [CATCH_REPORT95].Port_ID, [CATCH_REPORT95].Port_Name, [CATCH_REPORT95].Species_Code

HAVING ((([CATCH_REPORT95].Species_Code)="TA"));

In this example, a new table is created from two different tables (CATCH REPORT and LANDING PORTS), and 'TA' is the species code for the yellowfin tuna. The result contains only the required data, and is shown in Table 4.3.

Port_ID	Port_Name	Yellowfin Tuna_ Catch (kg)
1	KHASAB	5844.11
4	SHINAS	297.75
5	LIWA	630
7	SOHAR	10480.41
8	SAHAM	15406.96
10	WIDAM	255.75
11	SUWEQ	86207.86
12	BARKA	90816.29
15	SEEB	79222.84
17	SIDAB	677528.55
18	QARYAT	715369.13
19	DAGMAR	408661.8
22	SUWEH	42935.94
23	SUR	10922857.15
25	RUWES	1550
26	DAFFAH	70739.61
44	SADAH	4870
46	RAYSUT	9133.77
47	MIRBAT	94658.46

Table 4.3 Results for Example 4.1 shows the three required columns of Port_ID, Port_Name, and the catch for yellowfin tuna (*Thunnus albacares)* from the traditional fisheries of 1995. The result represents the annual catch port.

7.1.2 Example 4.2: Trawlers Tuna Catch

Retrieve the total amount of yellowfin tuna (*Thunnus albacares)* catch for each fishing area of trawler fisheries for 1995.

```
SELECT     [CATCH_REPORT95].Area_Code,
           Sum([CATCH_REPORT95].Species_Code) AS Sum Of
           Species_Code
FROM       [CATCH_REPORT95]

HAVING     (([CATCH REPORT95].Species_Code)="TA");

GROUP BY   [CATCH REPORT95].Area_Code;
```

The new table (Table 4.4) is created from the CATCH REPORT table for the yellowfin tuna of the trawler fisheries. The result contains only the required data, and is shown in Table 4.4. The original result table includes 57 records. Since this only an example, only those records showing non-zero are displayed. Other records have been eliminated. Notice that the amount of tuna catch by the trawlers when compared to the traditional or longliners is small.

Area	Yellowfin Tuna Catch (kg)
7502	20
7505	20
7528	220
7551	40
7555	40
7556	100
7557	40
7558	200
7559	140
7588	20
7592	20
7595	180
7598	180
7627	336
7644	40
7646	105
7647	40
7698	20
7713	140
7714	140
7715	60
7732	20
7733	20
7736	20

Table 4.4 Results for Example 4.2, shows yellowfin tuna (*Thunnus albacares)* catch by the trawlers per area in 1995. The total catch for each area is summed by area using the Area_Code field.

7.1.3 Example 4.3: Longlines Tuna Catch

Retrieve the total amount of yellowfin tuna caught by the longlines in 1995.

SELECT [CATCH_REPORT95].[Latitude(N)], [CATCH_ REPORT95].[Longitude(E)], Sum([CATCH_REPORT95]. Species_Code) AS Sum Of Species_Code

FROM [CATCH_REPORT95]

HAVING (([CATCH REPORT95].Species_Code)='TA');

GROUP BY [CATCH REPORT95].[Latitude(N)], [CATCH REPORT95].[Longitude(E)];

The result of the query is shown in Table 4.5. The original results table shows 2333 records. Table 4.5 shows only a sample of the results. Again, only those records showing amount of catch not equal to zero are displayed. Others with zero value have been eliminated.

When querying the longlines data, it is rather difficult to group the data as has been done in Tables 4.3 and 4.4, because both the traditional and the trawlers recorded their catch with regards to a specific area (port and square areas respectively), whereas longlines data is recorded as longitude and latitude coordinates. Although in example 4.3 the grouping operation was done with regards to these coordinates, the chance for the catch to happen at the same location several times is very small.

Record_NO	Latitude(N)	Longitude(E)	Yellowfin
14	1756	5900	1000
15	1745	5850	1000
16	1745	6035	1000
17	1806	6040	250
18	1810	6042	1400
19	1810	6012	400
20	1815	5956	500
29	1905	6010	200
30	1910	6005	400
31	1910	5955	400
32	1915	5956	1700
33	1918	5958	1800
34	1920	6000	600
35	1935	6014	1000
36	1950	6005	1500
37	1958	6000	1700
39	2000	6000	800

Table 4.5 Results table for Example 4.3 shows yellowfin tuna (*Thunnus albacares)* catch by the longlines fishery of the 1995. The total catch from each location is summed by longitude and latitude point location.

8. Linking To GIS and Implementation of the Marine Fisheries GIS

The intent of this section is to highlight the procedure for joining the attributes (fisheries data that are discussed throughout the previous sections) with those forming the spatial data that are processed and stored within ARC/INFO and ArcView.

This section is divided into two subsections. The methods of joining the two types of data will be explained briefly in the first subsection, and the second subsection presents the visual outputs of the three SQL queries listed above.

8.1 Linking to ArcView

One of the main advantages of linking the attribute and spatial data via the SQL option within ArcView is that the original data in Access will not be affected by any operation within ArcView. Any addition or modification to the original data will be automatically updated in ArcView.

8.1.1 Traditional Fisheries

For the traditional data, landing port location forms the geographical footprints and provides the field of joining. For the digital coverage, each traditional port has been given the same port ID number stated in Table 3.1 and presented in Figure 4.3. The common fields and the method joining of the traditional fisheries data with the spatial in ArcView can be viewed by the example shown in Figure 4.13.

Although the first attempt to map traditional fisheries was done for the amount of catch landed and recorded at each landing port (Figure 4.13) as suggested by the literature, this research has developed a different method for representing the data. This method will be discussed in detail in the next chapter.

8.1.2 Trawler Fisheries

Trawler fisheries are located as grid squares but represented within the database as polygons. Figure 4.14 shows the method used to joint the attributes and spatial data in ArcView.

8.1.3 Longline Fisheries

Longline fisheries areas exist as points distributed throughout the sea surface area. The primary data has recorded the fish location using the latitude and longitude coordinate system (Table 4.5). This is then converted to DD, as mentioned. For the purpose of creating the spatial data (points on the map), the fishing points have been generated within ARC/INFO and since the longline fishing areas differ from one year to another, five coverages of generated points have been created. When implemented, the two types of data (attributes and spatial) can be joined by using the two fields of latitude and longitude as the common field or by assigning a record number for each fishing record. This work has applied the latter method of joining the two data by the unique record number. Figure 4.15 gives an example of the output.

The display of all the visual results from three types of data will be presented in the following section.

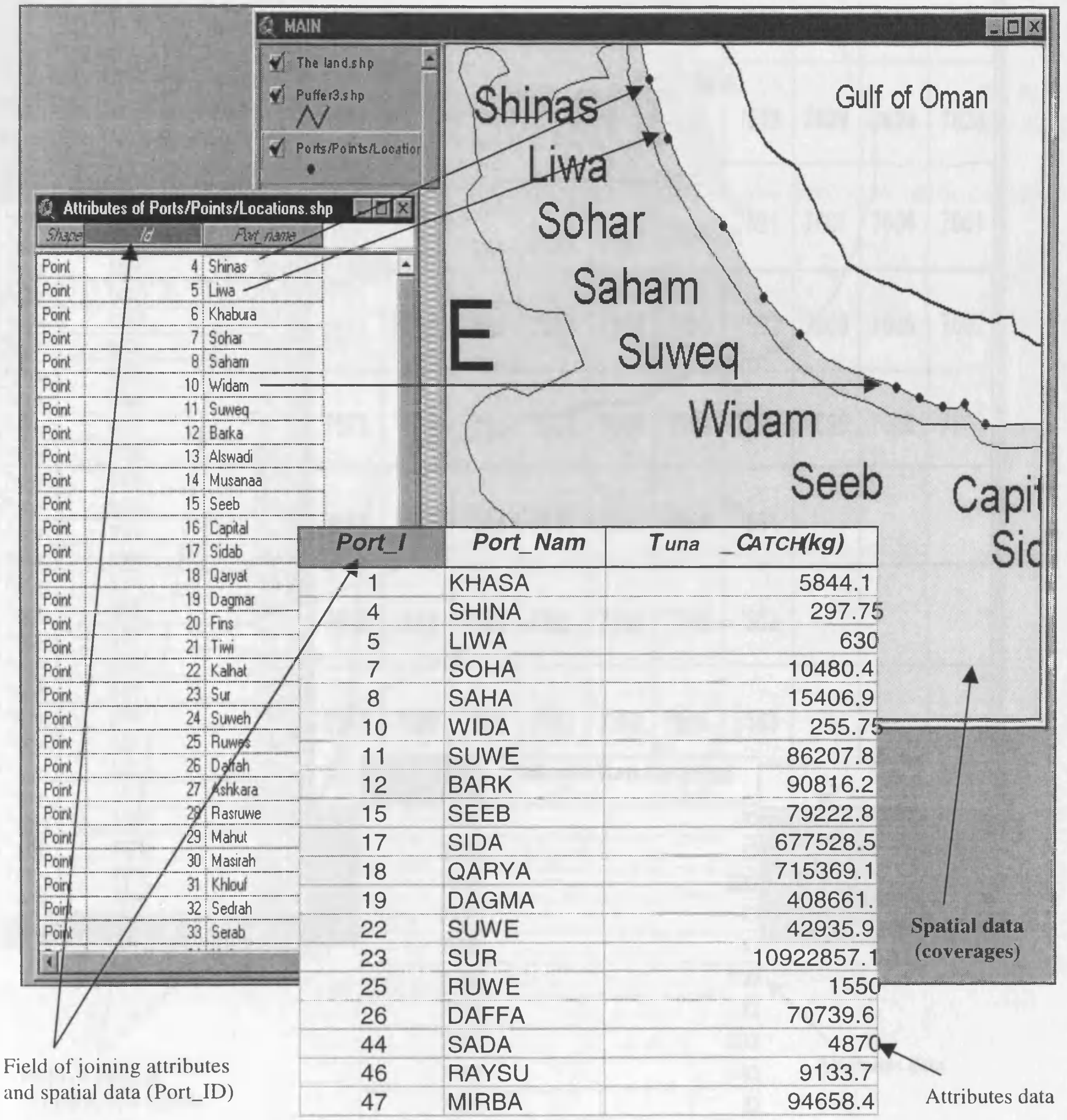
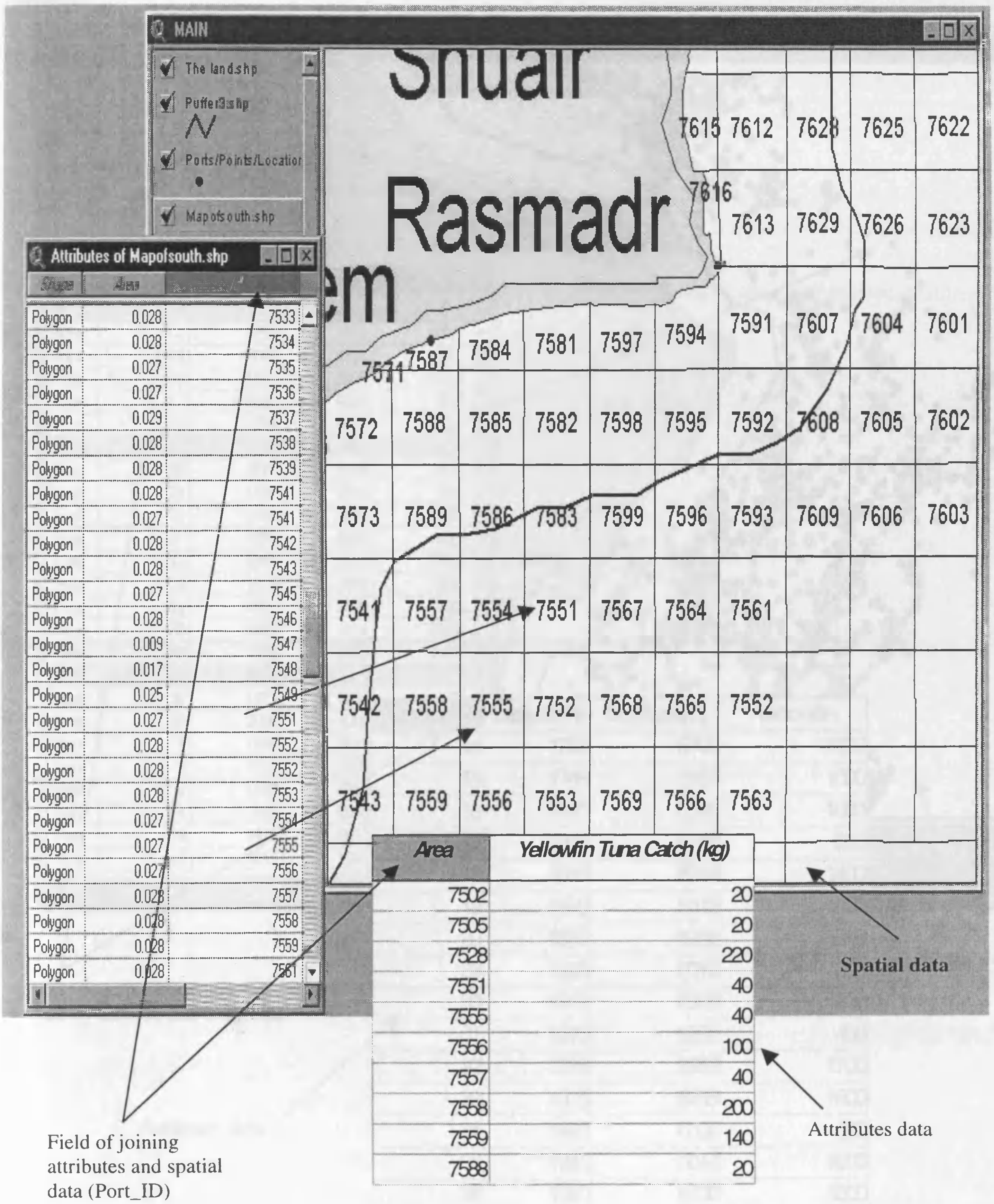


Figure 4.13 Joining attributes and spatial data of traditional fisheries in ArcView. The Port_ID field joins the spatial and the attribute data. Every port is represented by a point on the coastline of the country.



Area	Yellowfin Tuna Catch (kg)
7502	20
7505	20
7528	220
7551	40
7555	40
7556	100
7557	40
7558	200
7559	140
7588	20

Figure 4.14 Joining attributes and spatial data of trawlers. The spatial and the attribute data are joined by Area code. Each area code refers to a square area of 10 * 10 miles on the map.

G

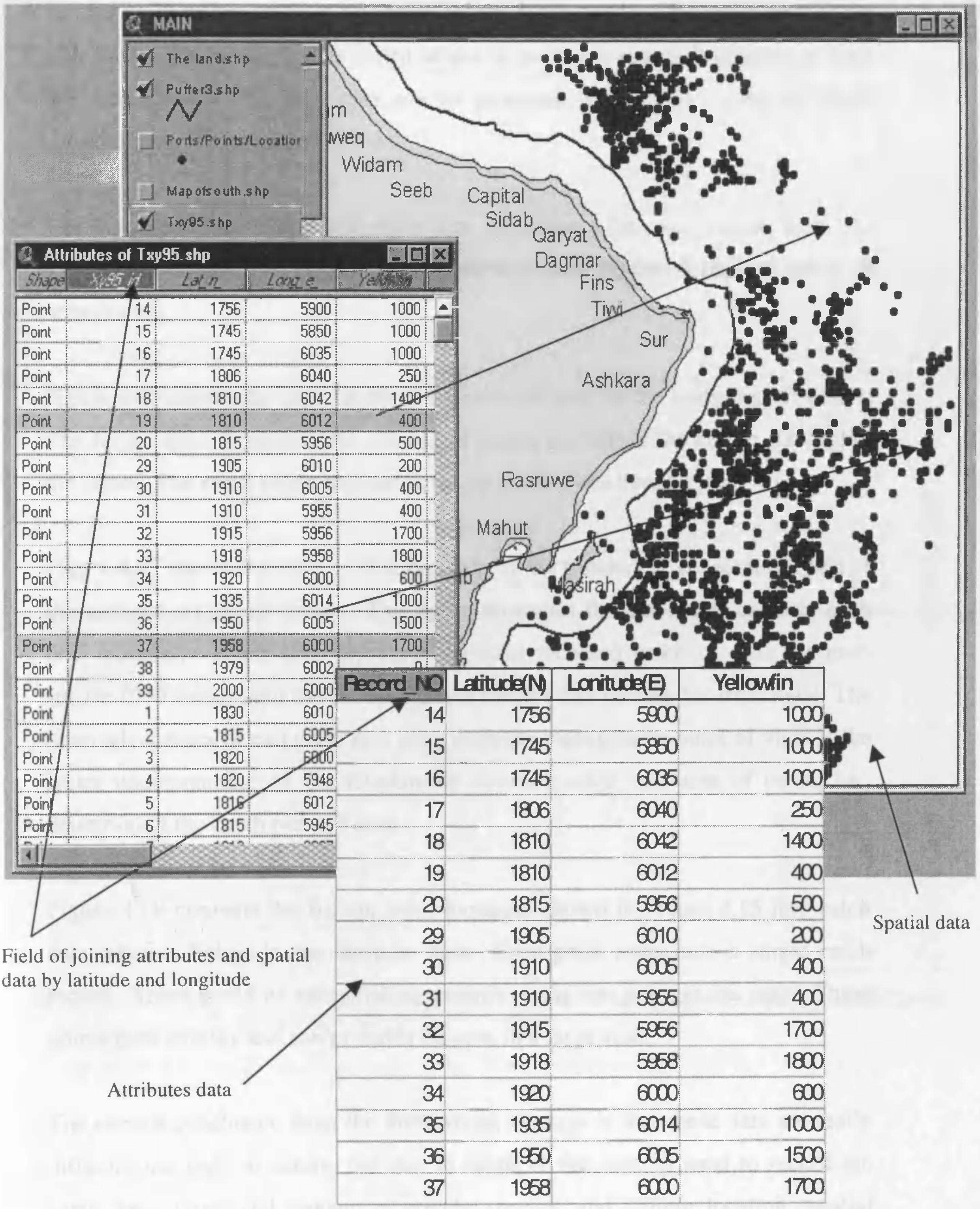


Figure 4.15 Joining attributes and spatial data of longline fisheries. The spatial and the attribute data are joined by longitude and latitude and represented as points on the map.

8.2 Implementation

The aim of this subsection as stated above, is to give a visual illustration of how the three types of fisheries data can be presented in ArcView, using the three queries discussed in section 6.1.

The visual outputs of the yellowfin tuna (*Thunnus albacares)* catch from the traditional, trawlers and longliners are illustrated as in Figures 4.16, 4.17 and 4.18 respectively.

Figure 4.16 shows the total landing of yellowfin tuna by the traditional fisheries. The large circle illustrates the amount of catch, the darker the colour the higher the catch. The small circle represents the location of the landing ports.

Figure 4.17 shows the amount of tuna catch by the trawlers in the southern part of the national waters of Oman. The figure illustrates the amount of catch in each grid (square). These data represent the total recorded catch of tuna for each square 1995 rather than the total estimated catches like the one for traditional. The main advantages of using the grid data, from the management point of view is the better understanding of the relationship between catch and area of catch, i.e., determining the catch per unit area

Figure 4.18 converts the fishing point locations shown in Figure 4.15 into catch data when it linked to the attribute data. Each point represents a single catch record. There could be many fishing records at any one point in the map. These points then overlay and can probably be seen in a large scale.

The overall conclusion from the three visual displays is that these data are really different not only in nature, but also in terms of the method used to record the catch data, types and amount of caught species, and fishing location (spatial footprints). The difference directly affects the method of data presentations.

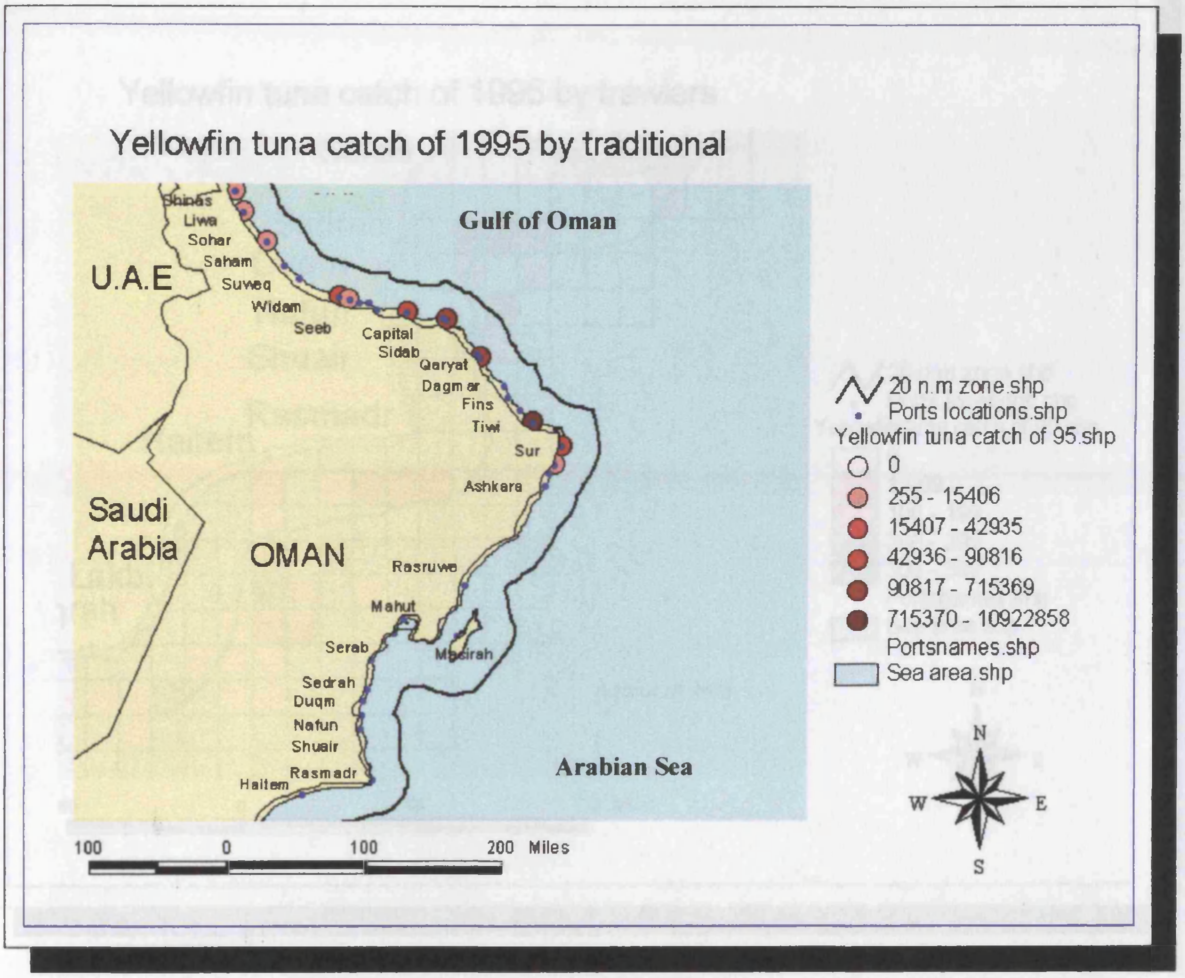


Figure 4.16 Yellowfin tuna catch by the traditional fisheries for 1995

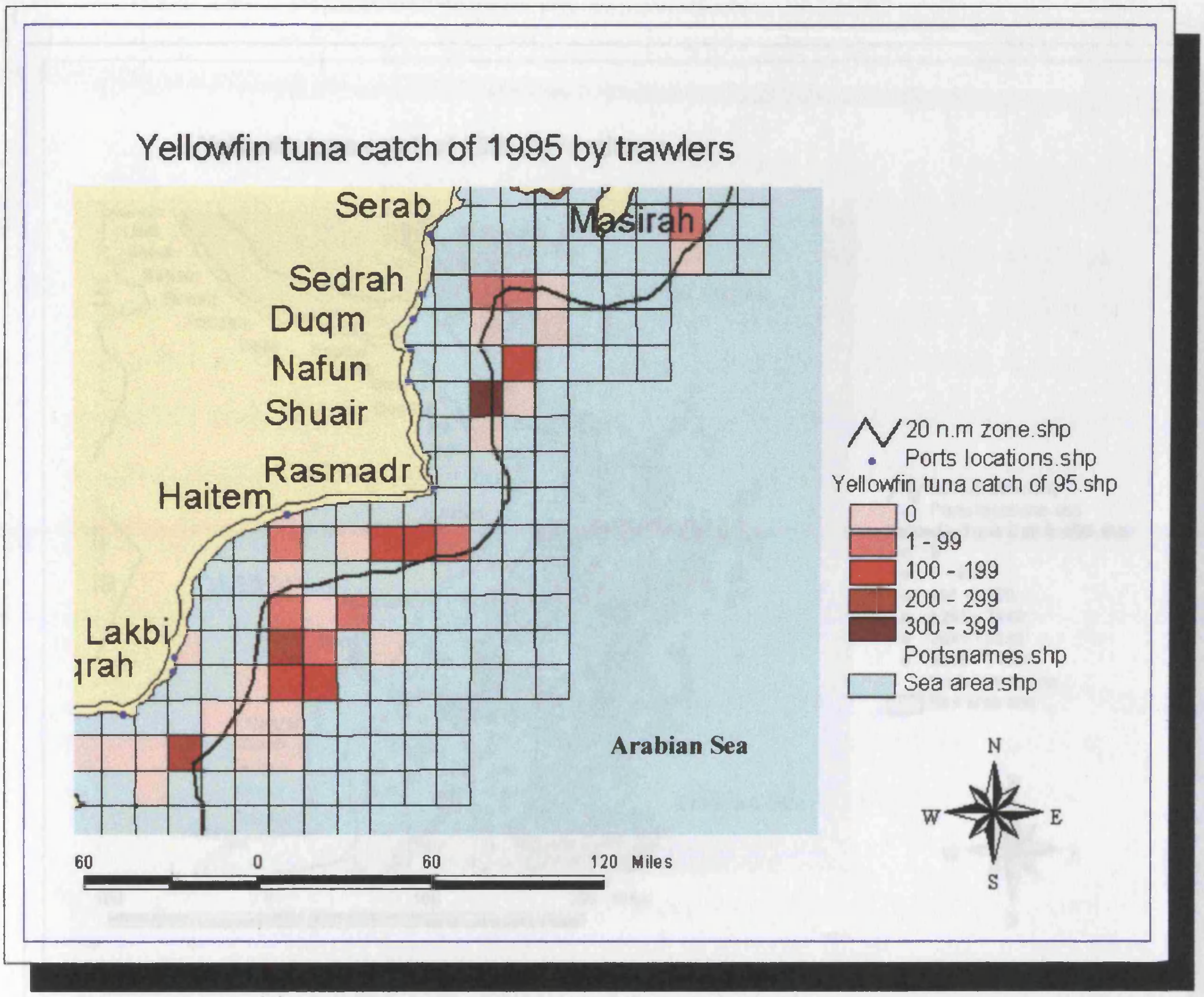


Figure 4.17 Yellowfin tuna catch by the trawler fisheries for 1995.

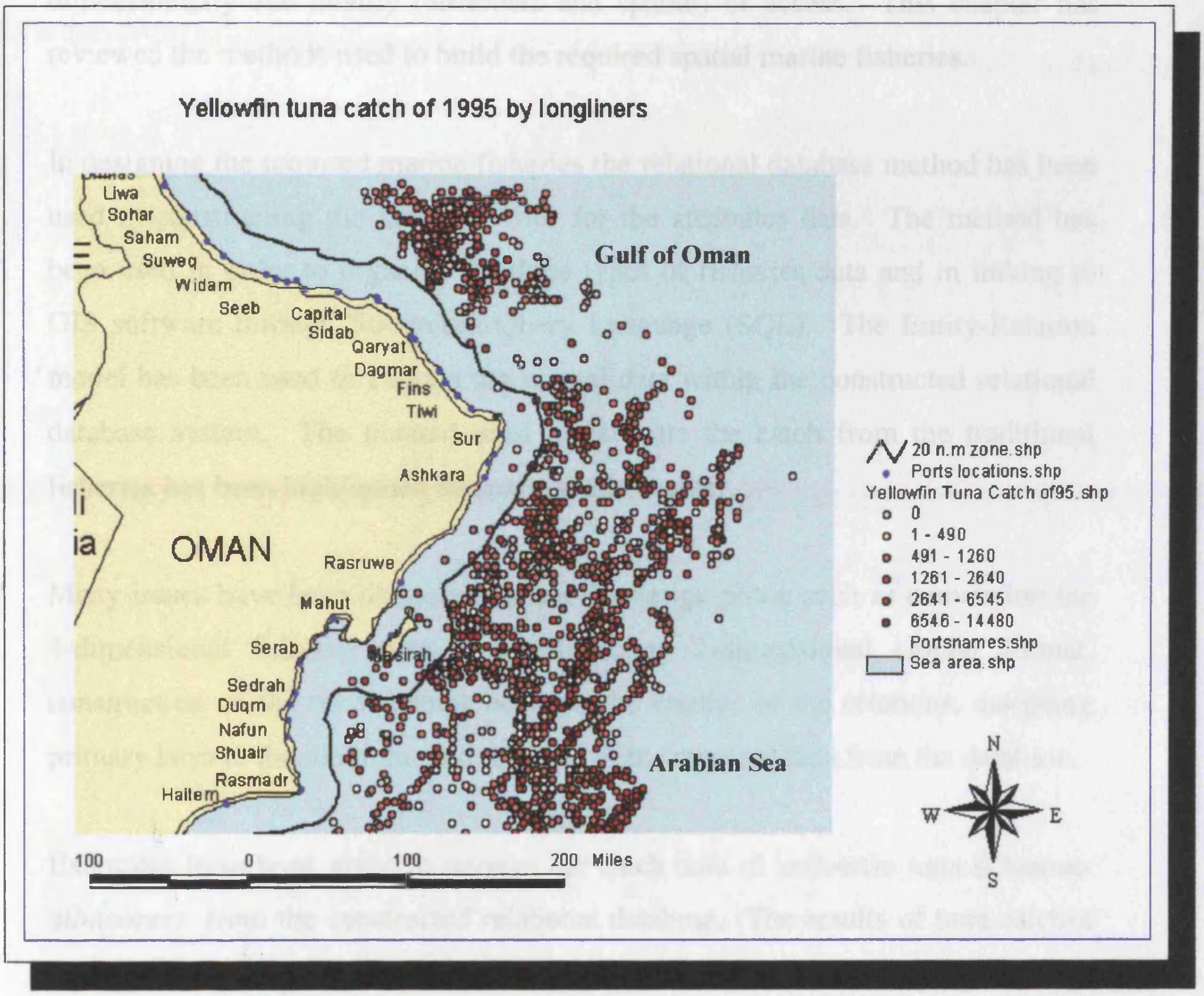


Figure 4.18 Yellowfin tuna catch by the longline fisheries for 1995

9. Summary and Conclusion

The nature of the spatial dimension of the marine fisheries data, the complexity of their original format, and the relationships between their entities, lead to the conclusion that it is not straightforward to design the database system for spatial marine fisheries. They are special with regards to continuity in space, multi-dimensionality and duality (attributes and spatial) of access. This chapter has reviewed the methods used to build the required spatial marine fisheries.

In designing the required marine fisheries the relational database method has been used in constructing the tables or files for the attributes data. The method has been used in order to organise the three types of fisheries data and in linking to GIS software through Structured Query Language (SQL). The Entity-Relation model has been used to explain the related data within the constructed relational database system. The method used to estimate the catch from the traditional fisheries has been highlighted throughout this chapter.

Many issues have been discussed during the design phase such as conversion the 4-dimensional fisheries data to a satisfactory 2-dimensional tabular format, construction of the relationships between the entities of the relations, assigning primary keys to the relations, and retrieval of the required data from the database.

Examples have been given to retrieve the catch data of yellowfin tuna (*Thunnus albacares)* from the constructed relational database. The results of tuna catches from the three types of data have been discussed and visualized using ArcView.

The display of the output leads to a better understanding of several fish related data such as areas of catch and the difference in total catch (weight) per area mainly from the trawlers fishery and slightly from the traditional. In terms of where exactly the fish have been caught, the point data of the longlines is more useful. However, to understand the total distribution of catch from three different types of fisheries is more difficult. This is because of the different footprints of the original recorded data, and so, in order to be able to map the total catch as one, the geographical or spatial footprints must be integrated first. The method of spatial data integration forms the main concern of chapter 5.

5

SPATIAL DATA INTEGRATION FOR MARINE FISHERIES MANAGEMENT

"Geographic data may be stored at different levels of positional accuracy. To some extent the locational data are always imprecise at some level of detail. Some data may be accurate to within a few centimeters, while other data may be accurate to 10 m."

(Aronoff, 1989, p.163)

1. Introduction

Spatial data integration is an important part of building any spatial information system and particularly those systems involves in the areas of natural resource modeling and management. As discussed in the previous two chapters, in the environment marine fisheries data are of different formats and complexities and all are essentially spatial. The three types of marine fisheries data (traditional, trawlers, and longlines) discussed in this research are diverse, and recorded and stored in different ways. One of the main differences is the geographical footprints for which these data were recorded. These footprints ranges from presenting data as points representing the landing ports for traditional and points for longlines, to square grids for trawlers. Unification of the spatial formats is beneficial especially for fisheries managers and decision makers, and development of a single, comprehensive format is the aim of the work reported in this chapter. For a better management system, fisheries data should be studied and analyzed spatially all together in order for the manager to recognize the spatial relationships of the data on maps. Once the geographical locations are integrated multiple data representations can easily be achieved.

This chapter then, describes the methods used to integrate the spatial marine dataset in the national waters of Oman. Section 2 discusses the meaning of integration used in this study as well as explaining its objectives. Section 3 explores the process of integrating the traditional fisheries data. Spatial data integration is discussed through section 4. This section is divided into two main subsections: the first explains the method of integration using point data, and the second discusses the process of integration using area data. Finally, three main methods of fisheries data representations (dot, grid, and proportional symbol maps) are highlighted in section 5.

2. Spatial Integration: Definition and Objectives

2.1 Definition

The word 'integration' is very generic and leads to different meanings depending on the task at hand. If there are large database files (non-spatial data) containing many attributes and complicated relationships, integration can be defined as the method to merge these database files together to form an integrated single file (Connolly et al. 1996). If particular software is involved, integration can be defined as the ability of that software to function directly with various types of spatial data, providing tools to link and convert between the different forms of representation (Laurini and Thompson, 1992). The integration discussed in this work means generating a uniform spatial dataset from the three different fisheries databases in an attempt to apply spatial analysis of the data presented on a single map layer.

2.2 Objectives

The need for integration in general is driven by the need to make better environmental choices (Parks, 1993). For the integration applied in this work, the main objective is to produce a map layer that can be visualized, and analyzed (spatially and statistically) as a complete national dataset. The importance of integration of different types of spatial data, whether at the level of the map or layer or at the level of computing procedures, occurs when particular spatial analysis tasks are undertaken. The attempt then, in general, is to facilitate the tasks of applying spatial analysis to the various spatial data.

As mentioned, integrating the spatial database is crucial especially for the fisheries data discussed in this research. Both the traditional and the trawler fisheries are concerned with the same types of demersal species caught, and share the same area. Yellowfin tuna on the other hand, is of a high commercial value and caught by all the different fishing methods, although the amount of catch by trawlers is small minimal compared to the other two. Nevertheless, from a practical decision making point of view, the total amount and distribution of tuna catch must be calculated and controlled at all times and throughout the total area.

Almost all polices, regulations and decisions are based on locationally recorded catch data provided by the different fishing parties. However, these polices, regulations and decisions have been designed to be applied to each type of fisheries separately, which means that each fishing type has been observed, studied, analyzed, and controlled individually. This gives an impression that there is a lack of concern about the condition of fish stocks resulting from the activity of all of the three types together. Determining the distribution of the total catch leads to better understanding of several other facts, such as catch per unit area, areas of high catch, and unexploited and overexploited areas of catch.

During the years 1994 and 1995 hundreds of traditional fishermen from the southern part of Oman complained about the decline in the amount of their catch. The fishermen indicated that the huge trawler vessels were fishing in the inshore areas "owned" by the traditional fisheries. It was understood that although the trawlers fishing effort was one of the reasons of such decline, the main reason was basically the poor statistical management system used. This system allows trawler and traditional vessels to fish in the same area causing controversy between the two as well as problems of stock damage. On the other hand, some of the latest statistical analyses of the traditional fisheries data in the Gulf of Oman and the Arabian Sea have indicated that there is more than one incident where the damage to fish stocks has been recognized (MAF fisheries statistical report, 1994).

In general, the importance of data integration can help in understanding the following (as well as to facilitate any required spatial and statistical analysis):

1. Whole fishing activity over the total fishing area
2. Total catch per unit area.
3. Spatial distribution of yield of different fish species.
4. Possible areas of unexploited and overexploited fish stocks.

It also helps in supporting the following management activities:

5. Supporting the changes in regulations according to the data retrieved from the whole fishing area. Some of these regulations are concerns with the following (for example):
   - Raise or reduce the amount of fishing effort per total or specific area.
   - Increase or decrease the number of fishing vessels (overall or per fishing type or for certain areas).
   - Extend or reduce the quotas assigned for each commercial vessel or company of the commercial fisheries.
   - Extend or reduce the fishing areas of each type of fishery and probably, introduce new buffer zones around some areas (similar to the one between the longlines and the traditional), if necessary, in order to reserve or protect them.
6. Supporting any related management activity, such as those concerns with fish biology and stock assessment researches.

For these reasons, it is essential to have a complete dataset represented by a single layer with all required data in a uniform format.

As discussed in chapter 1 the major difference between GIS and the use of the traditional cartography lies into the ability of the GIS to perform a greater variety of analysis and output. Furthermore, GIS has the ability to display the spatially and temporally distributed database and analyse whatever subset of the data that are required. So that the use of the GIS can help in control, review or experiment any stage of data implementation and analyses in order to achieve the meaningful outputs.

3. Integrating the Traditional Fisheries Area

It is important first for the traditional fisheries areas to be integrated with one of the commercial, in terms of fishing area before any further operations may take place. This is because the primary data for both types of commercial fisheries data recorded their catch in regards to the real or approximate areas of catch, whereas for the traditional, the recorded data is that for the area of landed catch. The goal is to map the estimated (representative) area of traditional fisheries catch since it is difficult to determine the exact area of fishing.

The process of mapping the traditional fishing areas must take two main tasks to be achieved. The first one is to calculate the estimated area of fish, identifying the estimated boundaries of area of the catch the traditional boat usually makes, starting from the location of each port. This requires measuring the distances the traditional boats travel during their fishing trips (see section 3.1). Second, representing the catch per each of these estimated areas. This means, referring the catch data to the new estimated areas that replace the original point locations representing the ports.

Once the fishing areas have been estimated and mapped then the following step is to integrate it with the commercial fisheries data since the fish could have come from anywhere within the area.

3.1 Generating Traditional Fishing Areas

Traditional fishing activity is assumed to be within 20 km from the landing port. The Ministry of Agriculture and Fisheries (MAF) calculated this assumption in 1995. The 20 km estimated distance was based on a survey carried out by the MAF staff based on sailing with a randomly selected number of boats from random ports. In addition to sailing, two other main factors were considered while estimating the area of catch:

1. The absence of any navigation system. Since traditional fishermen in Oman used no navigation system on board while making the fishing trips, they always need to be able to see the land at all time (mountain top during day time and lights during night time).
2. The limited amount of fuel on board.

Usually, the traditional boats make their trips in three directions from their ports each 20 km in distance. This gives a semi-rectangular area of 20*40 km (Figure 5.1) centered on the given port (the landed catch of tuna, for example, which has been shown in figure 4.11 can be applied to the 20 * 40 km area instead of the

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point of landing). This means that the recorded catch is spread over the estimated area of influence of the port. However, many of these ports are close to each other in location with less than 40 km distance between them. This means that any two ports, for example, that are less then 40km apart (see Figure 5.1, the area between 'Shinas' and 'Liwa') will have an overlapping fishing area between them. Therefore, multiple measurement operations have been applied to these areas.

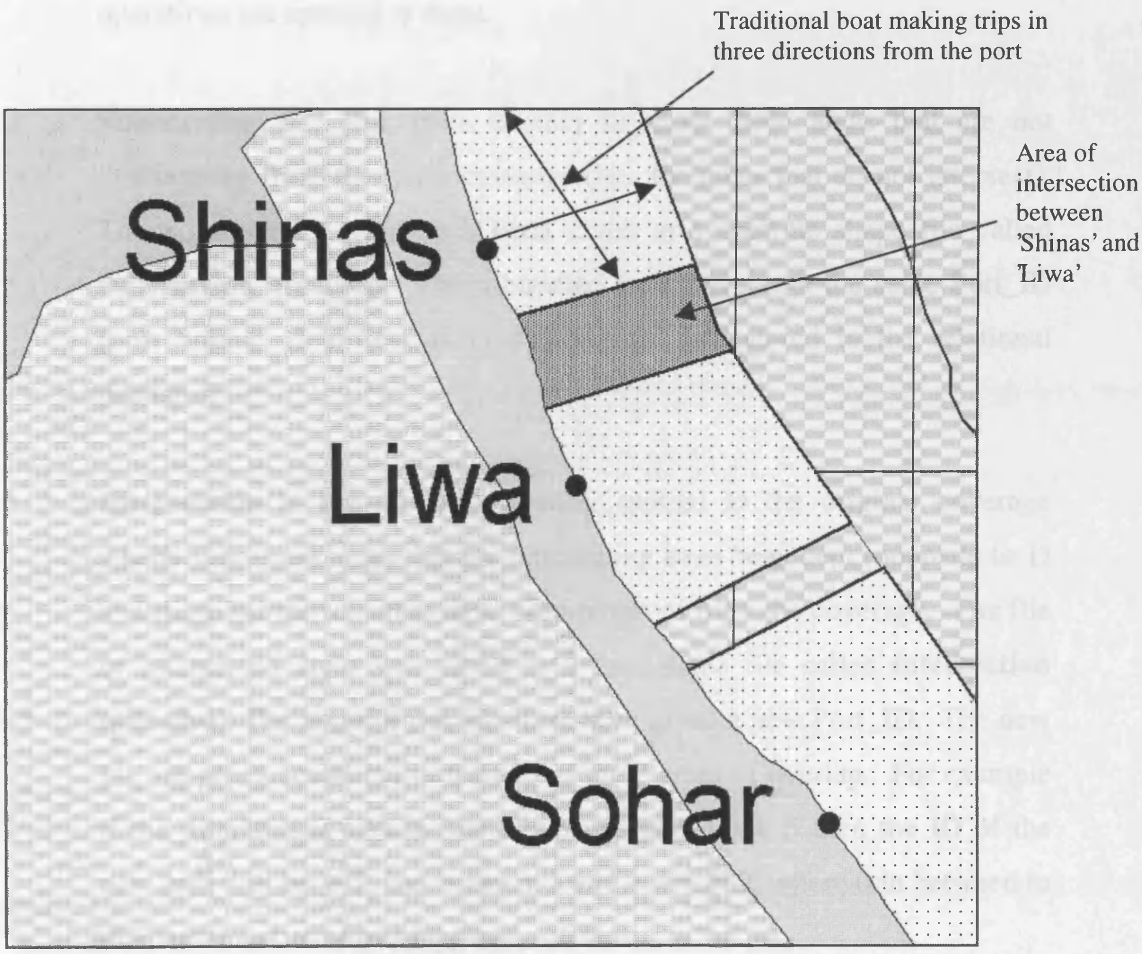

Figure 5.1 Explanatory figure of the estimation of fishing area of the traditional boats travelling in three directions from the shoreline of 'Shinas' landing port and the fishing areas of two ports 'Shinas' and 'Liwa' and the intersection area between them.

Generally, the original polygon areas around the ports and those overlapping areas are subtracted, intersected and joined and as a result the new intersected areas have been given a new unique identifier. The following paragraphs discuss these operations in details.

The method of creating the traditional fishing areas, intersecting and union has been achieved throughout the following steps:

1. **Digitizing** the 20 * 40 km areas. Because the ports are located along the winding coastline it was appropriate to draw the new areas on the map, around each of the landing ports manually and then digitize them. As a result, all fishing areas have been digitized on the map showing the estimated fishing areas around the ports and the overlapping areas (see Figure 5.1, for example). Once these areas are fully digitized, three other operations are applied to them.

2. **Subtracting** one area from another to show those areas that are not overlapping from the main coverage (i.e., the areas that do not intersect). Those subtracted areas have been saved in a separate shape file called **subtraction area.shp**. The subtracted areas have kept the same Port_ID (port unique identifier) as in the original data stored in the relational database.

3. **Intersection** is the second operation applied to the original coverage where only those areas that are intersecting have been kept (opposite to 1) and those subtracted areas have been removed from the coverage. The file of intersected areas was saved as a new shape file called **intersection area.shp**. The areas of this file have been given a new Port_ID. The new Ids are given according to the two or more areas of overlap. For example if the intersecting area is found between port 4 and 5 then the ID of the new area will be 405, and between 8 and 9 will 809, where 0 in between to indicate the state of overlapping.

4. **Union**. Joining the two files is the third operation that has been applied to both files in 2 and 3. This is done be using the **Union** operation available in ArcView. The resulted file has been saved as **traditional area.shp**.

In some cases where there are 3 or more ports found to be overlapping each other multiple methods of intersecting have been applied.

3.2 Measuring the Catch per Unit Area of Port

The amount of catch for each of the original areas and the overlapping ones are calculated by determining the percentage of the overlapping areas and subtracting that from the original (rectangles) areas. The amount of fish catch is measured according to the percentage of overlapping/remaining areas. In Figure 5.1, for example, assuming that the yellowfin tuna catches from port 'Shinas' (port ID number is 4) and port 'Liwa' (port ID number is 5) are 200 and 600 kilograms respectively. The overlapping area between them is equal to 20% of the total size of 'Shinas' area and 20% of the total size of 'Liwa' area then the amount of tuna from both ports and the overlapping area is calculated as follows formulas and description:

1. For 'Shinas' port, the new size is equal to:

$$p - p * 20\%$$

Where 'p' is the original port size which is equal to 20 * 40 km² = 800 km².

The new size (minus the 20% overlapping area) is equal to:

$$800 * 0.2\ km^2 = 640\ km^2$$

The overlapping area of 20% of the original size is equal to 160 km².

The same method is applied to the amount of yellowfin tuna catch:

$$c - c * 20\% = 160\ kg$$

Where 'c' is the original amount of yellowfin tuna (*Thunnus albacares)* catch.

Which means that only 160 kg of catch remains for the original area whereas 40 kg goes to the area of overlap.

2. The same calculation method is used for the second port 'Liwa'. The results can be seen in table 5.1 that also shows the new identity for the overlapping area.

The total amount of tuna in the area of overlap is then added reaching the total of 160 kg. The display of the yellowfin tuna catch from the above example is illustrated in Figure 5.2a before the calculation and Figure 5.2b after the calculation.

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Port Name	Port ID	Original Tuna Catch	Tuna catch after overlapping
'Shinas'	4	200	200 - 20% = 160 kg
'Liwa'	5	600	600 - 20% = 480 kg
Area of overlap	405	-	40 + 120 = 160 kg

Table 5.1 Calculated yellowfin (*Thunnus albacares)* tuna catch of two landing ports of 'Shinas' and 'Liwa' and the overlapping area between them.

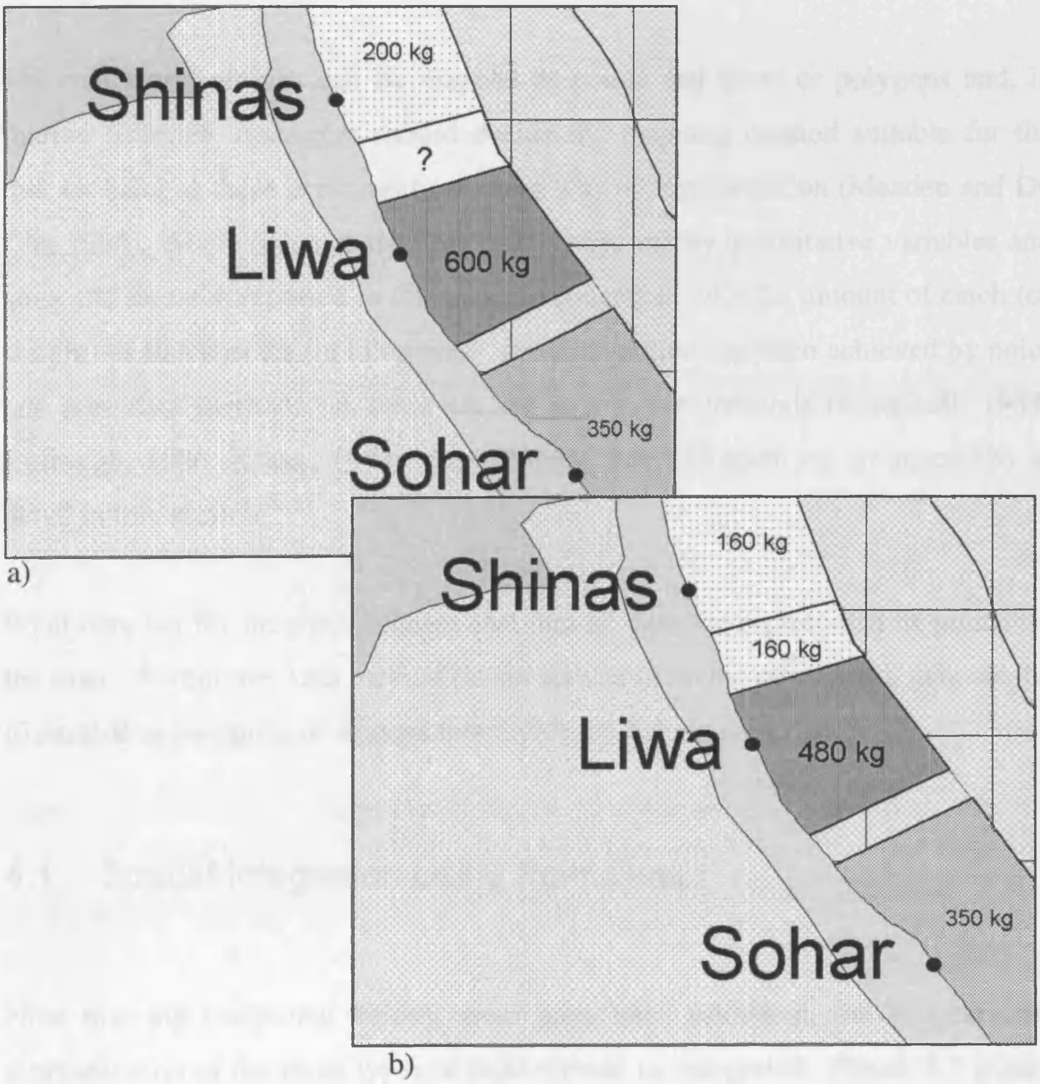


Figure 5.2 Amount of yellowfin tuna (*Thunnus albacares)* catch from table 5.1, a) before the intersection and b) after the intersection.

4. Spatial Data Integration

As mentioned, spatial integration is crucial especially for managing of natural resources areas. In general, Spatial data integration supports an intuitive understanding of complex environmental systems (Fedra, 1993) as well as assisting the process of decision making. Similarity in visual display allows evaluation of how certain phenomena vary in quantity or quality over the mapped area.

The real world entities can be mapped as points and areas or polygons and, in marine fisheries, managers should decide the mapping method suitable for the task on hand as there is no right or wrong way of representation (Meaden and Do Chi, 1996). Since fisheries data for catch are in reality quantitative variables and since the research reported in this paper is concerned with the amount of catch (or weight) of fish species (in kilograms), data integration has been achieved by point and area data methods, as these are the appropriate methods (Campbell, 1984; Burrough, 1986; Kraak, 1999; Mark, 1999). The two methods are discussed in detail in this section.

Point data (as for longlines) means that that all data are represented as points on the map. Within the Area method (as for trawlers), on the other hand, data can be illustrated as polygons or squares that divide the fishing area.

4.1 Spatial Integration Using Point Data

Now that the traditional fishing areas have been estimated, the geographical representation of the three types of fisheries can be integrated. Figure 5.3 shows the types of spatial data represented in a single map layer. The visual representation of the figure indicates the difficulties in analyzing the three types together since their geographic footprints are different.

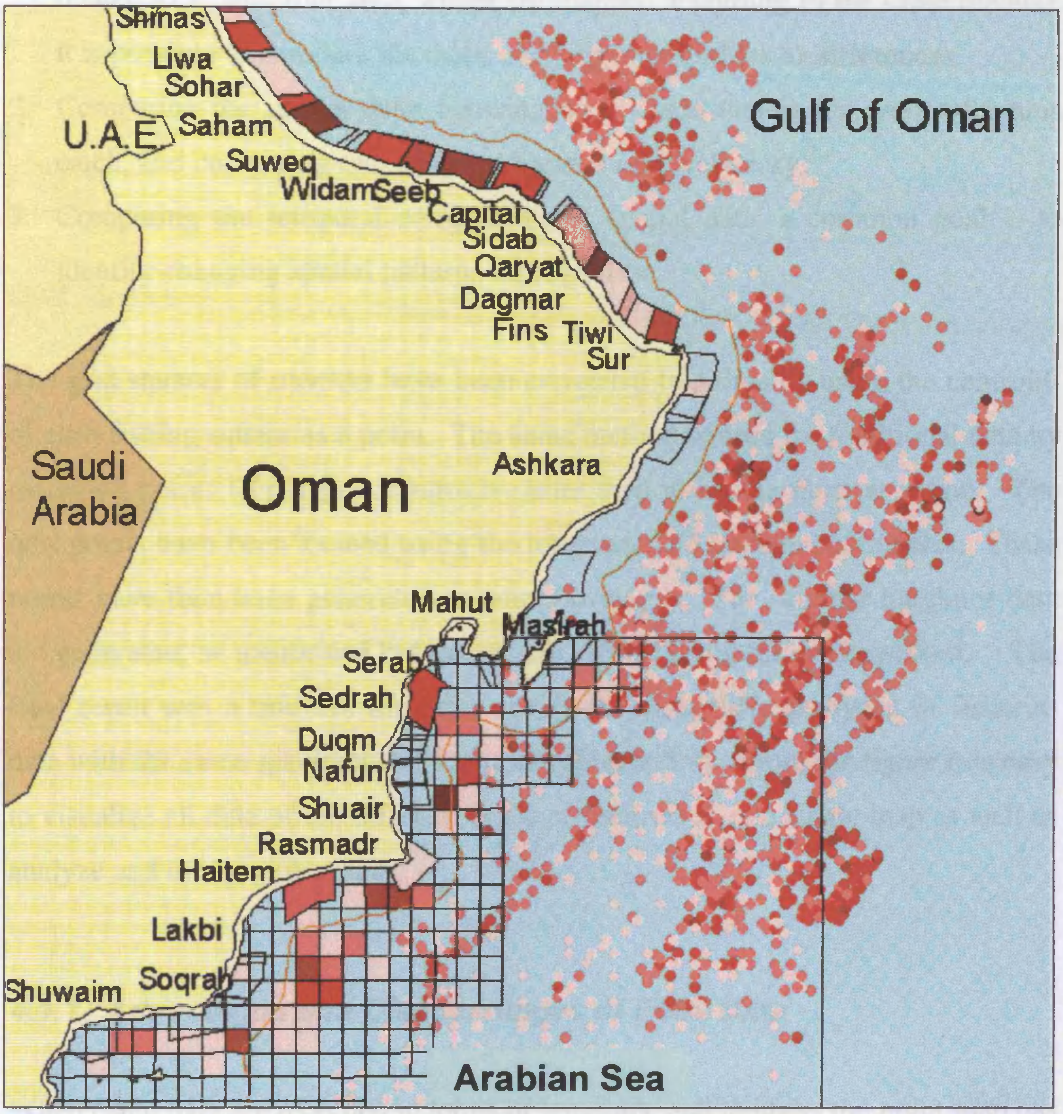


Figure 5.3 Yellowfin tuna (*Thunnus albacares)* catch of 1995 by the three types of fisheries (traditional, trawlers, and longlines), the darker the color the higher the catch. The figure illustrates the three different geographical footprints.

Most of the georeferenced data are gathered at points. However, trawlers fisheries are recorded as grid squares although finding their fishing areas is done via the GPS receiver, which originally records the locations as points in longitude and latitude. The goal of analyzing spatial inter-relationships between one data source and another often requires that sample observations should be at points. This is because comparison of one set of samples with data from different sets requires conversion to a common base for comparison. In general, similarity in mapping data is beneficial for the following reasons:

1. Comparing the attribute data: it is possible to compare two or more themes related to a particular area, which are mapped according to the same method; it is possible to compare the maps and judge similarities or differences.
2. Comparing the spatial data: focusing on a single theme, e.g. yellowfin tuna catch, and comparing two different areas is relatively easy.
3. Comparing the temporal components of spatial data: a common goal is to identify changing spatial patterns through time.

The grid squares of trawlers have been converted to points by using the centroid[1] of each fishing square as a point. The same method is used for traditional data by assigning points to polygon centroids rather then using the ports as points. The new points have been located using the longitude and latitude coordinates. These points have then been generated as point coverages. The original longlines data are generated, as mentioned before, in ARC/INFO using the same method. The final result was a uniform map that shows the three different types of fisheries data with the same geographical footprints (Figure 5.4). From the figure it is easy to visualize all data of the different types of fisheries as one single map as well as analyze and interpret the data.

4.1.1 Advantages and Disadvantages of Point Data

When catch data are recorded in terms of longitude and latitude, the point map has the advantage of determining exactly where the data have come from. However, the point map is handy if the data to be represented is of a few points at a large map scale, but when points represented on the map are very large and overlap it is very difficult to understand and interpret the map. An alternative approach is to map density of the points, the number of points per unit area (see Figure 5.9). Density mapping has the advantage of showing the amount of fishing activity that has been applied to any given cell or area (Bonham-Carter, 1994).

[1] Usually computed as the centre of an enclosed rectangle or of an enclosing or inscribing circle. It also the mean centre of a point distribution.

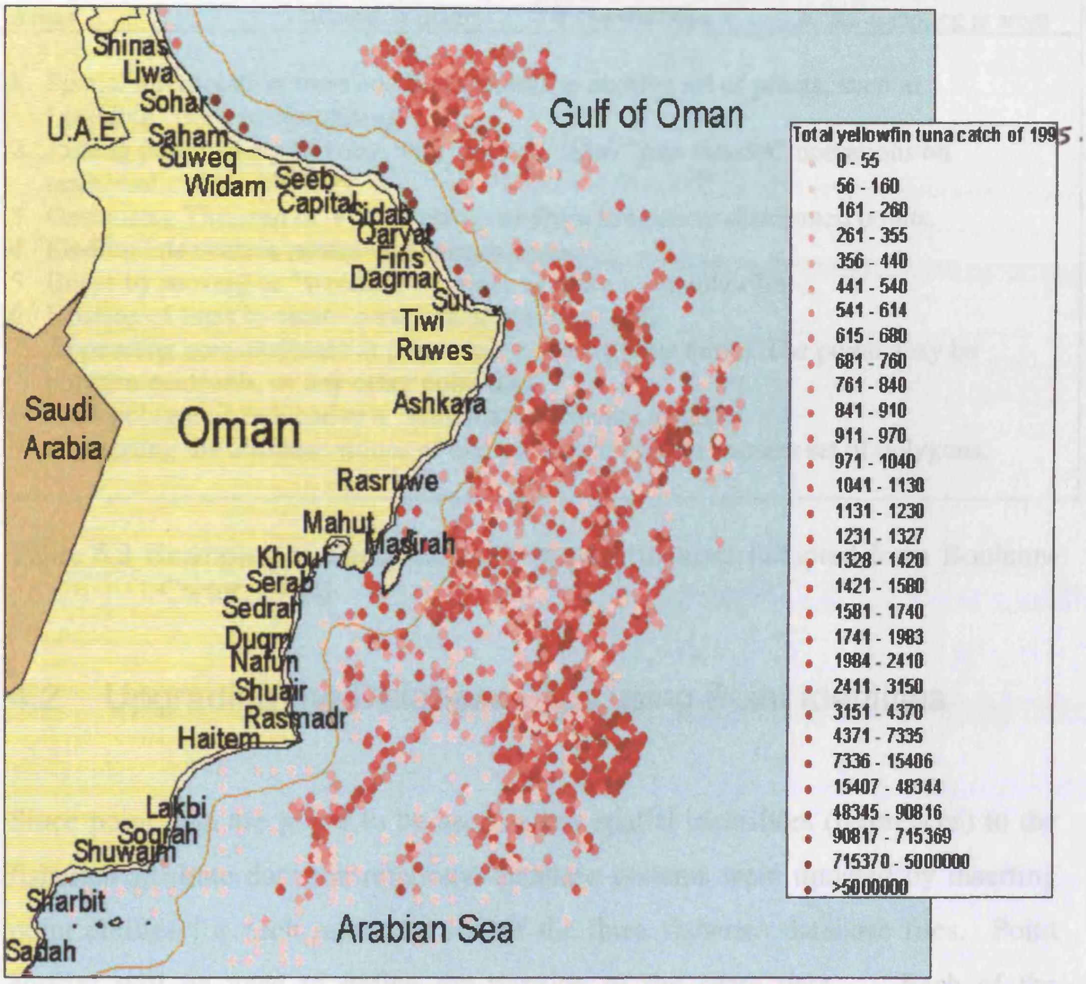


Figure 5.4 Integrating fisheries spatial data using point location. The traditional and trawlers polygons have been converted to points at the centroid of each polygon.

Most of the georeferenced data are gathered at a point, and generally speaking, point data are the most appropriate method to apply methods of conversion and transformation of data from one type to another (e.g., point to grid). Point data usually forms the basis for carrying out methods of data interpolation. Table 5.2 gives an example of elementary transformation available within the GIS.

From/To	Points	Lines	Areas
Points	1. Interpolation	2. Contouring	3. Thiessen polygons
Lines	4. Line intersections	5. Line smoothing	6. Buffer zones
Areas	7. Sample at points	8. Medial axis	9. Re-sampling at areas

1. Spatial interpolation from one set of points to another set of points, such as "gridding" prior to contouring
2. Joining points of equal value with isolines. Also "join-the-dot" operations on mathematical morphology.
3. Generating Thiessen or Voroni polygons from irregularly distributed points.
4. Finding intersection points where lines cross
5. Either by moving or "weeding" vertices to make a smoother line.
6. Dilation of lines to create corridors of specified radii.
7. Appending area attributes at points to a point attribute table. The points may be polygon centroids, or any other point data.
8. Each polygon is reduced to a "skeleton", or medial axis line.
9. Converting the attribute values of one set of polygons to another set of polygons.

Table 5.2 Examples of elementary GIS transformations (adapted from Bonham-Carter, 1994)

4.2 Upgrading the Database Files using Point Identities

Since point data are going to be used as key spatial identifiers (references) to the fisheries attribute data the relational database systems were updated by inserting point entities for each relational file of the three fisheries database files. Point entities will be used to define the position of the catch data. Each of the CATCH_REPORT tables of the three relational databases (traditional, trawlers, and longlines) has a new entity assigned to it, which refer to the point identifiers. In more detail, each port of the traditional fisheries table then has a unique point identity associated with it. For the trawler fisheries, the identifiers used to represent the trawlers area codes (e.g. 7558) are also used as the identities for the new points located at the centroids of each polygon.

For the point identifiers not to be duplicated within the three fisheries database tables, each fisheries type has been given a different scale of point ranges. For example, points IDs or numbers ranged from 1 to 5999 for the longlines fisheries (although fishing records are usually less then 4000 for each year). The point IDs ranged between 6000 to 6060 (since there are approximately six areas including those areas of intersection) to refer to traditional fisheries areas, whereas the IDs of over 7000 are given to the areas of trawlers. In this case two points from two different fisheries files cannot have the same point identity. Table 5.3a, b, and c gives a

Point_ID	***Tuna Catch***
6000	297.75
6001	630
6003	10480.41
6004	15406.96
6006	255.75
6007	43103.93
6008	90816.29
6011	79222.84
6013	677528.55
6014	715369.13
6015	408661.8
6018	21467.97
6018	4870
6019	10922857.2
6021	1550

a)

Point_ID	***Tuna Catch***
1	900
2	500
3	600
4	1450
5	0
6	1350
7	500
8	1650
9	1350
10	1650
11	1750
12	450
13	150
14	1000
15	1000

b)

Point_ID	***Tuna Catch***
7551	40
7554	0
7555	40
7556	100
7557	40
7558	200
7559	140
7568	0
7582	0
7587	0
7588	20
7589	0
7592	20
7595	180
7598	180

c)

Table 5.3 Example of using *Point_ID* as the unique identifiers of the relational database files. The tables shows the yellowfin tuna catch records for the a) Traditional, b) Longlines, and c) Trawlers fisheries.

4.3 Spatial Integration Using Area Data

Representing the geographical footprints of fisheries data as areas is another way of integrating the spatial data. This method represents the values on areas, and expresses it as a stepped surface, showing a series of discrete values with sudden changes at the edge of areas. An area representation is achieved by aggregating the points of fish catch into a polygon that replaces the points. Aggregation in general, means grouping distinct data (attributes and/or spatial data), and involves the assignment of one or more attributes of a point to a polygon. The polygon replaces the points and becomes the spatial object with which one or more attributes are associated. This operation involves a many-to-one mapping since more that one point can be found close or even overlaying each other within a very small area. The idea of aggregating the points of longlines is to integrate the spatial data within a certain size of area where each polygon must contain the value of the sum of all attribute data within that polygon. Figure 5.5 shows the data from figure 5.4 of tuna catch represented by a uniform grid of square areas.

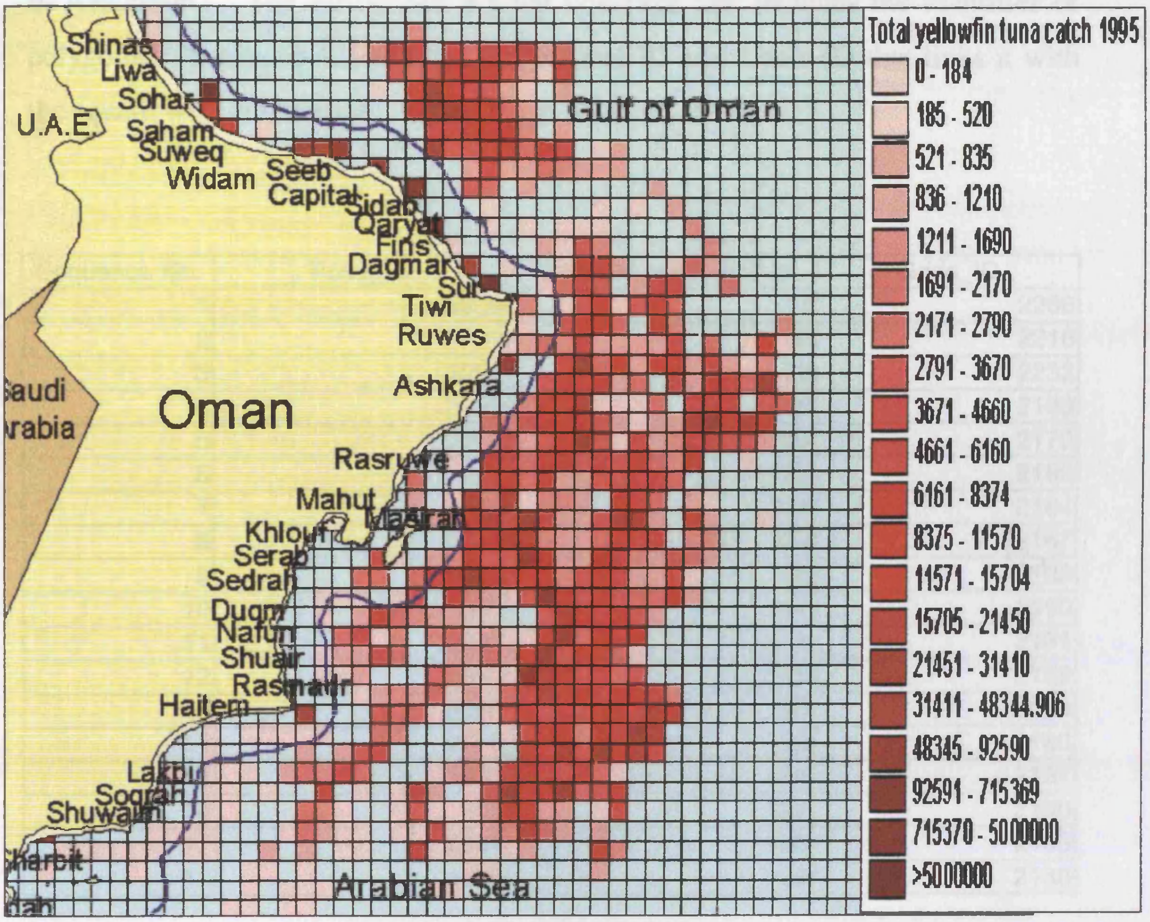


Figure 5.5 Integrating fisheries spatial data using square areas. The values of all points in Figure 5.4 are aggregated and each square of 10 * 10 miles represents the total amount of tuna catch for 1995.

The number of points in each square have been grouped or aggregated and the total amount within each square is presented. Square size can be changed if requested. The idea when deciding the size of the squares is to adopt the original sizes of the trawlers fisheries as is done in Figure 5.5. Apparently this size is appropriate for the marine fisheries area of Oman as the MAF has requested this size which believes to be sufficient for the purpose of management. Areas can be zoomed in if a certain area is to be analyzed.

The method of imposing squares on the area of fishing was to generate a fishnet of squares equal to 10 * 10 miles squares. Once the fishnet has been built as a polygon coverage, it was overlaid on the point coverages of fishing location for the five years. The method of overlay was achieved using the 'identity' command in ARC/INFO. The results are a point coverage that includes the identities of polygons. That is, each point has the original ID and a new ID that links it with the square were it is located. Table 5.4 gives an example.

Sequence No.	Point_ID	GridsIDs_witht_Points	Grids_ID
1	6000	11	2266
2	6039	59	2218
3	2062	73	2232
4	2059	120	2183
5	6001	107	2170
6	901	127	2190
7	2063	121	2184
8	2076	124	2187
9	1608	125	2188
10	896	127	2190
11	2081	118	2181
12	2082	119	2182
13	2058	120	2183
14	2075	123	2186
15	1607	124	2187
16	899	127	2190
17	2061	120	2183
18	1606	125	2188

Table 5.4 Example of the results from the process of 'identity' in ARC/IFO. The two tables, squares (fishnet) and point coverage have been overlaid and the results give every point an ID (Grids_ID) that links it with the square where it locates.

In the table several columns have been created. The first one gives a sequence number of the records in the table. The second column (Point_ID) indicates the original ID of the points, whereas the fifth column (Grids_ID) refers to the ID of the square where each point is located in the process of identity. Once this has been achieved then the values of the points were aggregated by square and the result is presented in Figure 5.5. The non-square areas that are closed to the shoreline are treated as if they are a complete square and their data of catch are represented whenever a point or points are located on them.

4.3.1 Advantages and Disadvantages of Area Data

Area maps are more effective in displaying the catch per unit area. This helps in understanding the state of fish stocks per area as well as better contributing (visually) to the areas of decision making and rule setting. It is probably the best method to divide the fishing areas into squares or polygons for better management as this method can gives the best visual interpretation and leads to better interpretation of the results. However, area representation is not the best way to determine where the catch has come from, that is, the exact location of catch. It is, however, essential to have both types of data at the time of decision making as this helps in evaluating the different results from different map representations.

5. Visualizing Fisheries Data

The general purpose of this section is to overview three types of data visualization that are used throughout the following two chapters. The method of visual display is essential when environmental and natural resources problems are to be solved (Parks, 1993). Visualization in general, is how the values or amount of fish data are represented in terms of graphs, colors, tables, and histograms. Color maps and graphics output, specifically, that representing the environmental and natural resources problems allow easy and immediate understanding of basic patterns and relationships (MacEachren, 1994; Kraak, 1999). Visual display allows evaluation of how certain phenomena vary in quantity or quality over the mapped area (Fisher et al. 1993). In this study, visualization refers to the method used to display the values of fisheries data on the maps that contain the attributes data of the integrated three types of spatial marine fisheries.

Generally speaking, data integration and visualization are recurring keywords in today's spatial modeling literature, and sometimes the idea behind integrating different spatial data is to obtain the best possible method of data visualization. The methods of data visualization are critical as some aspects require thematic comparisons of more than one map, which means looking at maps which use multiple display methods for the same area.

Three different data representations are discussed, namely dot density, choropleth, and proportional symbol maps.

5.1 Dot Density Maps

Dot density maps represent the amount of data in terms of dots on the map, with each dot equal to a specific amount, number or value (e.g. 1000 kg). Dot density maps are a special case of proportional symbol maps, as they represent point data using symbols where each dot denotes the same quantity, and are located as close as possible to the locations where phenomena occur (Goodchild, 1991; Demers, 1997; Elshaw and Thrall, 1999). Figure 5.6 shows a southern part of Omani waters with tuna catch from 1995 converted from the data presented in Figure 5.5 as dots. Every dot in the figure is equal to 2000 kg of tuna catch. The dot locations represent the actual catch location (squares) and it is helpful to understand some patterns such as the concentration and dispersion of the catch distribution.

Dot density maps are also very helpful if dots are placed on top of other map types. For example, this grid that shows related data such as water temperature. This can facilitate comparisons between the two types of data and exploration of their relationship. Figure 5.7, for example, illustrates the relationship between total shark (*Carcharhinidae, Sphymidae*) catch and average sea surface temperature. The dots show the weight of the total catch (every dot represents 100 kg of catch) between the months of July and September 1995, whereas the background grid, represents the average sea surface temperature for the same period of time.

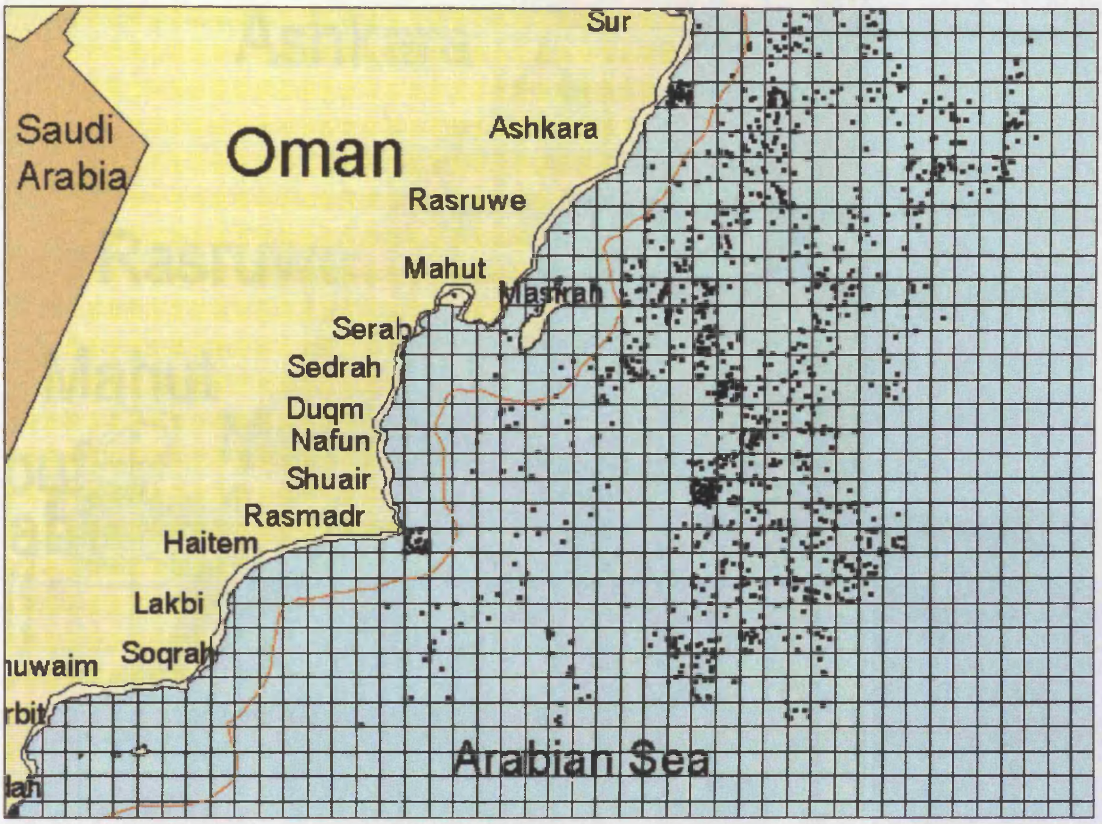


Figure 5.6 Dot map from yellowfin tuna (*Thunnus albacares*) catch of 1995 (converted from Figure 5.5). Each dot on the map represents 2000 kilograms of tuna catch.

Dot values can be easily changed if the number of dots at one place are too large for dots to be distinguished visually. The solution is to assign a new value to each dot (e.g., 8000 kg instead of 2000), as this will reduce the number of dots per area and produce a better visual display. The method is effective to understand the catch per unit square through a specific period of time (e.g., monthly, seasonally, or annually).

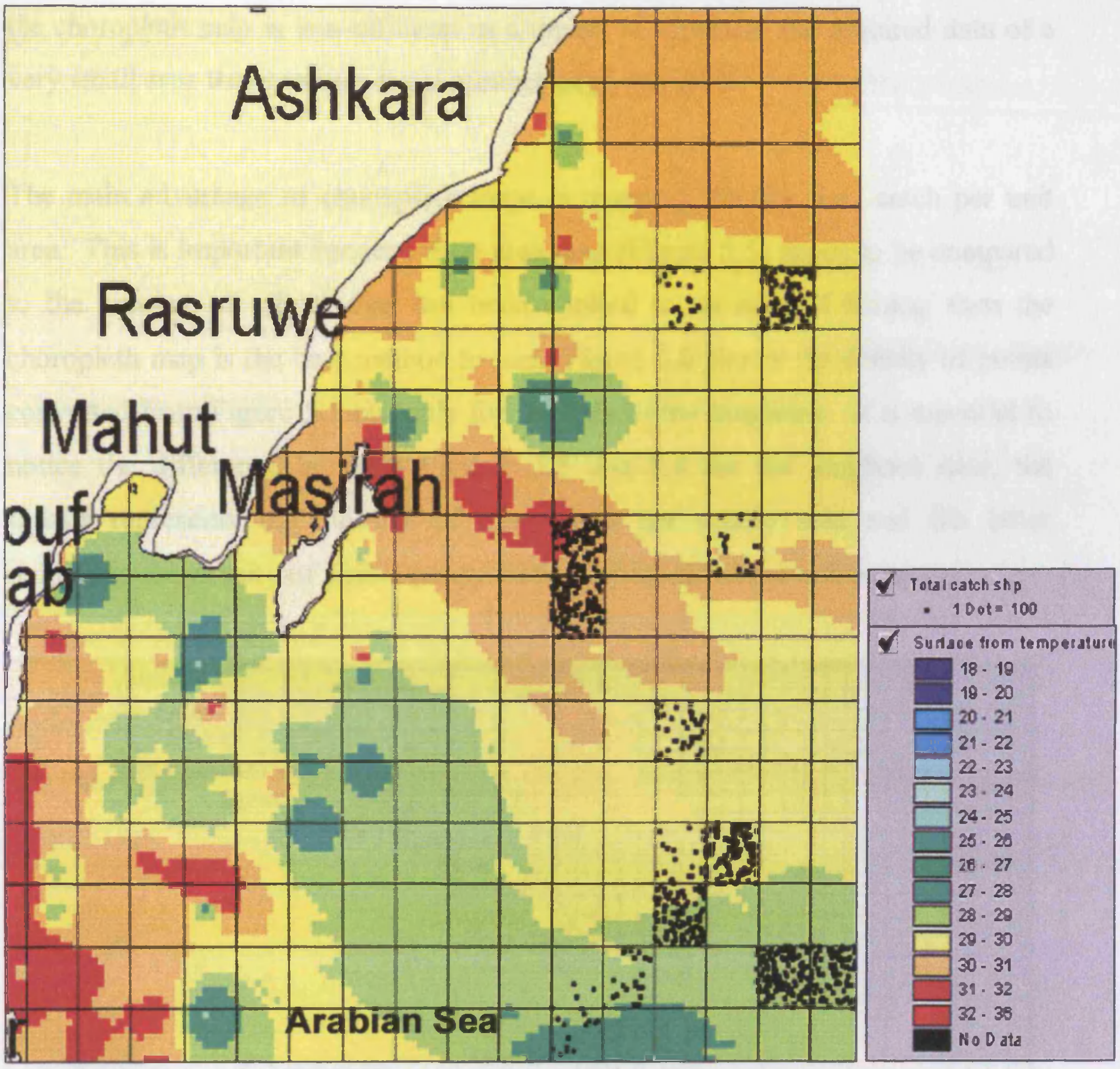


Figure 5.7 Example of using the dot map to illustrates the relationship between sea surface temperature and the amount of Shark (*Carcharhinidae, Sphymidae*) catch. Each dot is equal to 100 kilograms of Shark.

5.2 Choropleth Maps

Choropleth means represent the areas as values (Burrough, 1986; Kraak, 1999). As these values are represented through area symbols they can only be relative values. It is the differences in gray value, for example, or in the intensity of color that denote differences in intensity of a phenomenon, such as difference in catch density. Generally, the darker the grey (for example) values, the more intense or the higher the densities of the phenomenon. Figure 5.5 is an example of how the values can be shown on a color map. The method to display the data using choropleth maps is implicit in the area method of data integration. However, the usefulness of the choropleth map depends on the size of the areas to be analyzed and the number of point data located in these areas (Demers, 1997). In this case, the choropleth map is less efficient as a means to represent the required data of a very small area that contains large number of points on it.

The main advantage of choropleth maps is mapping density, i.e., catch per unit area. This is important because if an area map (Figure 5.5) needs to be compared to the amount of effort[2] that has been applied to an area of fishing then the choropleth map is the best method to use. Figure 5.8 shows the density of points converted from Figure 5.5 but only for the data of the longlines. It is essential to notice the difference between Figures 5.5 and 5.8 for the longlines data, the former represents the amount of tuna catch per square area and the latter represents the density of points per grid (the fishing effort per unit area)

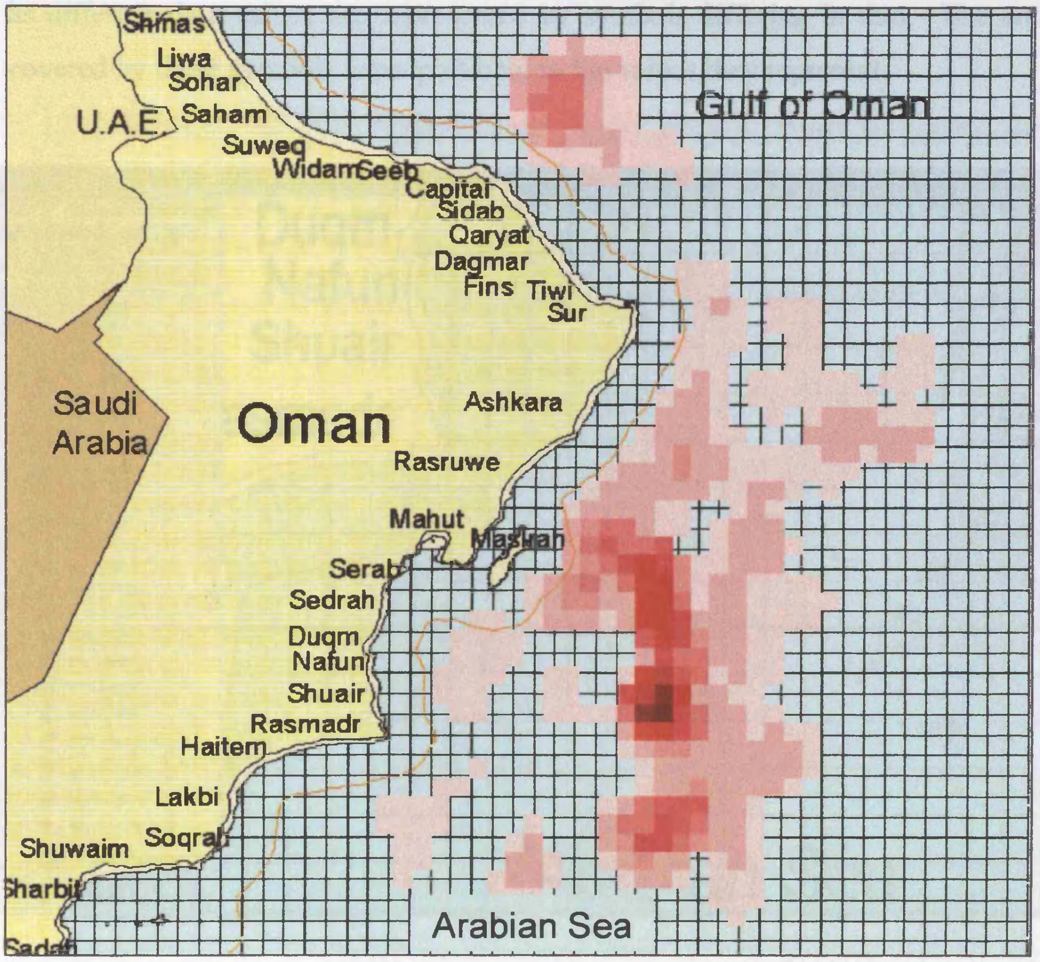


Figure 5.8 Map density of longlines yellowfin tuna catch of 1995, mapped from data in Figure 5.4.

[2] Effort here means number of fishing events or days.

It is also important that density maps of fishing effort can only be used when the point data represent an event per point. In case of the traditional fisheries this can be done by mapping the number of fishing boats reported to fish is that period instead of days of fishing.

5.3 Proportional Symbol Map

Proportional maps represent data as symbols of different sizes or shapes. Discrete absolute values, valid for point locations or for areas, can be represented by proportional symbols. Geometrically shaped proportional symbols are much better suited here. Figure 5.9 shows the proportional symbol map of tuna catch from Figure 5.6. The figure is focused on the southern part of the national waters as different data values are represented by symbols differing in size. The area covered by these symbols is proportional to the values they represent.

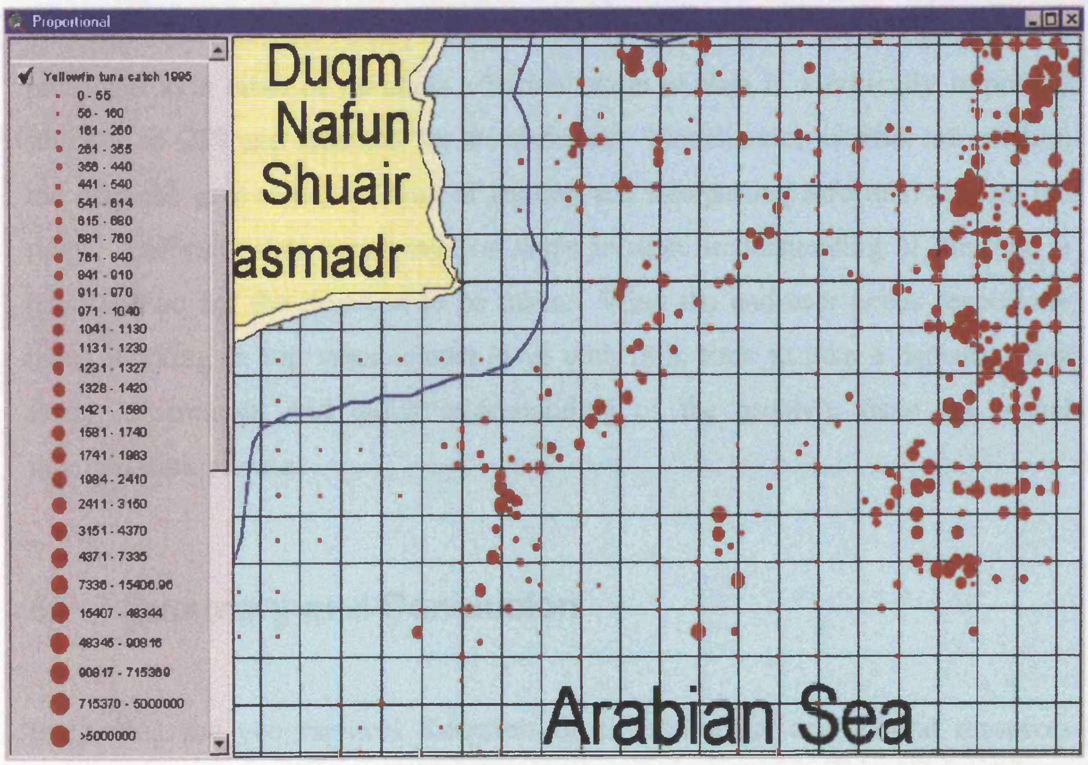


Figure 5.9 Proportional symbol map of yellowfin tuna (*Thunnus albacares)* catch of 1995 from the southern part of Oman (converted from Figure 5.4), the larger dots show greater catch.

This method can also be used instead of dot maps as a background map can show different phenomena. Thus the relationship between catch and water salinity can be mapped in this way too. Proportional symbol maps are used in Appendix B.

4.2 Conclusion on Methods of Data Representation

Each type of data representation that has been discussed has its own advantages and disadvantages. For the data display to have the maximum effective results for the decision making process, data must be presented using different methods of representation or visualization. The flexibility of the data to be transformed or converted to another, map type means that there are a number of options to be considered. One of the main advantages of the transformation of data is to assist the methods of analysis and comparison.

Human have an extraordinary ability to understand complex spatial relationships visually, whereas the same information may be quite unintelligible when presented as a table of numbers. Visualization of data is a critically important function in GIS and essential for the end-user. Visualization is what information the map can give to us, the way of gaining and interpreting information from the maps. Different data representation helps in more understanding of the task in hand and so for the decision to be taken. What the end-user needs (especially those working in top management level with little time to take a decision) is a ready information and quick understanding of the problem from the visual interpretation of data.

6. Summary and Conclusion

Integrating the geographical footprints of environmental and natural resources data is crucial within an analysis. Fish are mobile creatures but exist within a space in the sea and should be observed and managed in total. Understanding the fish distribution along the total area of fishing forms the basis of any decisions or regulations and influences other areas such as stock assessment and stock protection. The integration of the traditional fishing areas, which has been discussed in some detail, was important in order to understand the area of actual catch and to be able to integrate that with the data of commercial fisheries.

The three geographical footprints of fisheries data have been integrated using two methods, the point and the area. Integration by point means representing the fisheries catch data as points of fishing location. This has been achieved by assigning points to the centroid of each polygon and square of the traditional and trawlers fisheries areas respectively. Area integration that presents the catch data for representative areas has been achieved by imposing squares into the total area of fishing and aggregating the points of each square.

Visualizing the data is the main reason for the GIS is to be used as the method of mapping the data. The method of data representation affects any decision and any future plan. Three methods of data representation have been discussed in this chapter with the emphasis on the idea of flexible transformations between the three types. Multiple representations of data give multiple scenarios for better decisions.

6

SPATIAL INFORMATION SYSTEMS AS A DECISIONS MAKING TOOL FOR MARINE FISHERIES MANAGEMENT

"GIS systems are not perfect tools for many applications because they represent an implementation of a state of GIS Science. For an application in hand, a particular system may be good enough, but it may not"

(Peter Fisher, 1998, p.328)

1. Introduction

The purpose of this chapter is to illustrate the reward that a GIS can provide in the area of marine fisheries. That is, how a marine fisheries GIS might be a tool for assisting fisheries management and the decision making process in terms of visualizing and analysing fisheries locational data. However, the GIS analysis tools are still far from being a complete set that can be used in solving all natural resources problems regardless of the nature of the field they are to be used in.

This chapter will start by highlighting the limitations of GIS-based analysis that might be used in fisheries. Section 3 discusses on the method of measuring fishing effort. Section 4 is devoted to exploring the visual ability of GIS for mapping total catch distribution, the catch per unit effort per unit area, and fishing density. Mapping spatio-temporal catch data and their advantages in understanding the spatio-temporal presence of fish species are discussed in section 5. Section 6 explains the relationship between the movement of major commercial vessels and the amount of catch of these vessels. The use of advanced spatial analysis methods are highlighted throughout the rest of the chapter starting with section 7 which explores the method used to map the preferred areas of fishing. Section 8, explores the expected areas of fishing together with the expected amount of catch from each area using the five years base data. Projecting areas of multiple fish presence (areas of fish habitat) from the catch data is highlighted in section 9. Section 10 discusses the areas found to be unexploited or have a potential high catch and not yet being fully utilized. In contrast, section 11 explores areas of overfishing, that is, areas where effort has been consistently high and may have caused the catch to decline or the stock to be damaged.

2. Limitation of the GIS spatial analysis functions

GIS are powerful tools for organizing and visualizing spatial data, and by using a GIS many analysis operations can be achieved. However, this tool box is far from being a complete one in terms of its analytical functions. It is unlikely that one single GIS could provide a complete range of all the functions that would ever be needed, although most GIS already contain a modest toolbox of functions for analysis and modeling. The shortage in GIS analysis functions is partly due to the lack of a clearly developed theory of spatial analysis upon which developers can draw (Bonham-Carter, 1994). Usually, GIS users come from different fields that require different analysis tools (e.g., spatial analysis, modeling, and mapping). As a result, Bonham-Carter (1994) considered that there is a lack of analytic functions to meet the needs of environmental and natural resources applications, and therefore the additional linkage with external software such as spreadsheets and databases are used here for some extra functionality. There is probably a need to add these external softwares when considering GIS in fisheries.

The most noticeable thing while using the spatial analysis abilities of the GIS is that although these operations are called spatial analysis, not all rely on a spatial context. Rather, they apply to objects (within the map) that have geographical co-ordinates associated with them. Many analyses fall into this category, such as map classification, or the application of arithmetic or Boolean operators to the attributes of maps.

The method of applying spatial analysis using attribute data is clearly one of the advantages of using the GIS, especially if the data mainly of attributes like the fisheries data. However, it seems that the confusion between the definition of 'analysis of spatial data' and 'analysis of spatial attribute data' and 'spatial analysis' has caused a conceptual shortfall in developing the analysis functions of the GIS.

3. Measuring Fishing Effort

Before further discussion on the GIS abilities to analyse fisheries data, it is essential to highlight the method used to measure the fishing effort on the areas of fishing. This is because fishing effort can be measured in different ways with different data (Meaden and Do Chi, 1996). Some common ways of measuring fishing effort are 'catch per fishing trip', 'weight of fish caught per hook per hour', 'number of hours or days a vessel is at sea', and 'catch per unit of a vessel's horsepower' (King. 1995; Fabrizio and Richards, 1996).

Several management issues based on the knowledge of stock abundance which can be estimated if effort is known. As discussed in the previous chapters, the amount of catch is very much related to the characteristics of fishing vessels such as size, tonnage or speed. Stock assessment from yield data is only meaningful if effort is standardised. As Hilborn and Walters (1992) point out different designs of fishing boats and different types of fishing gear lead to different efficiencies of fishing. As a result, comparing the yield from multiple boats can be a misleading as a basis for stock assessment (Hilborn and Walters, 1992, p126).

Hilborn and Walters (1992) discusses a regression-based approach to estimating a standardised fishing effort. This is achieved by grouping boats in a fleet by their characteristics and applies a regression model based on their catch in the first year of records. Such a model of effort, however, requires records of boat characteristics. Although there is provision for collection of some such data in the records for the Omani waters (see Figures 3.4, and 3.9) that part of the records is not completely reliable or is not sufficient to provide a detailed break-down of boat type. Furthermore, the data records required were not available for this study. Therefore, in this thesis, most analysis must be restricted to examining catch within a single type of fishery (traditional, trawler or longlines), and the measure of effort used is 'fishing days' for the commercial fisheries and 'fishing trips' for the traditional fisheries (Hilborn and Walters, 1992, p12). Although not the most sophisticated indices, these are widely used by other researchers (Royce, 1984; Hunter et al. 1986; King. 1995; Fabrizio and Richards, 1996; Meaden and Do Chi, 1996; Freon and Misund, 1999;) and have the benefit of being available within the database for the current investigation.

4. Mapping Species Catch Distribution, Catch Per Unit Area Per Unit Effort, and Fishing Density

4.1 Mapping Species Catch Distribution

Mapping species catch distribution by the three types of fisheries is important in order to try to understand the possible geographical locations of each species, especially if fishing effort applied by the three fisheries are different. The three types of fisheries have different fishing efficiency and so in this thesis a common way of comparing the catch per unit effort is not applicable when mapping the total catch of a single species that have been caught by all three types of fisheries. The method of display for these sorts of data is straightforward once data of all different geographical footprints have been integrated. The concern here is to map total catch of each fish species that may be caught by one, two or three different fishing types.

Figure 6.1 shows the total yellowfin tuna catch (*Thunnus albacares*) for the five year period. The legends for the five maps are all the same, using the same values and colors of the red monochromatic sequence.

Figure 6.1 can be used as a straight indication of the possible locations of yellowfin tuna biomass or stocks since fishermen (traditional and commercial) in general tend to fish from the same areas where fish density is usually high (Hilborn and Walters, 1992; Fabrizio and Richards, 1996). The areas of darkest color represent the catch greater then 60,000 kilograms (60 tonnes) per square. Since tuna from traditional fisheries are caught on a daily basis throughout the year with many boats per area, it is normal that the amount of catch is large compared to those of commercial fisheries. However, the comparison of total catch of yellowfin tuna by traditional and longlines shows little difference. Table 6.1 shows the total yellowfin tuna caught by traditional, longlines and trawlers.

Type/Year	1991	1992	1993	1994	1995
Traditional	3103	3423	7609	7501	9173
Longlines	2309	3025	4519	4009	5289
Trawlers	11	19	17	6	12

Table 6. 1 Yellowfin tuna catch (*Thunnus albacares*) (in tonnes) by the three fishing types of fisheries (traditional, longlines, and trawlers) for the years 1991-1995.

The amount of yellowfin tuna catch by the trawlers is minimal. Although tuna is a pelagic fish, it is caught by trawlers that mainly catch demersal species because yellowfin tuna is known to move in horizontal and vertical directions, and so can be caught at any depth (Al-Abdessalaam, 1995).

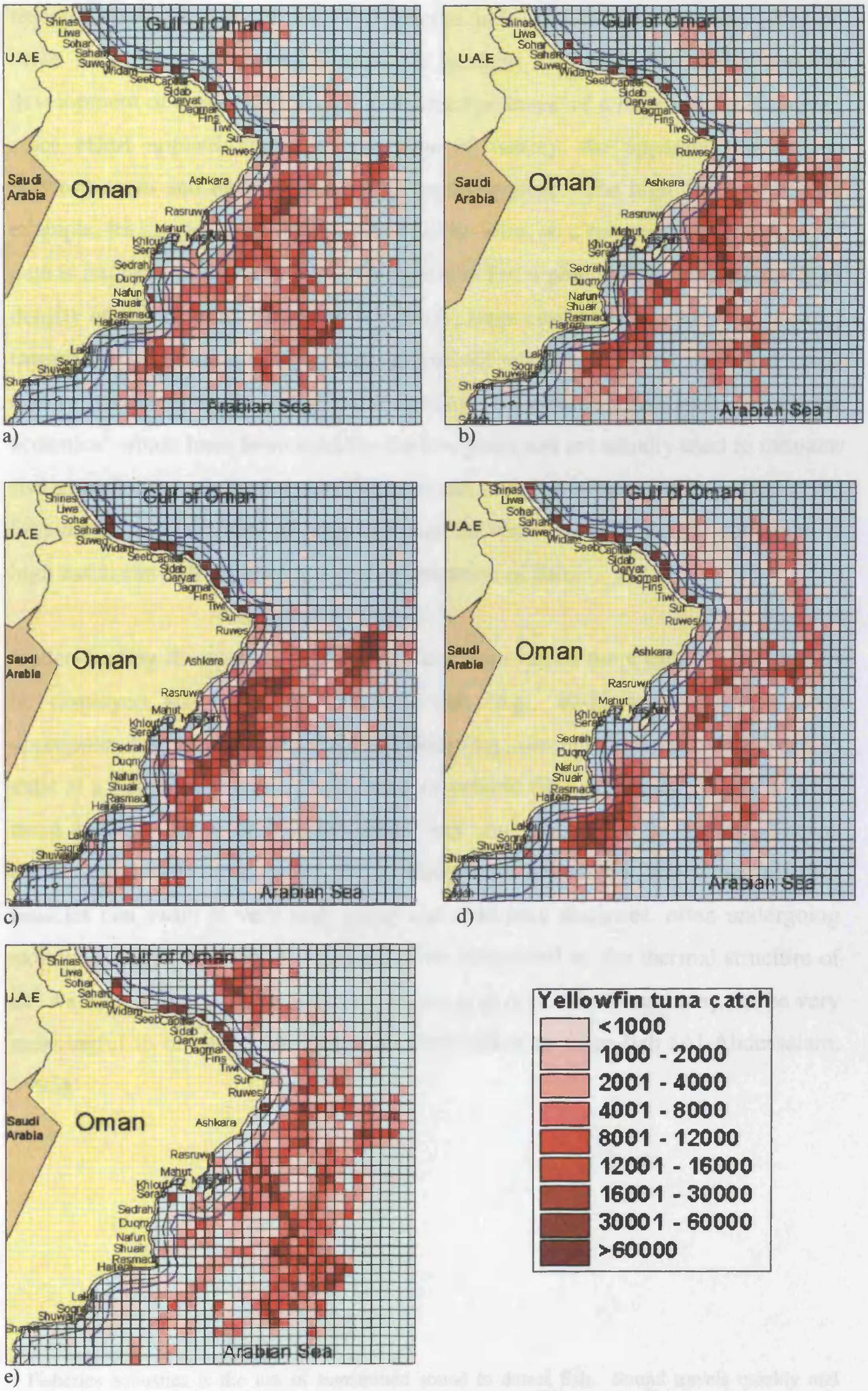


Figure 6.1 The display of the annual yellowfin tuna (*Thunnus albacares*) catch (in kilograms) from all types of fisheries for the years a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

Referring to Figure 6.1, again, from the fisheries manager's point of view, any research concerning developing the fisheries industrial areas must either focus on these areas of high catch in order to increase the yield, or in the possible development of areas that have an unrealized potential of a large catch. However, since effort applied varies by the type of fishery, the apparent relationship between catch and existing stock may be misleading. The high catch could, for example, be due to large fishing effort in the area, so a more detailed analysis of data is required to determine whether the area has a potential for holding the high density of fish or not. However, nowadays, large commercial vessels are moving towards targeted areas and species determined using either their historical catch data or maybe using the advanced technology for detecting fish such as fisheries acoustics[1] which have been used for the few years and are usually used to measure fish abundance and distribution (MacLennan and Simmonds, 1992). Therefore, looking at the movement of large commercial vessels (see section 6) and areas of high catch can still indicate a high concentration of fish.

Understanding the species stock using catch data can be more useful if the data to be displayed are for longer time periods (e.g., 20-30 years) and is more appropriate for some species than for others (e.g., demersal species which tends to exist at a determined area). In the case of pelagic fish, especially yellowfin tuna, more analysis needs to be done before any conclusions can be drawn. This is because yellowfin tuna, due to its hydrodynamic refinement and powerful (red) muscles can swim at very high speed and over long distances, often undergoing extensive migrations that are thought to be influenced by the thermal structure of the water column, and thus the catch in one year or in a few years may not be very meaningful in terms of the long term distribution of these fish (Al-Abdessalam, 1995).

[1] Fisheries acoustics is the use of transmitted sound to detect fish. Sound travels quickly and efficiently through water and reflects from fish and other organisms in the water. The returning echoes contain information on fish size, distribution, and abundance (MacLennan, 1990; Smith, et al , 1992).

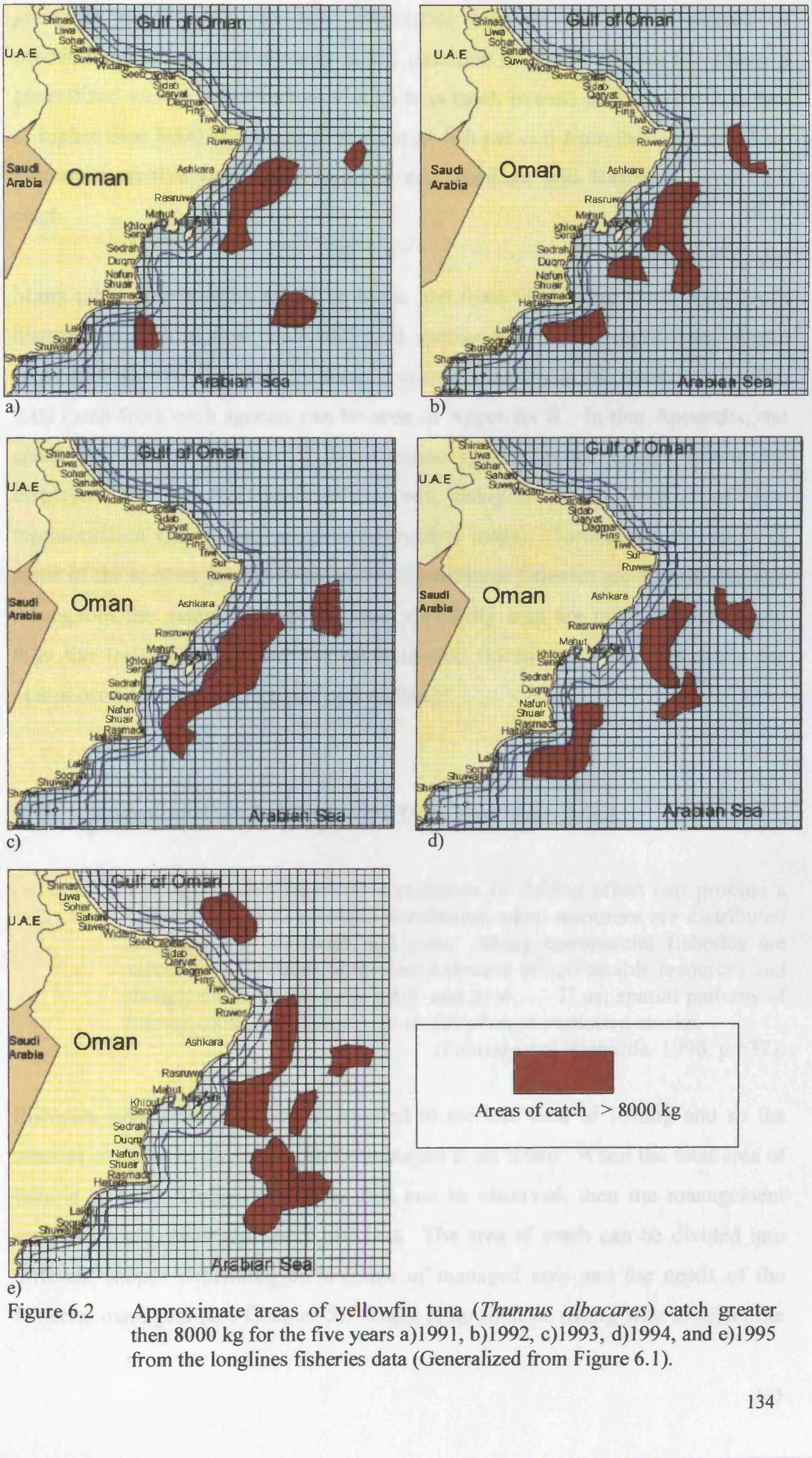


Figure 6.2 Approximate areas of yellowfin tuna (*Thunnus albacares*) catch greater then 8000 kg for the five years a)1991, b)1992, c)1993, d)1994, and e)1995 from the longlines fisheries data (Generalized from Figure 6.1).

The principal observation t be made from Figure 6.1 is that the large amount of yellowfin tuna caught by the commercial longline vessels, is located or concentrated at the southern part of the coastline of 'Sur '. Figure 6.2 shows a generalized view for those areas of high tuna catch in each year (the catch is that of higher then 8000 kilograms (8 tonnes) of fish per cell from the longlines data. Almost in all five years the area at the east 'Ashkara' and 'Rasruwes' is of high catch.

Many other observations might be made just from visualizing the species catch distribution such as how many different species have been caught from certain areas and whether the same patterns occurred annually in the same areas. The total catch from each species can be seen in Appendix B. In that Appendix, the catch distribution of some of the common species in the Omani waters are displayed for the five years of records, using a similar method of data representation (grids and proportional symbol maps). Notice that the areas of some of the species caught by trawler and traditional fisheries are almost identical throughout the years. Pelagic fish and especially tuna are migrant species and thus the indication of their annual existence (locations) gives less basis for comparison to those of demersal and shellfish.

4.2 Mapping Catch Per Unit Effort Per Unit Area

> The spatial and temporal distribution of fishing effort can provide a valuable index of resource distribution when resources are distributed non-randomly in space and time. Many commercial fisheries are successfully because of the concentration of harvestable resources and fishing effort in the same place and time.... Thus, spatial patterns of fishing effort can indicate the distribution of exploited stocks.
>
> (Fabrizio and Richards, 1996, p 637)

Fisheries management is usually applied to the unit area of fishing and so the amount of effort on that area can be managed at all times. When the total area of fishing is divided into small areas that can be observed, then the management issue becomes easier and more efficient. The area of catch can be divided into different shapes depending on the size of managed area and the needs of the fisheries managers (see Chapter 5). There is no right or wrong way to select the size of areas. The selection of cell size is based on the requirement of the fisheries management authorities in Oman as smaller unit can give more information.

Figure 6.3 shows a visual relationship between total longtail tuna (*Thunnus tonggol*) catch and total effort (fishing trips) of 1991 by the traditional fishery, whereas Figure 6.4a-e shows the catch per unit effort (fishing trip) per area of the same species for the period of five years (1991-1995) from a selected area at the northern part of the coastline of Oman. Longtail tuna species are usually caught by the traditional fisheries.

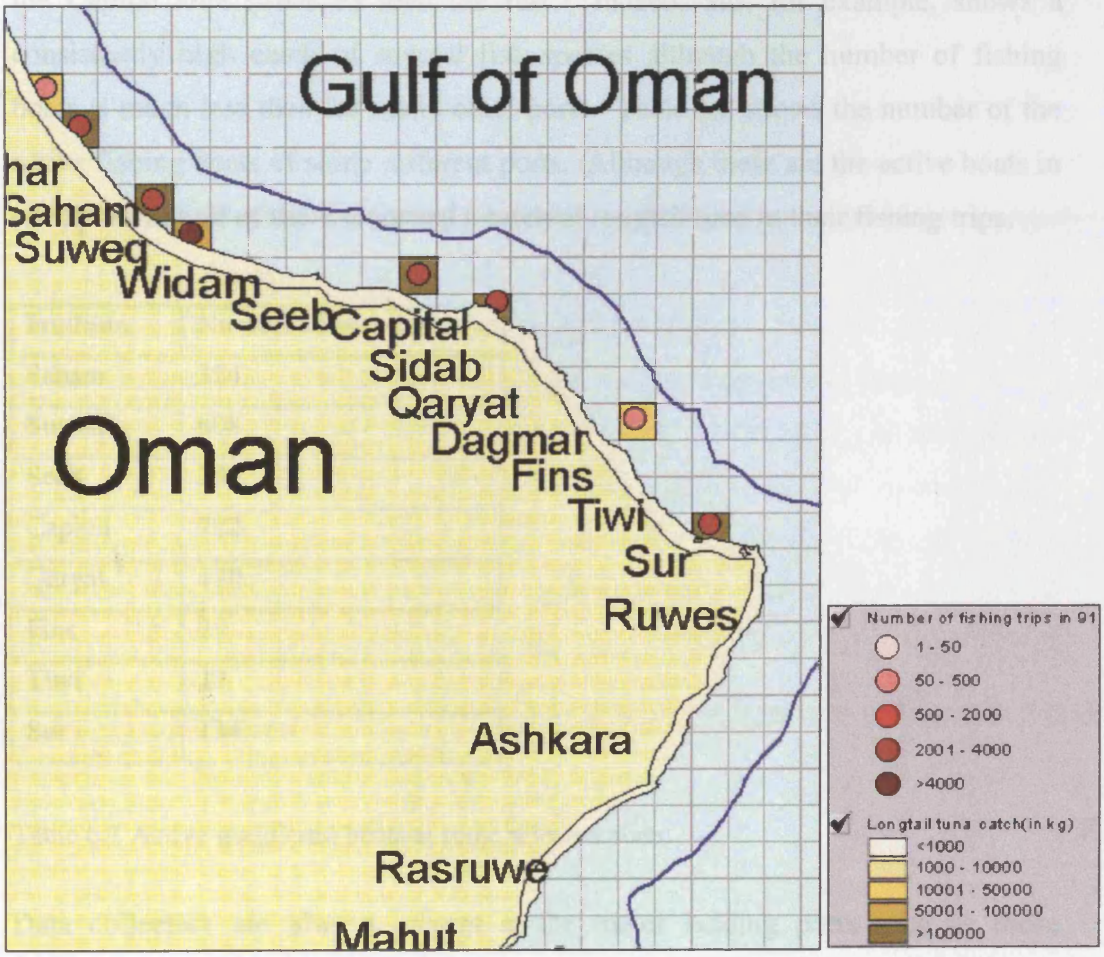


Figure 6.3 Total longtail tuna (*Thunnus tonggol*) catch (in kg) of 1991 per effort (fishing trips) per unit area (10*10 miles) by the traditional fisheries.

Several management practices depend on the knowledge of catch per unit effort per unit area, such as controlling the annual amount of catch from each area by controlling the amount of effort to the level where catch can remain sustainable over the years and avoid stock damage. Limiting the amount of catch to that level can be achieved by controlling factors such as the number of fishing boats and/or fishing trips. However, for the period of study, traditional fishing boats and, supposedly, the number of fishing days are consistent since no new developments or regulations have been imposed on the sector, and only one census has been conducted.

Several observations can be made from figure 6.4. In terms of catch per unit effort, there was a consistently high catch for little effort near the port of 'Sur' in almost all years. On the other hand, areas near 'Capital' and on the northern part of the coastline show a low annual catch although the number of boats is larger in the Capital area (Muscat) than the rest. Indeed, Sur, for example, shows a consistently high catch of several fish species although the number of fishing boats is much less then for many other ports. Table 6.2 shows the number of the active fishing boats of some different ports. Although these are the active boats in each port, not all of them recorded a catch of longtail tuna in their fishing trips.

Port/Site	Number of active boats
Saham	324
Suweq	608
Seeb	289
Capital	722
Qaryat	149
Fins	29
Tiwi	17
Sur	134

Table 6.2 Active traditional boats at some selected ports.

Data collectors are always present at the major landing ports such as those mentioned above. However, it can be seen from Figure 6.4 c and e, for 1993 and 1995 respectively, that there are some new areas to the south of 'Sur' which appear to have only one catch record each. The reason for this is that the data were collected from the two ports only for those two years. The locations of the two ports are found to be at the end of a desert area, and far from the residential area and only few boats were recorded there. From the fisheries management point of view, these areas should be investigated further and should go under a development program, as there might be a potential of high catch. This is especially the case for the southernmost area of catch in 1993 where catch per unit effort is noticeably high. Although the catch per unit area at these ports is sometimes less than for those of major ones, the catch per unit effort is sometimes higher, which certainly indicates a potential of high catch if effort increases. These areas too, from the government point of view, are appropriate to introduce new boats and so new employment. According to Fabrizio and Richard (1996) the patterns of fishing effort indicates the distribution of fish stock. From the fishery biologist's point of view, the catch of longtail tuna found at Sur, for example, may indicate a major stock, and since there are some indications of the possibility of that stock extending further to the south, this may be the edge of a large longtail tuna biomass.

The government believes that the catch from the traditional fisheries, although it is changeable at different locations throughout the years, remains at the same manageable level and that the fish stock allocated for traditional fisheries are in no danger of collapse or damage in the future. Several fisheries biological studies have indicated that although the catch is very high from several areas in Omani coastal waters, the fish biomass in total are in no danger from collapse (Oman Fisheries Report, 1995). Others have gone even further to say that, even with this amount of catch less then 60% of total fish stocks are being exploited (Oman, 1996). However, there is no recent study to prove such. GIS can help to understand the fluctuation of catch per each cell of the traditional fishery instead of taking total catch as an indication of any increase or decrease in catch.

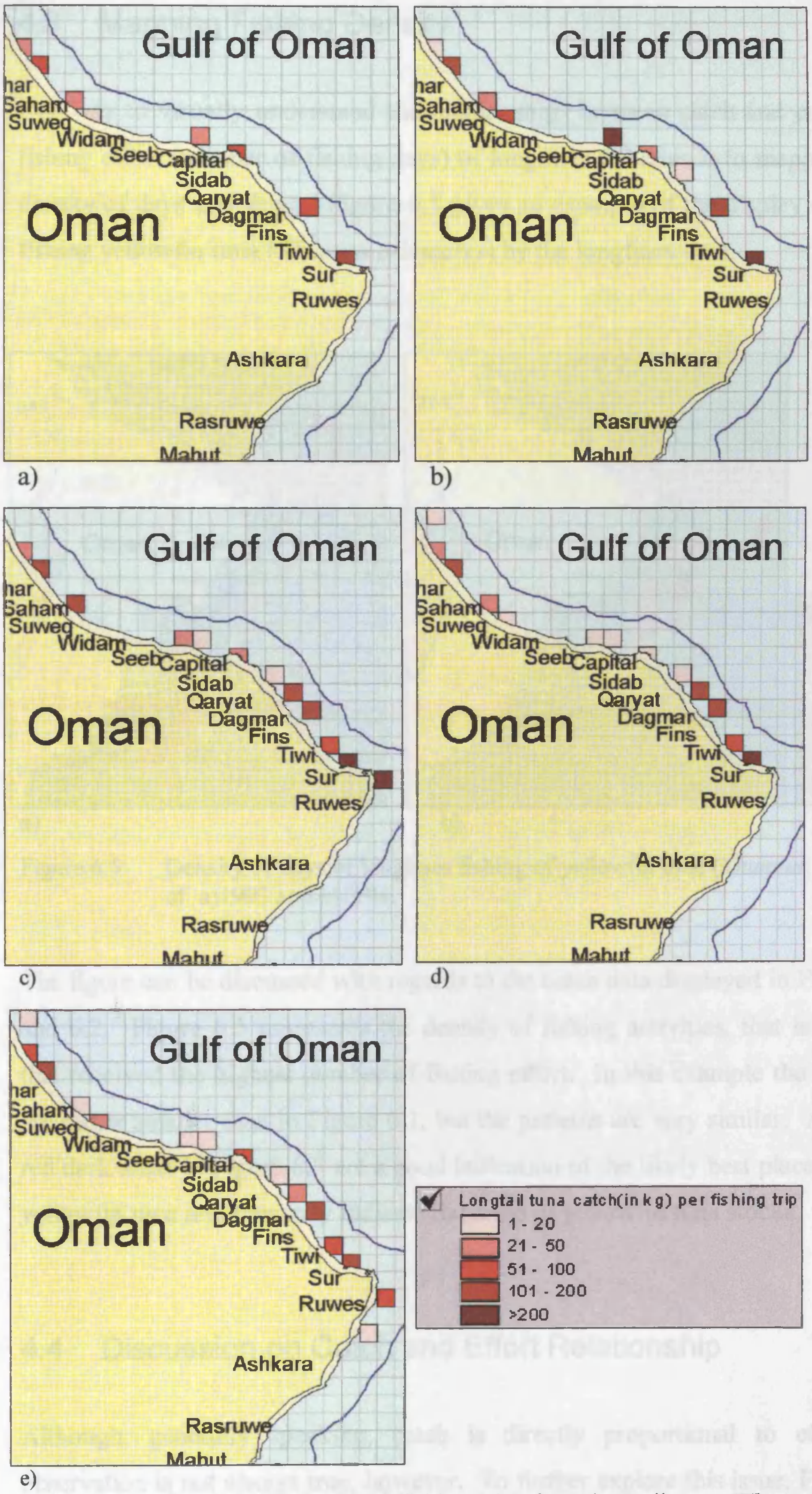
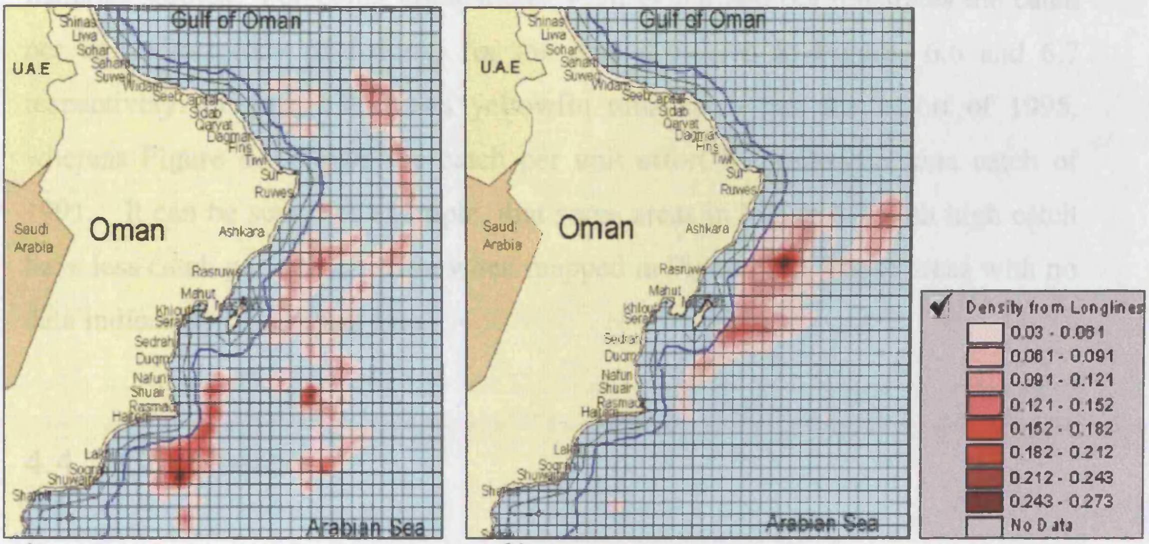


Figure 6.4 Catch per unit effort (fishing trip) from longtail tuna (*Thunnus tonggol*) catch (in kg) from the traditional catch of years a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995. The figure shows on average a consistent amount of catch during the five years period.

4.3 Mapping Fishing Density

One way to visually understand the relationships between catch and commercial fishing effort (number of fishing days) of longlines fisheries is to mapp the point density of days of fishing. Figure 6.5 gives an example of the display of days of fishing yellowfin tuna (*Thunnus albacares*) by the longlines fleet.



a) b)

Figure 6.5 Density of days of longlines fishing of yellowfin tuna (*Thunnus albacares*) of a)1993 and b)1994.

The figure can be discussed with regards to the catch data displayed in Figures 6.1 and 6.2. Figure 6.5 represents the density of fishing activities, that is the areas that received the highest number of fishing effort. In this example the grid sizes are rather smaller than in Figure 6.1, but the patterns are very similar. Again, the red dark areas in Figure 6.5 are a good indication of the likely best places to catch yellowfin tuna and thus may indicate the areas of yellowfin tuna stocks.

4.4 Discussion on Catch and Effort Relationship

Although, generally speaking, catch is directly proportional to effort, this observation is not always true, however. To further explore this issue, Figure 6.6, displays the yellowfin tuna caught by the longlines in 1995 from a selected area to the south of the country. The grid shows the amount of tuna catch whereas the each red dot indicates 10 days of fishing. Again, from this picture the straight conclusion is that there is more fish when there is more fishing effort. Figure 6.7 (of yellowfin tuna catch by the longlines in 1991), however, suggests a different observation. Each dot in this figure is equal to 20 days of fishing. From the figure, it is clear that some areas of high catch have had less then 20 days of fishing, and some with 20 days or more had little catch record associated with it. Mapping catch per effort gives a more precise view of the possible distribution of stocks and the method of calculating catch per effort has been widely used by fisheries studies. For better comparison, Figures 6.8 and 6.9 illustrates the catch per unit effort (day of fishing) for the data displayed in Figures 6.6 and 6.7 respectively. Figure 6.8 shows yellowfin tuna catch per unit effort of 1995, whereas Figure 6.9 shows the catch per unit effort for yellowfin tuna catch of 1991. It can be seen, for example, that some areas in Figure 6.7 with high catch have less catch per unit effort in when mapped in Figure 6.9. Those areas with no data indicates no recorded data.

4.4 Conclusion

So far the discussion has mainly focused on GIS data display and visualization. As mentioned before, although none of the advanced analysis operations have been used, the GIS ability of displaying geo-referenced data of total catch distribution and catch per unit effort per unit area are crucial, especially in a country like Oman, where, at the top management and decision making level, the visual data can be of great assistance. However, the approach discussed in this section does not identify those areas of 'preferred fishing'. Further analysis of interaction between catch and effort (fishing days) is included in rest of the chapter.

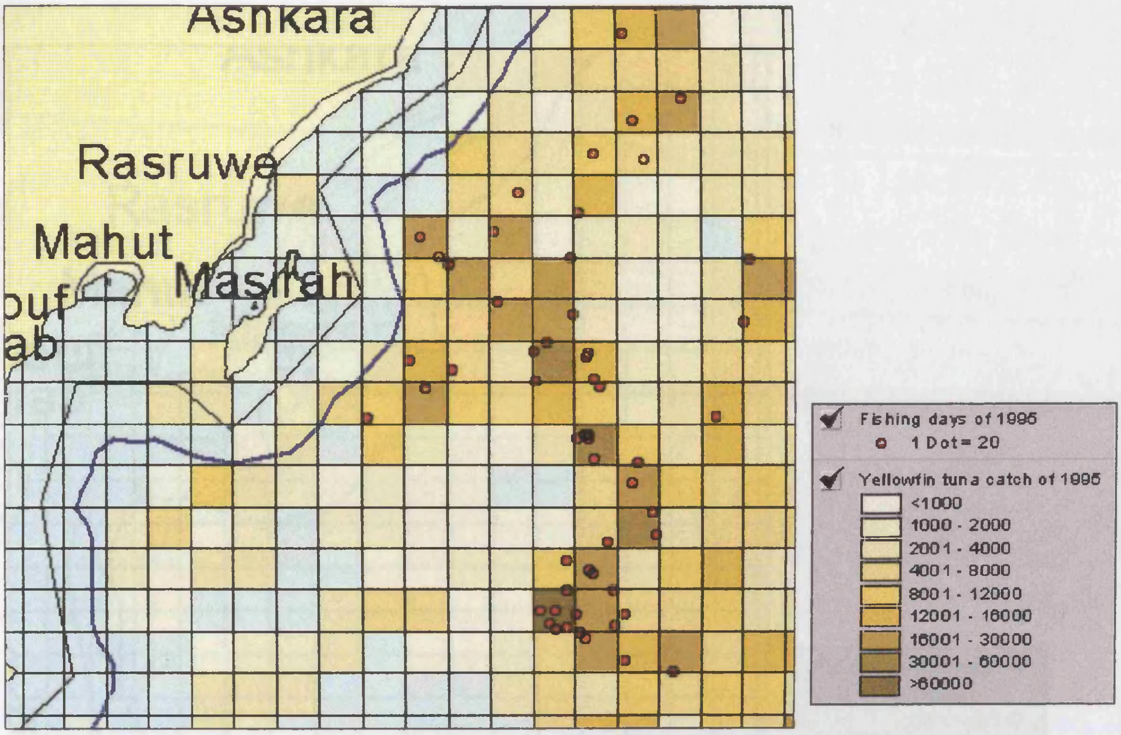


Figure 6.6 Catch and effort relationship from yellowfin tuna (*Thunnus albacares*) catch (in kg) by the longlines fishing of 1995 (at southern part of the country). The blue areas indicate no recorded data.

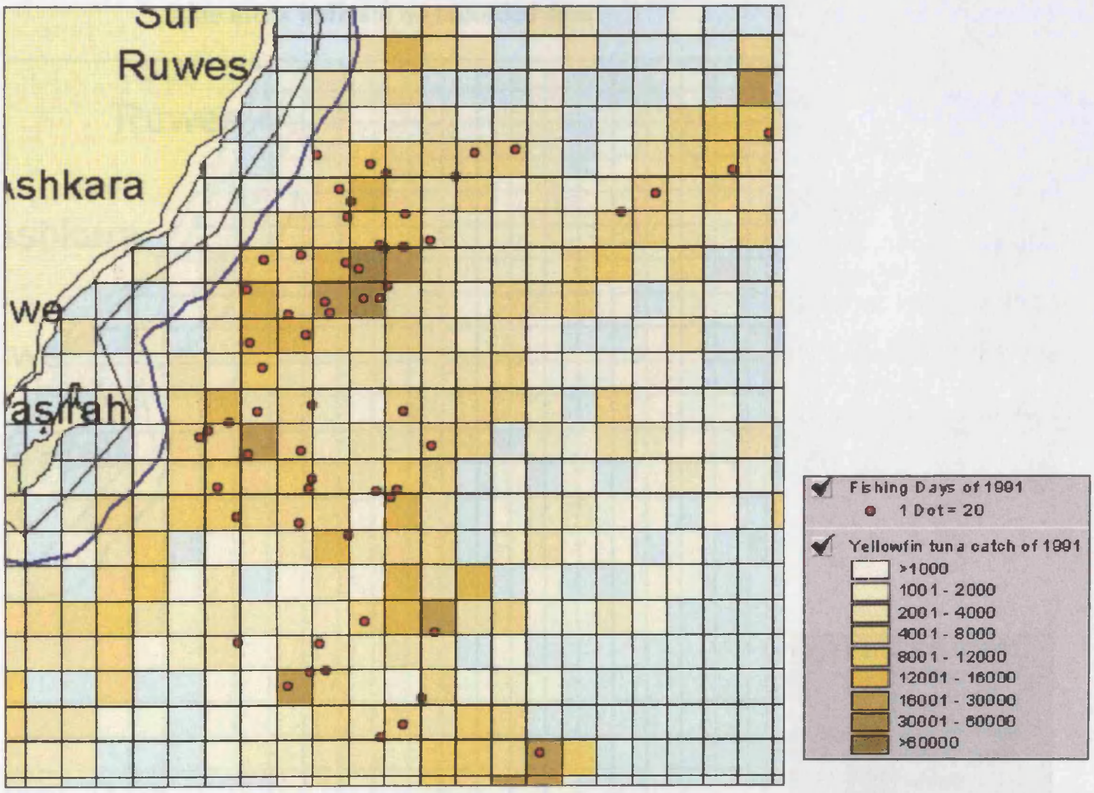


Figure 6.7 Catch and effort relationship from yellowfin tuna (*Thunnus albacares*) catch (in kg) by the longlines fishing of 1991 (at southern part of the country). The figure emphasis on the idea that not all areas of high effort necessarily produce high catch. The blue areas indicate no recorded data.

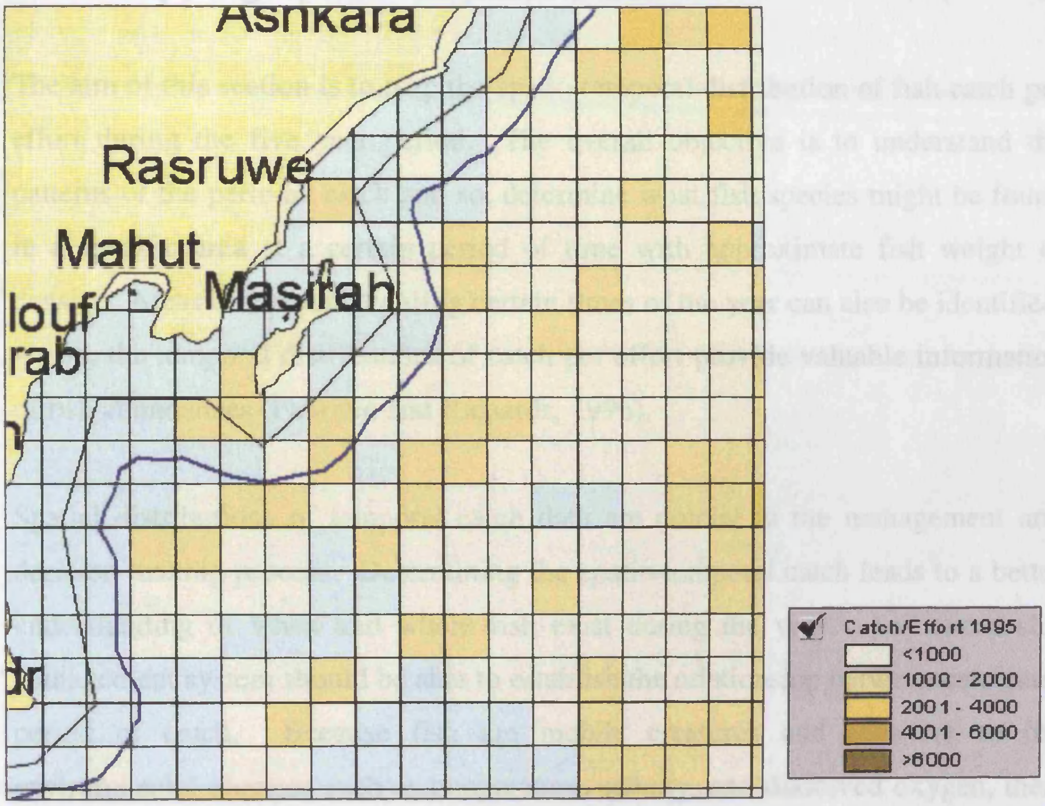


Figure 6.8 Catch per unit effort (fishing day) for the data displayed in Figure 6.6. The blue areas indicate no recorded data.

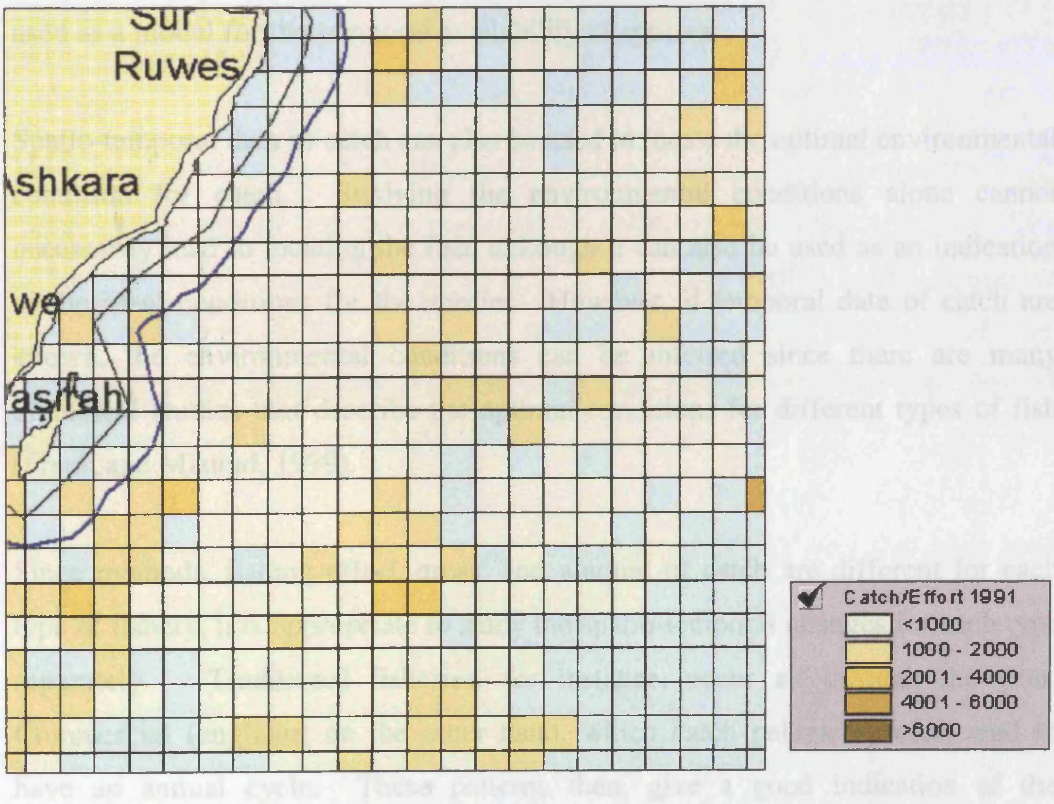


Figure 6.9 Catch per unit effort (fishing day) for the data displayed in Figure 6.7. The blue areas indicate no recorded data.

5. Mapping Spatio-temporal Catch

The aim of this section is to map the spatio-temporal distribution of fish catch per effort during the five year period. The overall objective is to understand the patterns of the periodic catch and so, determine what fish species might be found in a specific area at a certain period of time with approximate fish weight or density. Areas of low catch during certain times of the year can also be identified. Again, the temporal distributions of catch per effort provide valuable information of fish abundances (Fabrizio and Richards, 1996).

Spatial distributions of temporal catch data are crucial to the management and decision making process. Determining the spatio-temporal catch leads to a better understanding of when and where fish exist during the year. Any successful management system should be able to establish the relationship between catch and period of catch. Because fish are mobile creatures and sensitive to the environmental changes such as temperature, salinity, and dissolved oxygen, their spatial distribution can be expected to fluctuate as do these parameters predictably within the year, with some degree of prediction. These patterns could then be used as a model for the temporal availability of species.

Spatio-temporal data of catch can also be used to locate the optimal environmental condition for catch. Studying the environmental conditions alone cannot necessarily lead to locating the fish, although it can also be used as an indication of the ideal conditions for the species. However, if temporal data of catch are known, the environmental conditions can be inferred since there are many biological studies that describe the optimal conditions for different types of fish (Freon and Misund, 1999).

Since methods, fishing effort, areas, and amount of catch are different for each type of fishery, it is appropriate to study the spatio-temporal changes for each type separately. Traditional fisheries, for instance, occur all through the year. Commercial longlines, on the other hand, which catch pelagic species, tend to have an annual cycle. These patterns then, give a good indication of the movement of fish or stocks throughout the fishing season as long as there is fishing activity. In addition, since longlines target and follow the species, general movement of species can be determined, and in some cases it can be modeled to be used as a guide for any new fishing regulations. It can certainly be used from the commercial point of view to guide any new commercial fishing vessels that have just begun fishing in the area.

5.1 Traditional Temporal Catch

Traditional fishermen are active at all times of the year since fish is the only source of income for the individuals and family. Figures 6.10 a-d, through Figures 6.14 a-d, present the catch per unit effort (fishing trip) of quarterly catch of kingfish or Spanish mackerel (*Scomberomorus commerson*) for the years 1991-1995. Kingfish, especially for its high sale value for local consumption and markets, is caught almost every month of the season at several locations.

In Oman, the summer season starts during May or June and ends by September, with the temperature rising to over 32 °C in some places, but the fishermen still go to sea, although the amount of catch is usually less during the summer. The decline in catch seems to be due to the high temperature and fish migrations (Al-Abdessalaam, 1995).

The areas of high catch of kingfish are always similar throughout the year, although it is clearly is more concentrated in the north part of the coastline. One of the conclusions to be mentioned here is that there are no really distinctive temporal patterns of catch or temporal areas for the traditional fisheries, although in general, catch during cooler months (winter and spring) are higher then those of warmer ones (summer and autumn).

In general, with the study of the efforts (number of fishing trips that have been made per quarter (Figure 6.15)), applied to the area of catch per quarter the pattern from the traditional fisheries can be summarized as follows:

1. A large density of catch exists mainly in the Gulf of Oman (north of Sur).
2. The catch is less during the third quarter of the year (Figure 6.16 shows the quarterly total catch of kingfish species by the traditional fishery).

3. In general, the catch of kingfish seems to improve during the period of the last two years (1994-1995) and less during the first three years (1991-1993) due to the less effort that has been applied.

Fishing trips ranged from between 2640 to 6270 fishing trips per quarter, and have caught kingfish, with more total effort occurring between October and March each year. Its presence during this period is probably related to feeding rather than spawning (Oman Fishery, 1995). On the other hand, the appearance of kingfish in large numbers during the first and the last quarter of the year coincides with the abundance of small pelagic fishes, particularly sardine (see Appendix B) and anchovies (since kingfish is mainly piscivorous feeding on the other fishes (Al-Abdessalaam, 1995)).

The information displayed in Figures 6.10 to 6.14 and in Figure 6.16 confirmed some observations mentioned by Al-abdessalaam (1995) and the Oman Fisheries Report (1995) of the migration periods of kingfish. There are apparently two migrations of kingfish in Omani waters. The first migration commences at the end of February, lasts for two months (March and April), and appears to originate from the eastern part of the Arabian Sea and heads to the north towards the Parisian Gulf. This migration is probably associated with spawning (Alharthy, 1994). The second migration, which lasts longer than the first, occurs towards the end of August and lasts through to the end of October. The fish are certainly absent from the Arabian Sea catch during July-August in all years, although the catch in the Persian Gulf is unaffected.

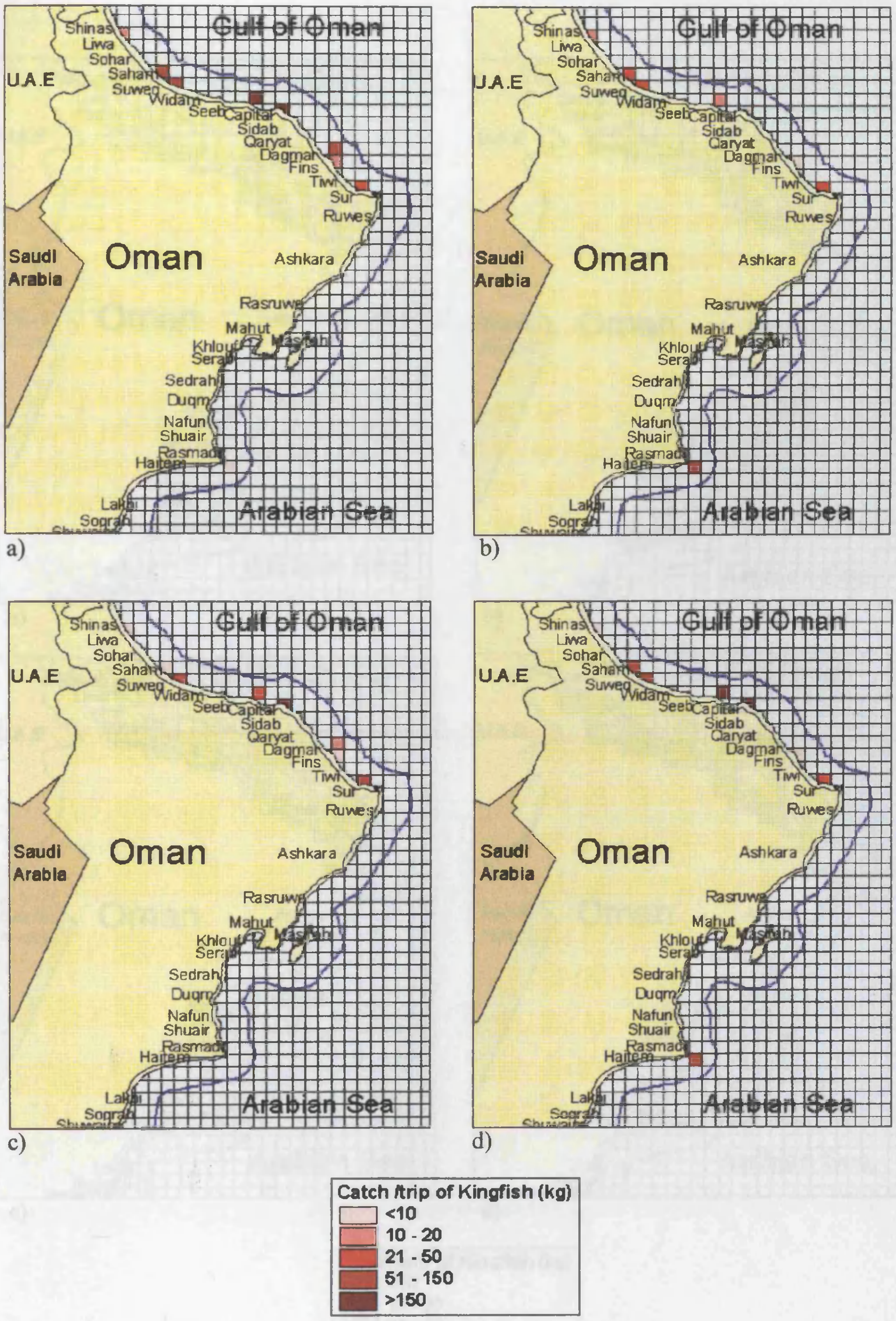


Figure 6.10 Spatiotemporal catch per effort of kingfish (*Scomberomorus commerson*) species of traditional fisheries catch during 1991 a) January to March, b) April to June, c) July to August, and d) September to December.

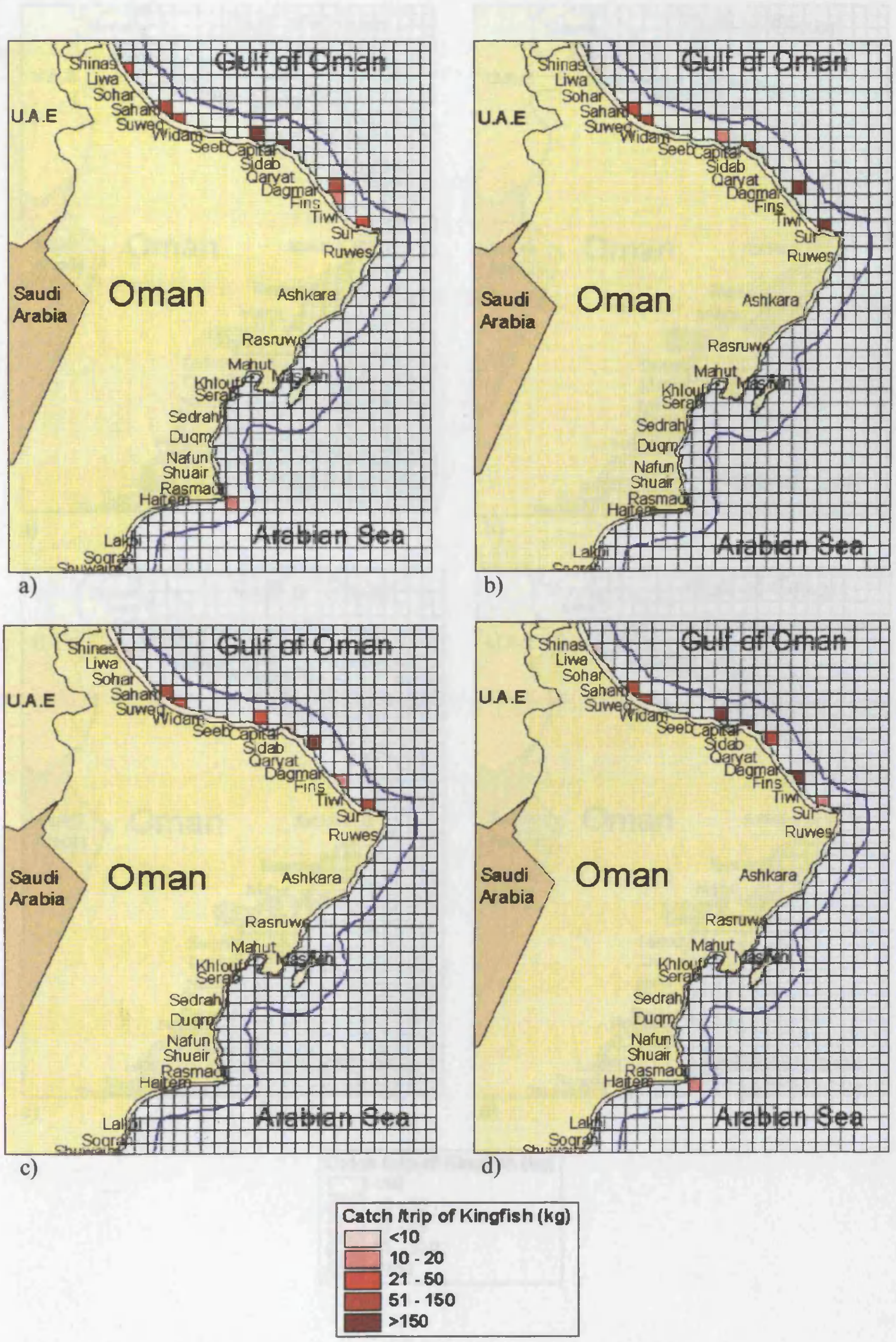


Figure 6.11 Spatiotemporal catch per effort of kingfish (*Scomberomorus commerson*) species of traditional fisheries catch during 1992 a) January to March, b) April to June, c) July to August, and d) September to December.

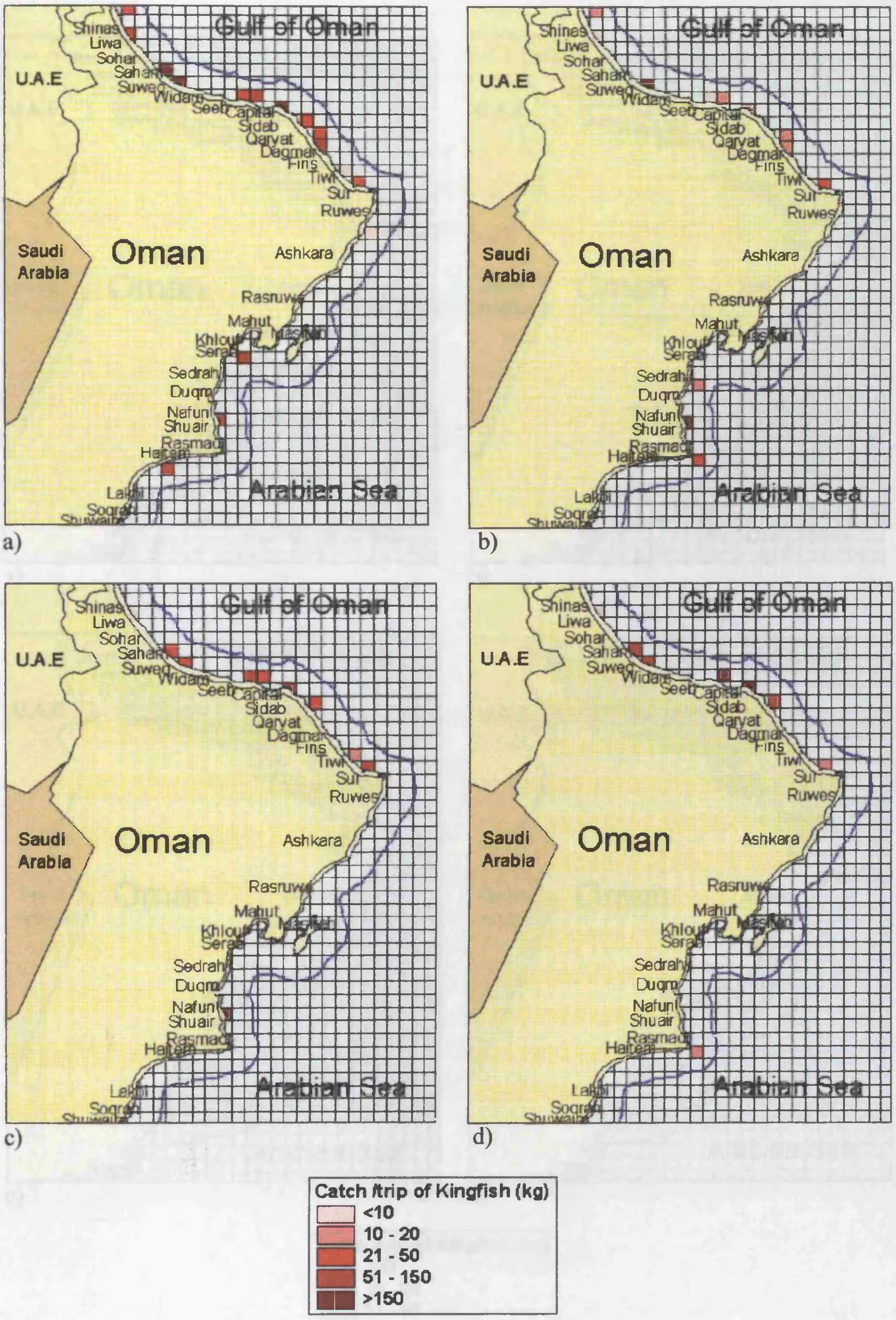


Figure 6.12 Spatiotemporal catch per effort of kingfish (*Scomberomorus commerson*) species of traditional fisheries catch during 1993 a) January to March, b) April to June, c) July to August, and d) September to December.

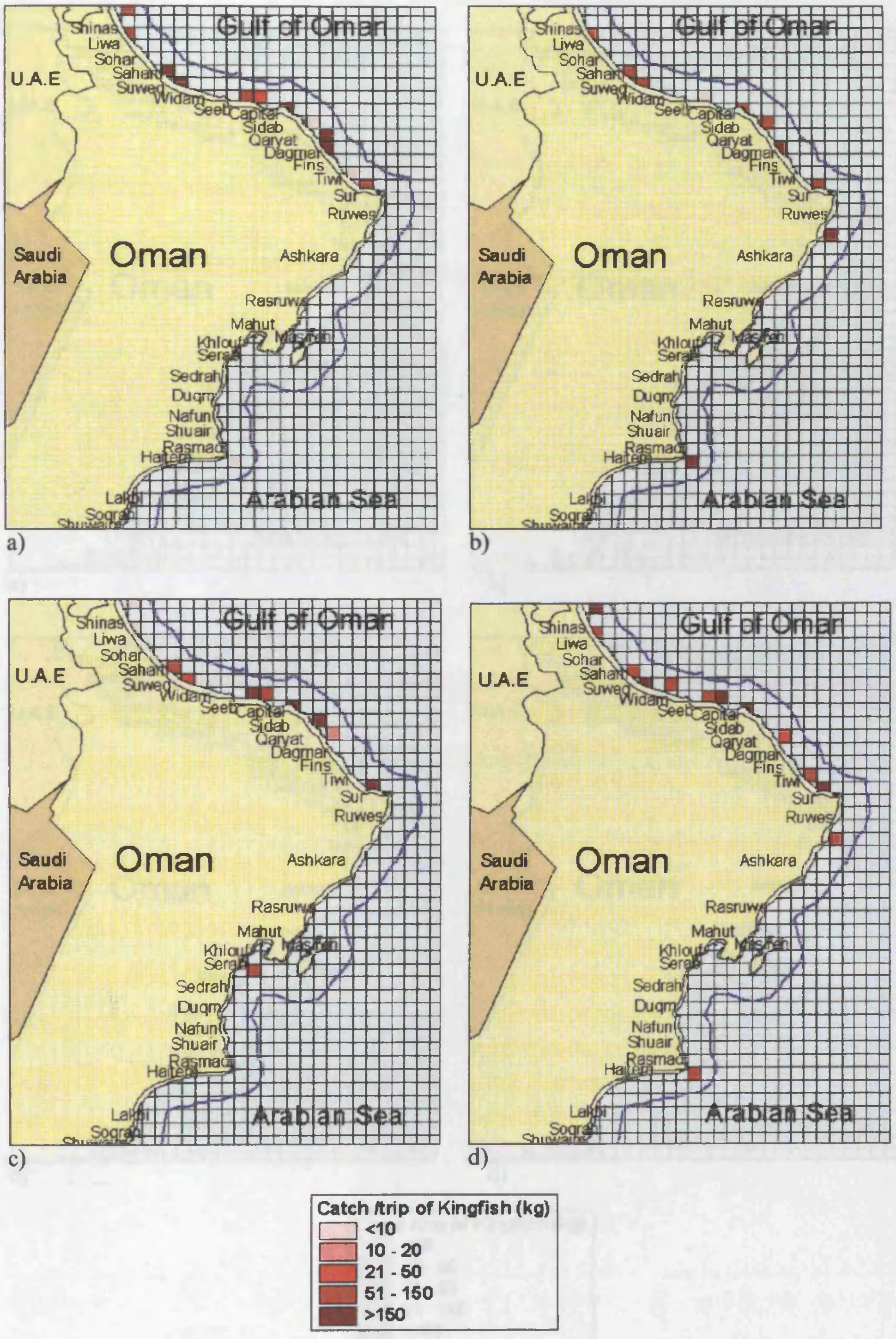


Figure 6.13 Spatiotemporal catch per effort of kingfish (*Scomberomorus commerson*) species of traditional fisheries catch during 1994 a) January to March, b) April to June, c) July to August, and d) September to December.

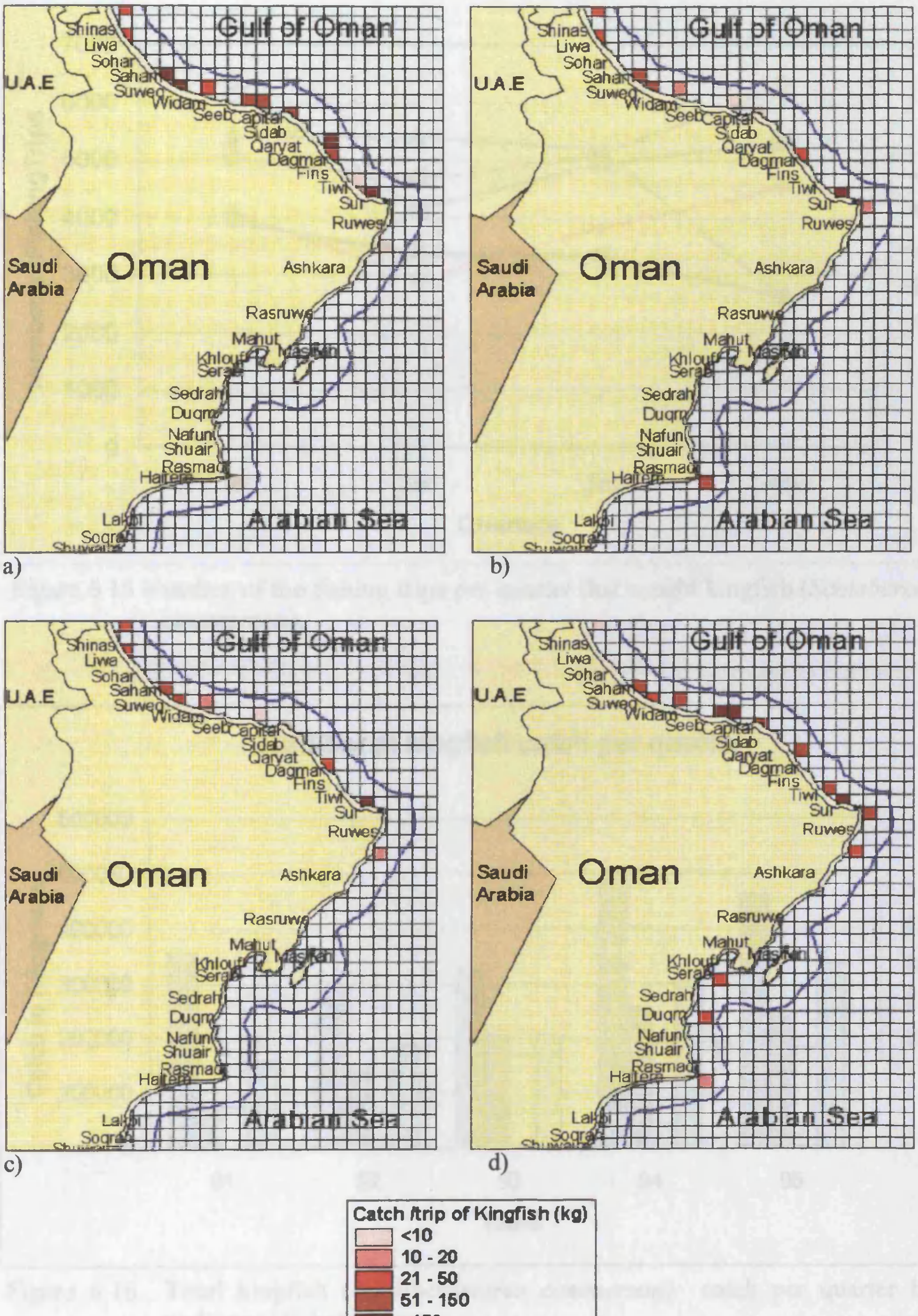


Figure 6.14 Spatiotemporal catch per effort of kingfish (*Scomberomorus commerson*) species of traditional fisheries catch during 1995 a) January to March, b) April to June, c) July to August, and d) September to December.

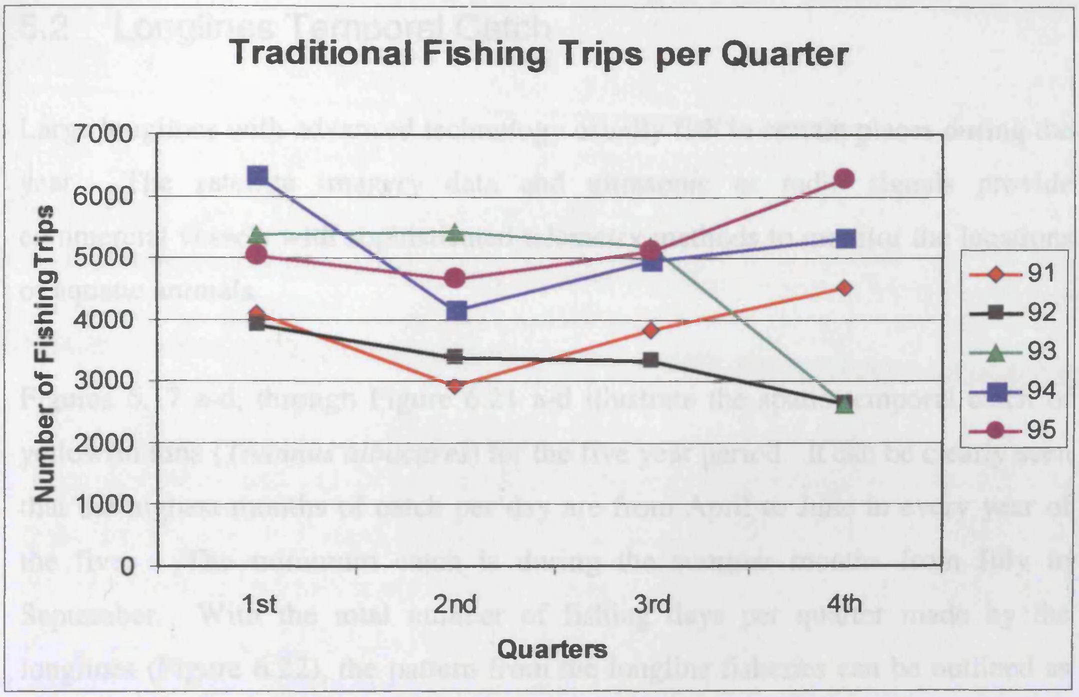


Figure 6.15 Number of the fishing trips per quarter that caught kingfish (*Scomberomorus commerson*).

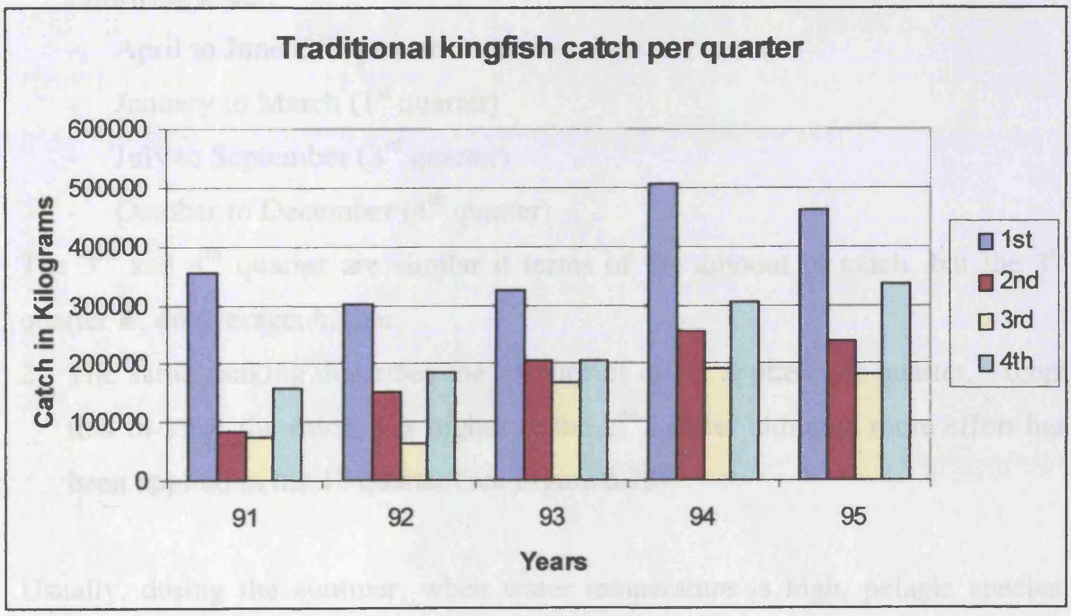


Figure 6.16 Total kingfish (*Scomberomorus commerson*) catch per quarter by the traditional fishery.

From Figure 6.15, less effort is recorded in 1991 and 1992. The increased demand for kingfish is evidenced by the increase in effort in the following years (Oman Fisheries Report, 1995). The strong decline in the effort recorded in the last quarter of 1993 and 1992 is anomalous since no changes have been introduced to the traditional fisheries sector.

5.2 Longlines Temporal Catch

Large longlines with advanced technology usually fish in certain places during the year. The satellite imagery data and ultrasonic or radio signals provide commercial vessels with sophisticated telemetry methods to monitor the locations of aquatic animals.

Figures 6.17 a-d, through Figure 6.21 a-d illustrate the spatio-temporal catch of yellowfin tuna (*Thunnus albacares*) for the five year period. It can be clearly seen that the highest months of catch per day are from April to June in every year of the five. The minimum catch is during the summer months from July to September. With the total number of fishing days per quarter made by the longlines (Figure 6.22), the pattern from the longline fisheries can be outlined as follows:

1. Quarters can be ranked from high to low in terms of catch per day in the following order:
   - April to June (2nd quarter)
   - January to March (1st quarter)
   - July to September (3rd quarter)
   - October to December (4th quarter)

The 3rd and 4th quarter are similar it terms of the amount of catch, but the 3rd quarter is, on average, higher.

2. The same ranking describes the amount of effort applied per quarter, except that in 1994 the catch was higher in the 2nd quarter although more effort has been applied in the 1st quarter (see Figure 6.22).

Usually, during the summer, when water temperature is high, pelagic species, such as yellowfin tuna, migrate to cooler water, probably towards the east of the Indian Ocean, and thus less fish are likely to be available to be caught. This may explain the reason for the decline in effort during the 3rd quarter. Yellowfin tuna survive at sea water temperatures between 24-30 °C, and most pelagic fish are able to detect temperature, which allows them to locate areas more favorable to their metabolism. The decline in catch and effort in the 4th quarter may be explained by the quota system. They appear mainly to concentrate their effort early in the year (1st or 2nd quarter) and to catch the authorized amount then (see section 6).

Catch per fishing days can help in understanding the density of fishing activity applied to yellowfin tuna. As mentioned before, since the longlines tends to target a particular location, the density of fishing effort could be directly proportional to yellowfin tuna biomass. Figure 6.23 shows the average catch per day of fishing per quarter.

In general, the catch per day from the 2nd quarter is highest. The catch per day from the 3rd quarter in most years was higher than the 1st quarter. This suggests that the longlines vessels tends to be active at certain time of the year where catch is expected to be high, and so fulfilling the authorized quota at that time.

It can also be seen that the area of high catch appears to be in the southern part of Omani waters, south of Sur. Although some high catch areas occasionally appear to the north they are relatively few and inconsistent. It can be concluded there is always a larger chance of catching yellowfin tuna in the Arabian Sea during April to June, but the catch between September and December is likely to be small.

The average catch per unit day for the 2nd quarter has been increasing between 1991 and 1993 where it reached its peak value of 1377 kg per day (Figure 6.23). This has declined in the following two years with an increase in effort during 1st and 4th quarters. The decline in catch per day during 1994 and 1995 during the 2nd quarter might be an indication of total biomass decline of the yellowfin tuna. This can be concluded by comparison with Figure 6.22 where effort has reached its peak value during the 2nd quarter of 1995, and the same can be said about 1994. With continuing high levels of effort and catch in the 2nd quarter (which, from Figure 6.22 seems very likely) it is possible that there will be a further decline in the future. This should be considered as vital for the future of species stocks, and should be treated with great concern by the fisheries managers. The amount of effort should be monitored during the 2nd quarter of the year, and periods of longlines fishing should be rescheduled if level of catch start to decrease then. This should be done in order to provide a more balanced catch to protect the total fish biomass from overfishing or damage.

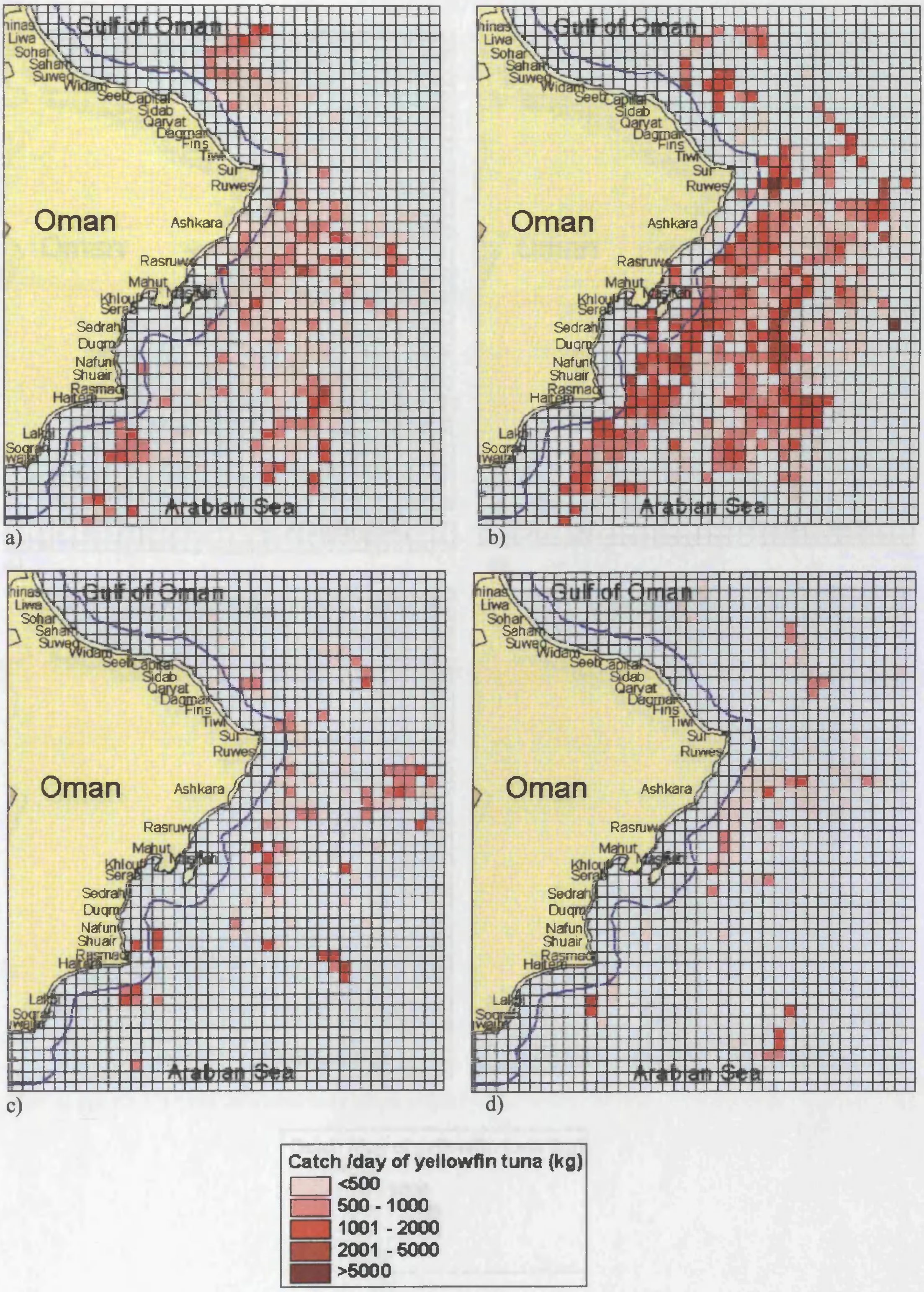


Figure 6.17 Spatio-temporal catch per effort of yellowfin tuna (Thunnus albacares) species of the commercial longline fisheries catch during 1991 a) January to March, b) April to June, c) July to August, and d) September to December.

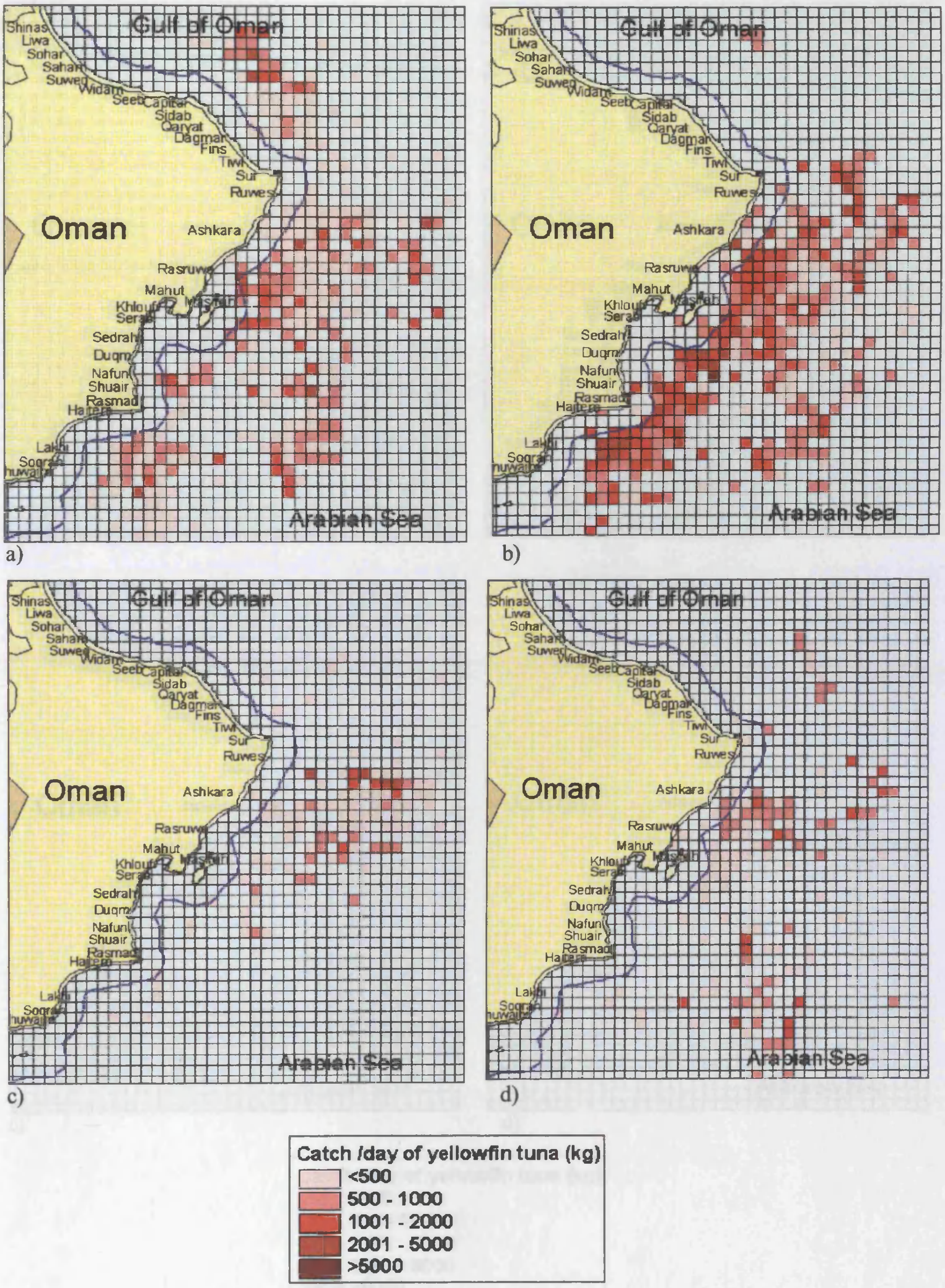


Figure 6.18 Spatio-temporal catch per effort of yellowfin tuna (*Thunnus albacares*) species of the commercial longline fisheries catch during 1992 a) January to March, b) April to June, c) July to August, and d) September to December.

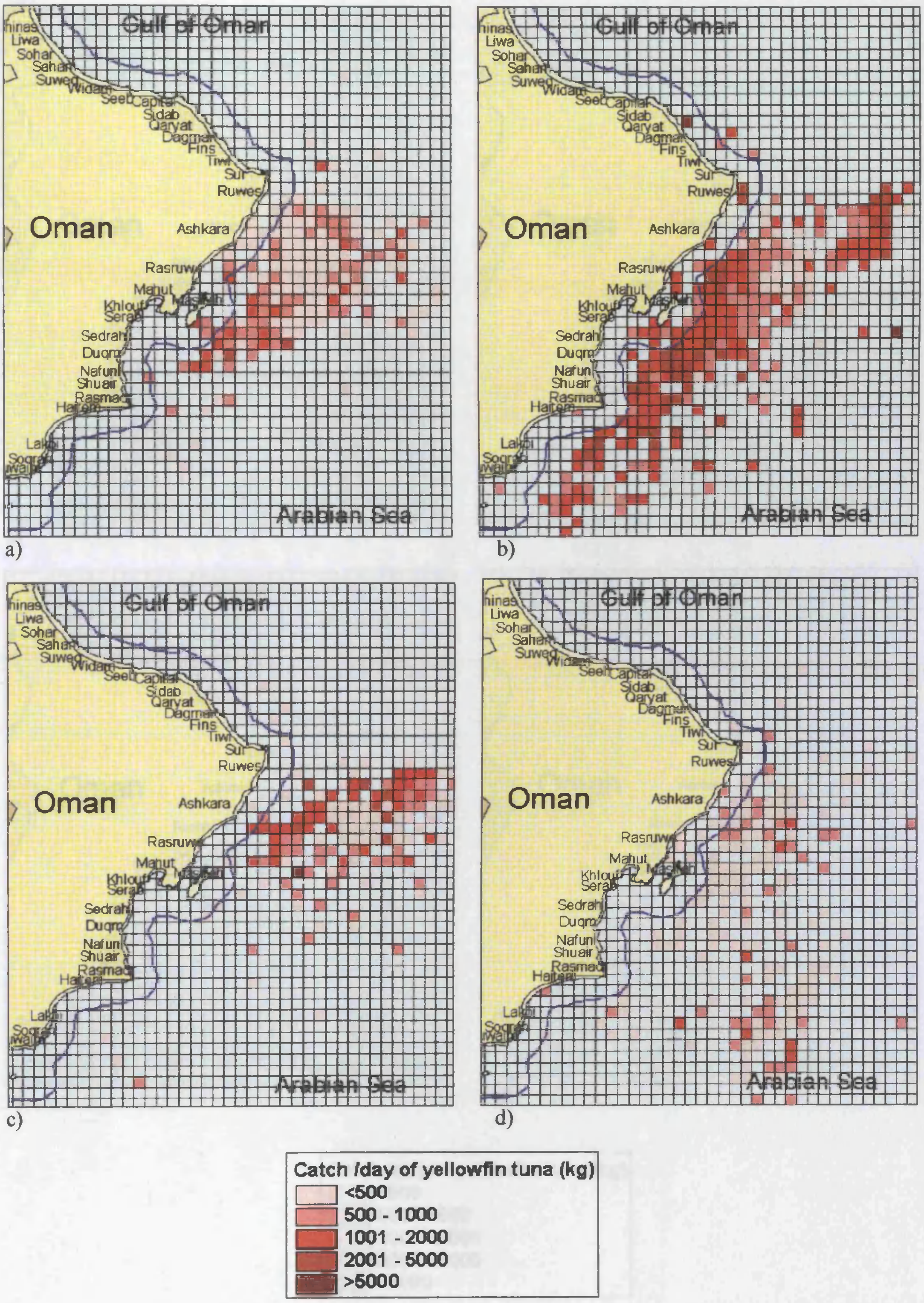


Figure 6.19 Spatio-temporal catch per effort of yellowfin tuna (*Thunnus albacares*) species of the commercial longline fisheries catch during 1993 a) January to March, b) April to June, c) July to August, and d) September to December.

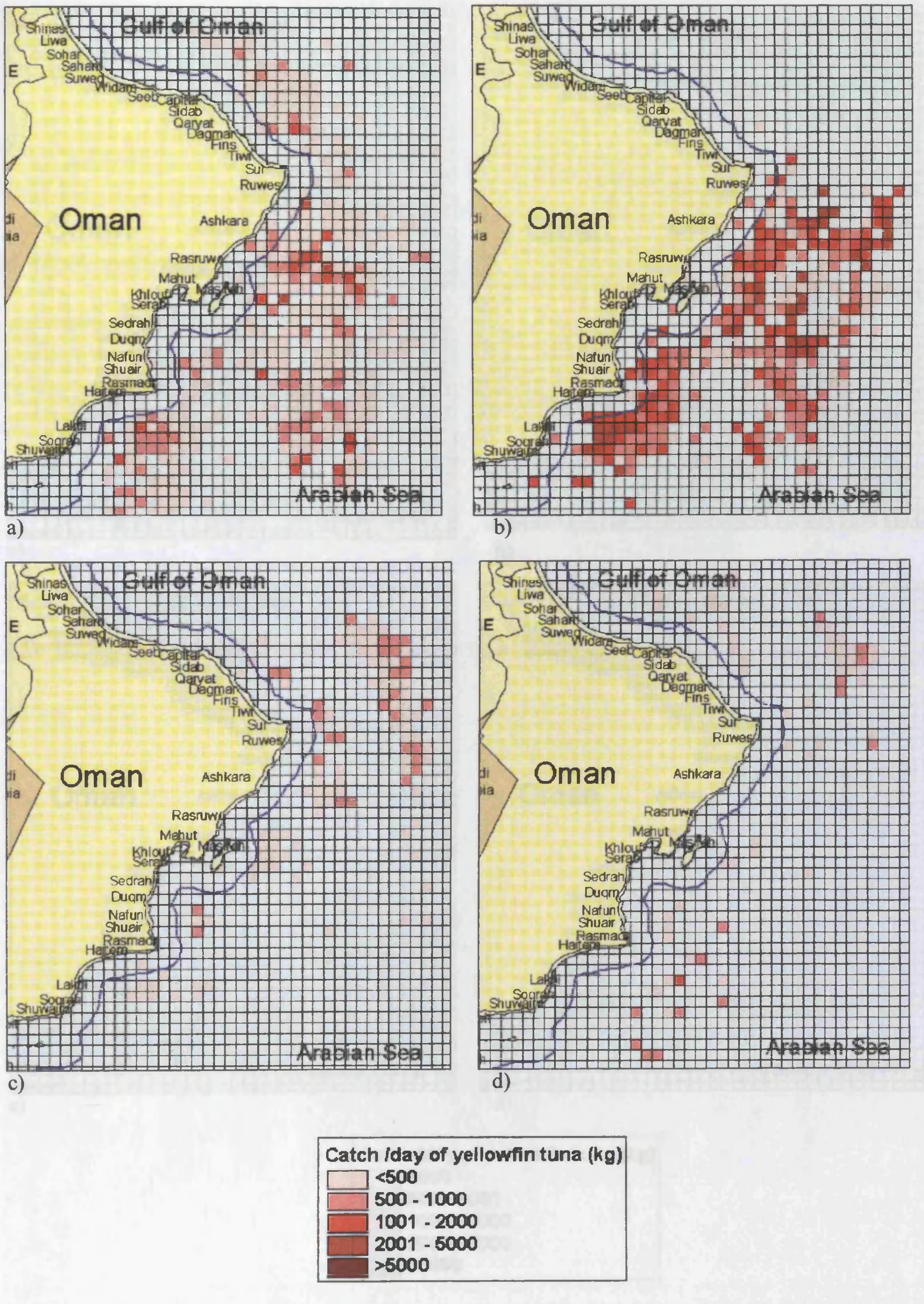


Figure 6.20 Spatio-temporal catch per effort of yellowfin tuna (*Thunnus albacares*) species of the commercial longline fisheries catch during 1994 a) January to March, b) April to June, c) July to August, and d) September to December.

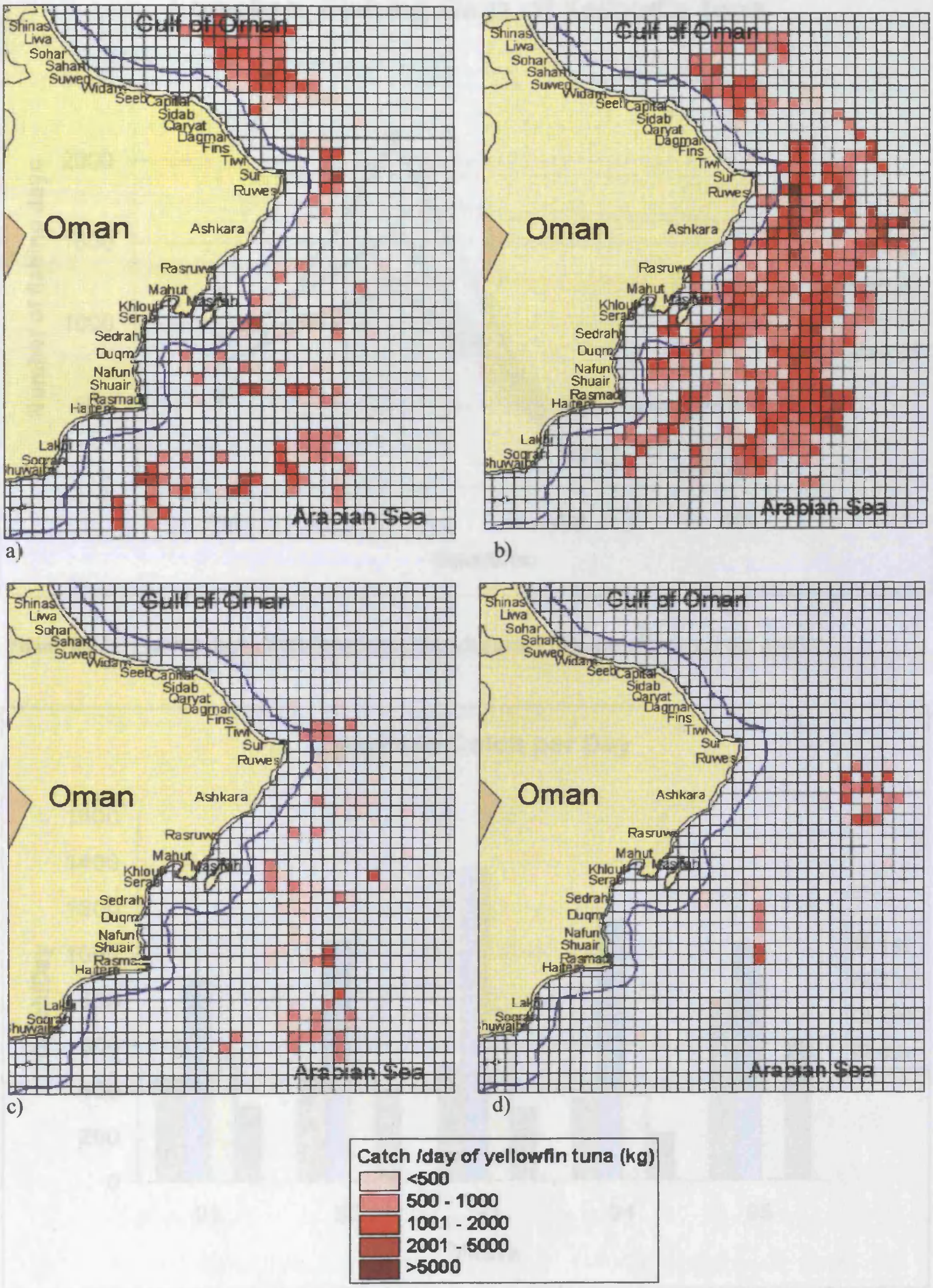


Figure 6.21 Spatio-temporal catch per effort of yellowfin tuna (*Thunnus albacares*) species of the commercial longline fisheries catch during 1995 a) January to March, b) April to June, c) July to August, and d) September to December

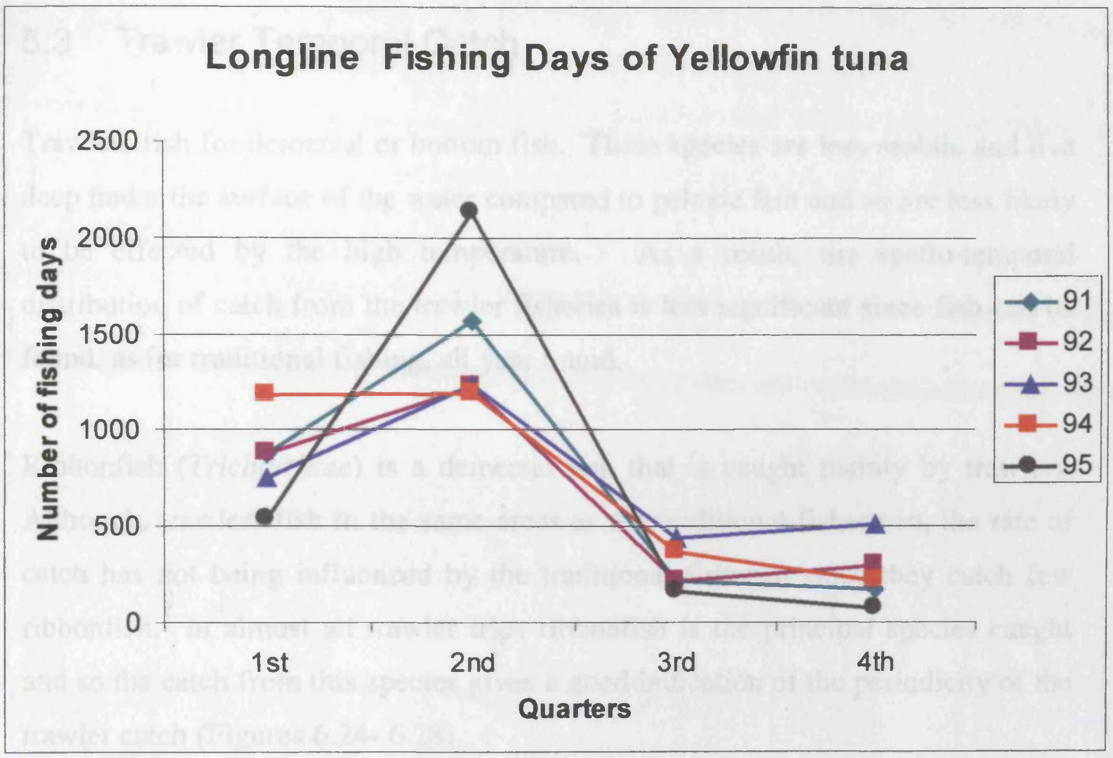


Figure 6.22 Fishing days of the longlines yellowfin tuna (*Thunnus albacares)* per quarter.

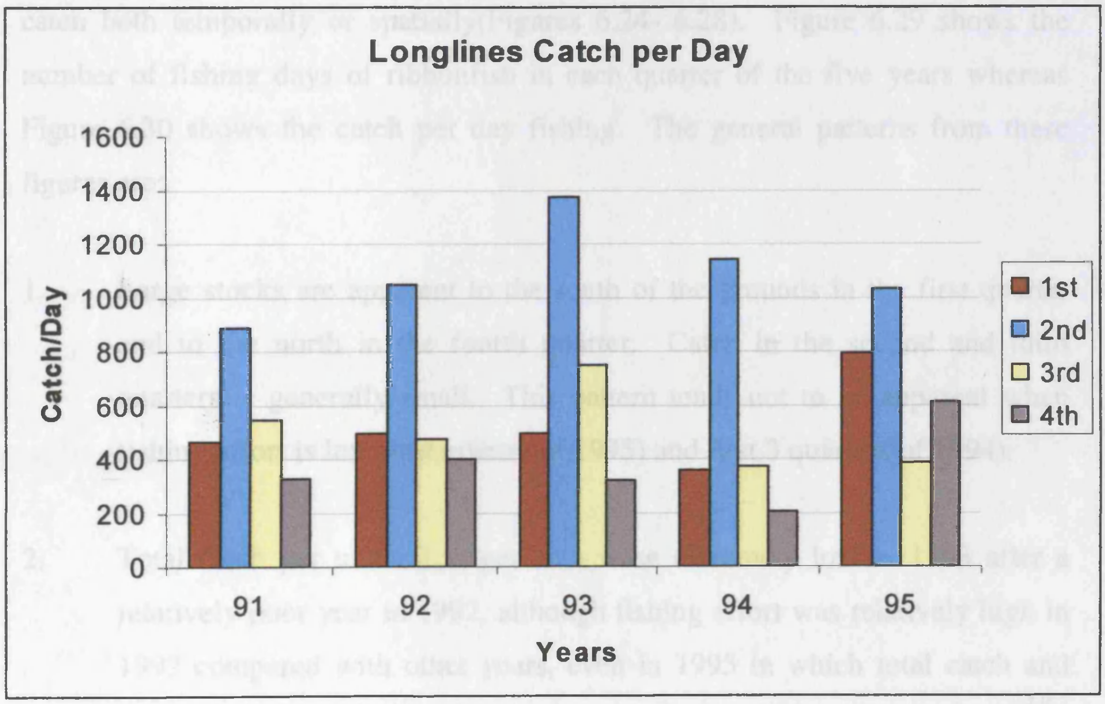


Figure 6.23 Average catch per unit day per quarter of the longline fisheries

5.3 Trawler Temporal Catch

Trawlers fish for demersal or bottom fish. These species are less mobile and live deep under the surface of the water compared to pelagic fish and so are less likely to be effected by the high temperature. As a result, the spatio-temporal distribution of catch from the trawler fisheries is less significant since fish can be found, as for traditional fishing, all year round.

Ribbonfish (*Trichiuridae*) is a demersal fish that is caught mainly by trawlers. Although, trawlers fish in the same areas as the traditional fishermen, the rate of catch has not being influenced by the traditional fisheries since they catch few ribbonfish. In almost all trawler trips ribbonfish is the principal species caught and so the catch from this species gives a good indication of the periodicity of the trawler catch (Figures 6.24- 6.28).

Clear patterns can be seen in these maps indicating regular fluctuations in the catch both temporally or spatially(Figures 6.24- 6.28). Figure 6.29 shows the number of fishing days of ribbonfish in each quarter of the five years whereas Figure 6.30 shows the catch per day fishing. The general patterns from these figures are:

1. Large stocks are apparent to the south of the grounds in the first quarter and to the north in the fourth quarter. Catch in the second and third quarters is generally small. This pattern tends not to be apparent when fishing effort is low (last quarter of 1995) and first 3 quarters of 1994).

2. Total catch per unit effort per area wase extremely low in 1993 after a relatively poor year in 1992, although fishing effort was relatively high in 1992 compared with other years, even in 1995 in which total catch and catch per day were very high. One reason for this decline during 1993 could be due to damage of ribbonfish stock in the high catch year of 1991. According to Fabrizio and Richards (1992, p. 637-8) 'changes in the spatial distribution of fishing effort can indirectly indicate decline in stock abundance as fisheries move from depleted areas to less depleted ones to maintain high catch rates'. High catch and effort occurs again in 1995 and

in 1994, and shows high variability, which may be due to lack of management of fishing activity. There is then, an urgent need for a proper management system especially concerning the catch of ribbonfish, otherwise further overfishing or stock damage is likely and this time it could be even worse.

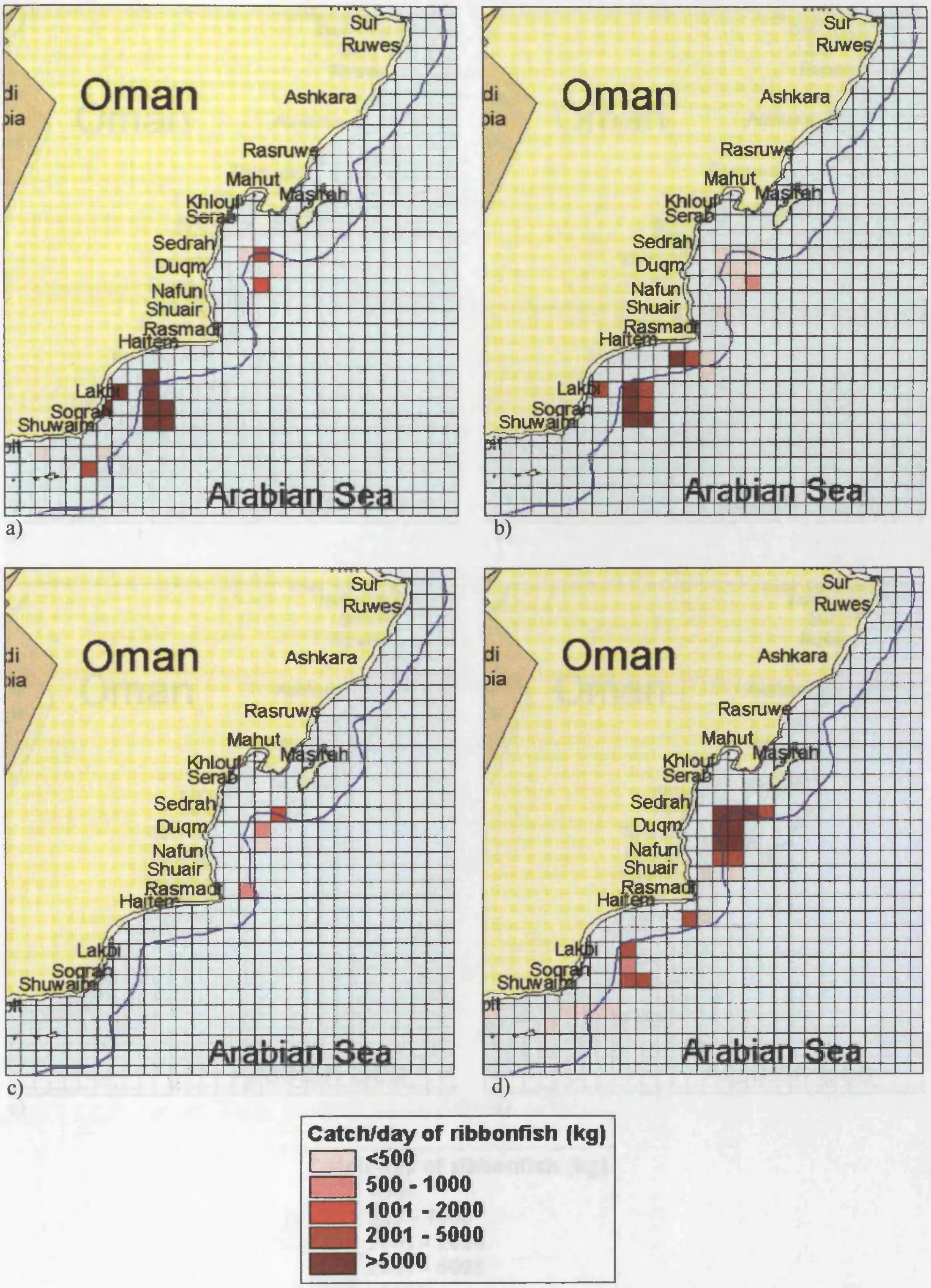


Figure 6.24 Spatio-temporal catch per effort of ribbonfish (*Trichiuridae*) species of the commercial trawler fisheries catch during 1991 a) January to March, b) April to June, c) July to August, and d) September to December

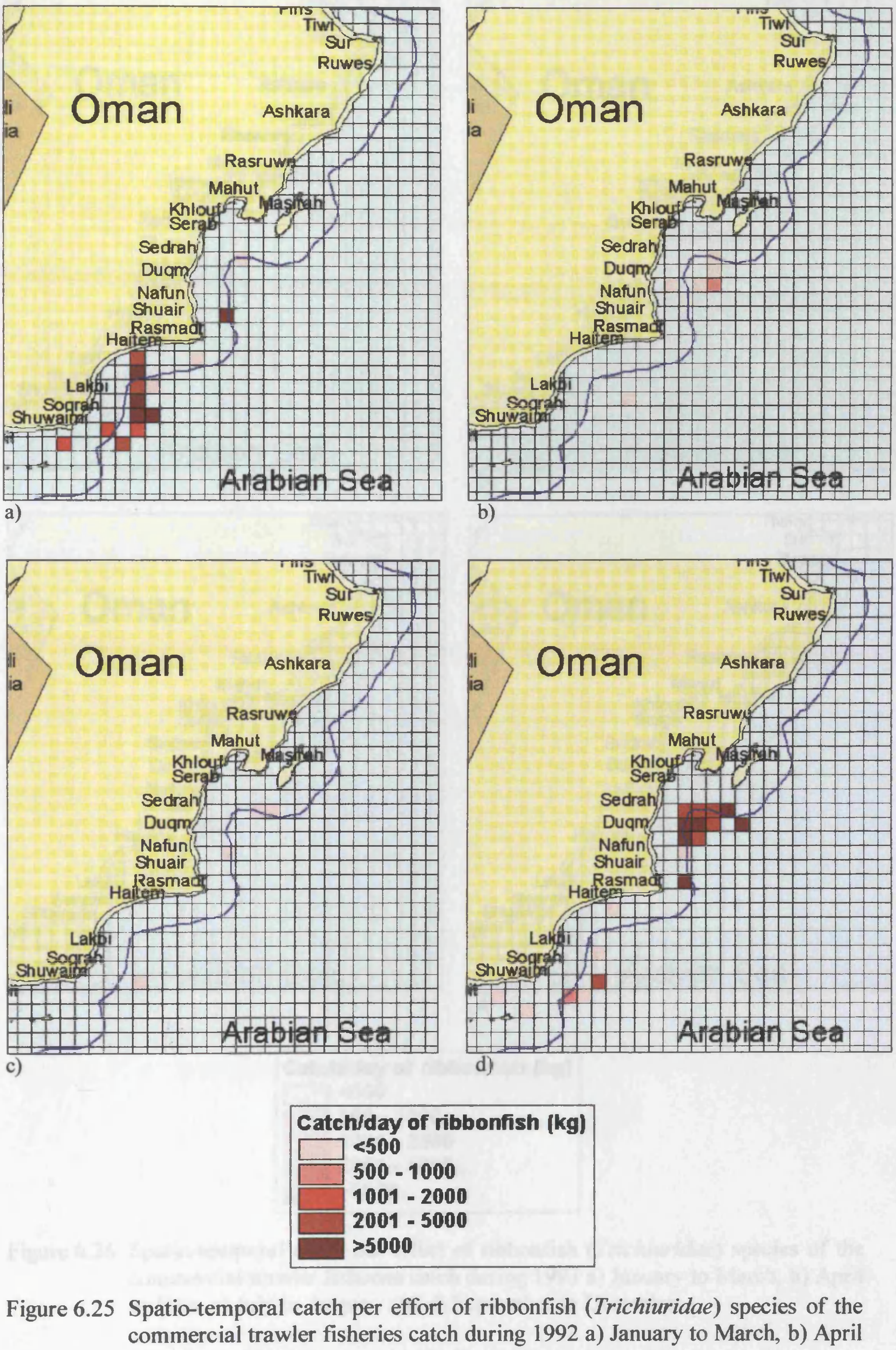


Figure 6.25 Spatio-temporal catch per effort of ribbonfish (*Trichiuridae*) species of the commercial trawler fisheries catch during 1992 a) January to March, b) April to June, c) July to August, and d) September to December

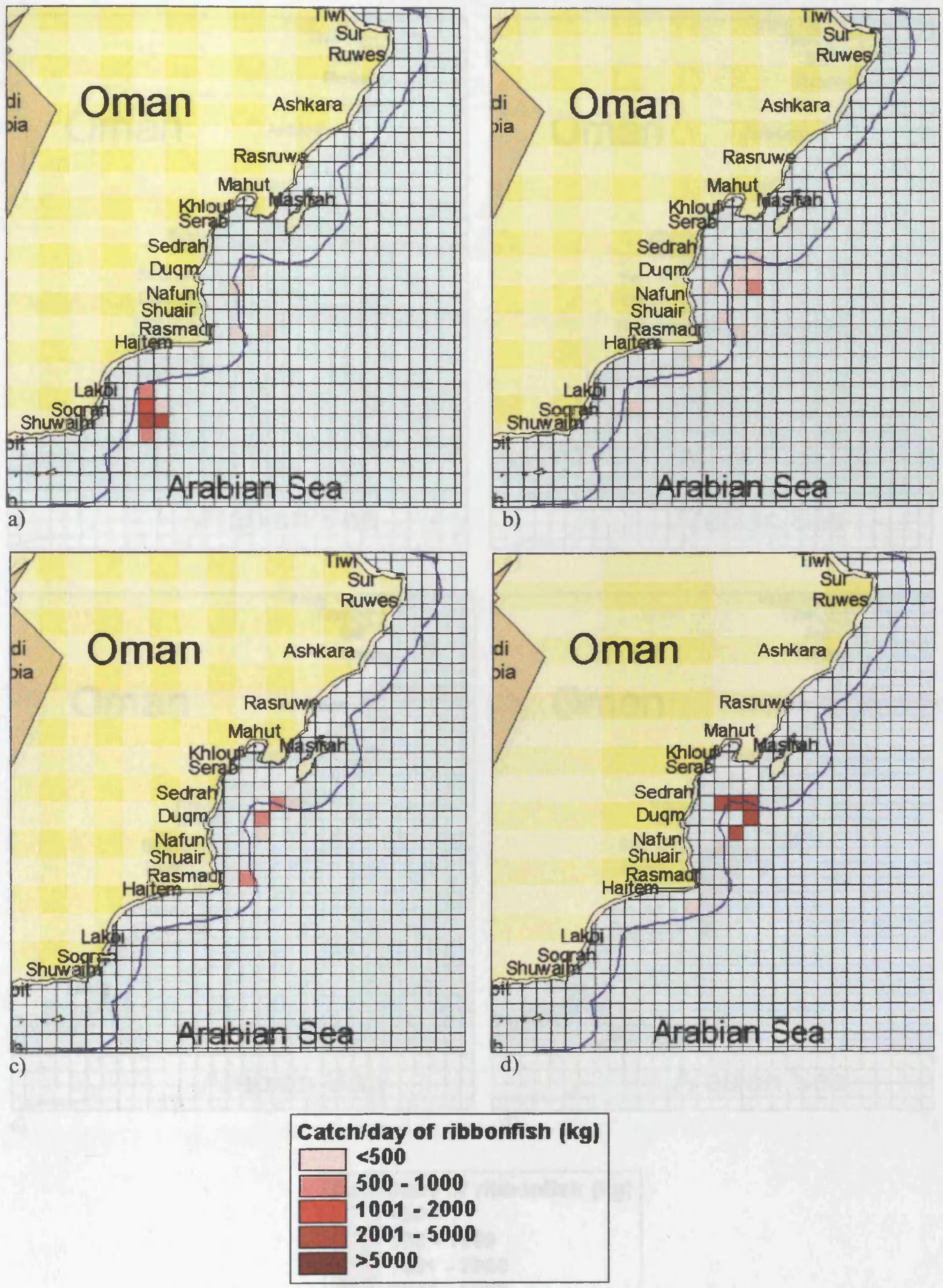


Figure 6.26 Spatio-temporal catch per effort of ribbonfish (*Trichiuridae*) species of the commercial trawler fisheries catch during 1993 a) January to March, b) April to June, c) July to August, and d) September to December

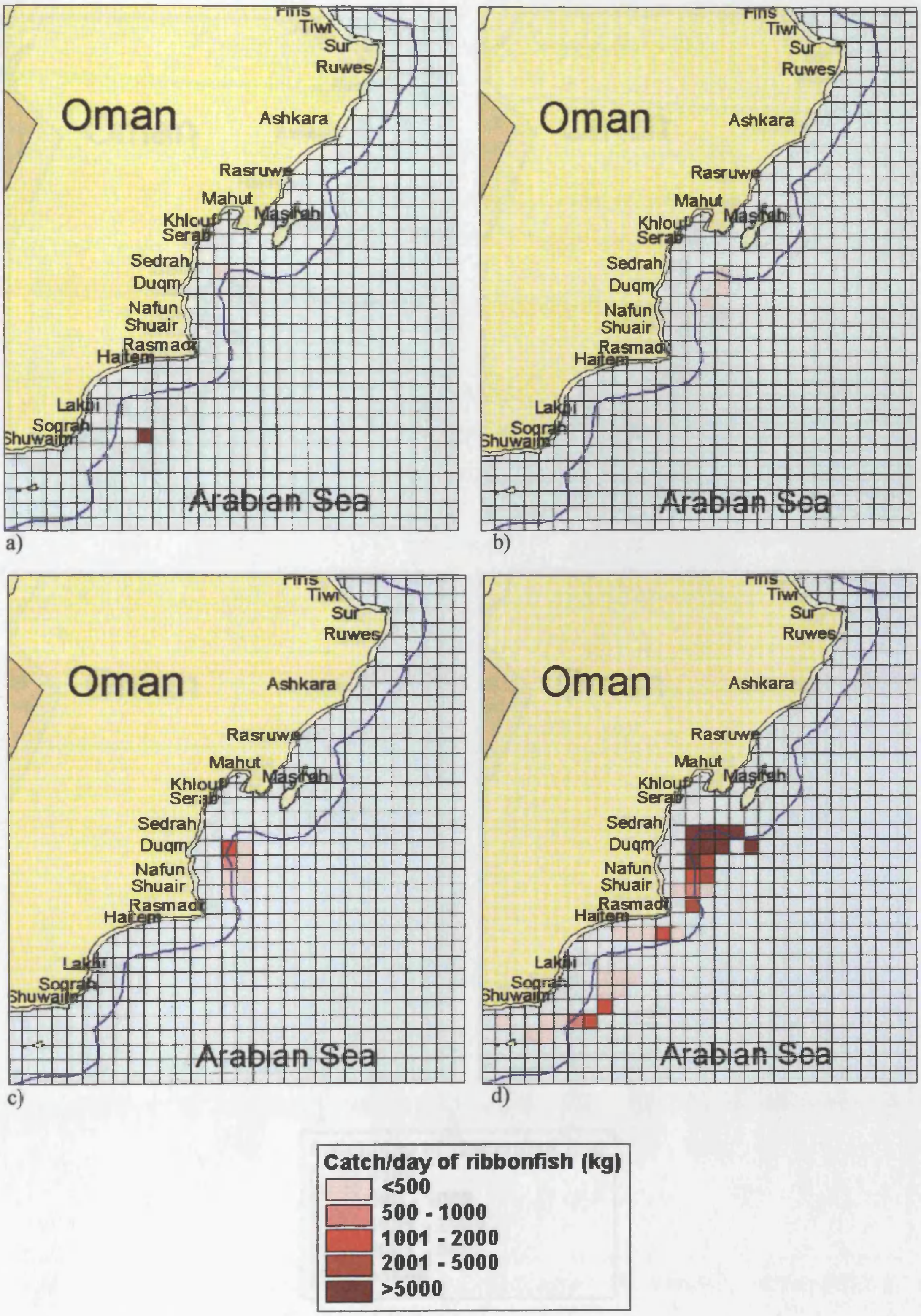


Figure 6.27 Spatio-temporal catch per effort of ribbonfish (*Trichiuridae*) species of the commercial trawler fisheries catch during 1994 a) January to March, b) April to June, c) July to August, and d) September to December

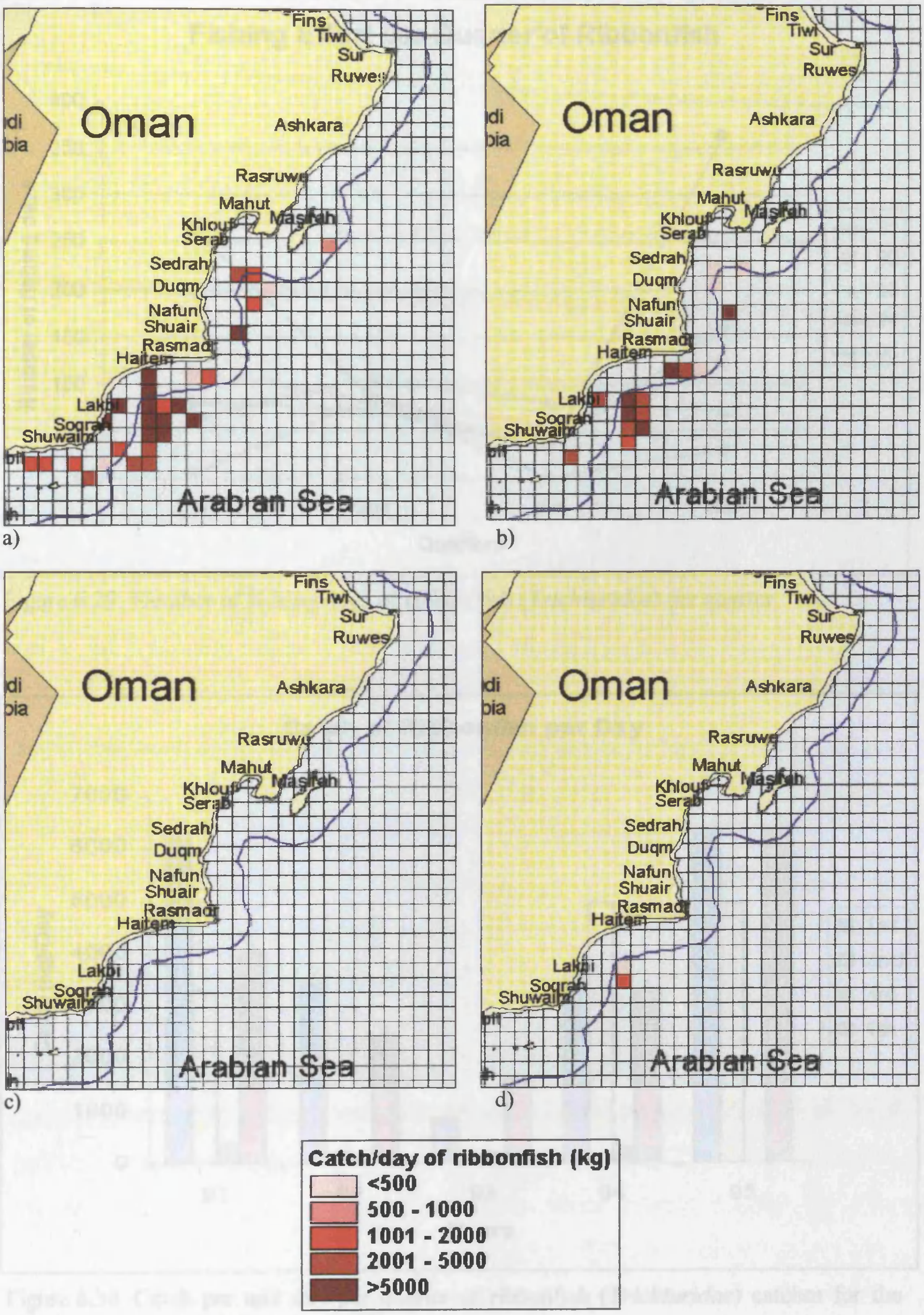


Figure 6.28 Spatio-temporal catch per effort of ribbonfish (*Trichiuridae*) species of the commercial trawler fisheries catch during 1995 a) January to March, b) April to June, c) July to August, and d) September to December

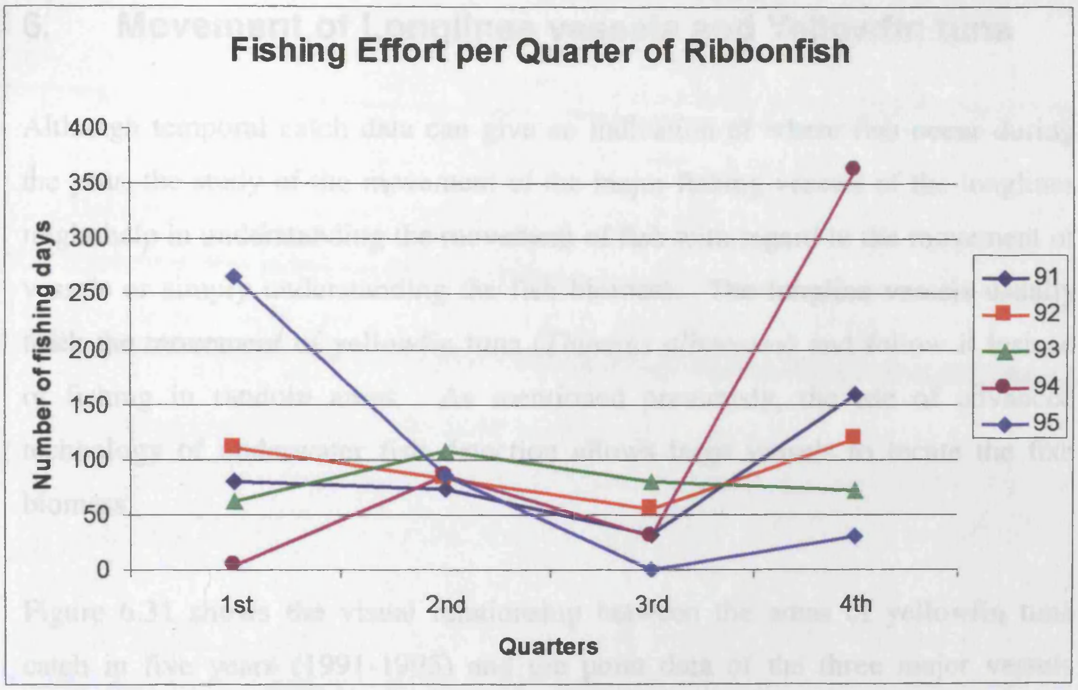


Figure 6.29 Number of fishing days of ribbon fish (*Trichiuridae*) per quarter

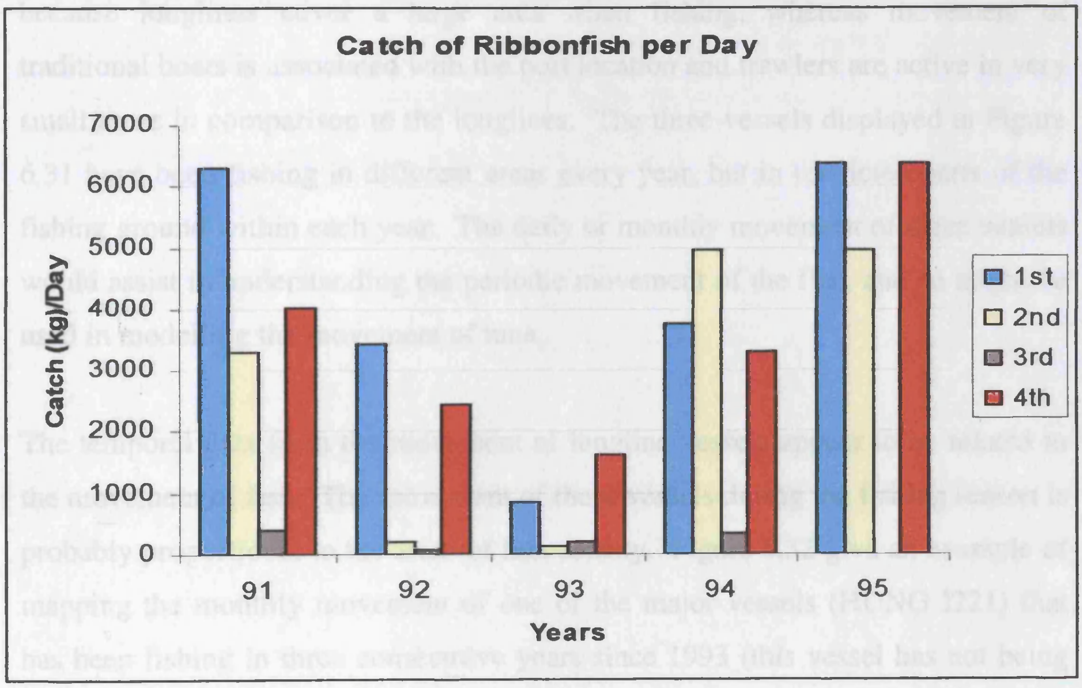


Figure 6.30 Catch per unit day per quarter of ribbonfish (*Trichiuridae*) catches for the trawler fisheries

6. Movement of Longlines vessels and Yellowfin tuna

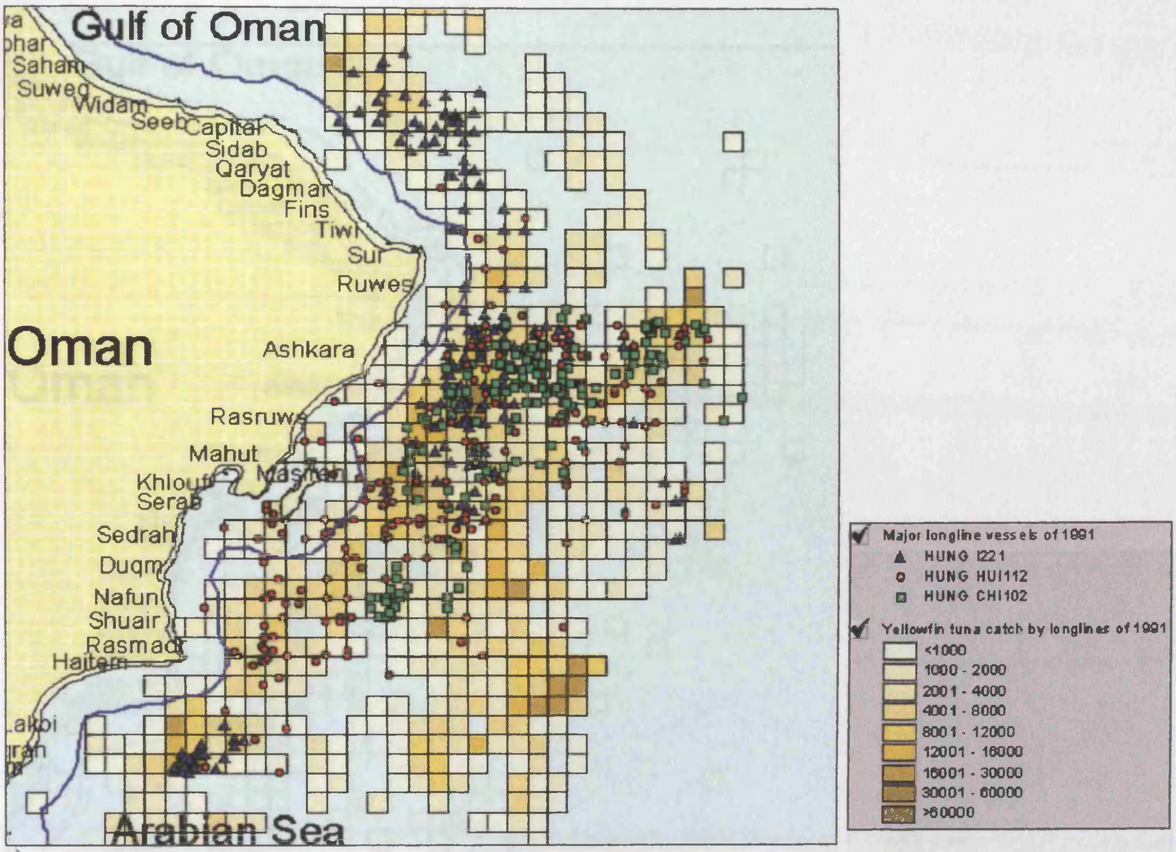
Although temporal catch data can give an indication of where fish occur during the year, the study of the movement of the major fishing vessels of the longlines might help in understanding the movement of fish with regard to the movement of vessels or simply understanding the fish biomass. The longline vessels usually track the movement of yellowfin tuna (*Thunnus albacares*) and follow it instead of fishing in random areas. As mentioned previously, the use of advanced technology of underwater fish detection allows large vessels to locate the fish biomass.

Figure 6.31 shows the visual relationship between the areas of yellowfin tuna catch in five years (1991-1995) and the point data of the three major vessels (major in terms of highest number of recorded days of fishing). The movement of longlines vessels is more significant than for the other two types of fishing because longlines cover a large area when fishing, whereas movement of traditional boats is associated with the port location and trawlers are active in very small areas in comparison to the longlines. The three vessels displayed in Figure 6.31 have been fishing in different areas every year, but in restricted parts of the fishing ground within each year. The daily or monthly movement of these vessels would assist in understanding the periodic movement of the fish, and so might be used in modelling the movement of tuna.

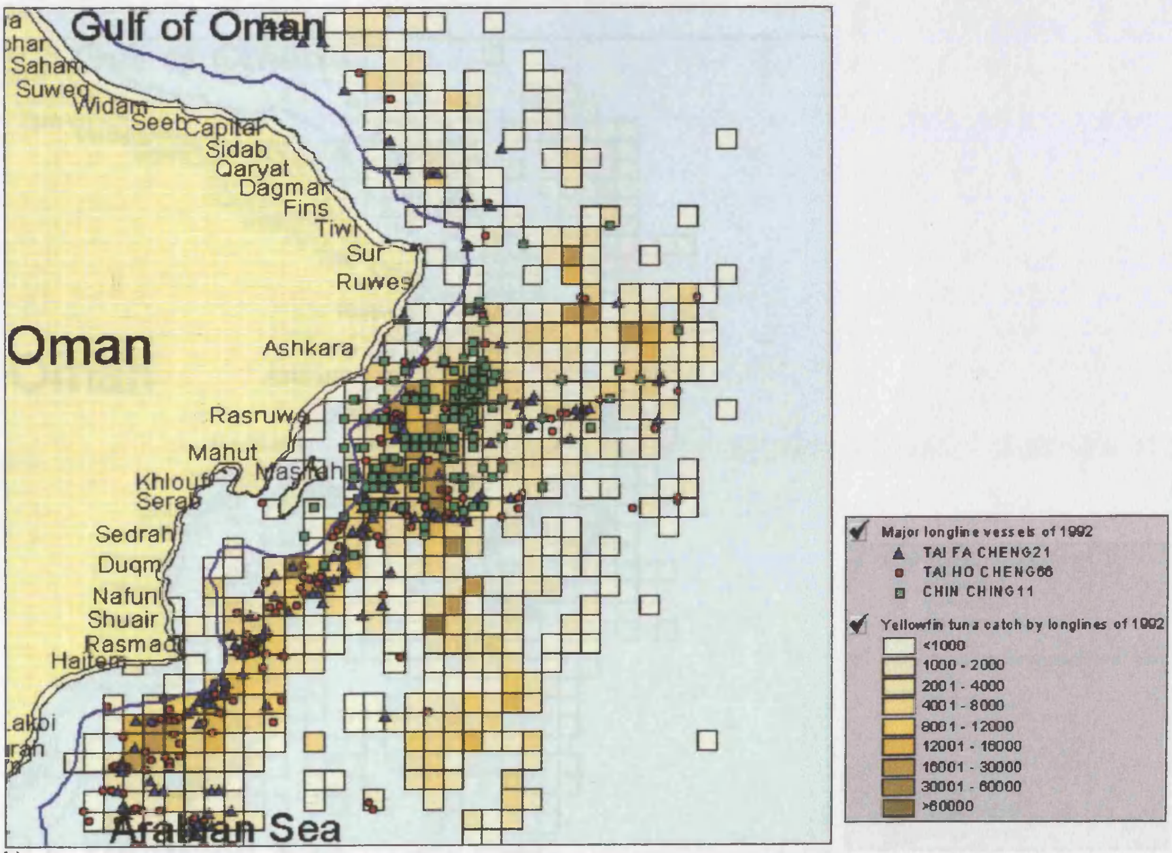
The temporal data from the movement of longline vessels appear to be related to the movement of fish. The movement of these vessels during the fishing season is probably proportional to the areas of fish density. Figure 6.32 give an example of mapping the monthly movement of one of the major vessels (HUNG I221) that has been fishing in three consecutive years since 1993 (this vessel has not being active during 1992), compared to the total spatial distribution of yellowfin tuna catch in each month.

This vessel activates during different months between March and June throughout the three years and has no fishing activity in the remaining months. Different observations can be taken from Figures 6.31 and the monthly spatio-temporal vessels/catch relation in Figures 6.32. These observations can be summarized as follows:

1. The spatial distribution of the major vessels in Figure 6.31 is highly associated with the areas of high catch of yellowfin tuna. This may indicate the past knowledge of these fishermen about where to fish at certain time of the year. However, this is not always the case.
2. The vessels in Figure 6.31 target mainly yellowfin tuna, and so areas of high fishing activity and less catch (e.g., at the south bottom of Figure 6.31e) might represents areas of low fish density.
3. When mapping monthly locations of these vessels it seems that their fishing season is directly proportional with the high catch (2nd quarter) season of the year.
4. The targeting of monthly high density areas by HUNG I221 (Figure 6.32) are improving every year. In fact, the relation is more obvious in 1995 than for the previous two years.
5. In general, HUNG I221 seems to have a systematic movement in 1994 and 1995 starting from the northern part of Omani water and towards the southern part at the end of its fishing trip, this could be associated with the movement of the yellowfin tuna.

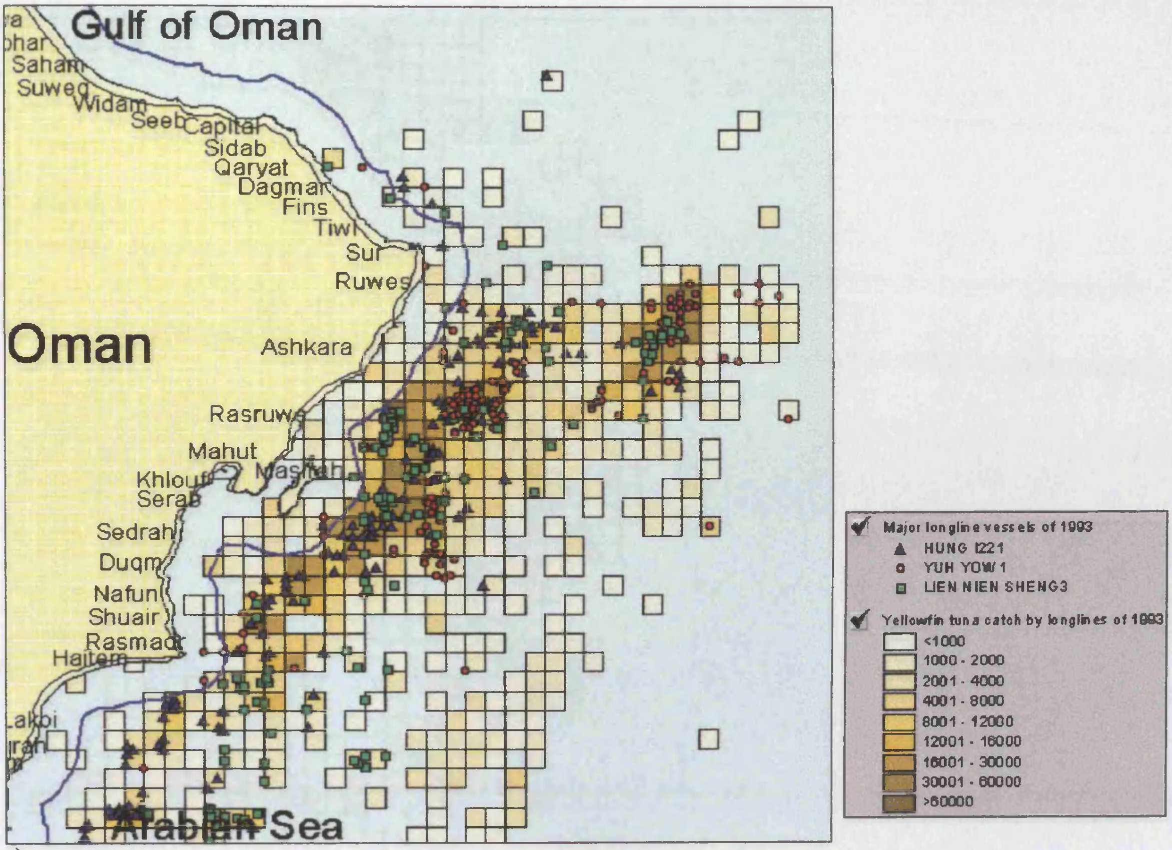


a)

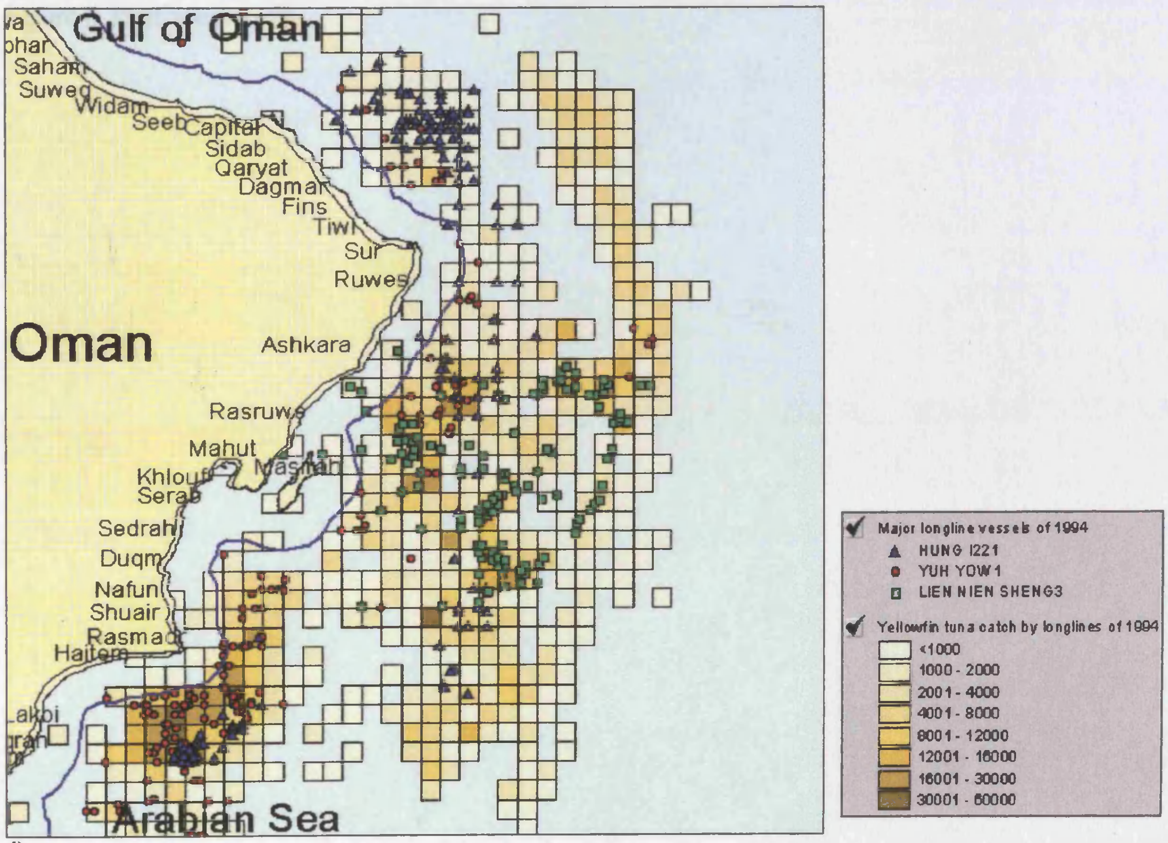


b)

Figure 6.31 Maps shows the areas of yellowfin tuna *(Thunnus albacares)* catch (in kg) in relation to the three major longlines fishing vessels for years a)1991, b) 1992, c)1993, d) 1994 and e)1995.

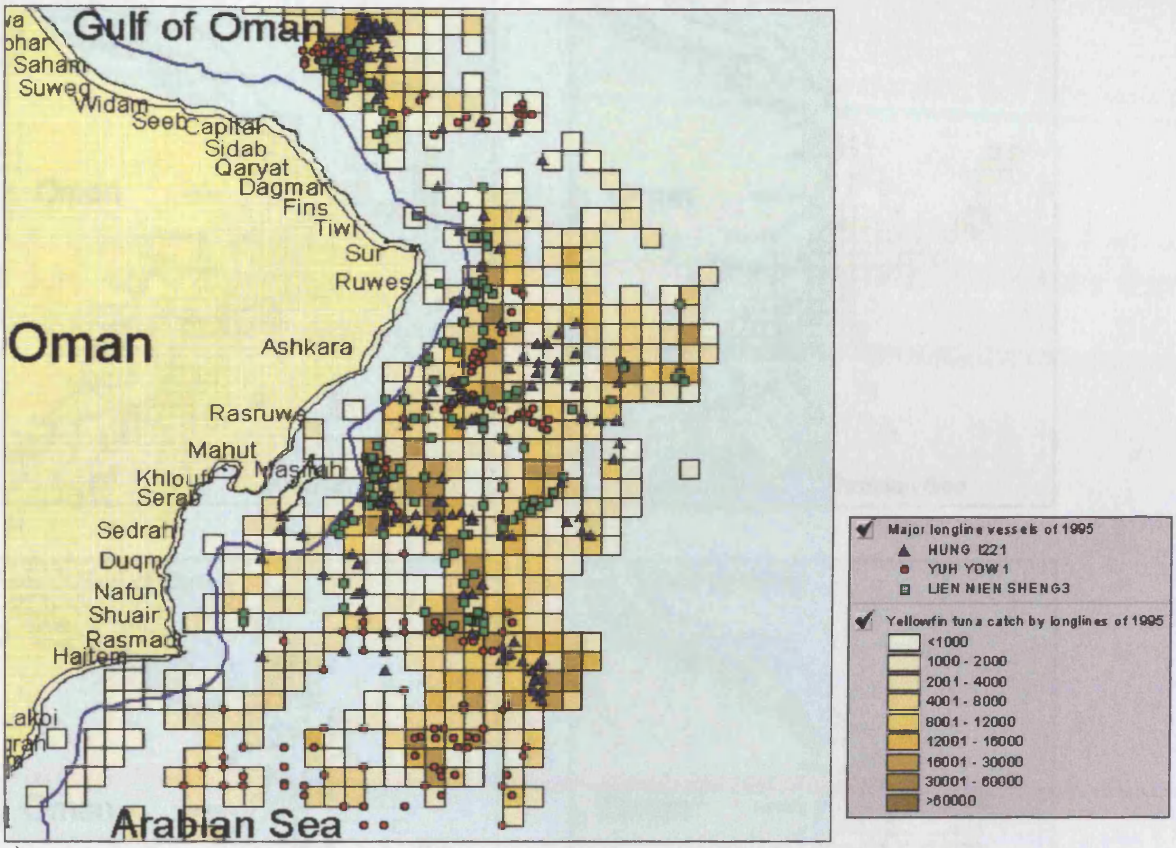


c)



d)

Figure 6.31 (*Continued*)



e)

Figure 6.31 (*Continued*)

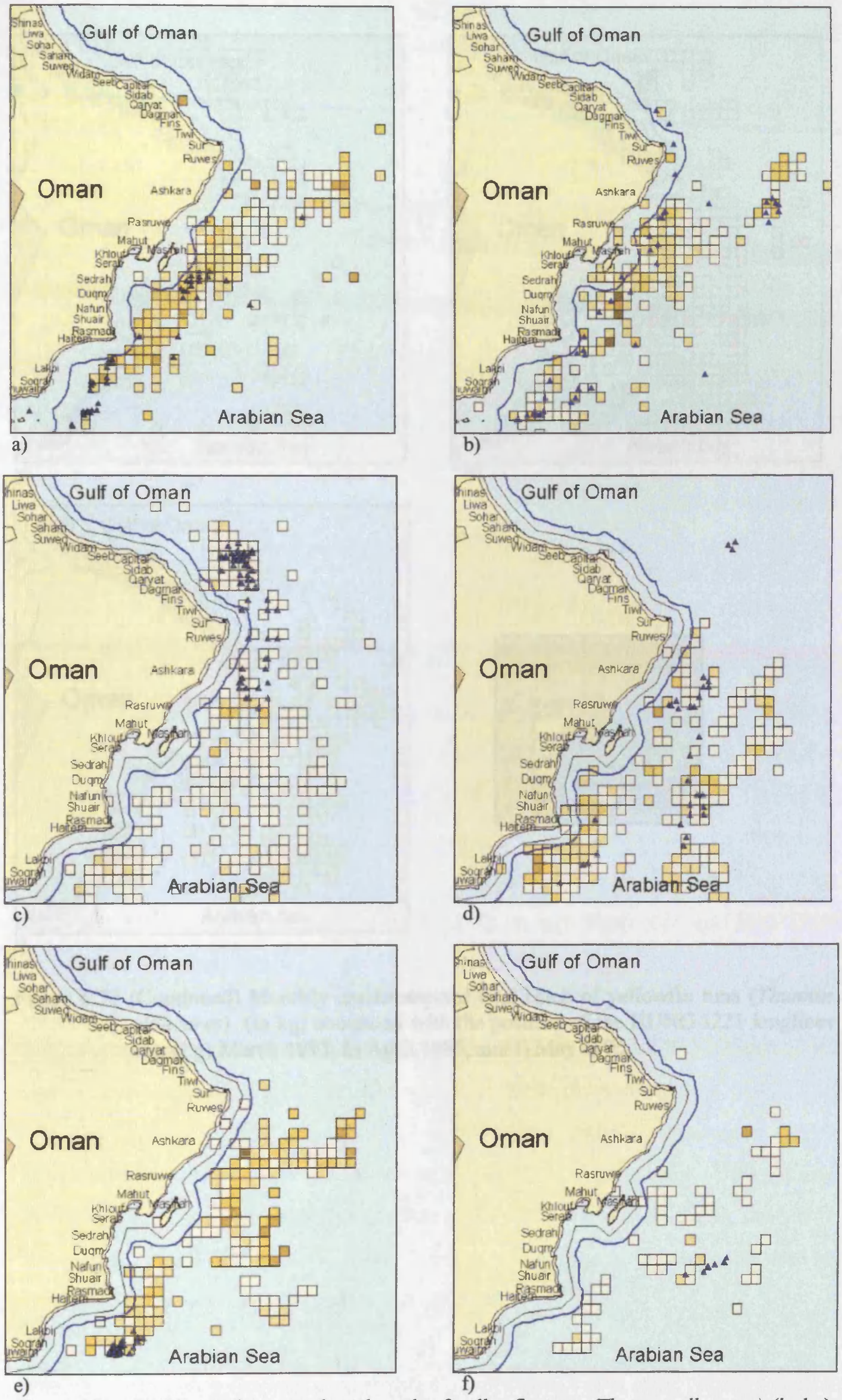


Figure 6.32 Monthly spatiotemporal total catch of yellowfin tuna *(Thunnus albacares)* (in kg) compared with the position of the HUNG I221 longlines vessel a) March 1993, b) May 1993, c) March 1994, d)April 1994, e) May 1994, f) June 1994,

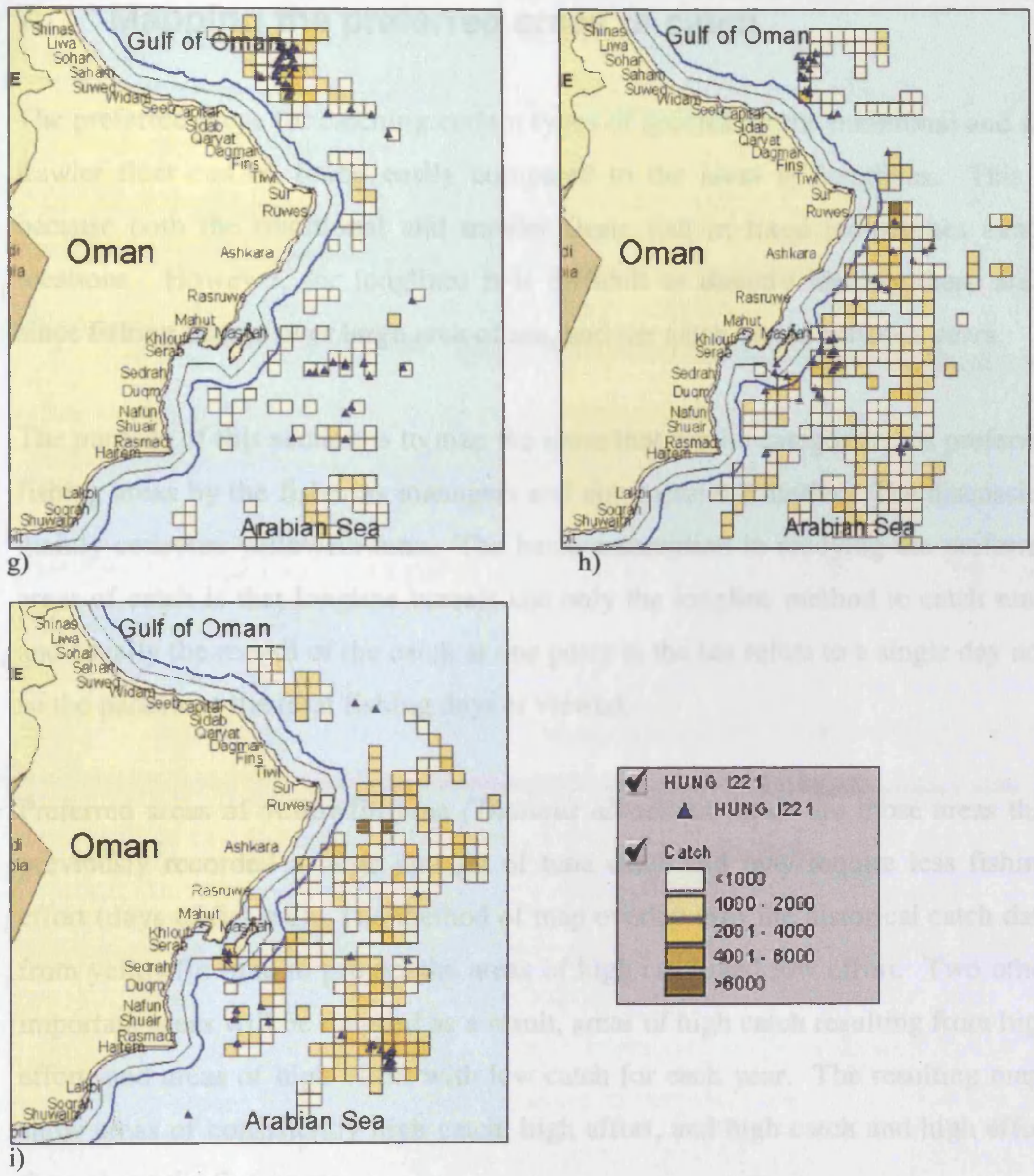


Figure 6.32 (Continued) Monthly spatiotemporal total catch of yellowfin tuna (*Thunnus albacares*) (in kg) compared with the position of the HUNG I221 longlines vessel g) March 1995, h) April 1995, and I) May 1995.

7. Mapping the preferred areas of catch

The preferred areas for catching certain types of species by the traditional and the trawler fleet can be found easily compared to the areas of longlines. This is because both the traditional and trawler fleets fish in fixed (sometimes exact) locations. However, for longlines it is difficult to directly identify these areas since fishing occurs over large area of sea, and the catch varies between years.

The purpose of this section is to map the areas that can be categorized as preferred fishing areas by the fisheries managers and commercial fisheries. The discussion mainly concerns yellowfin tuna. The basic assumption in studying the preferred areas of catch is that longline vessels use only the longline method to catch tuna, and usually the record of the catch at one point in the sea refers to a single day and so the pattern of the total fishing days is viewed.

Preferred areas of yellowfin tuna *(Thunnus albacares)* catch are those areas that previously recorded a large amount of tuna catch and may require less fishing effort (days of fishing). The method of map overlay uses the historical catch data from yellowfin tuna to project the areas of high catch and low effort. Two other important areas will be mapped as a result, areas of high catch resulting from high effort, and areas of high effort with low catch for each year. The resulting maps show areas of consistently high catch, high effort, and high catch and high effort throughout the five years.

The average yellowfin tuna catch by longlines is more then 12,000 kilograms per year (12 tonnes/year), and this rate occurs in 26% of grid squares with catch. There is usually no reference level of high and low catch and managers should decide the appropriate criteria since management has a high level of uncertainty (Buckworth, 1998). The average number of days of fishing is over 15. Therefore, more then 12000 kilograms is used to define a large catch, within a grid square and over 15 fishing days of defines a large effort.

The areas of high catch and high effort, high effort and low catch, and high catch and low effort for each of the five years are displayed in Figure 6.34. However, the discussion will use the data in 1995 as an example to illustrate the method used in determining these areas. The following steps were followed:

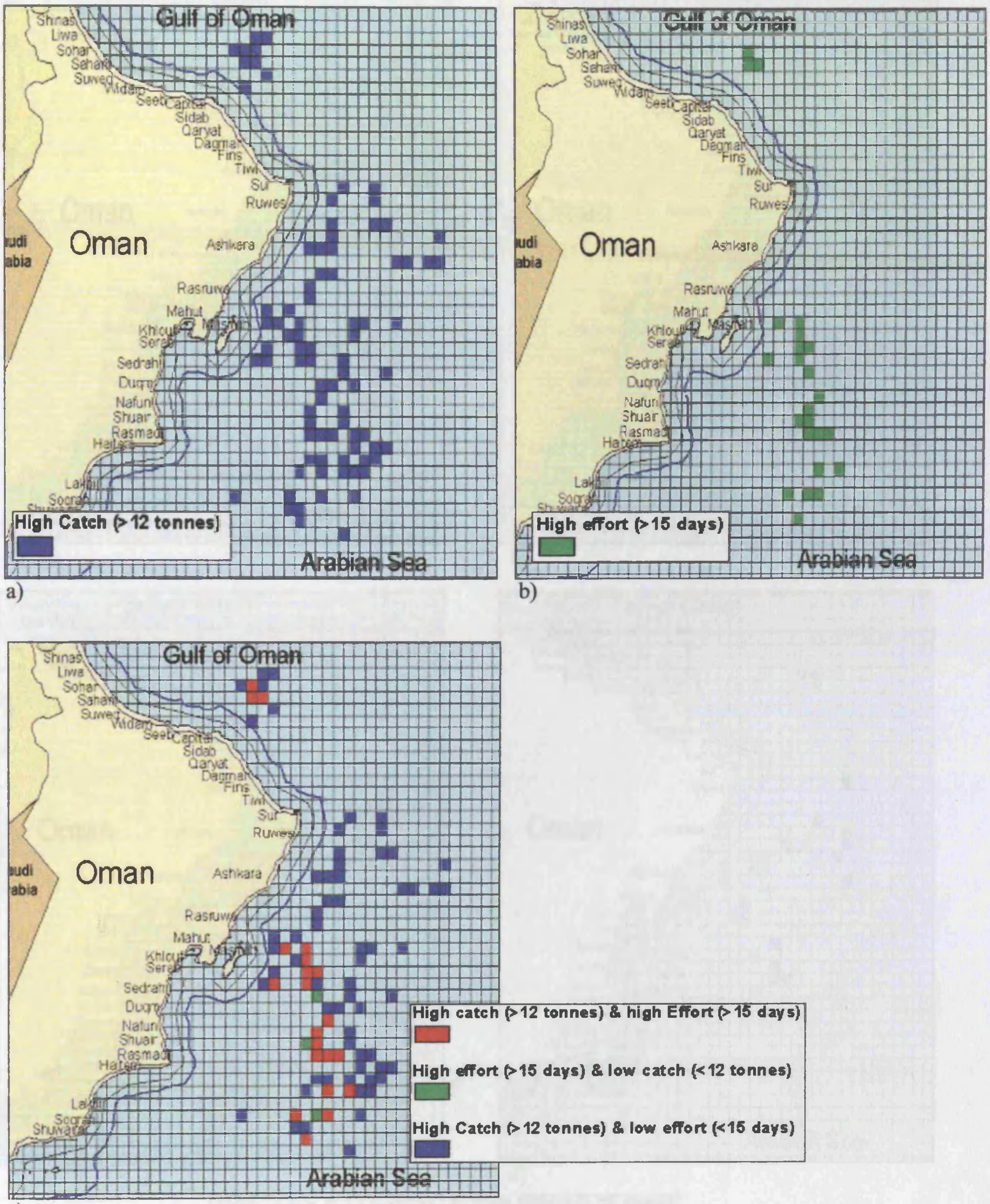
1. Select the areas with catch greater then 12000 kg for 1995. The result is shown in Figure 6.33a.
2. Select the areas with more than 15 days fishing. The result for 1995 is displayed in figure 6.33b.
3. The two maps from 1 and 2 are then overlaid and joined using the map arithmetic operators. The result (Figure 6.33c) shows those areas of high catch in blue and high effort in green. The areas where the two maps overlap are those of high catch and high effort and are shown in red.

The same method has been used to select the same areas, for the years between 1991-1994 (Figure 6.34).

From the fisheries management point of view, areas of red have probably reached the maximum level of catch and any increase in terms of fishing effort may lead to a problem of stock damage through overfishing. It would therefore be appropriate to control the level of fishing at that rate or to reduce it for extra precaution. The green areas may have less fish biomass or already be experiencing stock damage, probably due to the high fishing effort applied (section 9 discusses the areas that have been partially or not fully exploited, whereas section 10 explores in detail the overfishing areas). The blue areas are those of preferred areas of catch since the amounts of catch shown are high and the amount of effort is still low (less than 15 days). These areas, of high catch and low effort, hold the highest probability of containing the healthy species stock and it would be better to develop and improve the management in these areas.

Managing these areas is problematic but critical, because from the commercial point of view, they are the best locations for fishing considering effort as measured by the number of fishing days in which to capture large amounts of fish. This is relatively true if in any given area a consistently high catch has occurred in each of the five years. The areas of catch are displayed in Figure 6.35a classified as high catch 'In 5 years' in the theme legend, with the less significant areas classified as high catch 'In 4years'. Areas classified as high catch 'In 5 years' experience a consistently high catch every year and so the catch can presumably be sustained at this high level. Areas classified as 'In 3 years' on the other hand had a high catch record in three years but not in the other two.

The data displayed in Figure 6.35 could be used as the base data for future management. High effort, which resulted in high catch throughout the years (Figure 6.35c) should be controlled and probably reduced since it may harm the amount of fish stock if effort continuing to be at the same level. The areas in Figure 6.35b that have not occurred in either of Figures 6.35a and c, refers to the areas of consistence high effort but less catch (less the 12 tonnes). The areas shown in Figure 6.35b, are probably of low fish density or already suffering from unmanaged intensive fishing especially areas classified as high effort low catch 'In 4 years'.



c)

Figure 6.33 Areas of a) high catch (>12,000 kg) and b) high effort (>15 days of fishing) from yellowfin tuna (*Thunnus albacares*) catch by the longlines of 1995. c) shows areas of high catch and high effort (red colour), high catch and low effort (blue colour) and high effort and low catch (green colour) for the same data.

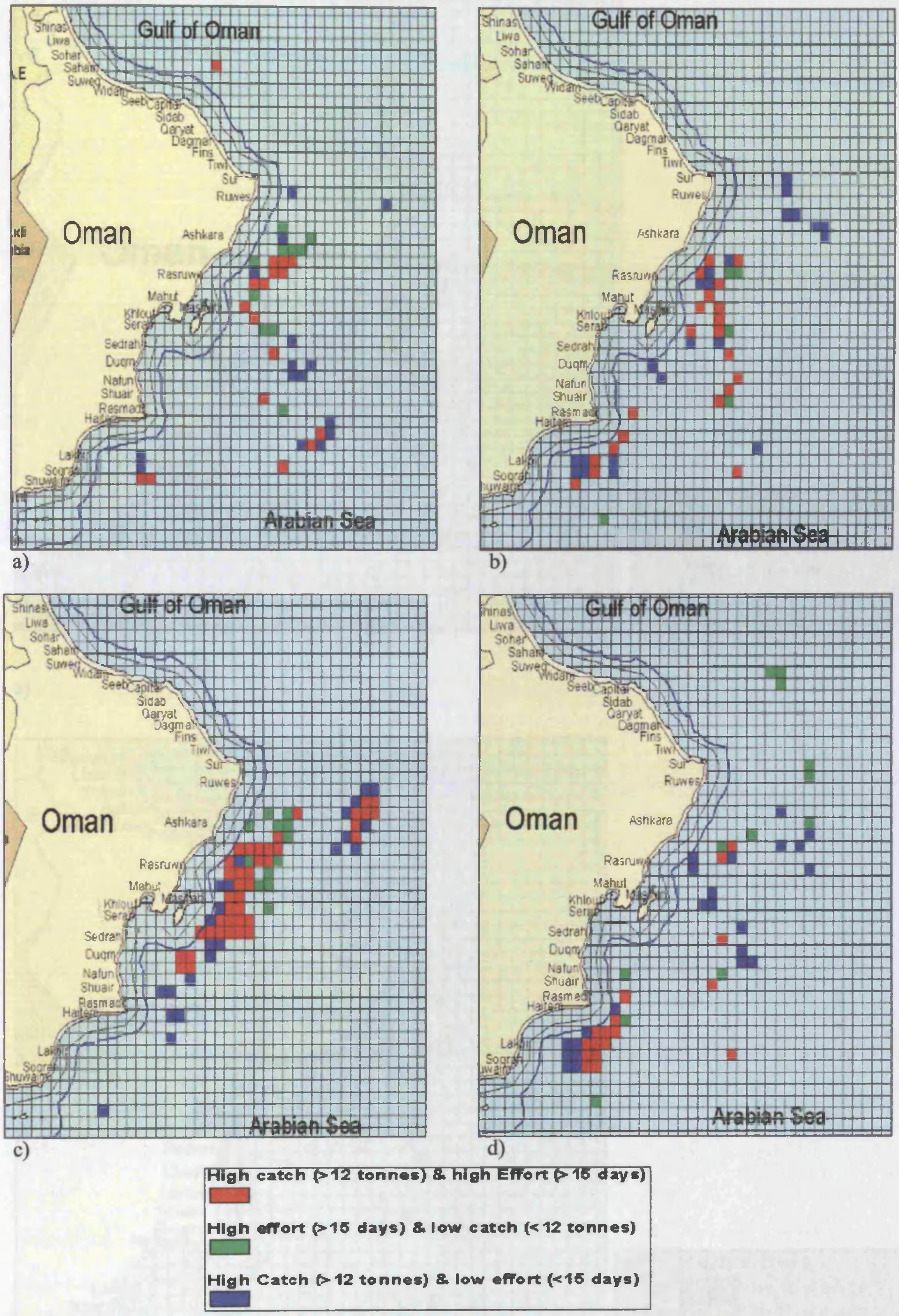
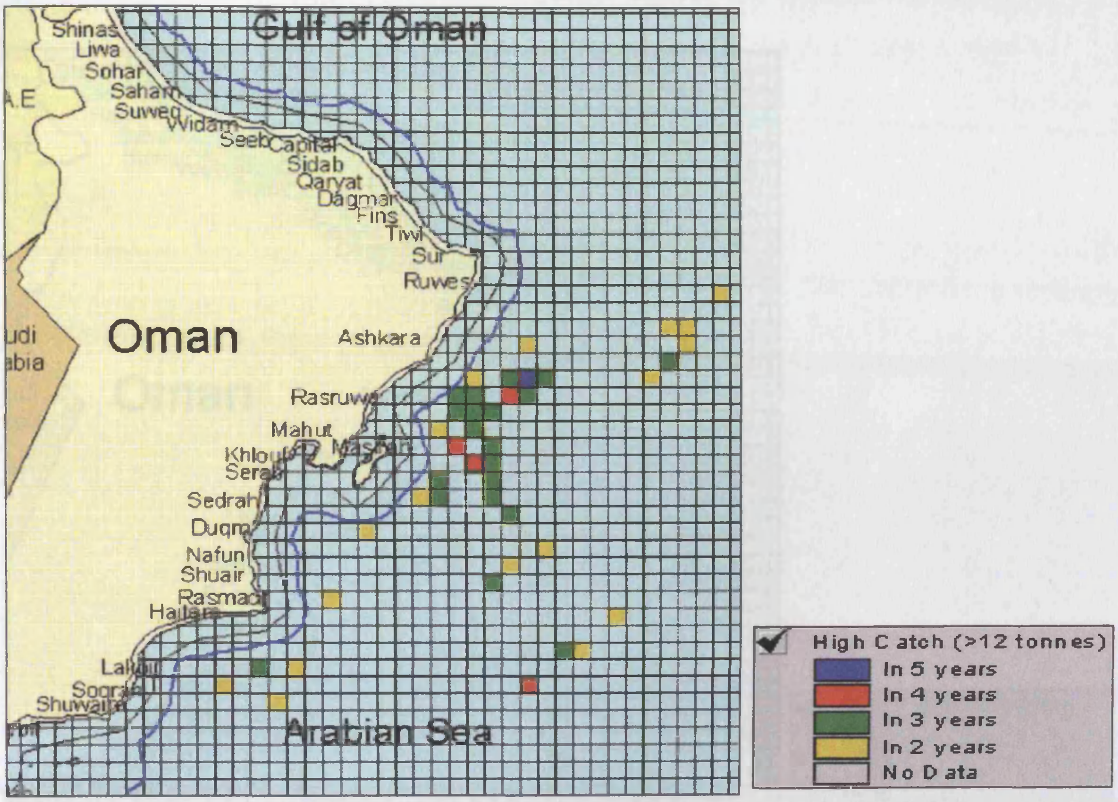
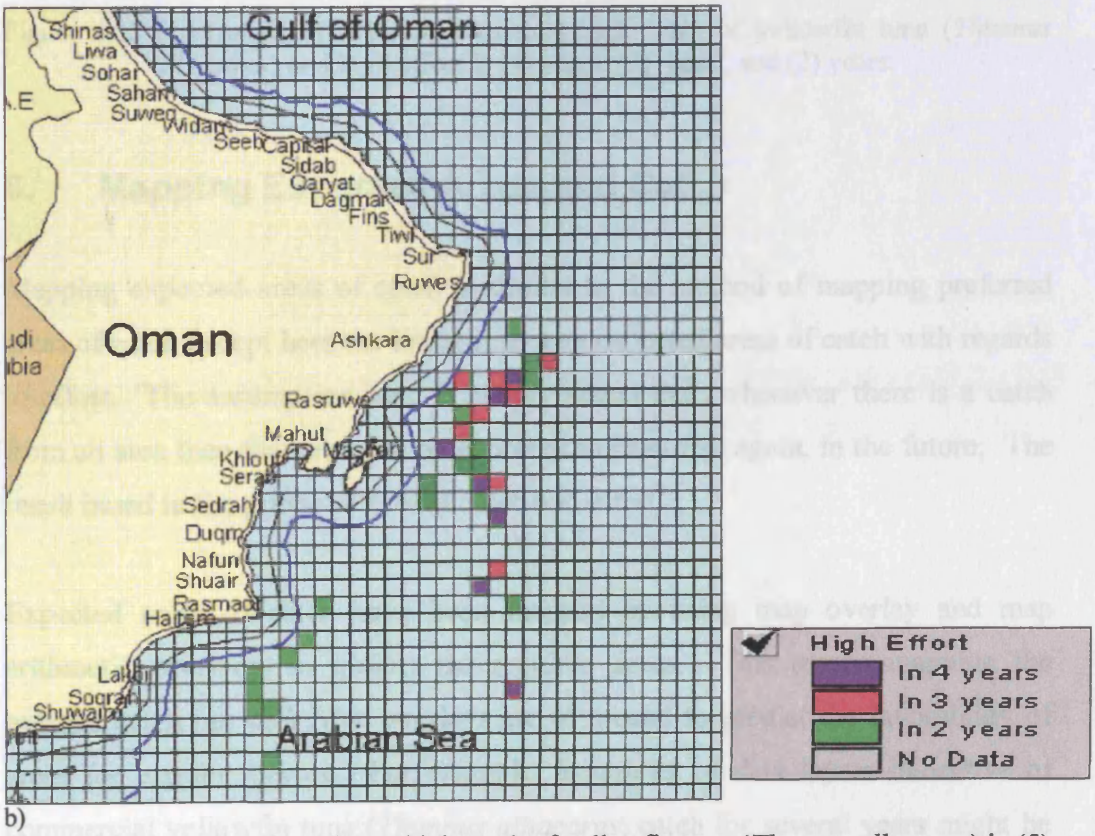


Figure 6.34 Areas of catch of yellowfin tuna (*Thunnus albacares*) >12000 kg, and effort >15 days (red colour), catch of >12000 kg and effort of <15 days (blue colour), and effort of >15 days and catch <12000 kg (green colour) for a) 1991, b) 1992, c) 1993, and d) 1994.

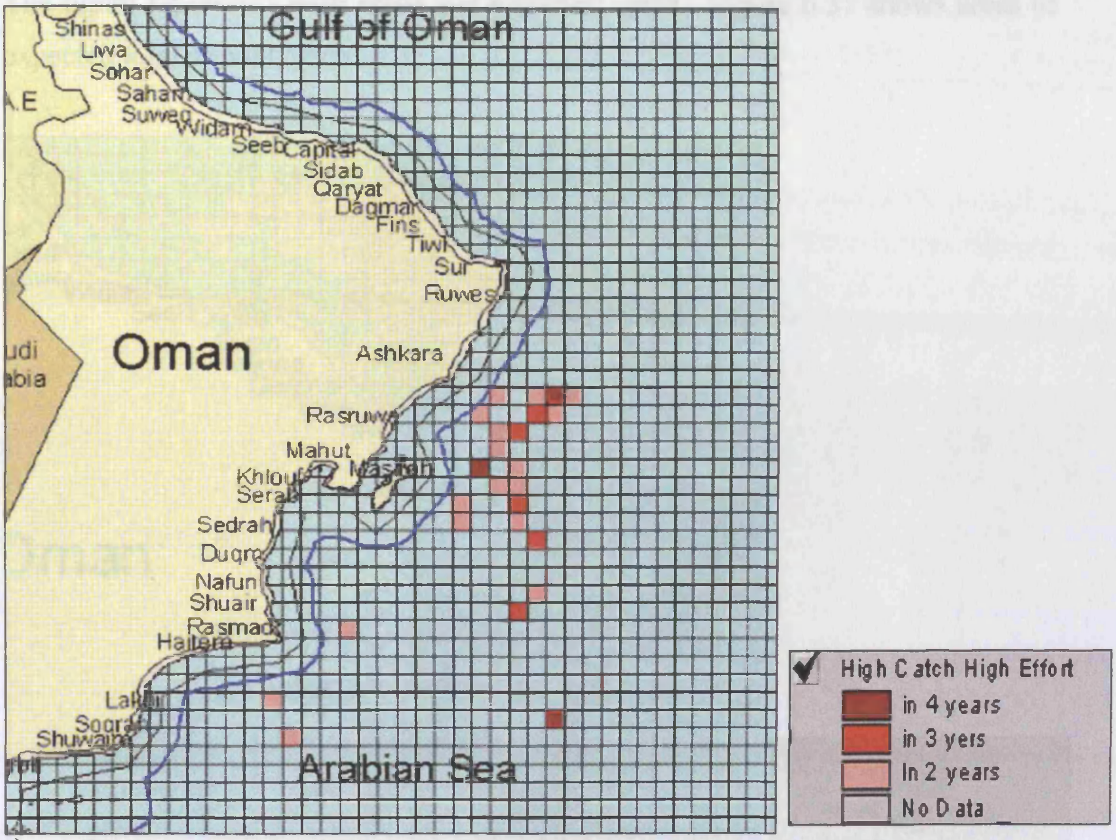


a)



b)

Figure 6.35 a) areas of consistent high catch of yellowfin tuna (*Thunnus albacares*) in (5) years, (4) years, (3) years, and (2) years. b) areas of consistent high effort in (4) years, (3) years, and (2) years.



c)

Figure 6.35 (continue), c) areas of consistent high catch of yellowfin tuna (*Thunnus albacares*) and high effort in (4) years, (3) years, and (2) years.

8. Mapping Expected Areas and Catch

Mapping expected areas of catch is similar to the method of mapping preferred areas of catch except here the intent is to map expected areas of catch with regards to effort. The assumption here is simply stated that, whenever there is a catch from an area then that area can be expected to have fish again, in the future. The result based in the previous data of catch and effort.

Expected areas of catch have been mapped by using map overlay and map arithmetic operators to project the required areas. This means mapping the average catch per cell. Map overlays are of crucial to predict the favorability of areas for certain species. For example, a number of data layers indicative of commercial yellowfin tuna (*Thunnus albacares*) catch for several years might be combined together to predict the favorability of tuna as a new map. Figure 6.36

shows the expected annual catch of yellowfin tuna by the commercial fisheries. The figure represents both areas and expected catch. Figure 6.37 shows areas of expected total annual catch.

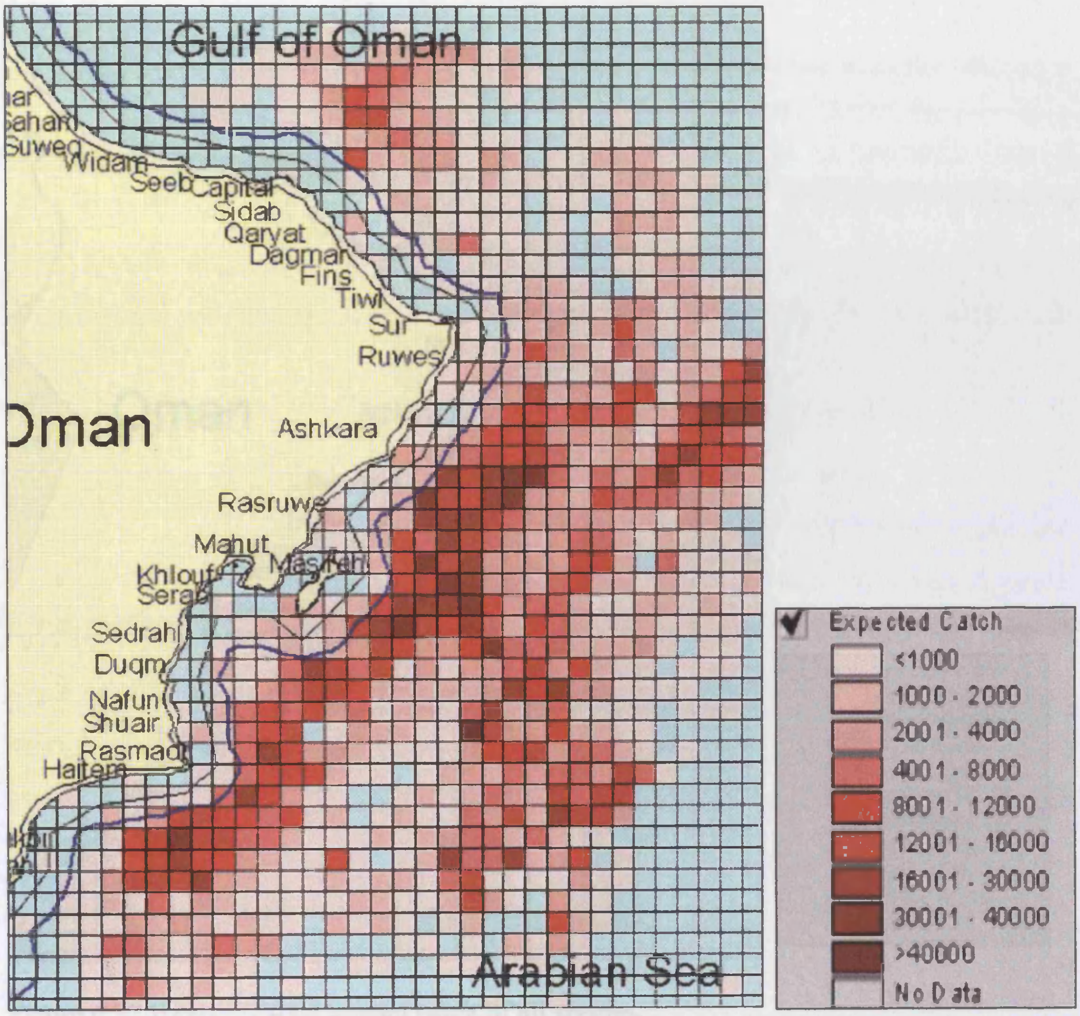


Figure 6.36 Expected catch of yellowfin tuna (*Thunnus albacares*) (in kg) in future years by the commercial fisheries of longlines and trawlers.

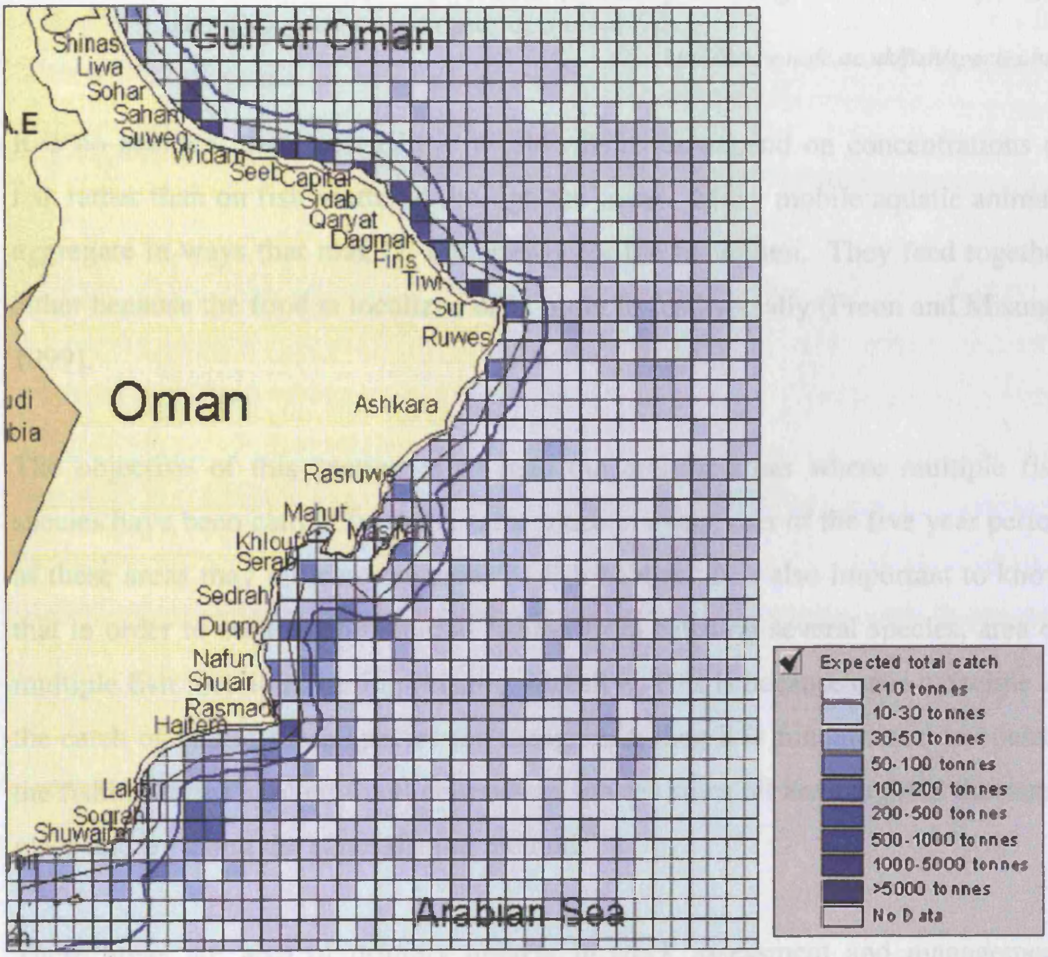


Figure 6.37 Expected total annual catch of all species.

9. Mapping Areas of Multiple fish Co-existence (areas of fish habitat)

> Demersal fish spend most of their time living on or in close association with the sea-bed, usually feeding on benthic (bottom living) organisms or other demersal fish.
>
> *http://www.nafc.ac.uk/fish/species.htm*

It is no accident that most of the World's fisheries depend on concentrations of fish rather than on fish scattered through the water. Many mobile aquatic animals aggregate in ways that make it rather easy for the fishermen. They feed together either because the food is localized or in order to feed socially (Freon and Misund, 1999).

The objective of this section is to map the area or areas where multiple fish species have been caught from the same place in every year of the five year period as these areas may indicate the areas of fish habitat. It is also important to know that in order to control commercial fishing from catching several species, area of multiple fish locations are important to identify. This is because once a decline in the catch of one of these species are recognized, then it is fundamental to control the fishing effort applied to all co-existing species since all are caught at the same place and by using the same fishing method.

These areas are also of primary interest in stock assessment and management because they are key to the identification of stock units in relation to exploitation. Moreover, if these areas are found to be a habitat then these govern the availability of the fish in both the horizontal and vertical dimension, and therefore the amount of catch. Understanding the fluctuations in catch are of economic interest for fishermen, and they are of scientific interest to fishery biologists who use them as abundance indicators in stock assessment models.

Areas where multiple fish co-exist can be seen more clearly by using the demersal catch data as an example. Figure 6.38 shows the areas of catch of the demersal species of Sea Braise (*Cheimerus nufar*), Rock cod (*Epinephelus*), and Emperor/Scavenger (*Lethrinidae*) respectively, for the year of 1995. From the maps it can be seen that these species are in much the same areas, which could be used as an indication of preferred areas of high catch of more than one species.

The highest areas of catch are those of the darkest color. Figure 6.38d shows those areas that contain more then 2 tonnes catch of all three species.

Studying all surrounding factors in these areas of high productivity such as climatic and oceanographic data as well as zooplankton levels could indicate suitable habitat areas. A proper fisheries management approach must be applied to these areas since commercial vessels will concentrate their effort on these areas and so may result in damaging the available stocks.

Another way to find the areas of multiple fish locations using GIS is by displaying the catch data related to each grid square. The display of each information for the grid lists the associated catch from it. Figure 6.39a and b, gives examples of data selected from two different grid squares (colored in yellow). The 'Identity Results' table shows the type of fish caught and the amount of catch in kilograms. In Figure 6.39a the catch record shows 11 different types of demersal species (except tuna) with more than 2 tonnes of each of ribbonfish, sea braise and puffers. The difference between the catch of any selected species can also be displayed as a histogram. In Figure 6.39a the histogram shows the catch differences between four species. In Figure 6.39b, by contrast, four different types of species have been caught, and only one of those, ribbonfish, is over 2 tonnes.

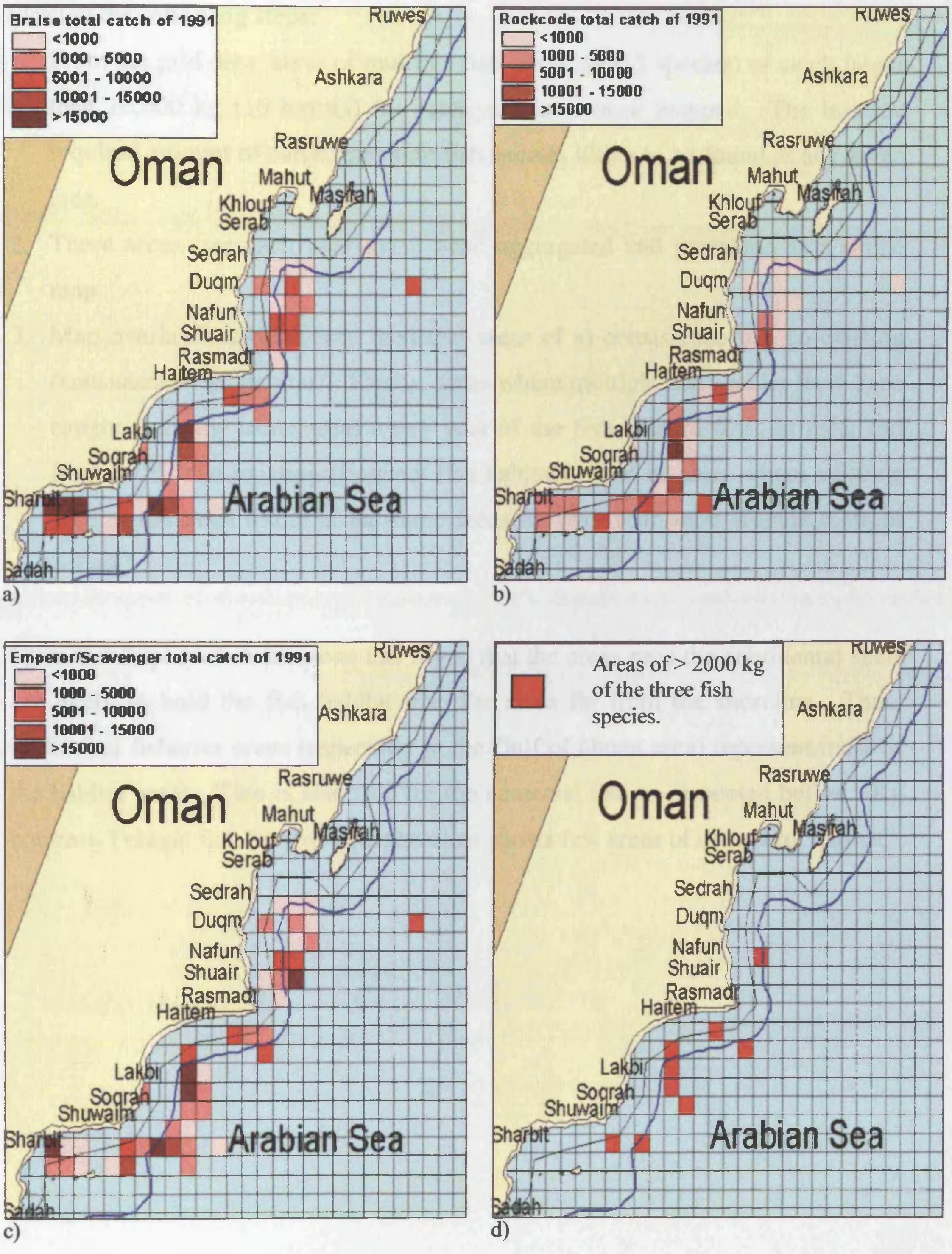
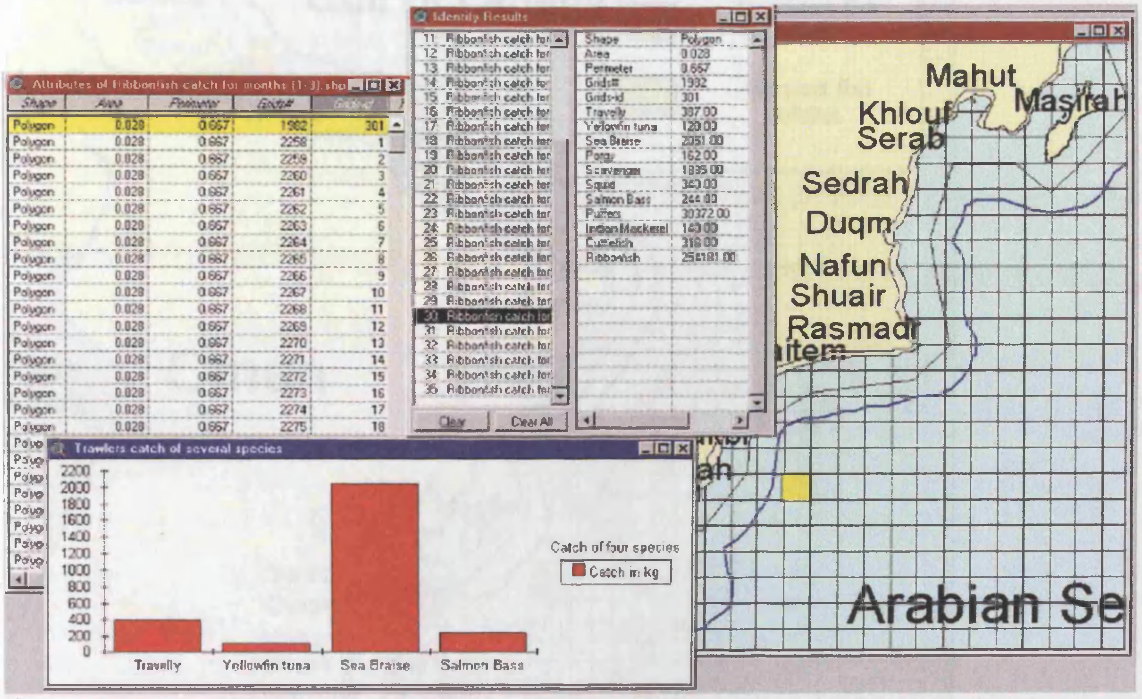


Figure 6.38 Trawlers catch in 1991 of three types of fish species a) Sea Braise (*Cheimerus nufar*), b) Rock cod (*Epinephelus*), and c) Emperor/Scavenger (*Lethrinidae*), d) presents the areas of catch larger then 2000 kg of each type of fish species. These areas are suggested to be a normal habitat areas of all three species and have a high productivity rate.

The method applied for a single year gives limited information. Showing the areas of consistent multi-species catch is of more interest. This has been achieved through the following steps:

1. From the grid data, areas of multiple fish (more then 2 species) of catch larger then 10,000 kg (10 tonnes) for each year have been mapped. The less the required amount of catch, the more fish species likely to be found at any given area.
2. These areas (for each year) have been aggregated and presented as a single map.
3. Map overlay has been used to detect areas of a) consistence fish co-existing (consistence fish habitat). That is, areas where multiple fish species have been caught from the same areas every year of the five (Figure 6.40, in red), and frequent fish co-existing (frequent fish habitat). That is, areas where multiple species has been found at the same areas for two- four years (Figure 6.40, in yellow).

From the displayed results, one can argue that the areas near the continental shelf are likely to hold the fish habitat than the areas far from the shoreline. Thus, traditional fisheries areas (especially in the Gulf of Oman area) represent most of the habitat areas. This is also true for the demersal fish as discussed before. By contrast, Pelagic fish far from the shoreline shows few areas of consistent habitat.



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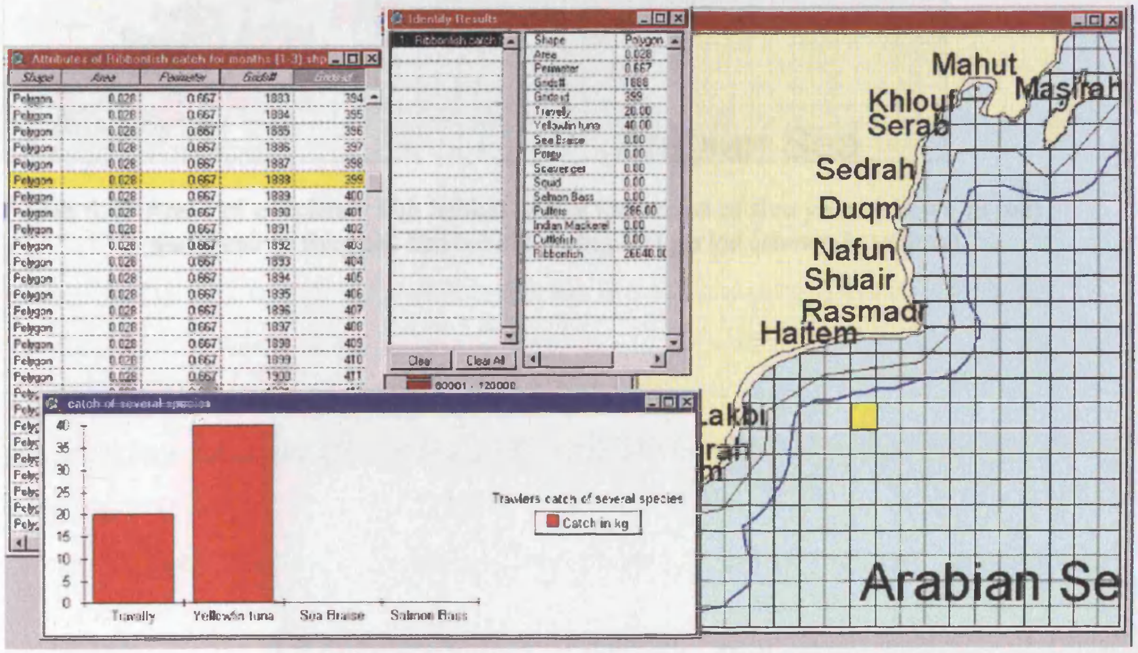

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Figure 6.39 Display of the type of species and amount of catch from each species per selected area of catch for two different grid area a) and b).

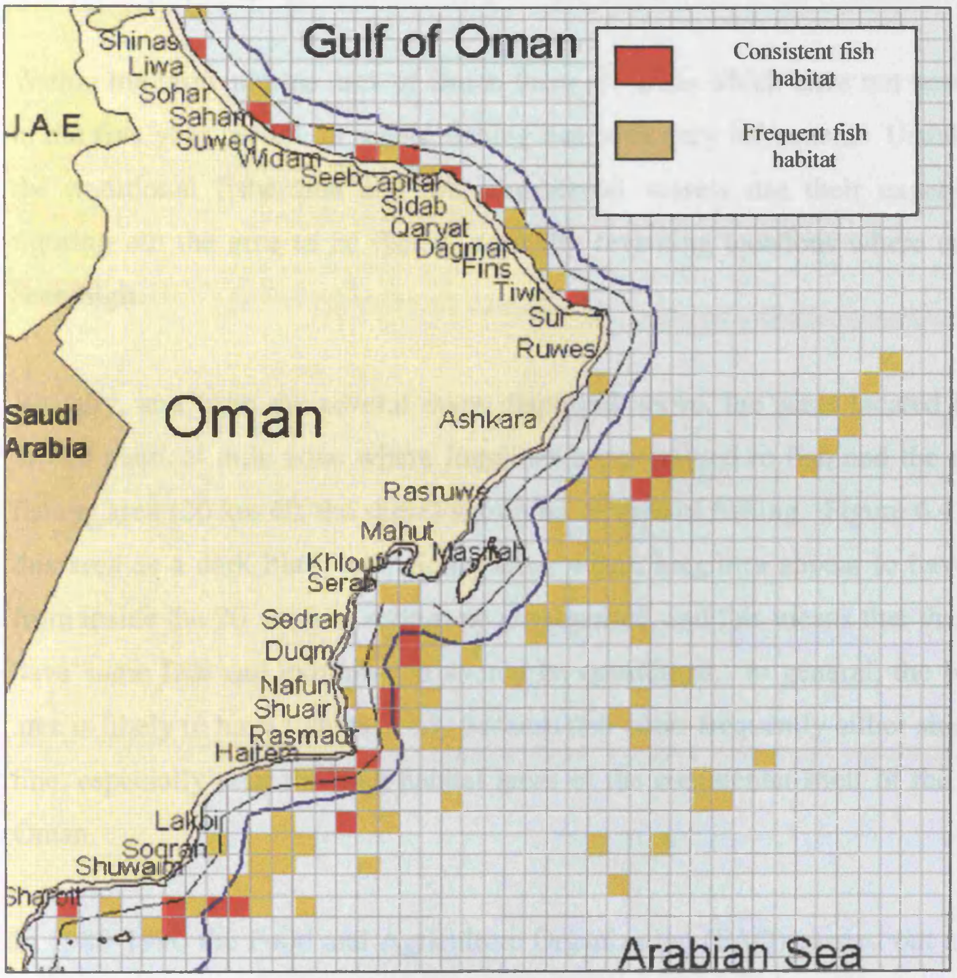


Figure 6.40 Areas of consistent fish habitat during the period of five years (shown in red) and areas of frequent fish habitat during that period (shown in yellow).

10. Mapping Unexploited Areas

Within the large marine area of Oman there are areas which have not been fished in the five year period, or where fishing has been very infrequent. Usually, both the traditional fishermen and the commercial vessels use their experience in figuring out the area to be fished, normally revisiting locations where catch has been high.

Visually, and from the several maps displayed above, the areas located between the 20 nautical mile zone where longlines are permitted to fish and the tradition fishing area (20 km off the shore) shows no records of fishing. Figure 6.41 shows this area as a dark blue line. Some areas where longlines appear to have fished from inside the 20 nautical mile zone are reported, and this means that these areas have some fish and exploitation should be considered. In general, the blue line area is likely to have fish basically because fish occur frequently either side of that line, especially near the high habitat areas of the continental shelf of the Gulf of Oman.

In 1989-1990 the Food and Agriculture Organization (FAO) carried out a project that was designed to assist the government to assess the total biomass, species composition, distribution and potential yield of small pelagic, mesopelagic and demersal fish stocks in Omani waters, but the project focused on the inshore areas rather than the whole area of fishing. The areas between the longlines and the traditional fisheries were not investigated by that project. Using map overlays for the total fish catch of the five years, Figure 6.42 shows three categories of cell. These are:

a) areas where fishing has occured at least in one of the five years are shown in pink,
b) areas which have been fished but with no catch are shown in green, and
c) areas where no fishing has been recorded during the five year period are shown in white.

Most of the areas shown in green, as well as some of the white areas, are located in the middle of areas of catch and some are located within the traditional fishing areas. The appearance of these areas might be because fishing has happened coincidentally (especially for the commercial fisheries). The blank areas on the other hand might be due to the lack of a comprehensive data collection system especially in the areas of the traditional fisheries.

The original government plan was not to allow the large longlines to enter the 20 nautical mile zone because one of the government's future plans is to develop the traditional fishing methods and extend the fishing areas. However, within the past ten years or so, these areas have not been investigated and the amount of fish biomass available is unknown.

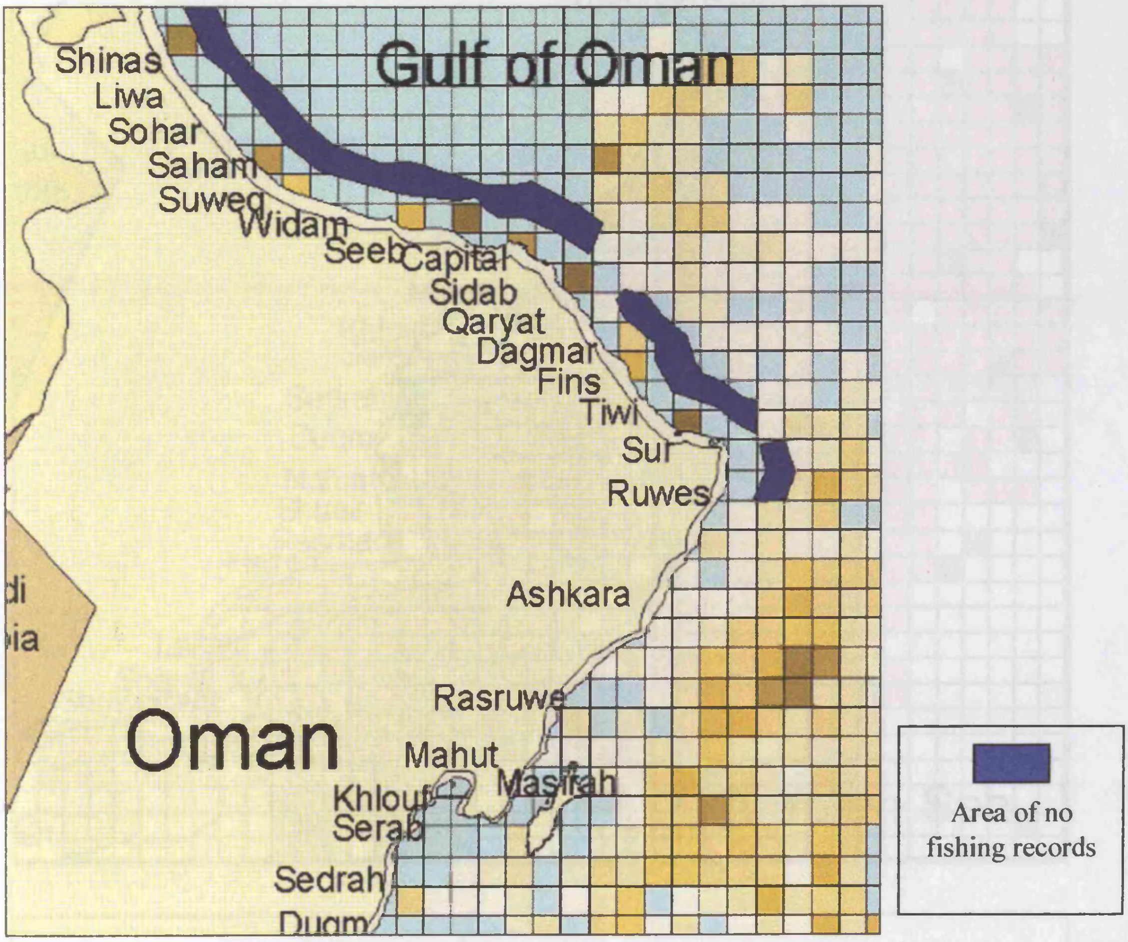


Figure 6.41 Map showing the areas between the longlines and the traditional fisheries where fish data are unknown. The grids data represents areas of catch surrounded the blue line.

Although areas lacking catch in Figure 6.41 and Figure 6.42 might have fish species, that is uncertain since no fishing has been recorded in them. There are, however, other unexploited areas where fishing is allowed. Other areas have catch records associated with them, but only a few as the fishing happens in frequently (less than three times in 5 years). The concern of this section is to investigate these areas.

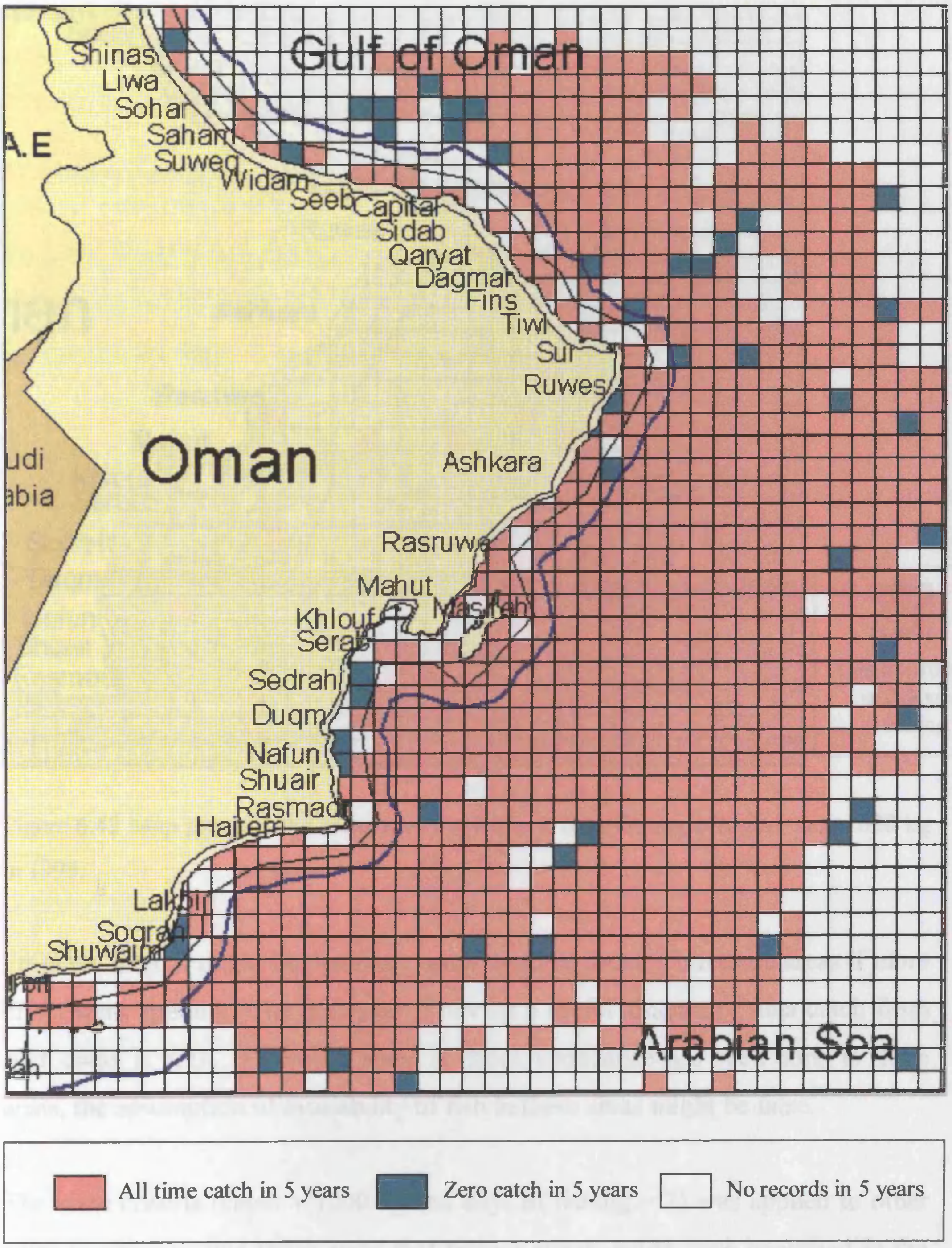


Figure 6.42 Areas of all time catch in five years (in pink), zero catch (in green), and no data (in blank).

The minimum days of longlines fishing per grid per year is found to be equal to 2 days. The catch per grid from the 2 days ranged between 550 kg to 1500 kg with an average of over 1000 kg. To give an example, Figure 6.43 represents areas with catch greater then 1000 kg from 2 days of fishing in 1995.

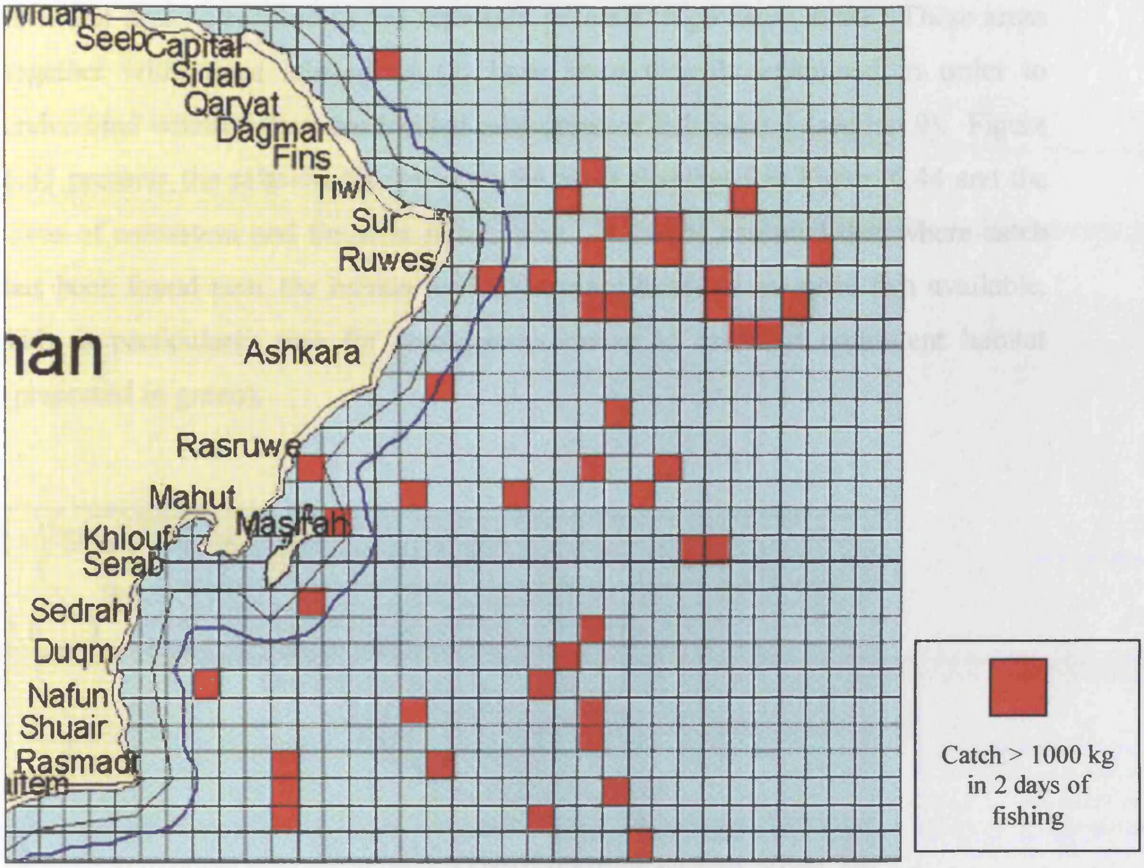


Figure 6.43 Map presents the areas where catch in 2 days fishing is higher then 1000 kg in 1995.

From the map, it might be that more catch could be found from these areas if more effort were applied. The potential of having a useful amount of tuna catch from such areas is high. However, since no stock abundance has been done in these areas, the assumption of availability of fish in these areas might be false.

The same criteria (catch > 1000 kg and days of fishing = 2) was applied to other years in order to find those areas that fishing events could have happened in the same areas but for different years. The results can be summarized as follows (see Figure 6.44):

1. Areas classified as (1) shows areas that have been fished at least once during the five year period.
2. Areas classified as (2) shows areas that have been fished in at least 2 years.

3. Areas classified as (3) displays areas that have been fished for 3 years.

No area appears to have been fished in more than 3 of the 5 years. It is likely then that areas classified as (3) represent potential high catch areas. These areas together with areas labeled as (2) have been visually examined in order to understand whether they are located near areas of fish habitat (section 9). Figure 6.45 presents the relationship between the areas displayed in Figure 6.44 and the areas of consistent and frequent fish habitat. It can be assumed that where catch has been found near the habitat areas, there are likely to be more fish available. This is particularly true for those areas closed to areas of consistent habitat (presented in green).

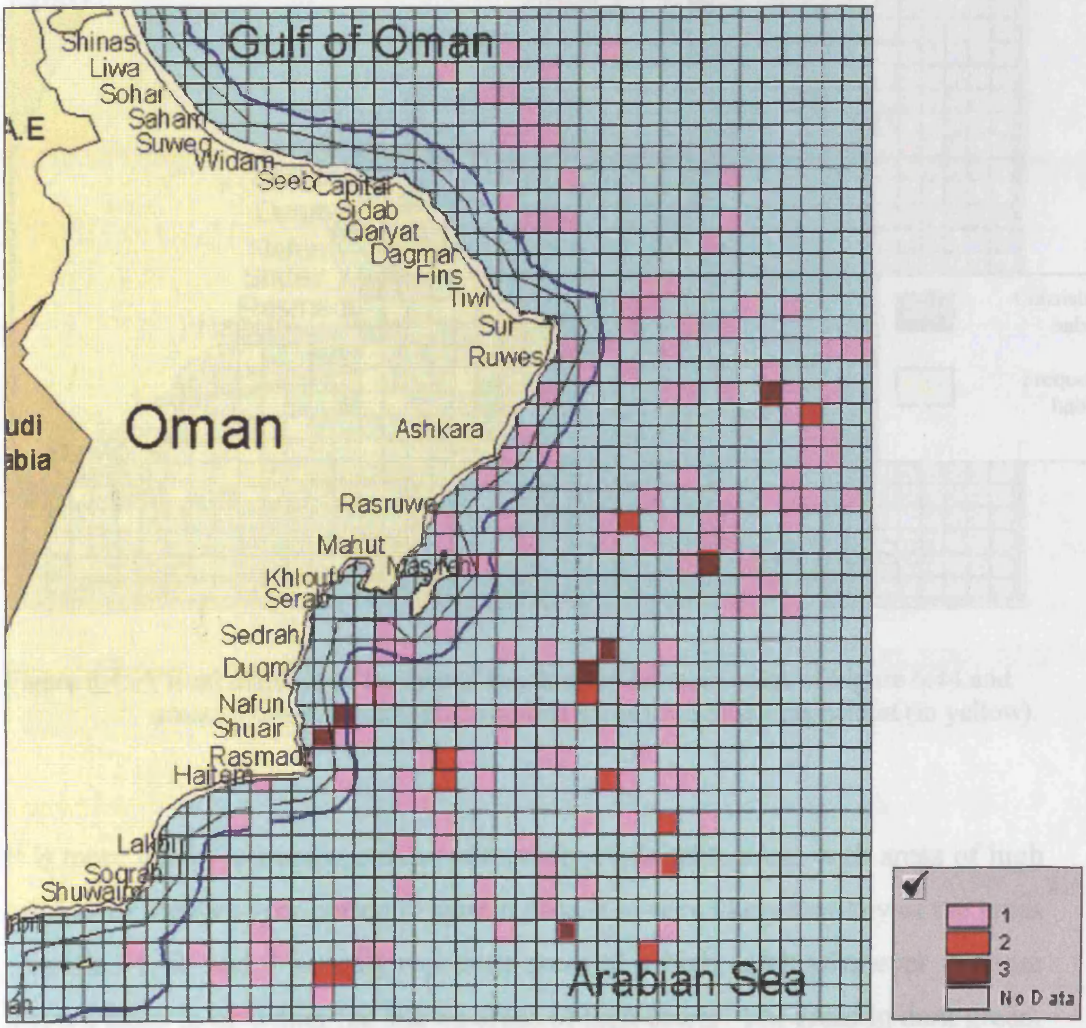


Figure 6.44 The areas of catch more than 1000 kg in 2 days of fishing as classified (1) areas fished in one of the five years, (2) areas where fishing has happen at least in two of the five years, and (3) refers to the areas where catch of fish has happen for three time in five years.

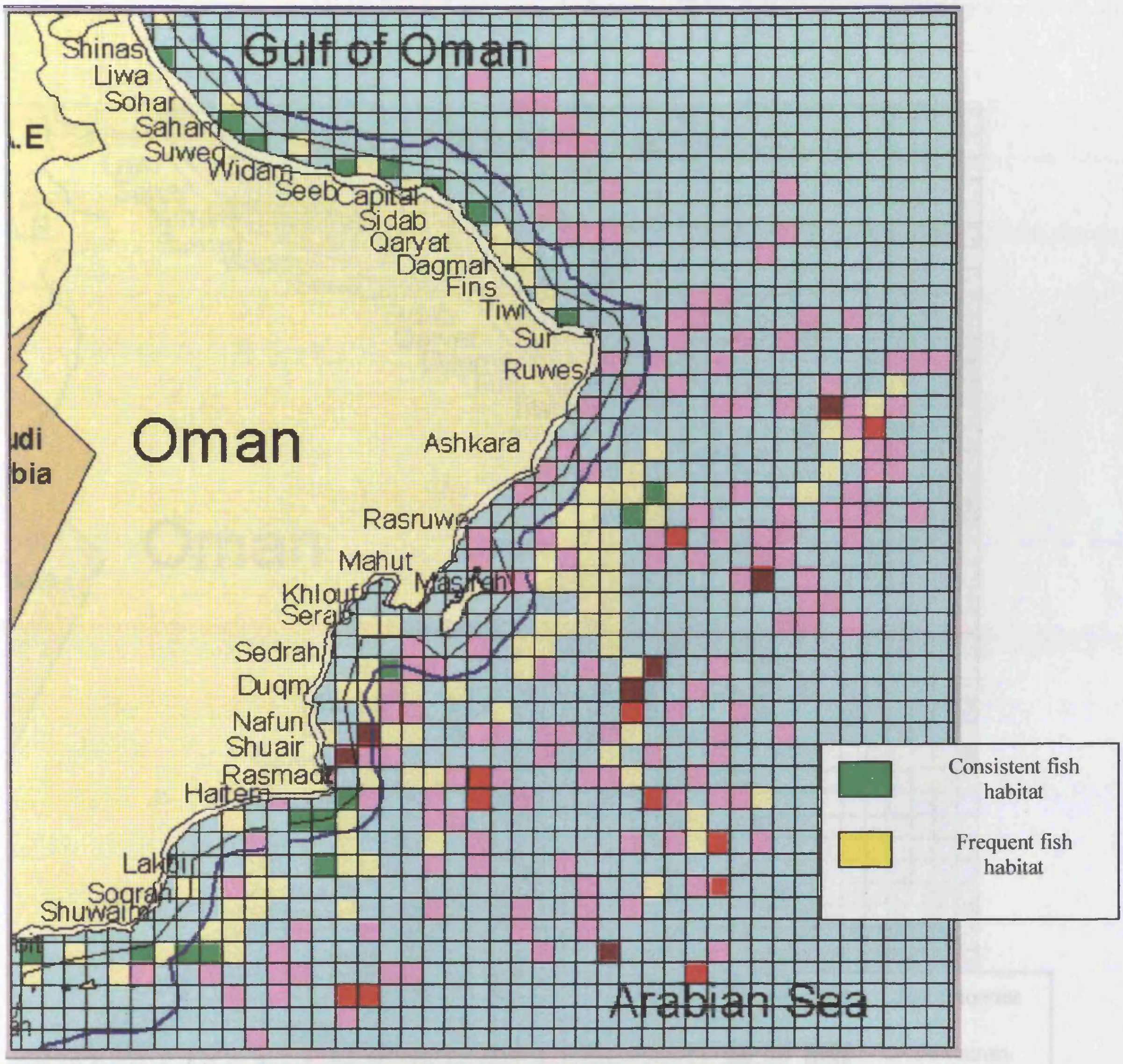


Figure 6.45 Visual displays of the spatial relationship between areas of Figure 6.44 and areas of consistence habitat (in light green) and frequents habitat (in yellow).

It is more useful to compare these potentially exploitable areas with areas of high catch over the five year period (Figure 6.46). It is very likely that any of the areas classified 1, 2, and 3 actually represent areas of a high catch whenever they are located close to or within the known areas of high catch. The areas in dark green, in particular, represent catch of more than 50 tonnes of yellowfin tuna and so any neighbouring areas, especially areas surrounded by high catch are likely to contain the same level of catch. Many of the unexploited areas in Figure 6.46 are either located near one of the areas of high catch or surrounded by them. However, since these are no evidences of such, these areas might contain no fish at all, or might be difficult to fish from.

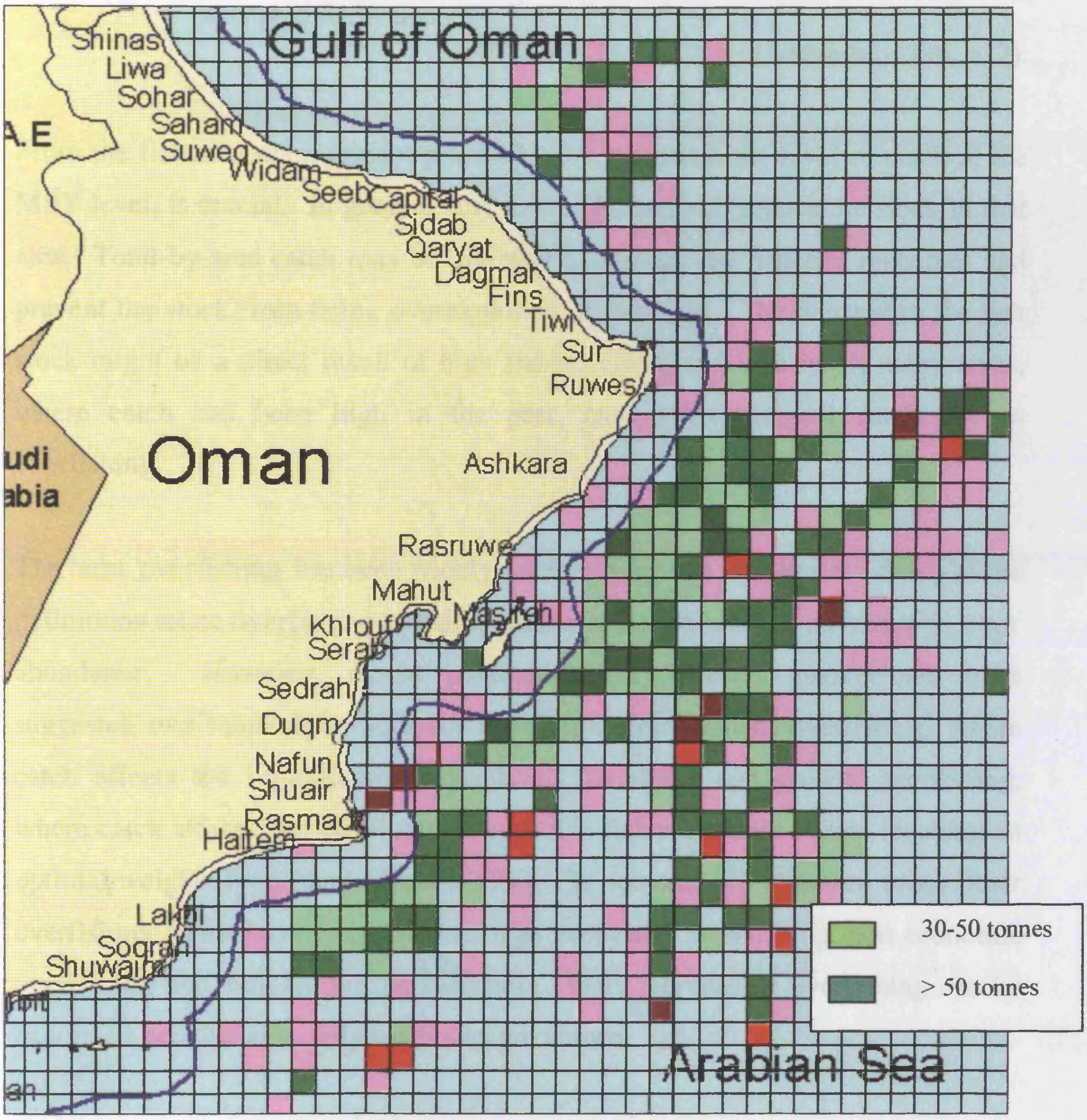


Figure 6.46 Visual displays of the spatial relationship between areas of Figure 6.44 and areas of high catch (30 to 50 tonnes in light green, and >50 tonnes in dark green).

11. Mapping Suspected Areas of Overfishing

> The term 'overfishing, is often found in the fisheries literature in connection with fisheries management, implying that the objective of fisheries management is to prevent overfishing. The term overfishing is, however, subjective and has no exact, universally accepted definition
>
> (Laevastu, 1996, p32).

From the fisheries management point of view, to sustain the level of catch at the MSY level, is crucial. In general, any sort of fishing will reduce the stock in that area. Total-by-area catch may be one way to manage the fisheries resources and prevent the stock from being overexploited or damaged. The damage to the fish stock might be a direct result of high fishing effort, and as a result many areas, where catch has been high in the past, may suffer reduced catch due to overfishing.

The term 'overfishing' has been widely used with regards to fisheries. Some of the definitions relate overfishing to fish mortality rate even without reference to stock abundance. However, recent publications in fisheries management have suggested two main definitions for overfishing: recruitment overfishing, where catch affects the reproduction capacity of the stock, and growth overfishing, where catch affects fish development such that fish are caught before reaching an optimal weight (Fréon and Misund, 1999). In some of the literature many other overfishing terms have been used such as ecosystem overfishing, and economic overfishing but they are not pursued here. Only recruitment overfishing can be examined here because only catch data are known.

Overfishing has been examined by studying the areas where high catch has been recorded in the past and then declined sharply in the following year while fishing effort remains the same. Specifically, those areas where catch from 1991 to 1994 has been high and dropped sharply during the year 1995 are mapped since the main objective of mapping areas suspected of overfishing is to prevent that areas from more damage and further stock collapsing in the following years.

Figure 6.47 shows the area of high catch and high effort in 1991 to 1994. Since there are four maps overlaid the areas of the recent years are superimposed on those of the previous one and so, the blue colour, for example, which refers to areas of high catch and effort in 1994 may overlay areas of high catch and effort in previous years. The point here, however, is to map those areas with high catch and high effort in any of the four years.

The maps showing in Figure 6.47 has been overlaid by the map of low catch (or no catch at all) and high effort for the year 1995. In order to show those areas that have experienced a sudden decline in the amount of catch, effort has been chosen to go over the average number of fishing days, i.e. more than 20 days of fishing in 1995.

Figure 6.48 projects only those areas that have appeared previously with high catch and a consistent effort of over 20 days of catch and in 1995 the catch has dropped sharply enough to raise a suspicion of damage to stock. However, this could be not the case since stock sizes in these areas are not known. More investigation should be carried out to determine the level of damage to these areas.

For fisheries managers, these areas should be placed under a rehabilitation program and should be restricted from fishing for some period of time. The period required for the stock to return to its previous level depends on the amount of damage. Once the production reaches its normal level, catch and effort should then be controlled at all times to the ideal level. However, these areas of Figure 6.48 are isolated and in the case of an immigrant species like yellowfin tuna, any action is probably difficult. In general, these conclusion are based on the available data and their output, however, the total catch of yellowfin tuna shows no evidence of overfishing. These areas, however, can be crucial if overfishing is found in multiple neighbouring grids.

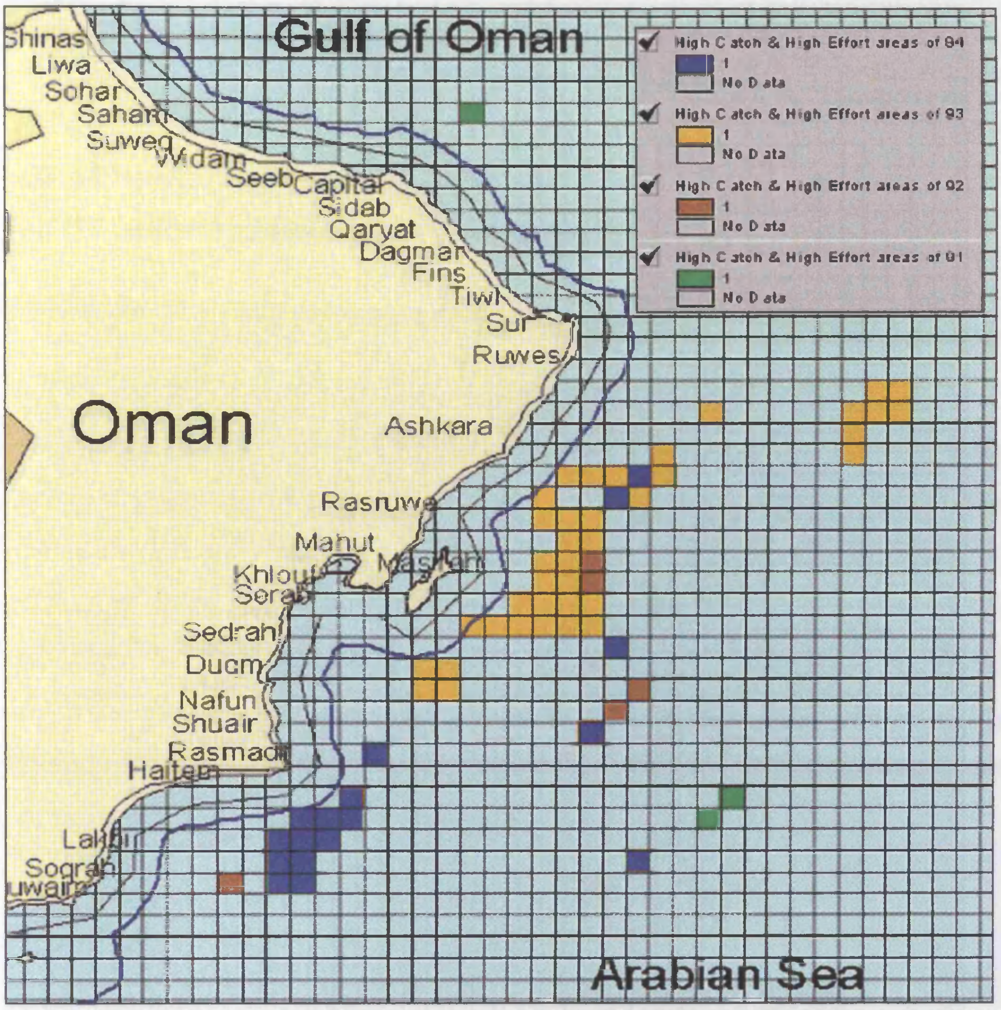


Figure 6.47 Areas of high catch from catch data of 1991-1994 period by colours: green for 1991, brown for 1992, orange for 1993, and blue for 1994

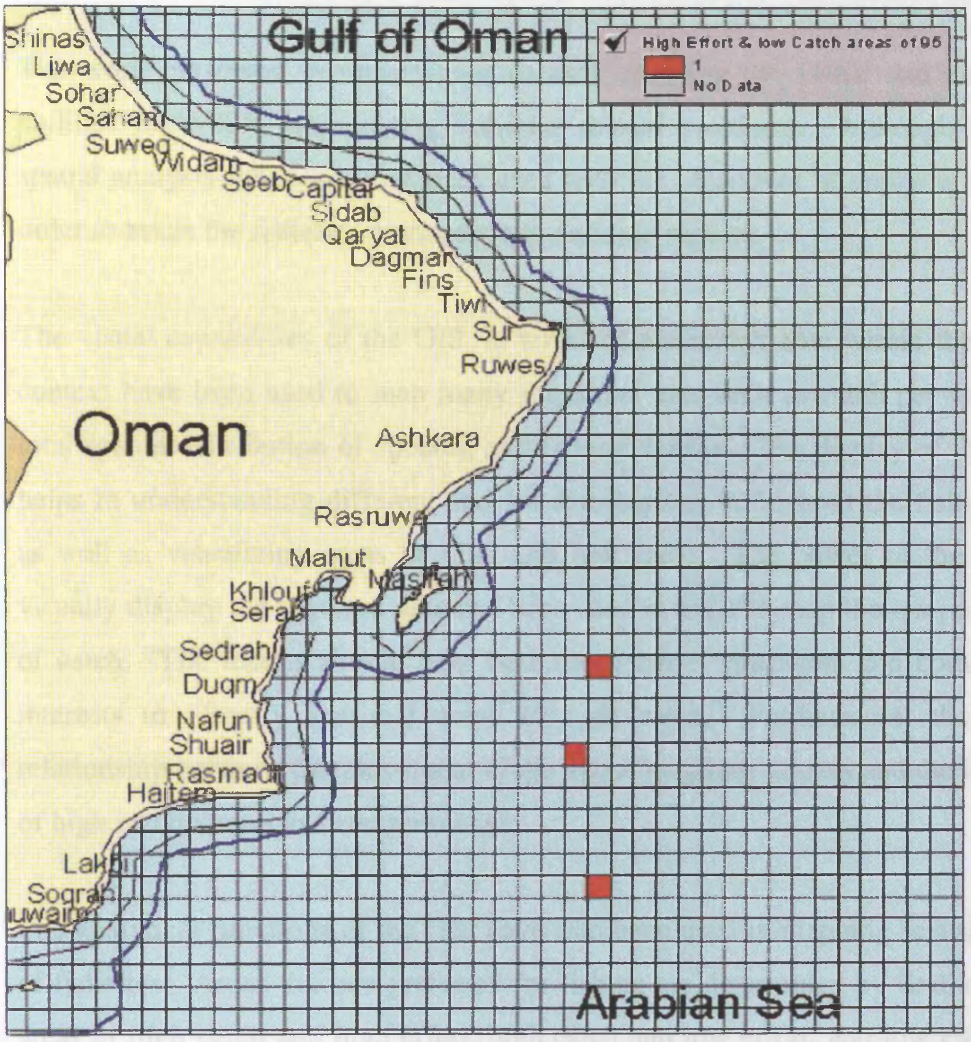


Figure 6.48 Areas suspected of overfishing in 1995. The three areas had a high catch in the previous four years and dropped sharply in the 1995 with the same fishing effort applied to all.

Areas that are suspected of being overfished are critical for the managers and decisions makers, since all polices and regulations are based on the idea of maintaining the catch level as well as protecting the resources from overexploitation. Consequently, effort in terms of vessels horsepower and capacity must be known for better understanding of stock sizes in these areas.

12. Summary and Conclusion

The work presented in this chapter focuses on using the visual and analytical abilities of a GIS for assisting fisheries related problems. Although limited, spatial analysis functions have been used with the objectives of applying them in order to assist the fisheries managers and decision makers.

The visual capabilities of the GIS, in terms of presenting data within the spatial context have been used to map many important data such as catch per unit area, total spatial distribution of species, and fishing density. The display of the catch helps in understanding different species distributions throughout the fishing area as well as visualizing areas of high and low catch. The power of the GIS to visually display the required data has been used in order to map the temporal data of catch. The results should help both the fisheries managers and commercial interests to identify seasonal areas of high catch. Furthermore, the visual relationship between the movement of the major longlines vessels and the location of high catch areas has been presented.

The analytical functions of the GIS have also been used in mapping several areas of fisheries. Areas that are preferred for fishing are determined by finding these areas of high catch and high effort, high catch and low effort, and low catch and high effort. Expected areas of catch and the amount of catch per unit grid have been presented too.

A similar method was used to map the unexploited areas, where catch has been less than the real potential of the areas. In contrast, areas that have been overexploited in 1995 have been identified. These results should certainly help fisheries managers to increase the fishing effort in the first areas (unexploited) and to reduce or stop fishing from the second areas (overexploited or suspected of overfishing).

The main conclusion that can be drawn from the work presented in this chapter, is that using the GIS to both, display and analyze the spatial data would certainly help the managers towards a better understanding of the condition of the available fish stocks in different areas. As a result, better management of fish resources may be achieved. It is apparent that, when fisheries information systems are integrated within a GIS it provides a temporal and spatially distributed view of the information, which is richer than those provided by manual and statistical packages, and that fisheries management systems would therefore benefit from using this technology in both estimating the stock size and applying new regulations.

7

HYDRO-BIOLOGICAL DATA AND MARINE FISHERIES GIS

"Of the ocean features believed to influence tunas directly or indirectly, the most important are considered to be temperature, oxygen, and food supply (zooplankton)"

(Maul, G et al. 1984, p.470)

1. Introduction

The purpose of this chapter is to investigate the relationship between fish catch and the hydro-biological or marine data in general, and to explore GIS integration with these data in particular. Although the initial research has focussed on the catch data, there are two main reasons for including a chapter on hydro-biological data. First, since marine organisms depend on environmental factors, it is essential for the GIS to include such data. Second, since the introduction of GIS into Omani fisheries management is recommended, and the Marine Science and Fisheries Centre (MSFC) in Oman has started a long-term project of collecting daily marine data, both types of data (catch and marine data) can be integrated right from the beginning. The GIS fisheries management system, from the fishery managers point of view, will be a more powerful tool if it includes many types of related data. Knowing that sea surface temperature plays a major role in the lives of fish, it is essential to record these together with the catch data. The relationship between sea surface temperature and other marine data are discussed too since sea surface temperature effects the levels of some other marine variables like oxygen and salinity. In marine biology, in general, if the water temperature is known then several environmental parameters (marine data) can be predicted.

In the marine environment, the habitat of the organisms and the hydrographic factors are considered as the vital parameters which control the primary productivity and they in turn control the secondary producers followed by the higher trophic levels in the food chain of the sea.

Obviously, marine organisms rely on several environmental factors. Temperature, salinity, Dissolved Oxygen (DO) and zooplankton are some of very important factors that the fish species depends on and are discussed here. GIS techniques enable the establishment of the relationships between seawater quality and the amount of fish caught or fish biomass to be found in certain areas (D'Amours, 1993; Cushing, 1995). It would be useful to include many other factors when studying the relationship between marine water quality data and the catch distribution such as water colour content, turbidity, sea current, and data from coral reefs and sea grass beds, those data are not readily available, however.

In this chapter, only data for 1995 are highlighted and discussed. This is because, the ongoing project of collecting marine data was only begun at the end of 1994. Section 2 explains the characteristics of the available marine data. Section 3 discusses sea surface temperature and its relationship with catch. Sea surface temperature is one of the key factors in the life cycle of fish. Section 4 explores the relationships between salinity and sea surface temperature, on the one hand and fish catch on the other. Section 5 examines the relationships between dissolved oxygen, temperature and amount of catch. Section 6 discusses the concentration of zooplankton biomass and how that effects the rate of catch.

2. Characteristics of the Available Data

Figure 7.1 shows the point locations where the water data have been collected and recorded. Hydro-biological data were collected from different parts of the national seas, both from the Gulf of Oman and the Arabian Sea. Starting at the end of 1994, hydro-biological surveys were made, utilizing all the available conveyances from opportunistic to regular time series surveys by fishing boats and departmental boats. Hydrographic parameters were measured by hydrolab (Model SVR 2-SV) in the surface waters as well as from a few different depths. The hydrolab can be used to measure the hydrographic parameters within the ranges of the following: Temperature -5 to +45°C; DO 0 to 200mg/l; Depth 0 to 100m. Zooplankton samples were collected horizontally from the surface waters by bongo nets of 80 and 200 μ mesh size respectively and vertical open haul for zooplankton was made at certain times by 200 μ mesh size nets from 5 meters above bottom to the surface in the shelf waters.

These data collected from all parts of the region covering the whole 1,700 km coastal stretch of Oman. Most of these data are concerned with waters 1-50 meters deep, and so can only be discussed in relation to the pelagic fish since demersal fish live deeper than 50 meters within the continental shelf area. However, there are very few records concerns depths deeper than 50 (varied between 2 to 5 records per month at different areas), the general discussion on the relationship between depth and marine data is included throughout this chapter. At the same time, these data were collected from the continental shelf, which make it difficult to include catch data from the commercial longlines which fish in deeper water.

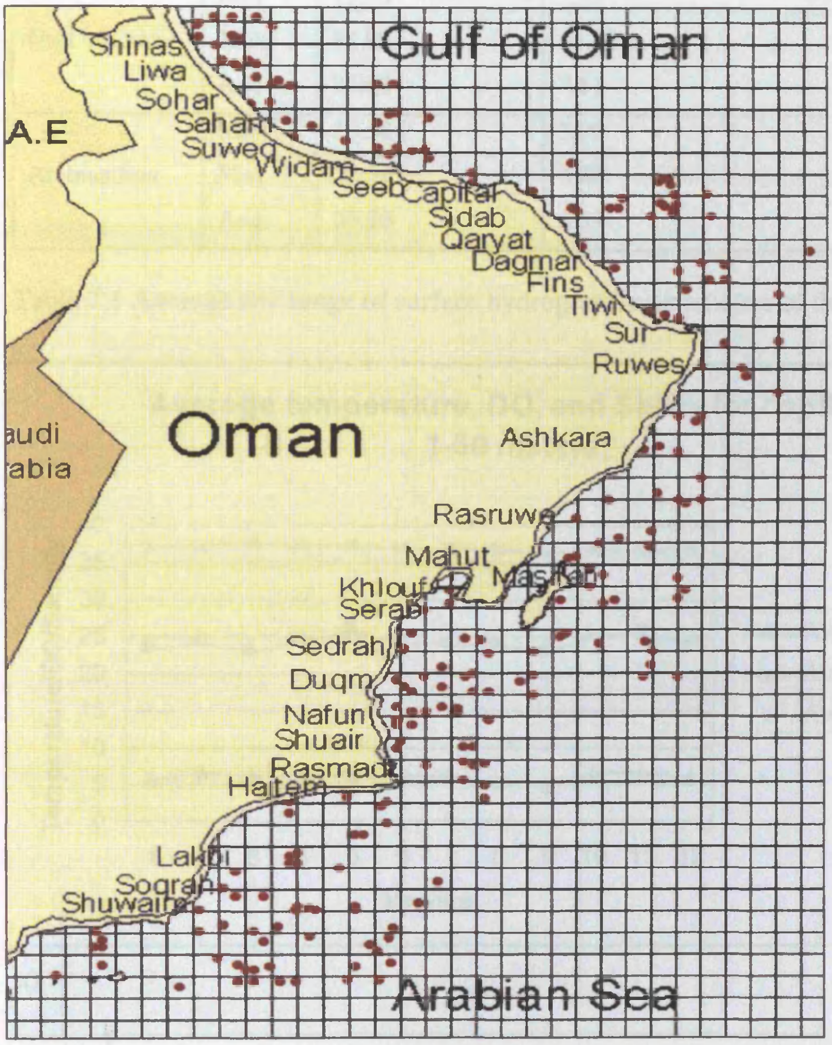
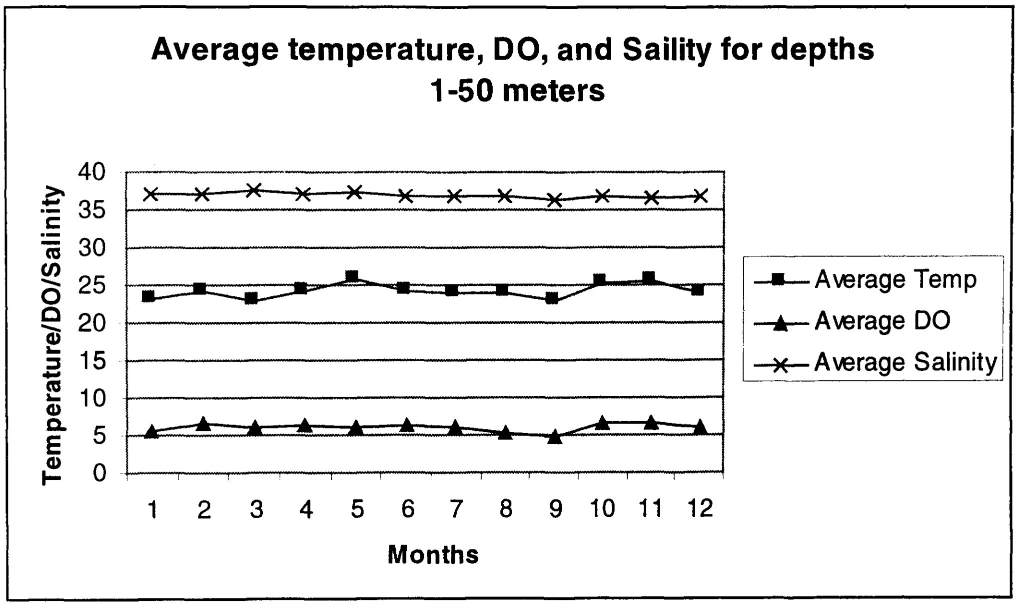


Figure7.1 Point data locations for the hydro-biological data collected during the year of 1995. From each point, data of sea surface temperature, salinity, dissolved oxygen, and zooplankton were collected.

For the purposes of this study, most of the data have been collected from the Marine Science and Fisheries Centre (MSFC) but also from some other institutes and Ministries involved in marine studies such as the Ministry of the Environment. Data from both seas (the Gulf of Oman and the Arabian Sea) of the Omani waters are varied and discussed separately with regards to marine data and catch. Table 7.1 shows the average surface hydrographic parameters of the two seas in 1995. In general, the monthly relationships between sea surface temperature (1 to 50 meters), salinity and dissolved oxygen are shown in Figure 7.2. The figure illustrates the average reading of each type of data per month in all sea area of Oman at two different depths: 1-50 meters and 50-100 meters.

Sea area	Range	Temperature (°C)	Dissolved Oxygen (mg/l)	Salinity (oo/o)
Gulf of Oman	Min	19.79	5.57	36.5
	Max	31.95	10.19	38.9
	Ave	25.63	7.51	37.0
Arabian Sea	Min	19.58	3.99	36.0
	Max	32.59	8.08	37.7
	Ave	24.20	6.59	36.7

Table 7.1 Average and range of surface hydrographic parameters of the areas off Oman.



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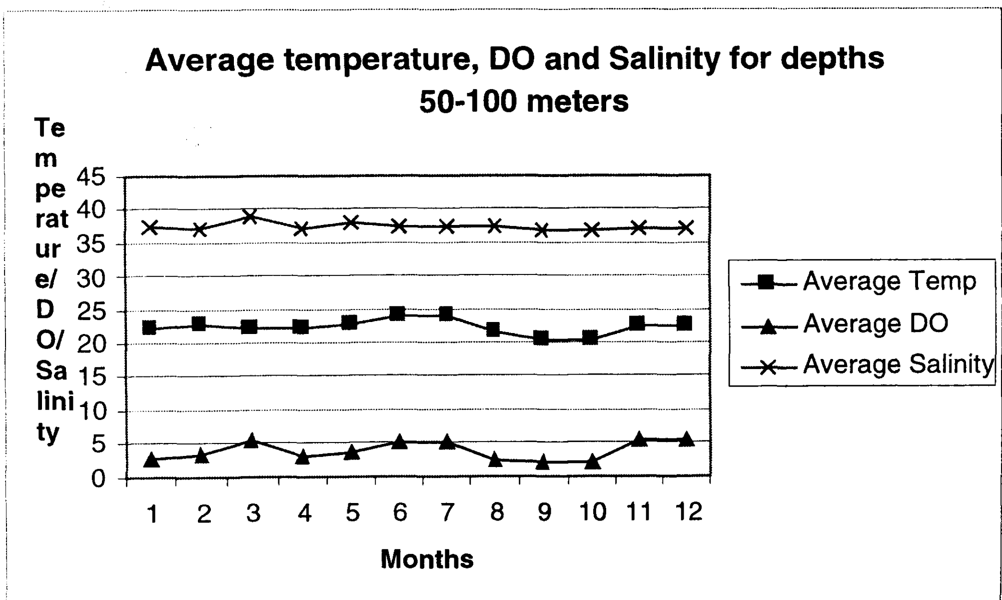


b)

Figure 7.2 Monthly average of sea surface temperature (°C), DO (mg/l), and salinity (o/oo) for depths a) 1-50 meters, and b) 50-100 meters.

3. Sea Surface Temperature

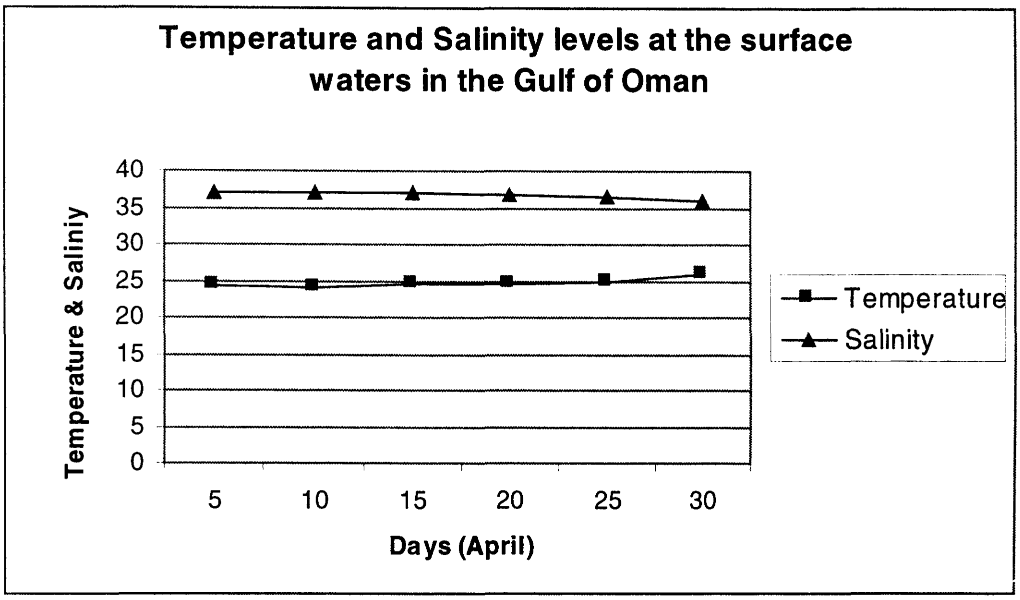
3.1 General Overview

Survey trips were made mostly in the months of March, April, and August 1995. The surface water temperature of the Gulf of Oman varied from 19.79 to 31.74°C with the mean temperature of 25.63 °C. From the few reading of the other months however, the temperature was between 29.14 °C and 31.95 °C in June and August. Few readings have been taken in the 4th quarter of the year, with an average temperature between 28.1 °C and 32.59 °C in October and November respectively. Figures 7.3 and 7.4 shows the level of sea surface temperature (for the Gulf of Oman and the Arabian Sea) during selected months of April and August together with the level of salinity which will be discussed in section 5.

The vertical distribution of temperature was measured at different depth intervals and depicted in Figure 7.5 of depths 1-100 meters. The water temperature declined uniformly as the water depth increased. There was a temperature difference of 10 °C from surface to 100 meters depth at some locations.

In the Arabian Sea (Figure 7.4), the surface temperature varied from 19.58 °C to 32.77 °C with the mean temperature of 24.20°C. The lowest temperature was recorded on 29th March and the highest on 10th August. The relationship between water temperature and depth is shown in Figure 7.5.

Although data for sea surface temperature are available world wide through many international organizations such as NOAA (the US National Oceanographic and Atmospheric Administration) and FAO Fisheries Data Centre of the UN in Rome and others, only those data outlined above were used in this study. This is because these data are more accurate in terms of locations and measured at different depths, which are applicable for more analyses.



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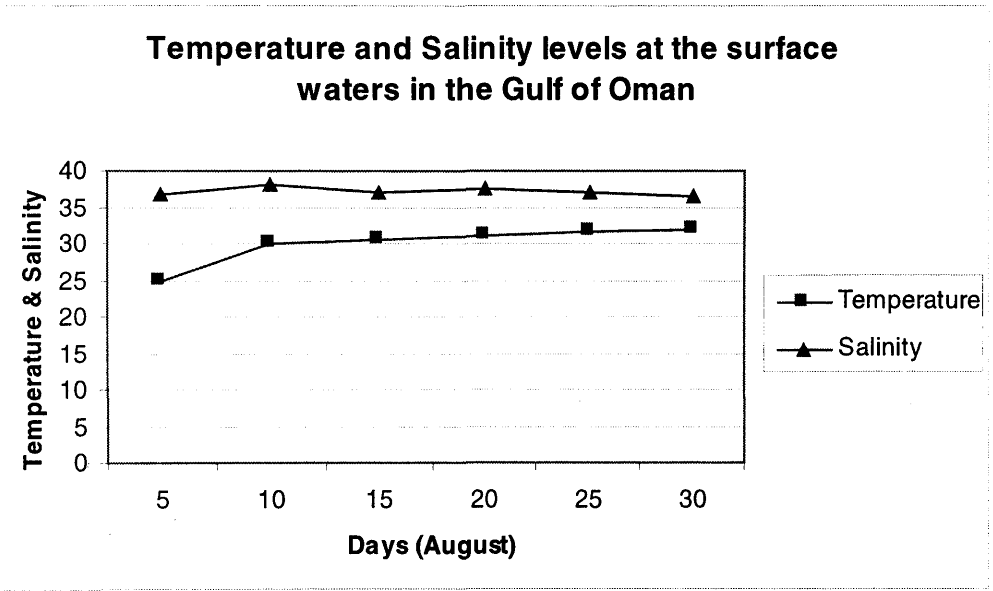

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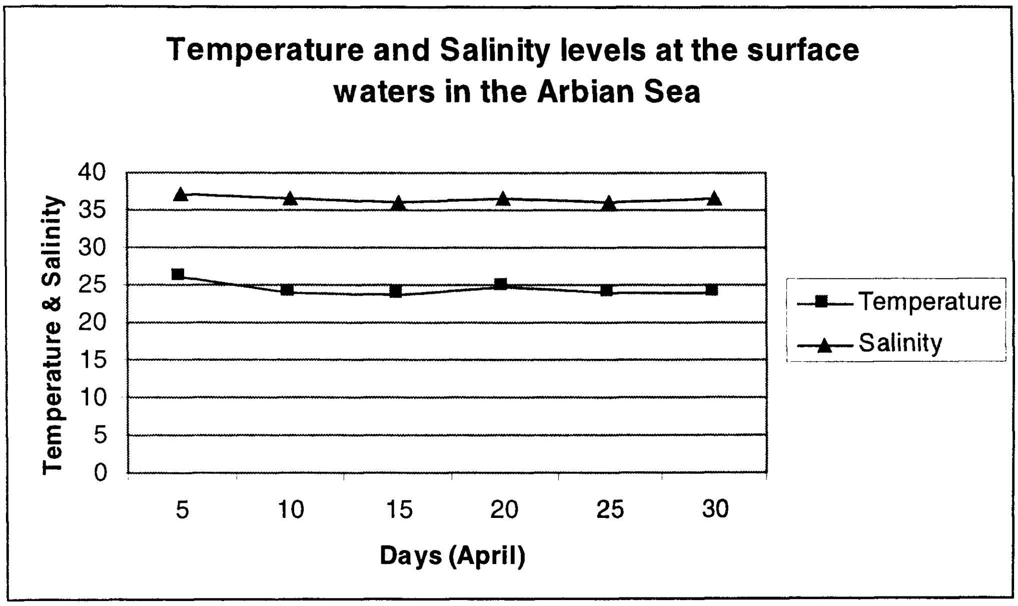
Figure 7.3 Temperature (°C) and Salinity (oo/o) levels at the surface waters in the Gulf of Oman a) for April, and b) for August.



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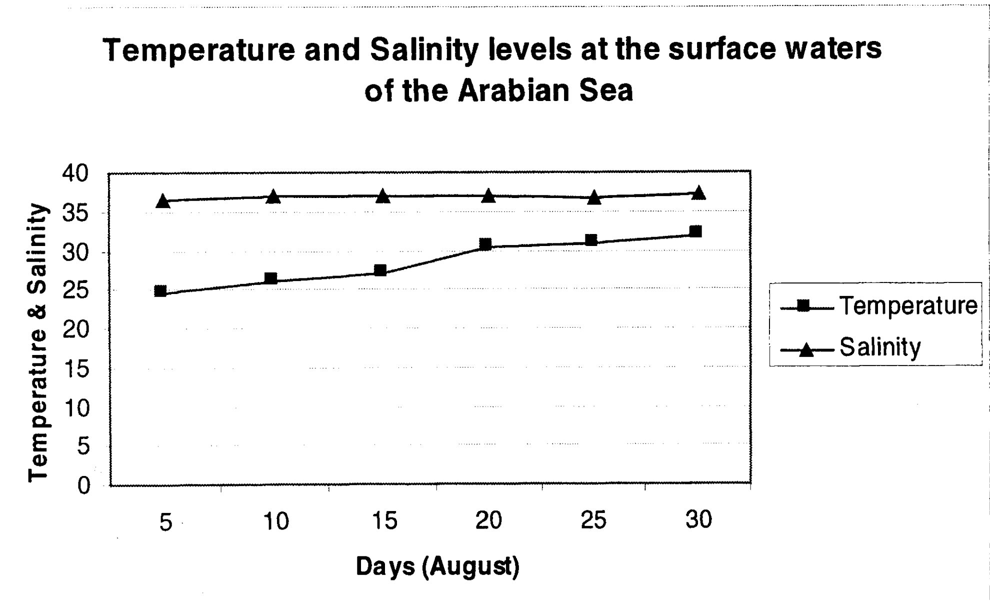
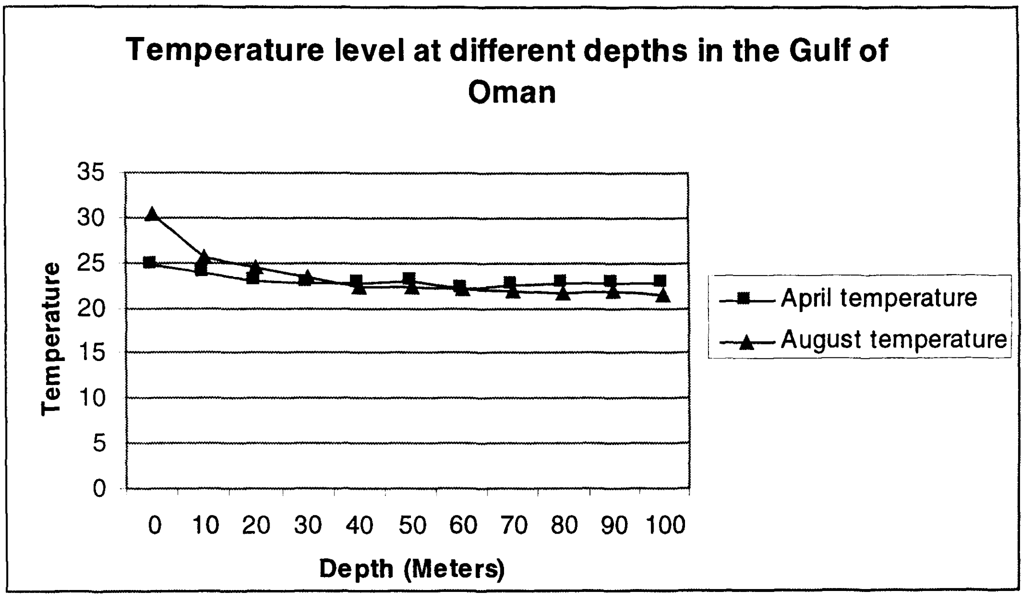
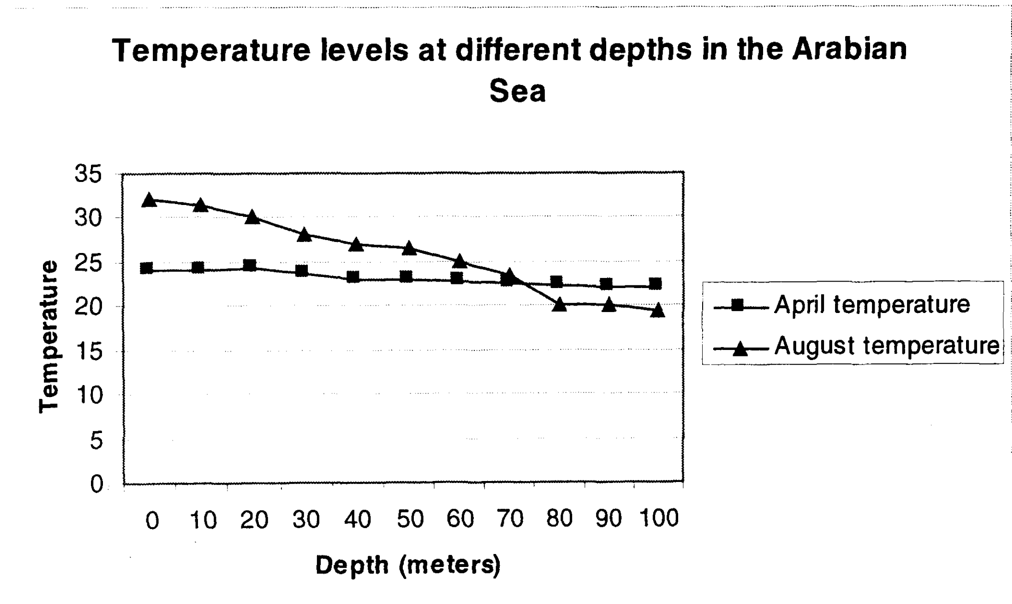


b)

Figure 7.4 Temperature (°C) and Salinity (oo/o) levels at the surface waters in the Arabian Sea a) for April, and b) for August.



a)



b)

Figure 7.5 Temperature (°C) levels at different depths (in meters) in the a) Gulf of Oman, and b) Arabian Sea

3.2 Relationship between Sea Surface Temperature and Catch

The relationship between sea surface temperature and fish distribution has been widely studied (e.g., Blackburn, 1965; Sharp, 1978; Sund et al. 1981; Holland et al. 1990; Esconmids and Vogiatzis, 1992; D'Amours, 1993; Cushing, 1982, 1995). The conclusion from almost all of the studies is that fish species are sensitive to temperature. Although they are ectotherms, they are nevertheless able to thermoregulate by selecting appropriate water temperature and avoiding those that are harmful. A precise knowledge of habitat is of primary interest for tuna fisheries because tuna have an extremely wide distribution in the open oceans and perform rapid horizontal and vertical migrations; they are therefore difficult to locate. Most pelagic species are able to detect temperature variations as small as 0.1C (Hoar and Randall, 1979) as is confirms by comparisons between satellite images and the location of tuna catches (Stretta and Petit, 1989).

More recent studies show that even with a wide water temperature range where fish are distributed, there is a narrower range for optimal catches (Stretta and Petit, 1989; Castillio and Gonzalez, 1996; Holland *et al.*, 1990; Freon and Misund, 1999). Table 7.2 shows the value of sea surface temperature that effects the existence of the yellowfin tuna, for example.

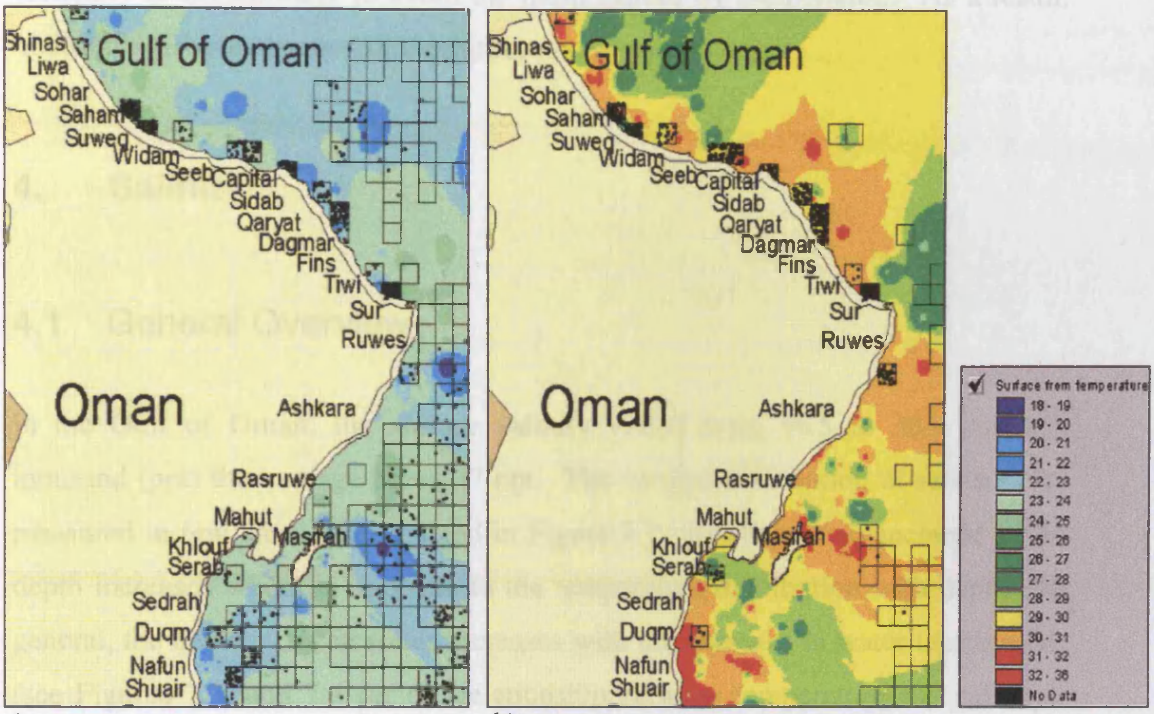
Species	Minimum lethal Temperature (°C)	Temperature of highest catch	
		Surface	Deep longline
Yellowfin	14	24-30	19-22

Table 7.2 Effect of sea waters temperature on yellowfin tuna species: lethal temperature (the lowest water temperature which will support live tuna, average temperature in the distribution area and temperature in areas of highest catches according to the gear[1]. (adapted from Freon and Misund, 1999).

Figure 7.6 displays the distribution of average sea surface temperatures for April and August of 1995. The dots in the figure show the yellowfin tuna catch for the same period of time. The tuna catch has been selected for the same areas as the marine data. Each dot represents 10000 kg (10 tonnes) of tuna catch. Only the

[1] Gear refer to methods of fishing

area near the coastline is shown for which there is marine data. The map of April can be visually compared to that of August. Although there was considerable effort indicated by empty grid squares, especially of longlines, there is very little catch.



a) b)

Figure 7.6 Relationships between average sea surface temperature (background) and yellowfin tuna catch (dots) during a) April, and b).

Water temperature is believed to have a significant effect on the existence of yellowfin tuna, and as a result, usually, during the hot season, the catch of tuna both from the longlines and the traditional fisheries (in total) declines. However, the suggestion from these displays is that yellowfin tuna in Omani water may have different temperature sensitivities to these described in Table 7.2. There is still catch of tuna at temperatures over 31 °C. The temperature might be lowered locally, on the other hand, due to the upwelling that occurs in this area at this time.

From the figures it can be suggested that the decline in longline yellowfin tuna catch during the 3rd quarter of the year (July to September) was actually due to the high sea surface temperature. Since yellowfin tuna is a pelagic species and so affected more by the sea surface temperature, this study of the relationships is certainly more appropriate with the longlines tuna. The reason for the high catch by the traditional and low catch from longlines can be explained with regards to the method of catch. Basically, longlines use surface longlines to fish, and so their catch is effected directly by sea surface temperature, whereas traditional fisheries use a variety of methods (especially handlines, pole and line). In case of high surface temperature, as mentioned previously, tuna tends to migrate either vertically or horizontally to avoid the harm caused by temperature. As a result, traditional fishermen can still catch those in deeper water.

4. Salinity

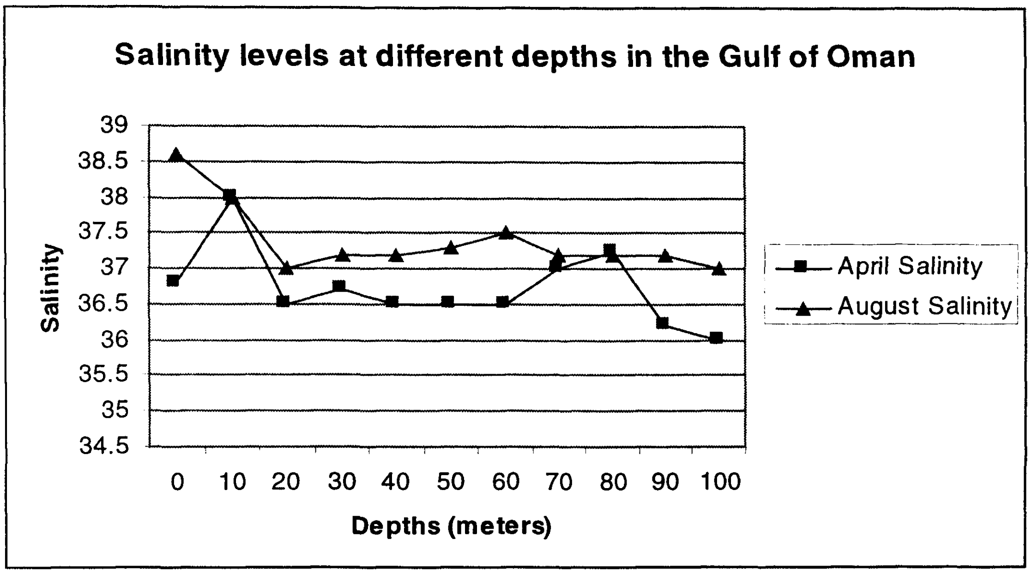
4.1 General Overview

In the Gulf of Oman, the surface salinity varied from 36.5 to 38.9 part per thousand (ppt) the average being 37 ppt. The vertical distribution of salinity was measured in few areas and depicted in Figure 7.7. Salinity levels increase as the depth increases which is opposite to the temperature distribution with depth. In general, the density of sea water increases with the decrease in water temperature (see Figures 7.3, and 7.4 for the relationship between temperature and salinity). The influence of salinity on habitat selection might be complex especially during spawning.

The spatial distribution of salinity indicates a high surface salinity at the entrance of the Gulf of Oman, near the area of 'Sur'. This means an area of mixing water and so a high level of salinity.

In the Arabian Sea, the surface water salinity was ranging from 36 to 37.7 ppt with the mean of 36.7 ppt. The lowest level (36 ppt) was measures in September whereas the highest level (37.7 ppt) was measured in December.

The salinity concentration levels were measured from surface to deep layers of waters and the maximum depth measured in this area was 100 meters (Figure 7.7). In deep waters, however, fluctuating levels were also noticed due to the mixing of different layers of waters at different depths.



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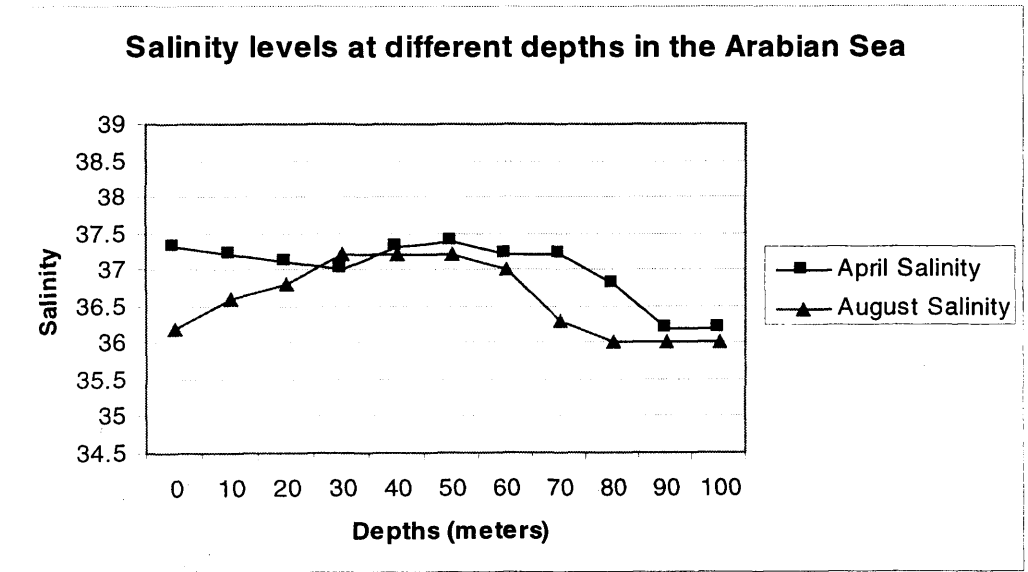
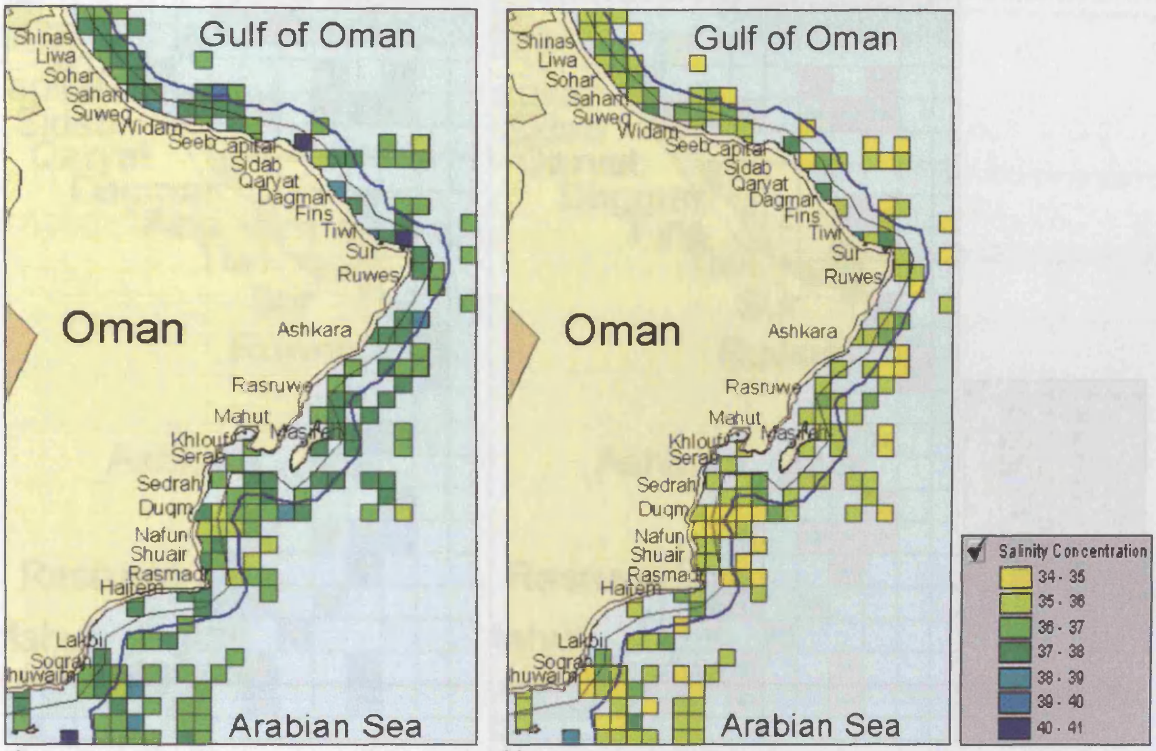


b)

Figure 7.7 Salinity levels at different depths in the a) Gulf of Oman, and b) Arabian Sea

4.2 Relationship between Salinity and Catch

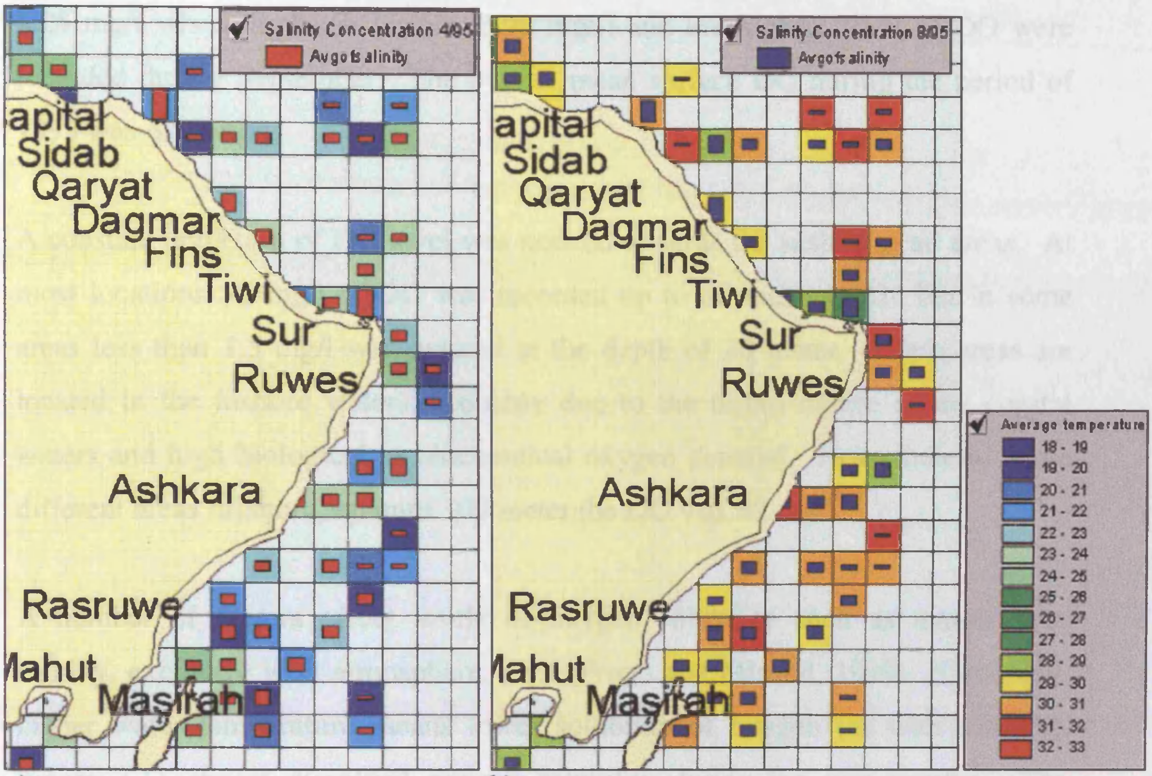
In general most of the main commercial fish stocks (especially pelagic) develop their whole life history in sea water where the salinity is generally over 32 ppt. Figure 7.8 represents the average surface salinity per grid during April and August. Salinity, however, does not seem to directly influence the distribution and behavior of the most common commercial species of tuna within the range of their usual habitat (Stretta and Petit, 1989). In all cases it is difficult to distinguish the role of salinity from the role of the associated factors of water like temperature, zooplankton (Reid et al. 1997).



a) b)

Figure 7.8 Average salinity (per grid per month) distribution during a) April and b) August.

Salinity as a factor should not be studied alone since it more or less depends on water temperature. Although their relationship is usually considered a complicated one, it can be seen in Figure 7.9 that temperature and salinity are directly proportional; in areas where temperature is found to be high salinity is usually low.



a) b)

Figure 7.9 Relationships between sea surface temperature and salinity (in several grid areas) during a) April and b) August. The red and the blue rectangle shapes represent the levels salinity in both months.

5. Dissolved Oxygen

5.1 General Overview

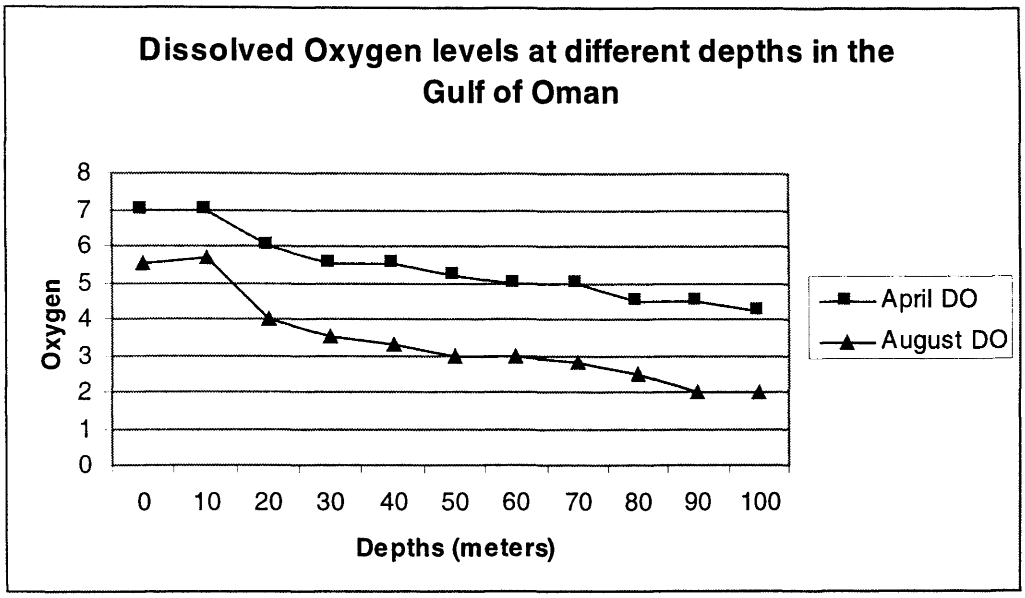
Dissolved Oxygen (DO) in surface waters of the Gulf of Oman between March and May was measured as 5.57 and 10.19 mg/l with the mean value of 7.51 mg/l, whereas between June and August was 5.31 and 7,87 mg/l, and October and November 4.65 and 6.90 mg/l respectively. The level of DO decreases as the depth of water increases (Figure 7.10).

The vertical distribution of dissolved oxygen was measured and steadily decreases with depth in some areas while in a few areas little fluctuation was noticed with depths. Both in winter and summer in most of the areas the water was well oxygenated and found the DO level was >2 mg/l. at 100 meters.

The DO levels in the surface waters of the Arabian Sea was between 3.99 and 8.08 mg/l where both the lowest (3.99 mg/l) and the highest level of DO were recorded during September. The overall mean surface DO during the period of 1995 was 6.59 mg/l.

A constant depletion of DO level was noticed towards the seabed in all areas. At most locations >2 mg/l of DO was recorded up to 60 meter depth, but in some areas less than 1.5 mg/l was noticed at the depth of 20 meter. These areas are located in the inshore waters, probably due to the turbid nature of the coastal waters and high biological or biochemical oxygen demand. Nevertheless, at the different areas offshore, up until 100 meter the DO was >2 mg/l.

A number of factors effect levels of oxygen solubility such as temperature, salinity, exchange with atmosphere, etc. (Freon and Misund, 1999). Generally, higher water temperature means lower solubility of oxygen (as with salinity). Figure 7.11 shows dissolved oxygen solubility during the two months. The observation from the two displays is that oxygen solubility is higher when the temperature is low (April).



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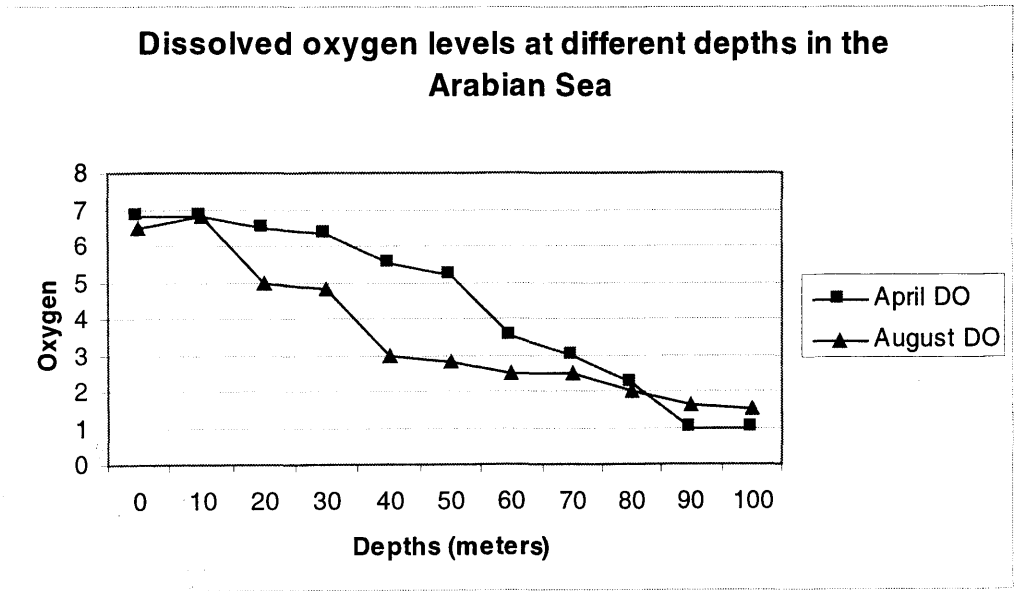

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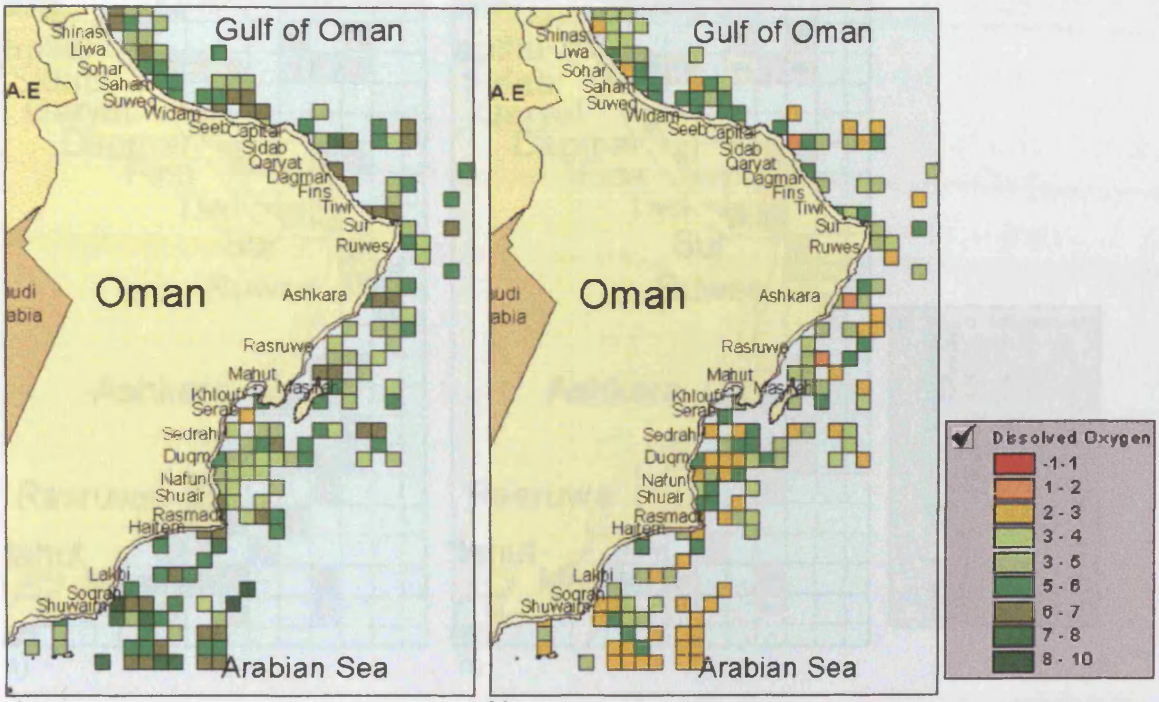
Figure 7.10 Dissolved oxygen levels (in mg/l) at different depths in the a) Gulf of Oman, and b) Arabian Sea



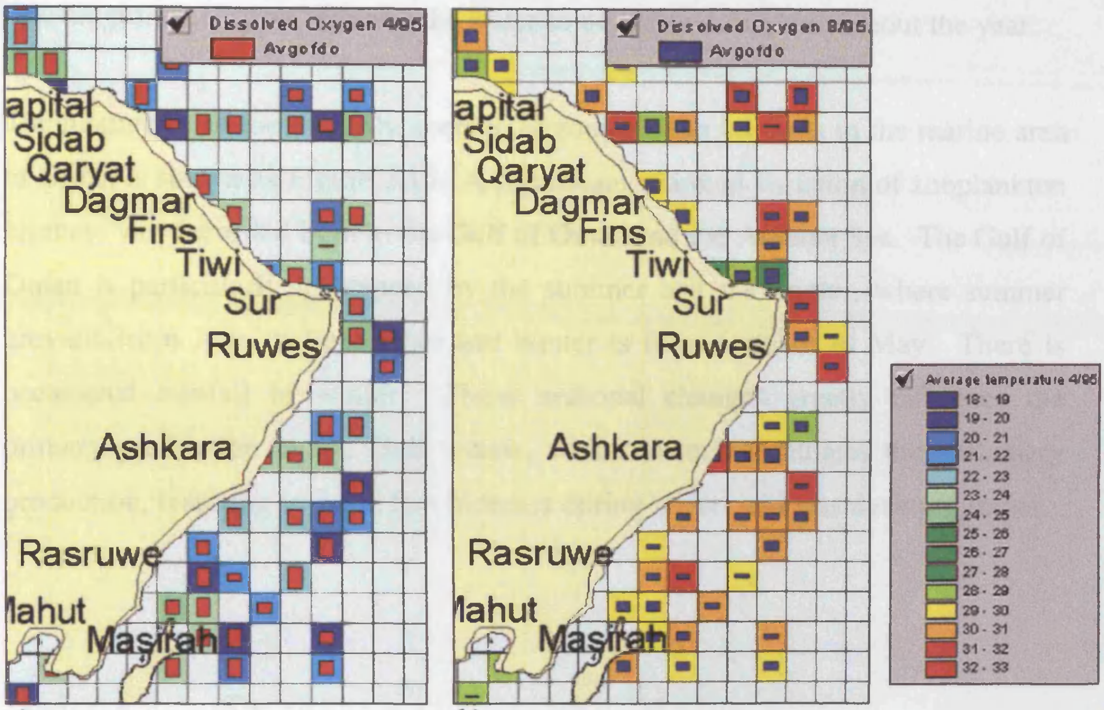
a) b)

Figure 7.11 Level of dissolved Oxygen (in mg/l) during a) April and b) August

5.2 Relationship between Oxygen, Temperature and Catch

Figure 7.12 shows the relationship between temperature and dissolved oxygen per gird areas. Generally, the solubility of oxygen increases with a lowering of water temperature.

Yellowfin tuna are sensitive (decrease of heart rate) to reduced oxygen values between 4.3 and 3.6 mg/l, although their lethal concentrations are estimated at 2.1 ml/l. Pelagic fish mortality is rarely observed due to their quick ability to changing their habitat and/or behavior in response to lower oxygen levels (Freon and Misund, 1999).



a) b)

Figure 7.12 Relationship between sea surface temperature (background grids) and dissolved oxygen (small boxes, in mg/l) for a) April and b) August

6. Zooplankton

6.1 General Overview

Zooplankton serves as a direct food for fish and marine mammals. Figure 7.13 gives an example of typical zooplankton organisms. Zooplankton concentration is one of the major factors determining fish occurrence (Maul et al. 1984; Thangaraja, 1992).

Recent atlases on zooplankton biomass of the Indian Ocean, as based on the data collected by the International Indian Ocean Expedition (IIOE), indicates high zooplankton concentrations in the northern and western parts of the Arabian sea, in particular. The highest biomass of zooplankton was found near the Gulf of Oman. Figure 7.14 shows the biomass distribution drawn originally by Qazim, (1977) and others, and levels are believed to have remained at similar levels since. In addition to that, Sharma (1988) analyzed the historical oceanographic data off

Oman waters, supplied by World Oceanographic Data Center (WODC), Washington D.C., and reported the water to be nutrient rich throughout the year.

The histogram of the monthly average of zooplankton biomass in the marine area of Oman is shown as Figure 7.15. A significant seasonal variation of zooplankton biomass was recorded both in the Gulf of Oman and the Arabian Sea. The Gulf of Oman is particularly influenced by the summer and the winter, where summer prevails from June to September and winter is from October to May. There is occasional rainfall in winter. These seasonal changes greatly influence the primary production in the Gulf waters, which in turn stimulates the secondary production, resulting in more fish biomass during winter and less during summer.

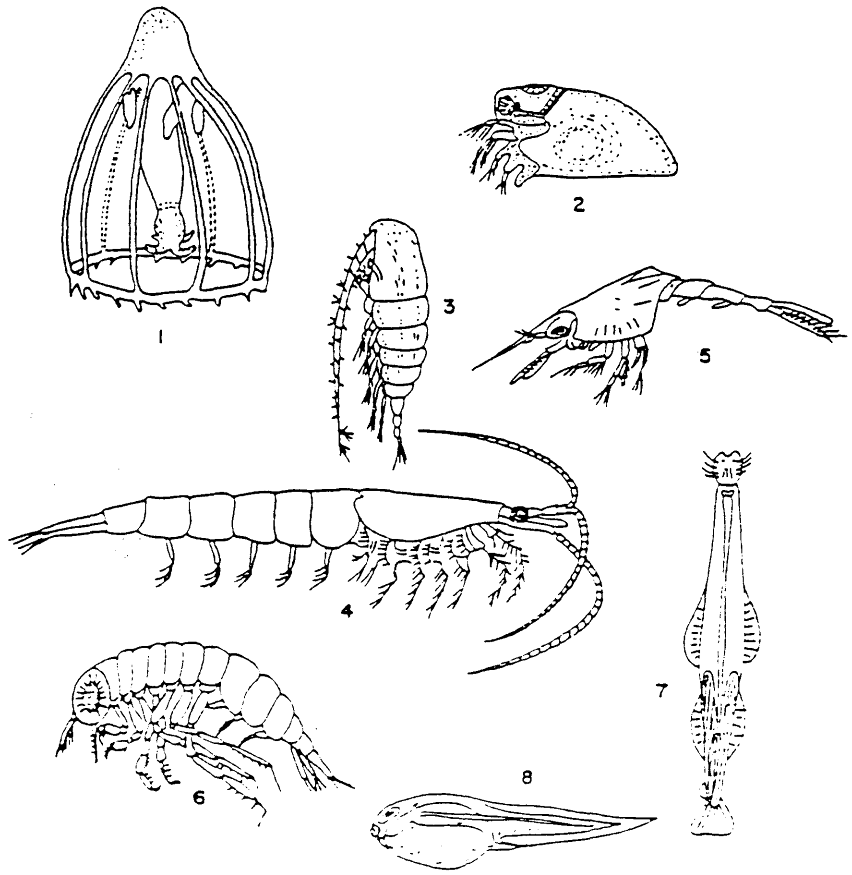


Figure 7.13 Examples of zooplankton organism (enlarged 10-100 times) (1) *Aglantha digitalis* (O.F.Muller) (Hydroza); (2) *Evadne nordmanii* (Loven) (Cladocera); (3) *Calanus finmarchincus* (Gunner) (Copepoda)(larva); (6) *Thermisto abyssorcum* (Boeck) (Amphipoda); (7) *Sagitta elegans* (Verrill) (Chaetognatha); (8) *Pleuronectes flesus* (L) (Pisces) (Larva). (from Laevastu, 1996)

The Arabian Sea has its own seasonal pattern, which is quite different from the Gulf of Oman. The southern part of Oman is greatly influenced by the southwest monsoon winds which cause seasonal upwellings on the southern coast of Oman in the Arabian Sea which brings the nutrient rich bottom waters to the surface and causes an enormous production of phytoplankton and zooplankton in the following months.

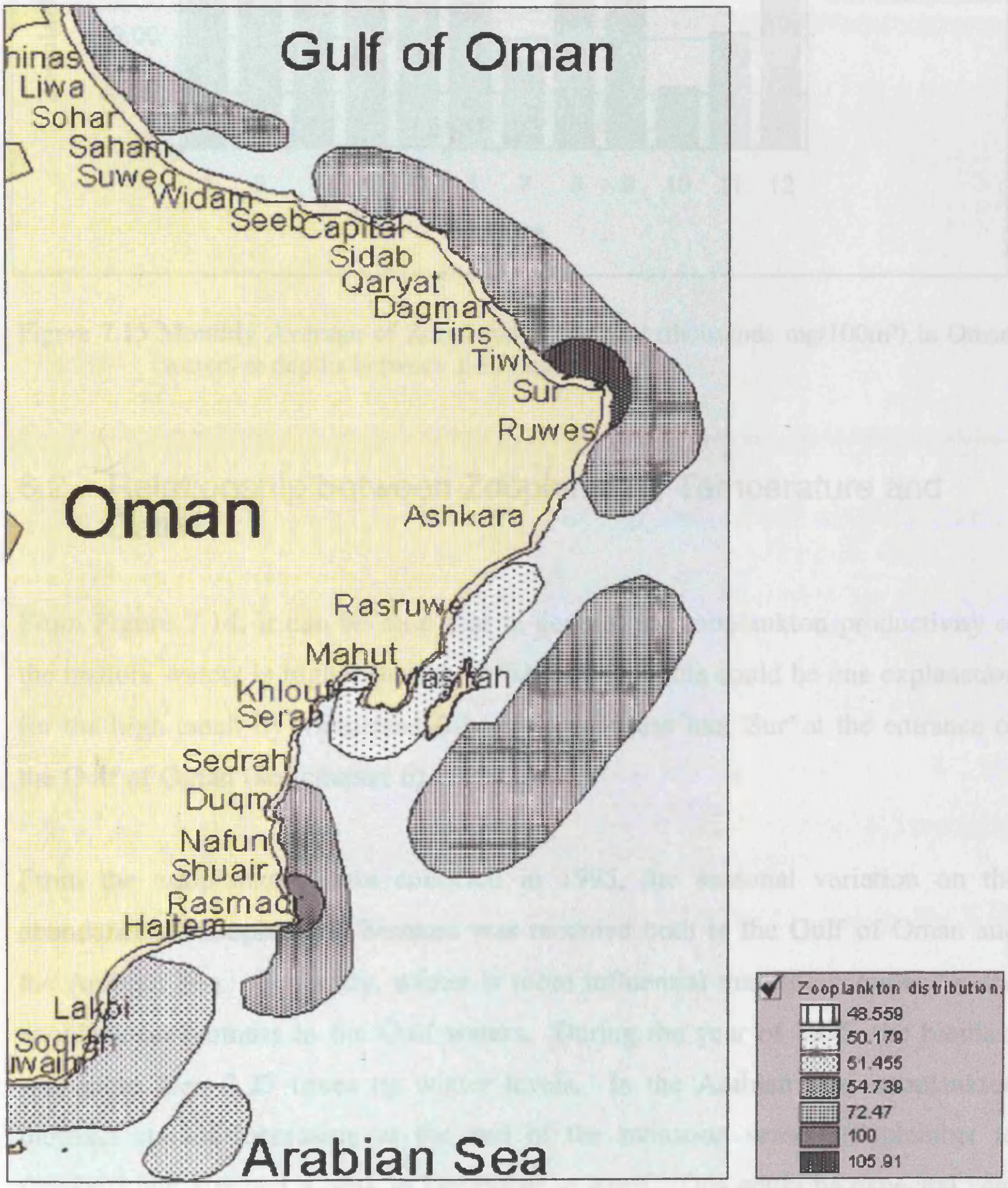


Figure 7.14 Annual average zooplankton biomass (thousand mg/100m³) as studied and described by Qazim (1977) and several other researches.

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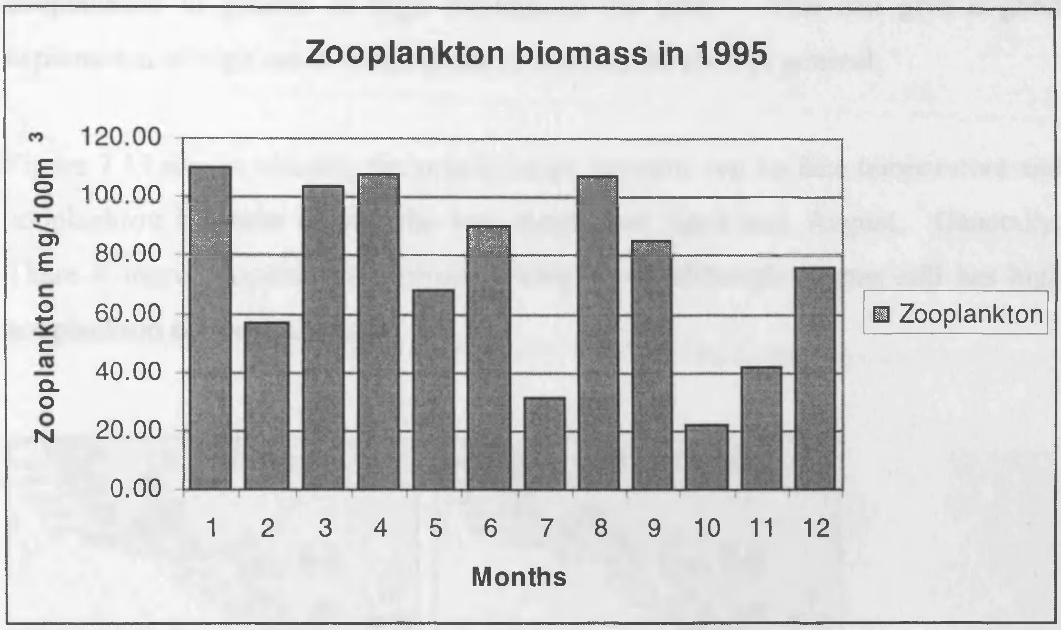

Figure 7.15 Monthly Average of Zooplankton biomass (thousands mg/100m³) in Omani waters at depths between 1-50 meters.

6.2 Relationship between Zooplankton, Temperature and Catch

From Figure 7.14, it can be seen that in general the zooplankton productivity of the inshore waters is higher then the offshore one. This could be one explanation for the high catch by traditional fisheries from areas like 'Sur' at the entrance of the Gulf of Oman (see chapter 6).

From the zooplankton data collected in 1995, the seasonal variation on the abundance of zooplankton biomass was recorded both in the Gulf of Oman and the Arabian Sea. Generally, winter is more influential than the summer for the zooplankton biomass in the Gulf waters. During the year of 1995, the biomass was more then 2.27 times its winter levels. In the Arabian Sea, zooplankton biomass started increasing at the end of the monsoon season (September to October) and attained a peak in December to April. This could be expected year after year in the southern part of Oman, which is always influenced by the upwelling at the time of the southwest monsoon.

Figure 7.16 shows the distribution of zooplankton for the two months of April and August. Although affected by the sea surface temperature, the level of zooplankton in general is high throughout the year. This can give a good explanation of high catch in the areas of continental shelf in general.

Figure 7.17 shows visually the relationships between sea surface temperature and zooplankton biomass during the two months of April and August. Generally, There is more zooplankton biomass during April, although August still has high zooplankton concentrations.

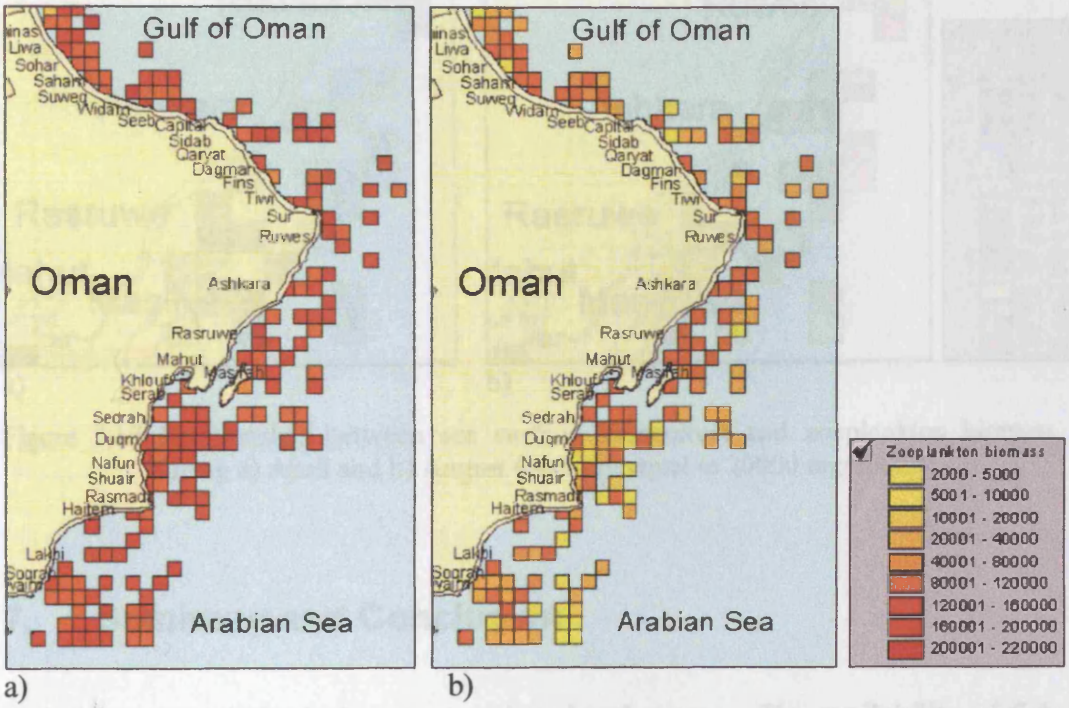

Figure 7.16 Average zooplankton distribution (in mg/100m³) at the Gulf of Oman and Arabian the Gulf during months of a) April and b) August

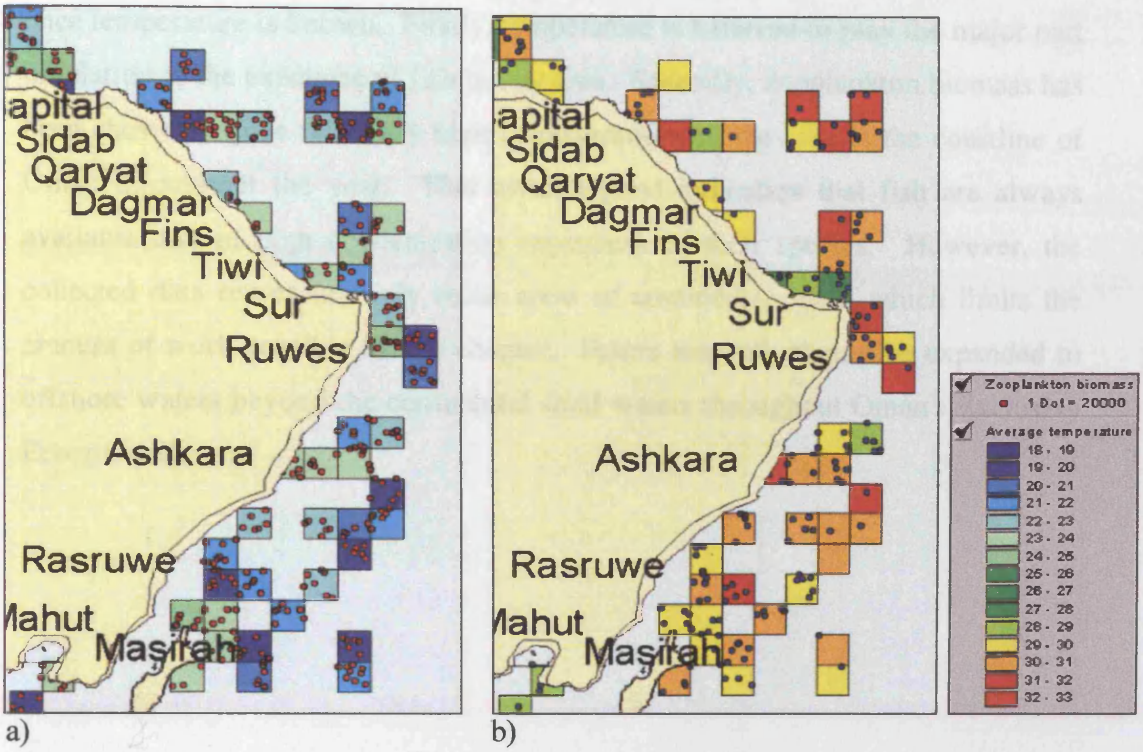

Figure 7.17 Relationship between sea surface temperature and zooplankton biomass during a) April and b) August (each dot equal to 20000 mg/100m³)

7. Summary and Conclusion

Fish depend on their environment to breed and spawn. The availability of fish species at certain locations could be estimated if marine environment data are known. Fish tends to exist at different levels of sea surface temperature, dissolved oxygen, salinity, zooplankton and factors. In relation to fisheries management, the knowledge of these data is essential. Specifying the location and amount (quota) forms the basis of any fisheries management. However, determining marine data can give the managers a broad picture of the optimum areas of catch. In addition, the areas of optimal environmental conditions should be controlled and protected at all times as these represent the fish habitat areas and species stocks. In general, for the GIS to be a better tool in assisting the managers and decision makers, marine data are critical and should be included.

This chapter has introduced the basic relationships between the sea surface temperature, salinity, dissolved oxygen and yellowfin tuna catch. It was clear that at certain temperatures fish disappear from the area or migrate. The relationship between catch and other factors is apparent, but many of these can be predicted once temperature is known. Firstly, temperature is believed to play the major part in relation to the existence of fish in any area. Secondly, zooplankton biomass has been shown to have relatively high concentrations in the area of the coastline of Oman throughout the year. This gives a good indication that fish are always available and in high concentration regardless of their species. However, the collected data represents only those areas of continental shelf, which limits the amount of work possible in this chapter. Future research should be expanded to offshore waters beyond the continental shelf waters throughout Oman's Exclusive Economic Zone.

8

SUMMARY, CONCLUSION, AND FURTHER DEVELOPMENT

Many difficulties arise from the uncertainty that pervades the fishery management process, and how it has been dealt with. Uncertainty should be explicitly considered - by imposing safety margins in target fishing levels, by dealing with uncertainty and risk in harvest decisions, and by creating institutional arrangements in which such decisions are transparent and subject to checks and balances. Because there will always be some uncertainty about resource status, and the behavior of fishers and decision makers, actions must be reversible.

(Buckworth, 1998, p. 3)

1. Introduction

This chapter intends to give an overall summary of the different aspects of this research and to provide general observations of findings and some suggestions for future investigations. There are three major parts in the thesis: 1) construction of the marine fisheries database; 2) integrating the spatial data within the GIS; and 3) applying GIS based analysis to the fisheries data to assist management and decision making. The following sections discuss and summarize the results from the previous chapters, particularly stressing what GIS can offer in terms of assisting the management of marine fisheries.

2. Database management System

Methods of constructing both the spatial and attribute data are given in chapter 4. In that chapter, different software packages used to store and organize the spatial, attribute, and spatiotemporal data were described. ARC/INFO together with ArcView, was used to store and organize the spatial data, and Microsoft Access was used to hold the spatio-temporal and attribute data. The three types of data were linked using the Structure Query Language (SQL).

Data from the three types of fisheries were originally gathered from different sources. The nature and format of these data were discussed in detail in chapter three. The three types are diverse and have different geographical footprints. Traditional fisheries allocated their landing catch via ports, whereas trawlers and longlines allocate their actual catch records via squares cells and points location respectively. Both commercial fisheries (trawlers and longlines) use Global Positioning Systems (GPS) to target their fishing area.

2.1 Spatiotemporal Data

The study gathered data from January 1991 to December 1995. The purpose was to have as much historical data as possible of the catch as this is believed to assist in achieving the objectives of the research. Together with the attributes, these data have been stored and organized within the relational database.

2.2 Data Implementation

The three types of fisheries data were then linked with the spatial data in ArcView and three different maps were produced directly from the GIS. The three figures that are shown at the end of chapter 4 indicate three different data sets each with different geographical footprints.

3. Spatial Data Integration and Visualization

3.1 Spatial Data Integration

The methods of integrating the different geographical footprints of the fisheries data are discussed in chapter 5. Since both the commercial fisheries represent their fish catch by area of fishing, whereas traditional fishery uses port location as a geographical footprints, the port locations of the traditional fishery was integrated. The main goal was to map the area of actual catch in order to replace the area of landing catch. The area in which traditional fishing boats are active around their ports was estimated to be 20 * 40 km according to the results from the survey that has been carried by the Ministry of Agriculture and Fisheries (MAF) in Oman. These areas were mapped and replaced the original port areas.

Two methods of geographical footprint integration were explored, point and area. First, the areas of traditional and trawlers fisheries were converted to point data by assigning points at the centroid of each traditional fishing area and trawler squares. These were then integrated with point data of longlines to establish an integrated map layer that holds all types of spatial data. Second, data have been integrated using an area method. 10*10 mile squares were applied to the fishing areas. By using the method of point aggregation, the point occurrences are summed within the grid to give total catches for each grid cell of each species.

3.2 Data Representation

Integration is important for data representation and analysis. Once the data are fully integrated and all fish catch are located in their original and estimated areas several data representations can be imposed on data which leads to different observations. Emphasis is placed on the idea of being able to have different data representations at the time of making a decision because, from the management point of view, this may lead to a better understanding of the problems of the task at hand.

Three main methods of data representation were highlighted and discussed namely dots, grids, and proportional symbol maps. Dot maps present the point location from which data have been recorded or captured. This gives almost the exact location of where the fish have been caught. Grid maps facilitate better visual interpretations especially if patterns are be analyzed. Proportional symbol maps signify the size or density of represented data.

4. GIS Display and Analysis

In Chapter 6 the capabilities of the GIS in the area of fisheries were demonstrated. Several result) were achieved that are believed to assist in the management and decision-making operations in understanding the status of the stocks in each fishing area. Some of these outputs where directed towards answering the main objectives of this study listed in chapter 1.

In general, the visual and analytical functions of the GIS were used in order to map the following outputs:

1. Mapping total catch distribution of each species.
2. Mapping the catch per unit area (square) per unit effort (fishing trip/day).
3. Determining the relationship between catch and effort (days of fishing).
4. Mapping spatio-temporal data of catch. The method used to visualize the temporal catch for some of the common fish species caught by each of the fisheries methods.
5. Highlighting the relationship between the movement of the major commercial vessels and the existence of fish species.
6. Mapping the preferred areas of catch. That is, the area that recorded high catch with less required effort. Areas of high catch and high effort, and low catch and high effort, were also presented in that process.
7. Mapping areas of natural fish habitat.

8. Mapping Unexploited areas of fish.
9. Finding areas that might experience resources overexploitation or overfishing.
10. Mapping efficient areas of catch and expected amount of catch from these areas.

Since fishing regulations are initially based on locationally crude catch and effort data from manual data input, these georeferenced outputs in general were believed to have the potential to be used in determining the future fisheries regulations and policies. These crucial outputs were not, in any way, possible for Omani waters before this study and as mentioned before locational data of catch were totally neglected in the processes of storing and studying the data. Furthermore, the types of data applied in this research are not previously documented for any other national fisheries. The suggestion is then, that with further work, the GIS for marine fisheries of Oman should be applied as soon as possible.

5. Introduction to the Relationships between catch and hydro-biological data

Chapter 7 emphasized the study of the relationship between fish catch and marine hydro-biological data. Different types of hydro-biological data were examined and the results show some strong relationships. Temperature was discussed in depth as it is believed to play the key factor in changing other marine factors such as salinity and dissolved oxygen. The results can be summarized as follows:

1. Fish are sensitive to temperature. Yellowfin tuna, for example, appears to be present in a temperature range from 24-30 and absence if the temperature is higher (figure 7.3a and b of chapter 7).
2. The relationship between the water temperature and the level of dissolved oxygen and salinity are directly proportional and so density of fish is found to be higher when they are higher.
3. Zooplankton biomass is found to be high along the coastline of Oman almost throughout the year. The high level of zooplankton is believed to have played a major part in the existence of the high catch.

All of these indicate that using the GIS can help in establishing a better fisheries management and decision making systems. However, little data was available, and as mentioned in chapter 2, the use of the GIS in marine fisheries is still in its early stages and many areas need to be investigated and developed.

6. Conclusion and General Observations

Several important results have been achieved through the work reported in this research. The relational database has been successfully designed to hold the different fisheries data, and the spatial data have been constructed within the GIS, and links between the two are efficiently handled using SQL.

This study has demonstrated the application of GIS to processing various data sets particularly for exploration of different types of fisheries data. These techniques were used successfully in order to visualize areas of crucial impacts in management and decision making such as those listed in section 4. In addition to those, many other conclusions can be drawn from the different outputs of this research, such as:

1. The records show more concentrations of the pelagic fish catch (such as yellowfin tuna (*Thuunus albacares*), longtail tuna (*Thunnus tonggol*), shark (*Carcharhinidae, Sphymidae*), *kingfish (Scomberomorus commerson*), etc) in the northern part of the country (from 'Sur' to the north). The reasons may relate to zooplankton distribution but the root causes could beneficially explored further.

2. Other pelagic species such as sailfish (*Istiophoridae*), B. marlin (Black marlin) (*Istiophoridae*), swordfish (*Xiphiidae*), and mahi-mahi or dolphin fish (*Coryphaena hippurus*) are caught mainly by the longlines fishery.

3. Demersal fish species (such as emperors (*Lethrinidae*), groupers (*Serranidae*), snappers (*Lutjanidae*), etc) are distributed along the country's coastline, and caught by both, the traditional and the trawler fisheries. These species usually occur within the area of the continental shelf.

4. Ribbonfish (*Trichiurus lepturus*), one of the important commercial species that have been caught by trawlers, are voracious predators inhabiting mostly deeper waters over the continental shelf and slope. They are very gregarious occurring in large shoals and in Oman are mostly caught by bottom trawlers. This species occurs along the entire coastline but appears to be particularly abundant in the area located between the 'Island of Masira' and the 'Shuaimia' at the south. The annual catches of ribbonfish are approximately ranging from 3000 to 7000 tonnes. However, this species has been avoided by the traditional fishermen due to its lack of popularity in the local fish markets, but would appear to have potential to be developed by this fleet.

5. Pelagic fish, especially tuna are more sensitive to sea surface temperature, and due to that, the catch rate usually drops during the high temperature season. Although, in June the sea temperature is high the catch of tuna remains very high due to several other factors, but mainly because of the upwelling.

6. Although the GIS techniques were able to show those areas suspected of overfishing, such areas are very few. According to the total fish catch, fish stock in general are potentially high and probably undamaged, and so it may be possible to increase the level of catch. However, there are a few species where catch has declined recently and that should be taken into consideration in order to avoid any unexpected results that may harm or damage stocks of those species.

7. Recommendations for future work

1. The use of the GIS in estimating the stock assessment must be improved further by improving the data concerning fishing effort. As discussed, the fishing efficiency of fishing vessels is different. Quite clearly, small fishing boats used by the traditional fishermen have different efficiency to the large, powerful commercial vessels. A different fishing gear and the knowledge and experience of different crews within any one fleet will also effect efficiency. Several data must be collected from these fleets together

with the catch data. For the traditional fishery, the size of the boat, engine power, gear type, number of crew, and hours of fishing could be used, but crew size, for example, may fluctuate. For the commercial vessels, on the other hand, data such as size of the vessel, power, tonnage, speed, and the number of crew are possible variables. The basic idea here is that, if these data are available together with the catch data, more precise catch per unit effort (CPUE) can be calculated, and thus stock assessment per unit area of fishing can be more accurately and meaningful. Stock assessment, forms the basis of any fisheries management since the amount of fishing effort and allowed quota from each area are dependent on the knowledge of stock abundance in the area.

2. Different sectors of the fisheries industry involve different levels of management, from protecting the traditional fishermen to increasing the national income. Ecological data also needs to be addressed including sea ground, coastal zone area, mangrove, and continental shelf area. These further investigations may lead to an important, data-rich integrated fisheries management.

3. Methods of recording catch data, especially by the commercial vessels should include several other data such as the depth at which fish have been caught. The depth data could then be studied and analyzed with regards to water conditions. This will increase the knowledge of fish biology and so many other related areas such as fish biomass (stocks).

4. Marine data should be considered as essential data when GIS are to be implemented for fisheries management. Based on the baseline presented in chapter 7, further comprehensive studies have to be undertaken to achieve a clear picture of the hydro-biology of Oman. Studies such as physio-chemical parameters, trophic levels, intertidal, interstitial and benthic fauna and their ecology should also be included in any future study. Species composition and diversity in relation to the ecology of the area have to be studied extensively, and further programs of collecting marine data should be expanded to offshore waters beyond continental shelf waters, up to Oman's 200 mile Exclusive Economic Zone.

5. Due to the high fishing activity recorded, the area of Sur could be fruitful for further study. In general, the area of the traditional fisheries, to the south Sur could be developed and extended.

In summary, application of the GIS in fisheries science in general, and fisheries management, in particular, is still in its early stages and much research is required in order to achieve the maximum benefit of the system. However, the work described in this thesis demonstrates the use of GIS in assisting fisheries management by facilitating the visualization and analysis of the georeferenced data of catch and effort.

Commercial data of catch and effort are used in assisting the process of stock assessment. However, effort data, needs to be improved further for better estimates of stock abundance. Greater knowledge of stock abundance is fundamental to the process of management and decision making so that the amount of effort applied can be controlled with regards to the availability of stocks. Marine data should also be included in order to understand their relationship with the availability of fish species in certain areas and at certain times.

*I shall soon sleep**

By: Younis Alakhzami

I shall soon sleep,

But before it I shall close the doors,

And shall go to the toilet

And sleep.

But before that also,

I shall open the door of the other room,

To see if my wife has slept

And if my young daughter has lied down

And I shall then sleep.

But before this also

I shall prepare my clothes for tomorrow,

And switch off the lights,

And then sleep.

But I shall do one last thing before it,

I shall open the window

And wait for a new thing before I sleep.

From a collection of short stories, 'Humma Ayaar' written by Alakhzami (in Arabic).

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APPENDIXES

Appendix A.

Table A. FISH_DESCRIPTION table for the relational database files for the three fisheries types. Sorted Alphabetically by the Species_Code column.

Species_Code	*Species_Name*	*Scientific_Name*
ABAL	Abalone	*Haliotis spp.*
ARI	Catfish (Sea catfish)	*Ariidae*
AUXT	Frigate Tuna	*Auxis thazard*
BEL	Needle fishes	*Belonidae*
BRA	Braise	*Cheimerus nufar*
BSPA	Butterfly Bream (Threadfin Bream)	*Nemipteridae*
CLU	Sardines	*Sardinella spp.*
COR	Mahi Mahi (Dolphin fish)	*Coryphaena hippurus*
CRAB	Crabs	*Decapoda*
CUT	Cuttlefish	*Sepia pharaonis*
ELAB	Rainbow Runner	*Elagatis Bipinnulata*
ENG	Anchovies	*Stolephorus spp.*
EUTA	Kawakawa	*Euthynnus affinis*
HAE	Sweet Lips/Grunts	*Haemulidae*
HOLO	Sea Cucumber	*Holothuridae*
ISTP	Sailfish	*Istiophoridae*
KATP	Skipjack Tuna	*Katsuwonus pelamis*
LCAR	Large Jacks	*Alectis indicus*
LET	Emperor/Scavenger	*Lethrinidae*
LUT	Snappers	*Lutjanidae*
MAKI	B.Marlin	*Istiophoridae*
MUL	Grey Mullet (Flat Head Mullet)	*Valamugil seheli*
OCTO	Octopus	*Octopus*
ODEM	Other demersal	*Parupenesus rubescens*
OSCO	other tunas	*Scomber japonicus*
OSPH	Barracuda	*Sphyraenidae*
PAN	Spiny Lobster	*Panuliridae homarus*
PENI	Shrimp	*Peneaidae monodon*
PRIS	Jobfish	*Pristipomoidae*
PSPA	Porgy Seabream	*Argyrops filamentosus*
RACH	Cobia	*Rachycentron canadum*
RAST	Indian Mackerel	*Rastelliger kanagurta*
RAY	Rays	*Teraponidae*
RCB	Rock Code Bass	*Epinephelus sp*
RIB	Ribbonfish (Largehead hairtail)	*Trichiurus lepturus*
SALB	Salmon Bass	*Argyrosomus heinii*
SARD	Indian Oil sardine	*Sardinella longiceps*
SARO	Striped Bonito	*Sarda orientalis*
SCAR	Small Jacks/Trevally	*Decapterus kurroides*
SCI	Croakers	*Sciaenidae*

SCK	Kingfish (Spanish Mackerel)	*Scomberomorus commerson*
SER	Grouper	*Serranidae*
SHA	Shark	*Carcharhindae*
SIG	Rabbit fish (Whitespotted spinefoot)	*Siganidae*
SPA	Seabreams	*Argyrops spinifer*
SQUI	Squid	*Loligo duvauceli*
SSCI	Silvery Croaker	*Argyrosomus hololepdotus*
SWRD	Swordfish	*Xiphiidae*
TA	Yellowfin Tuna	*Thunnus albacares*
TER	Pufferfish	*Tetraodontidae*
TIGR	Tigerfish	*Teraponidae*
TT	Longtail Tuna	*Thunnus tonggol*

Appendix B.

Catch Distribution of some selected common fish species found in the seawaters of Oman.

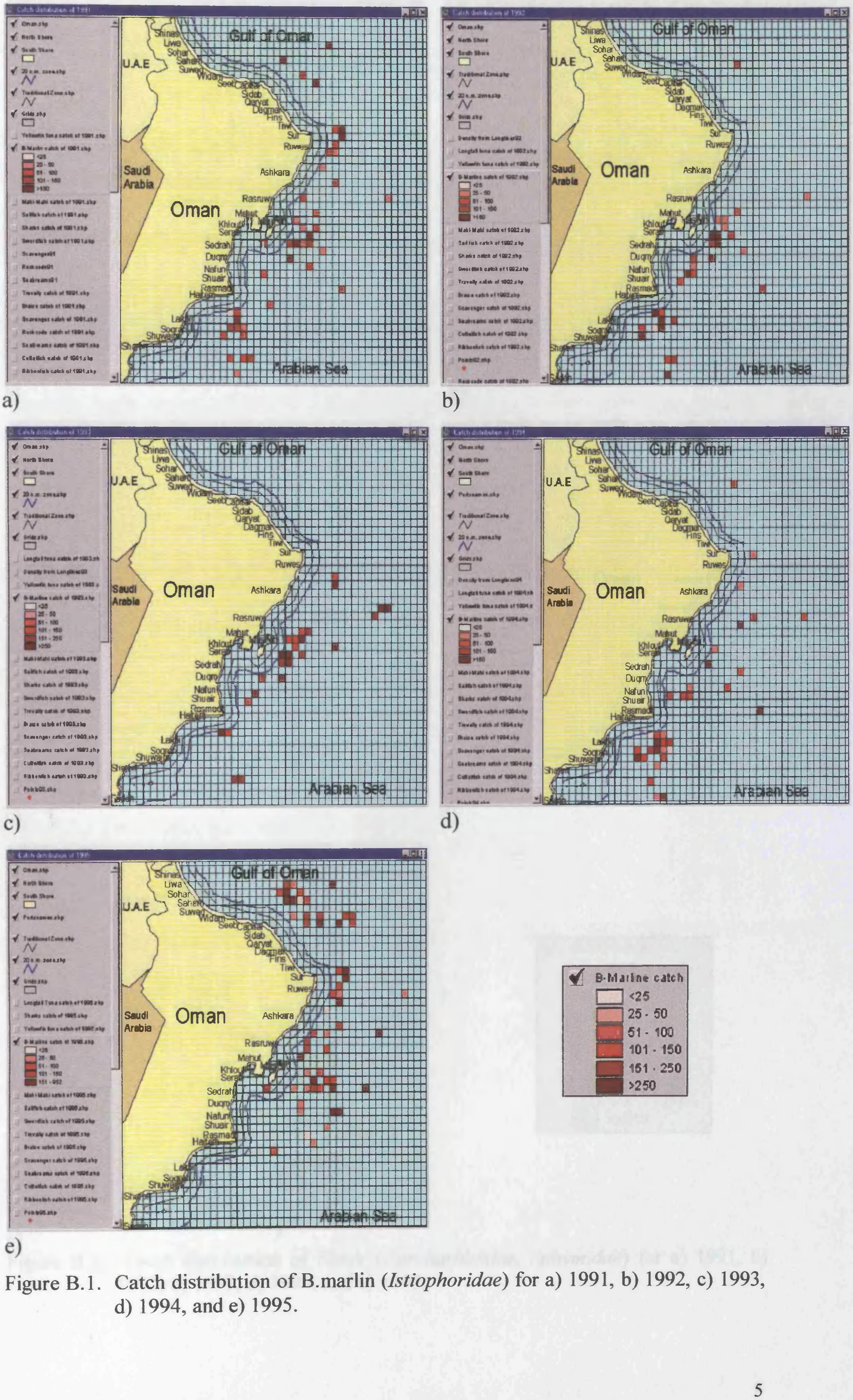


Figure B.1. Catch distribution of B.marlin (*Istiophoridae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

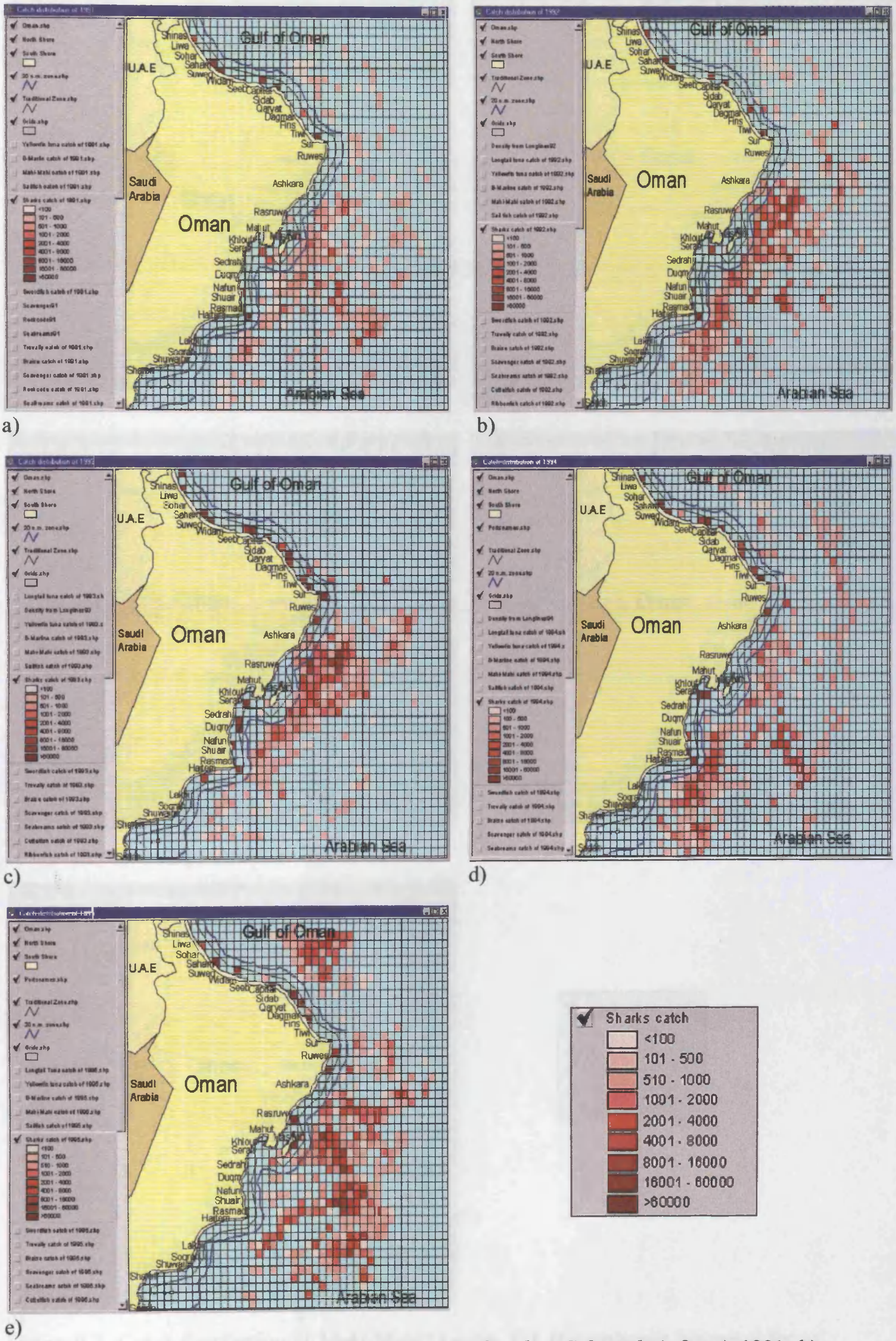


Figure B.2. Catch distribution of Shark (*Carcharhinidae, Sphymidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

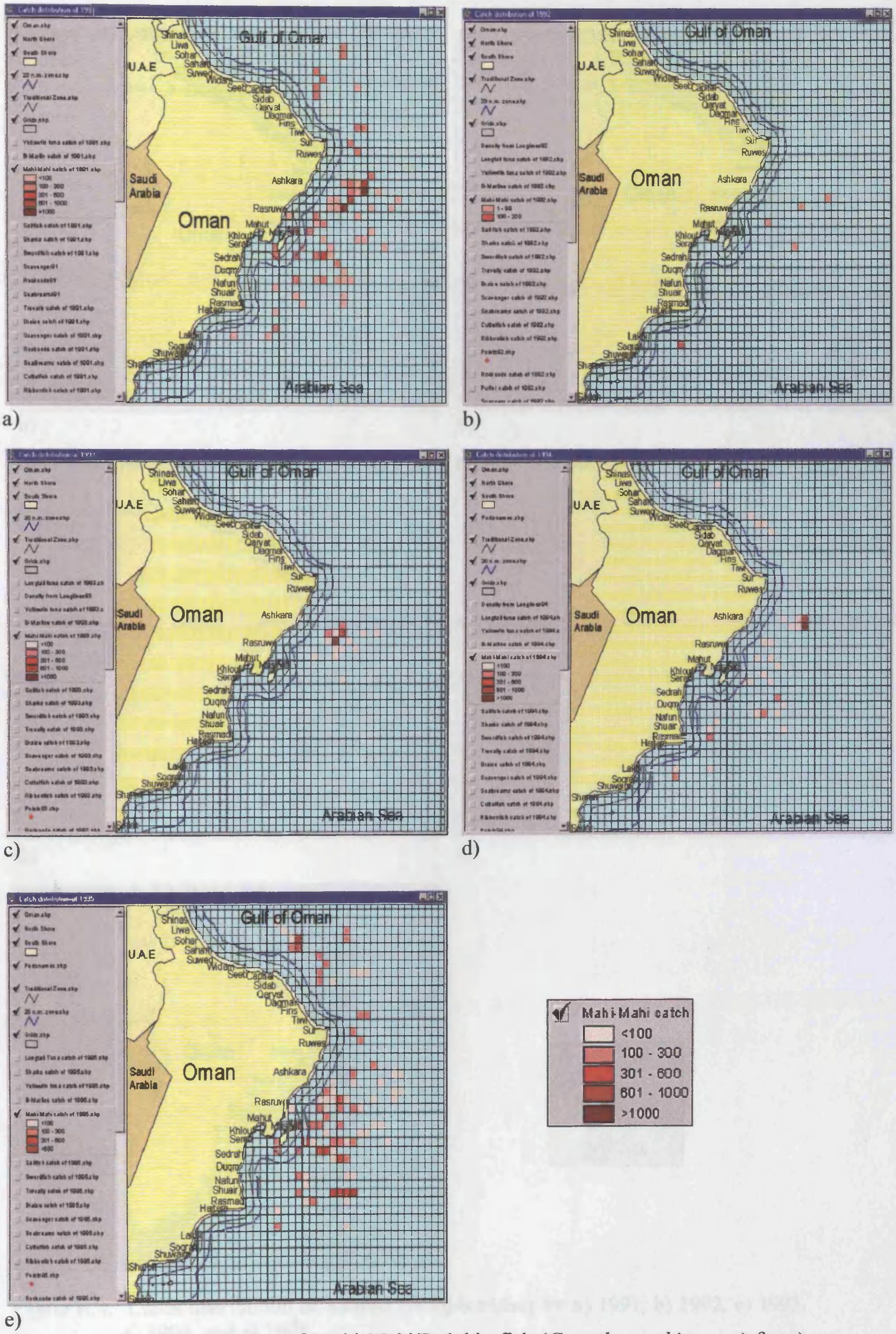


Figure B.3. Catch distribution of Mahi-Mahi/Dolphin fish (*Coryphaena hippurus*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

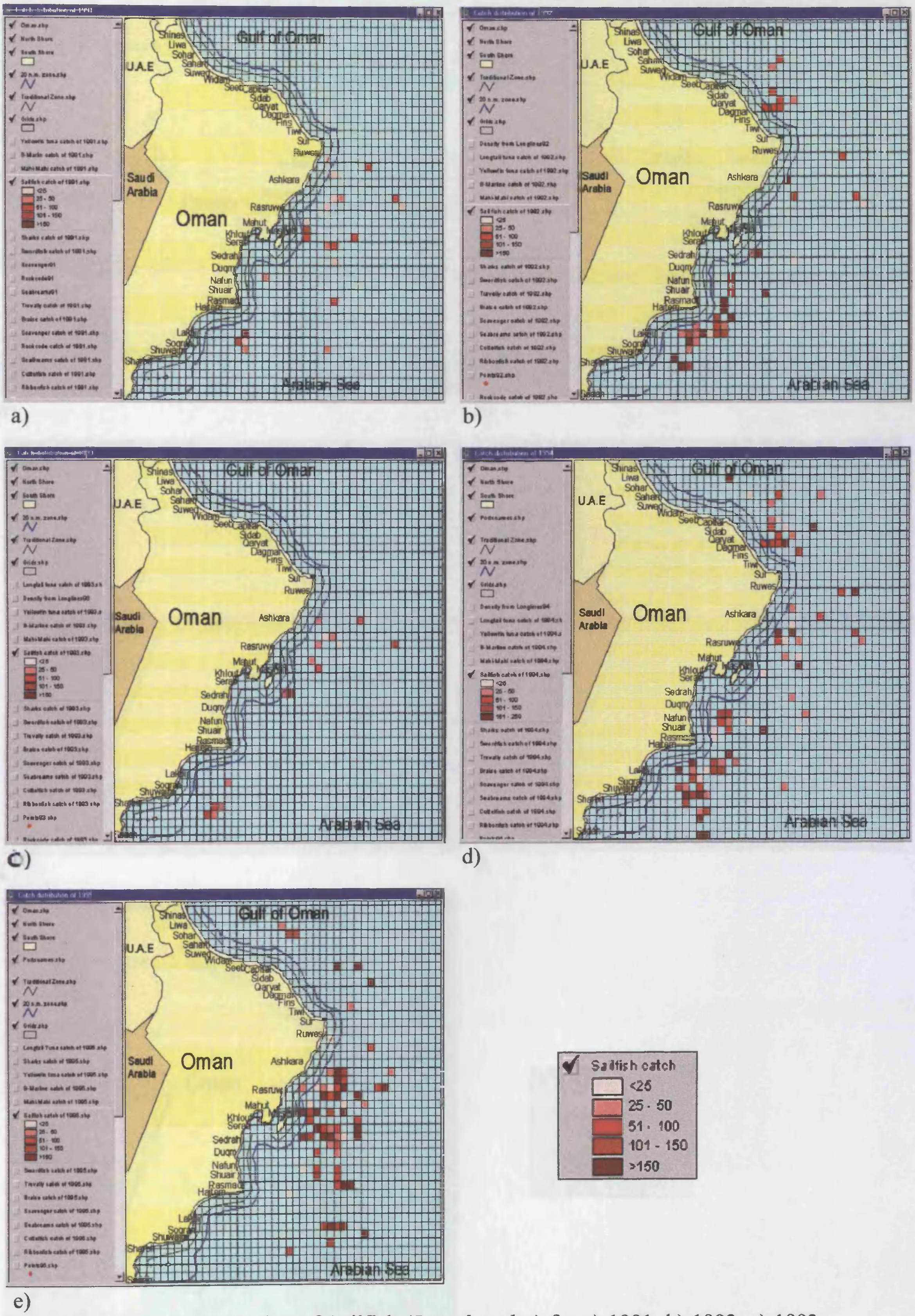
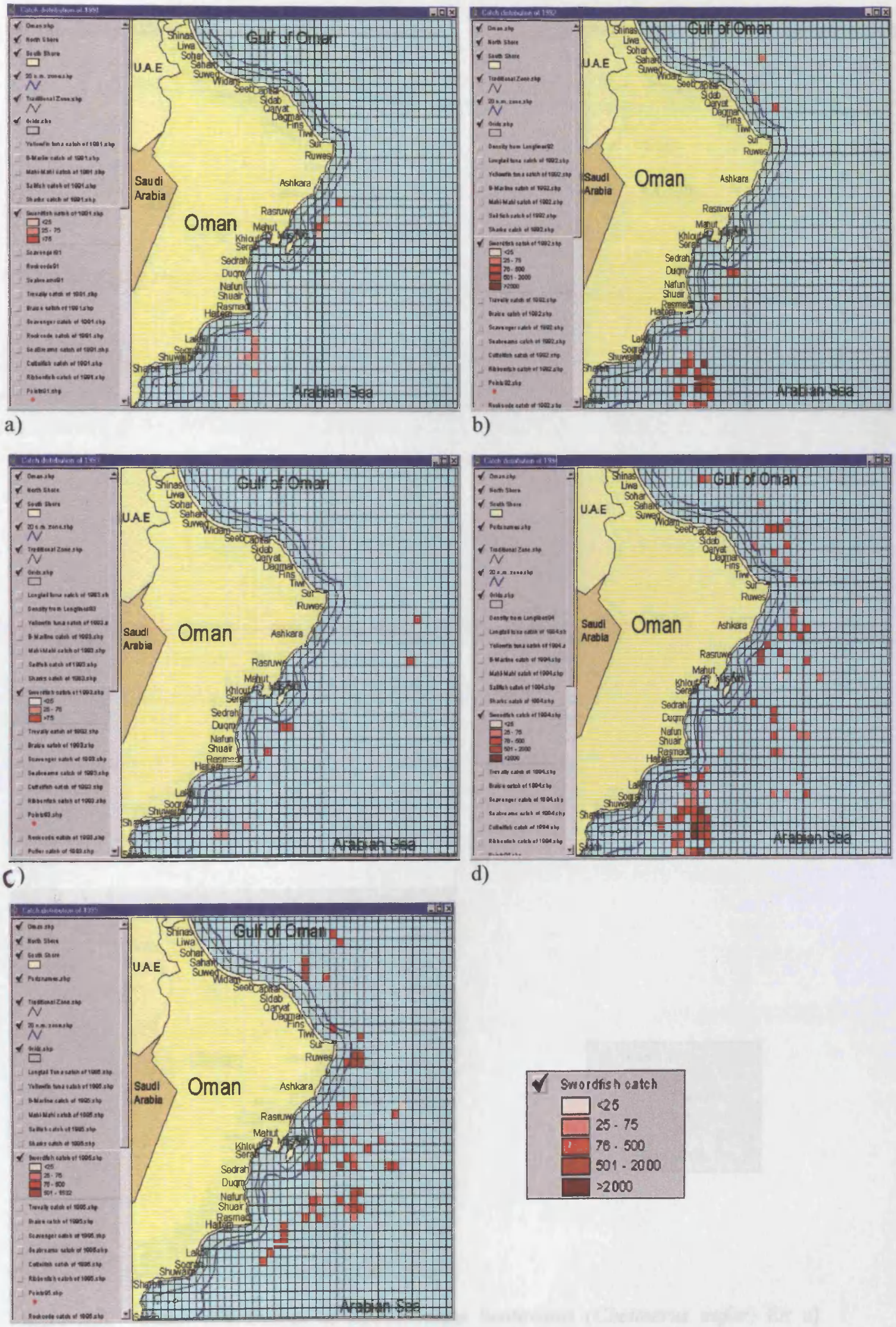


Figure B.4. Catch distribution of Sailfish (*Istiophoridae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995



a) b) c) d) e)

Figure B.5. Catch distribution of Swordfish (*Xiphiidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

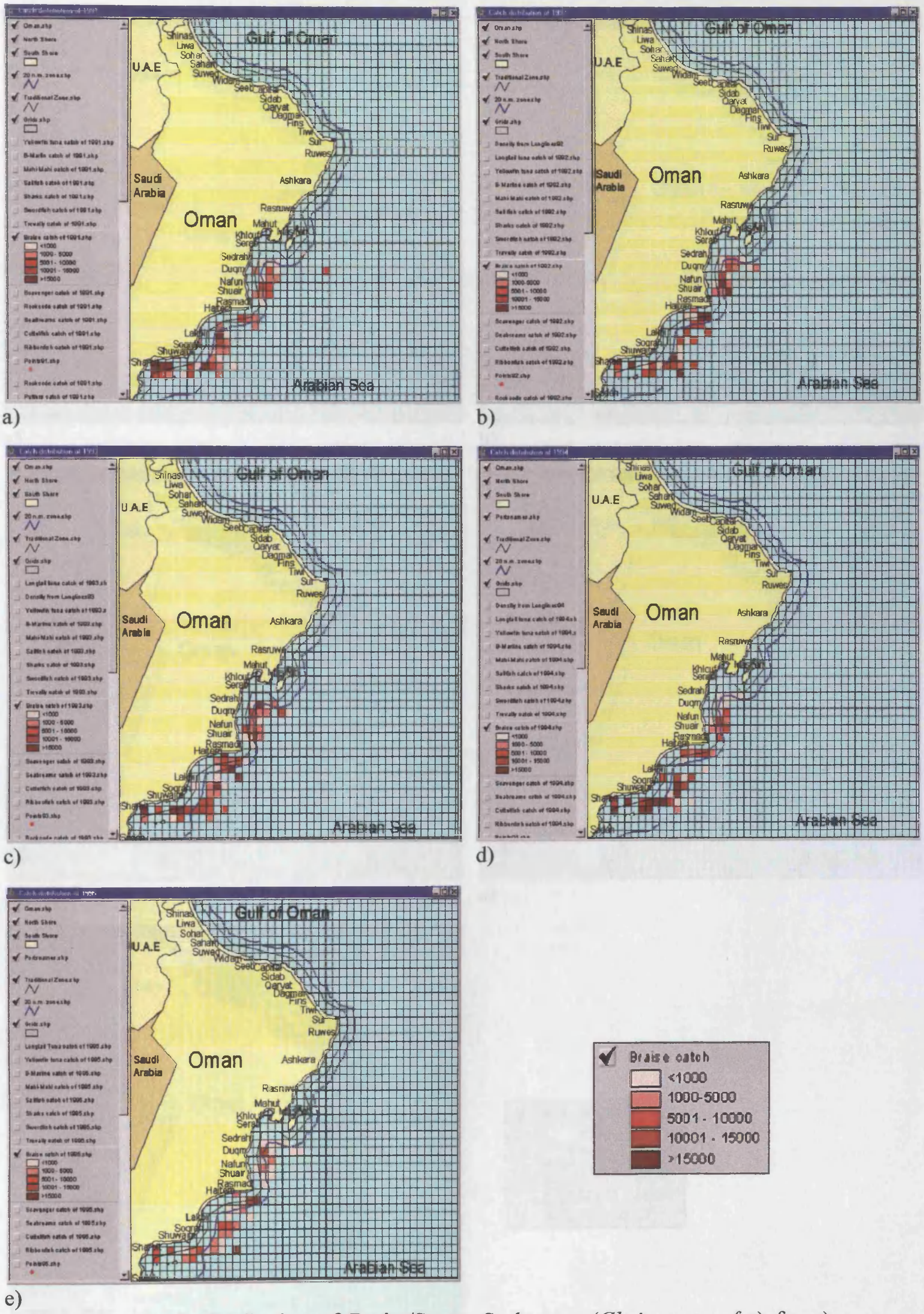


Figure B.6. Catch distribution of Braise/Santer Seabreams (*Cheimerus nufar*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

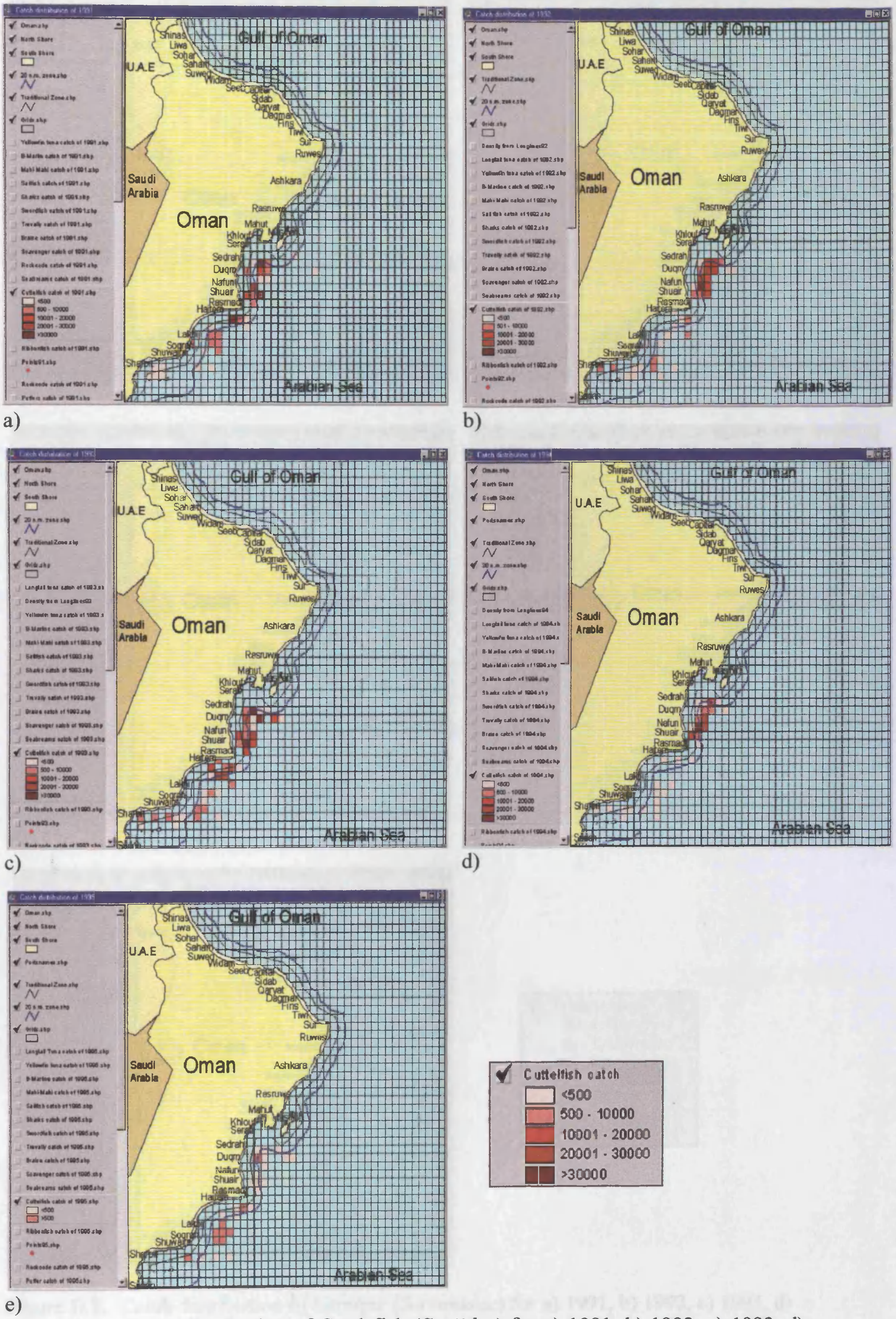


Figure B.7. Catch distribution of Cuttlefish (*Sepiidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

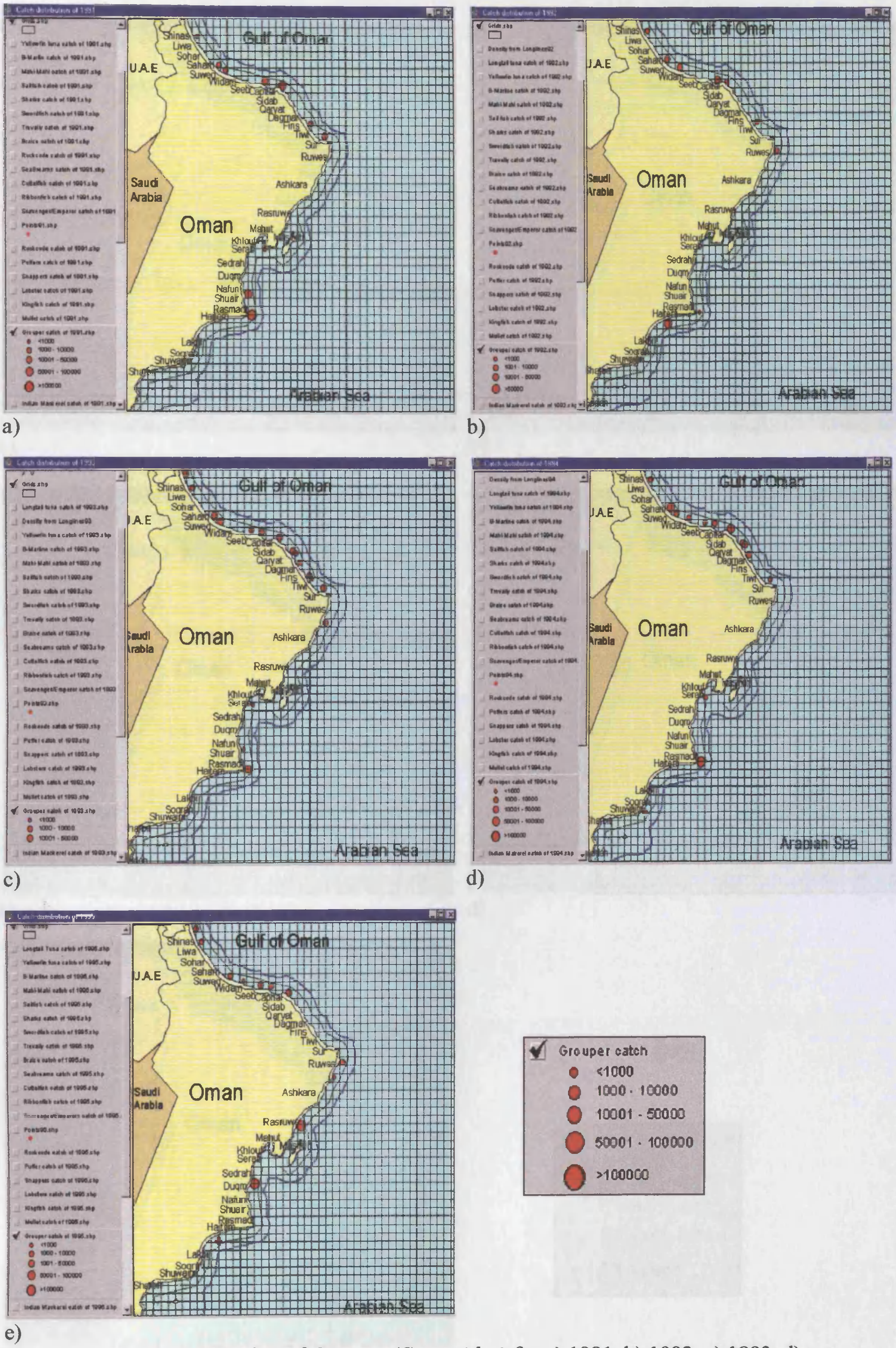


Figure B.8. Catch distribution of Grouper (*Serranidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

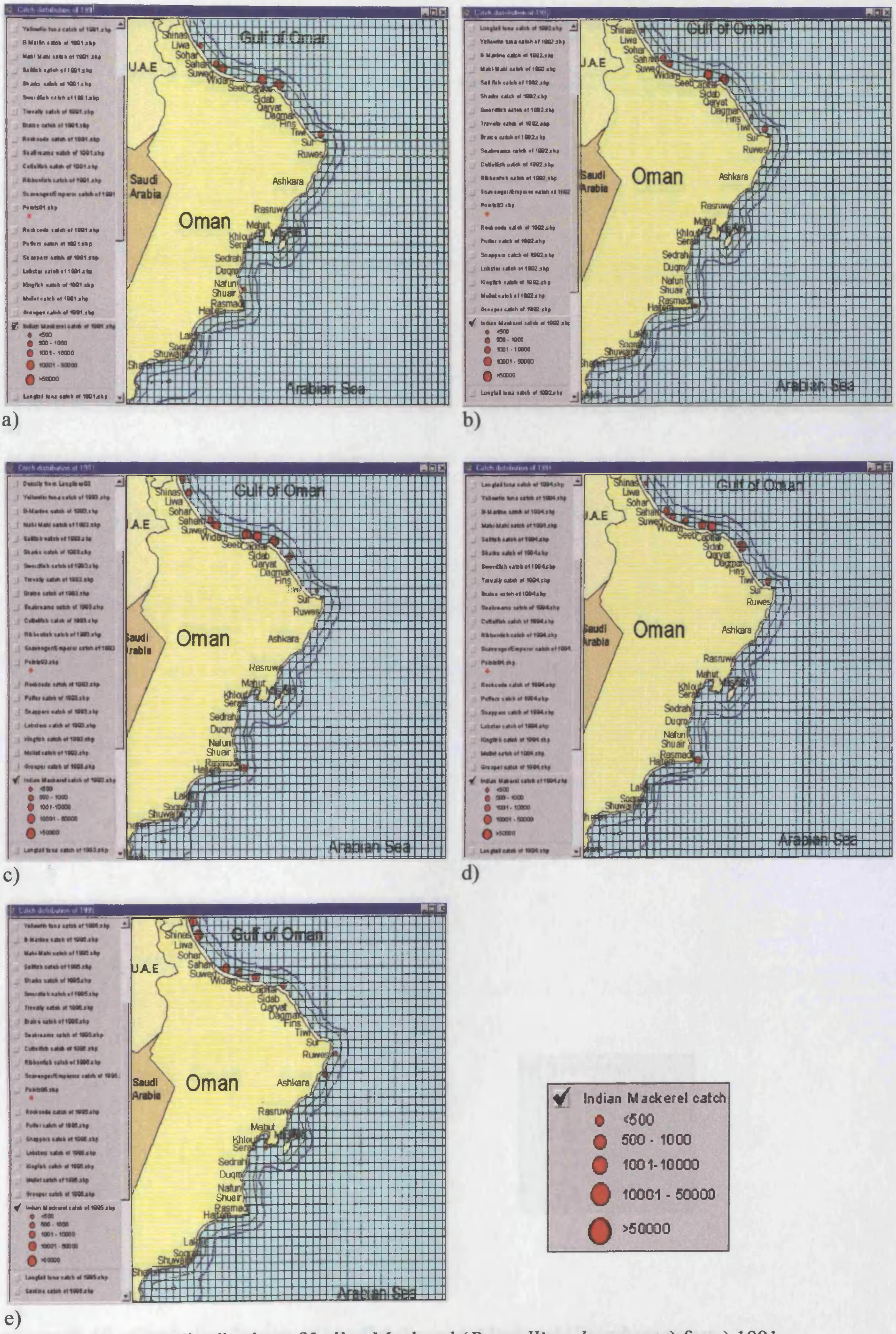


Figure B.9. Catch distribution of Indian Mackerel (*Rastrelliger kanagurta*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

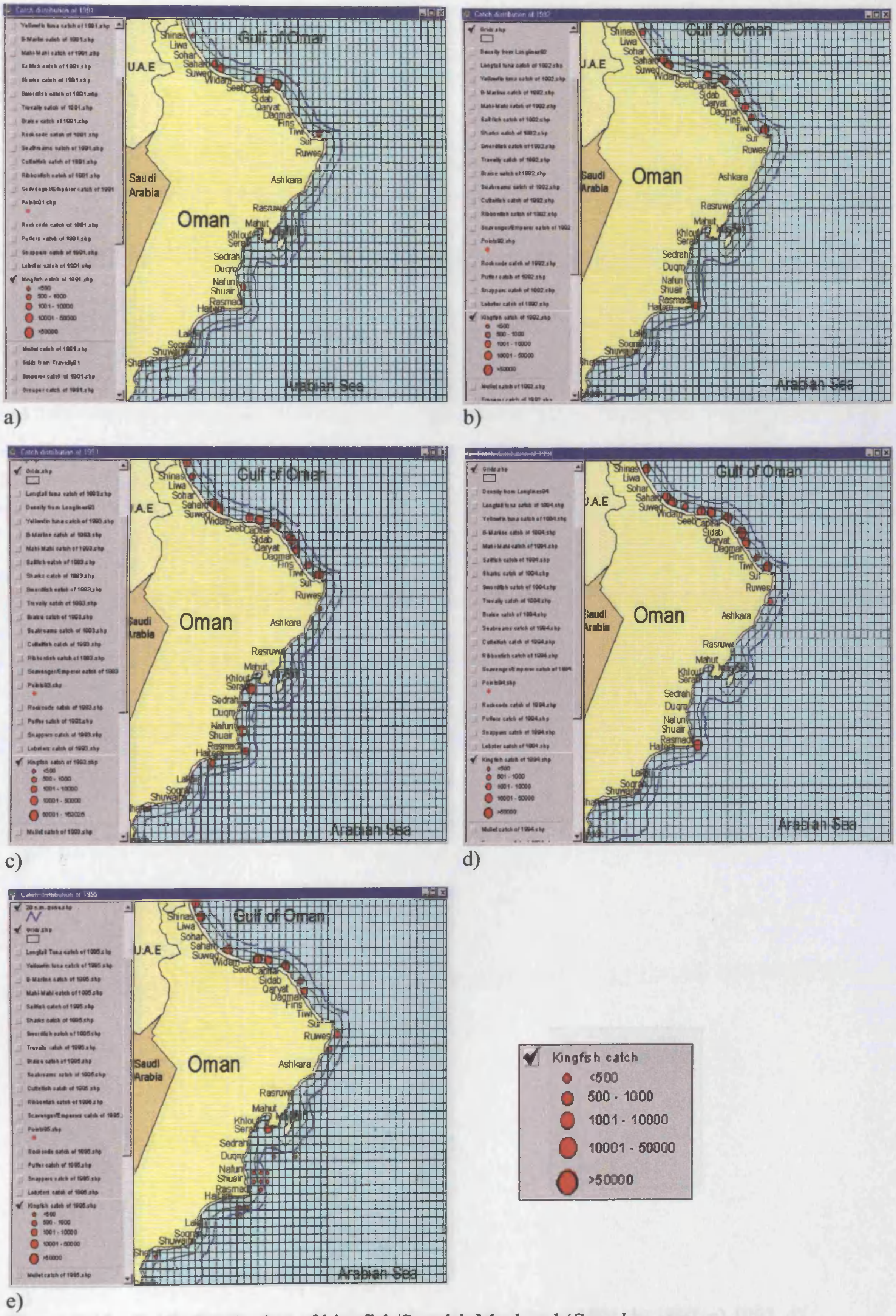


Figure B.10. Catch distribution of kingfish/Spanish Mackerel (*Scomberomorus commerson*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

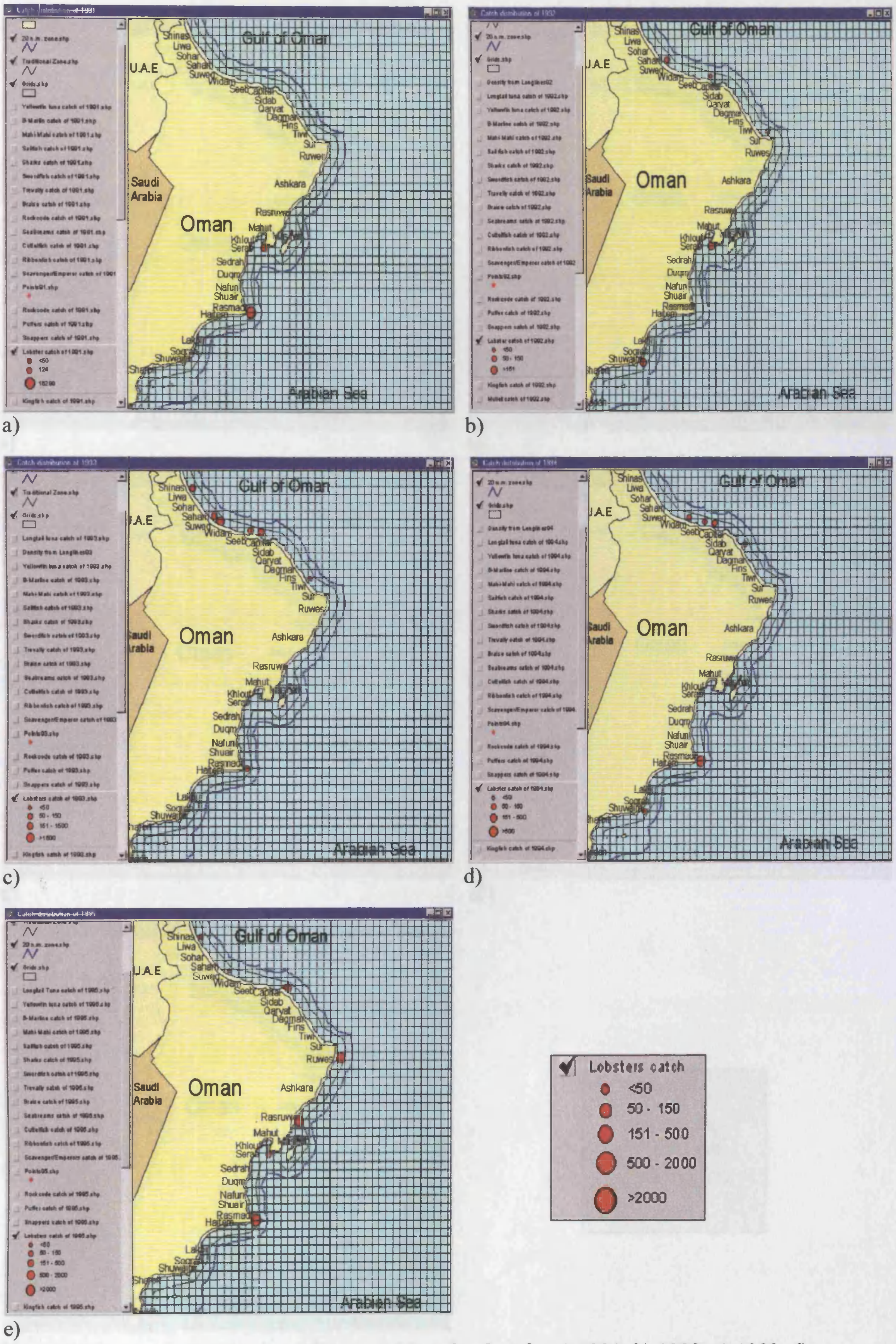


Figure B.11. Catch distribution of Lobster (*Panuliridae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

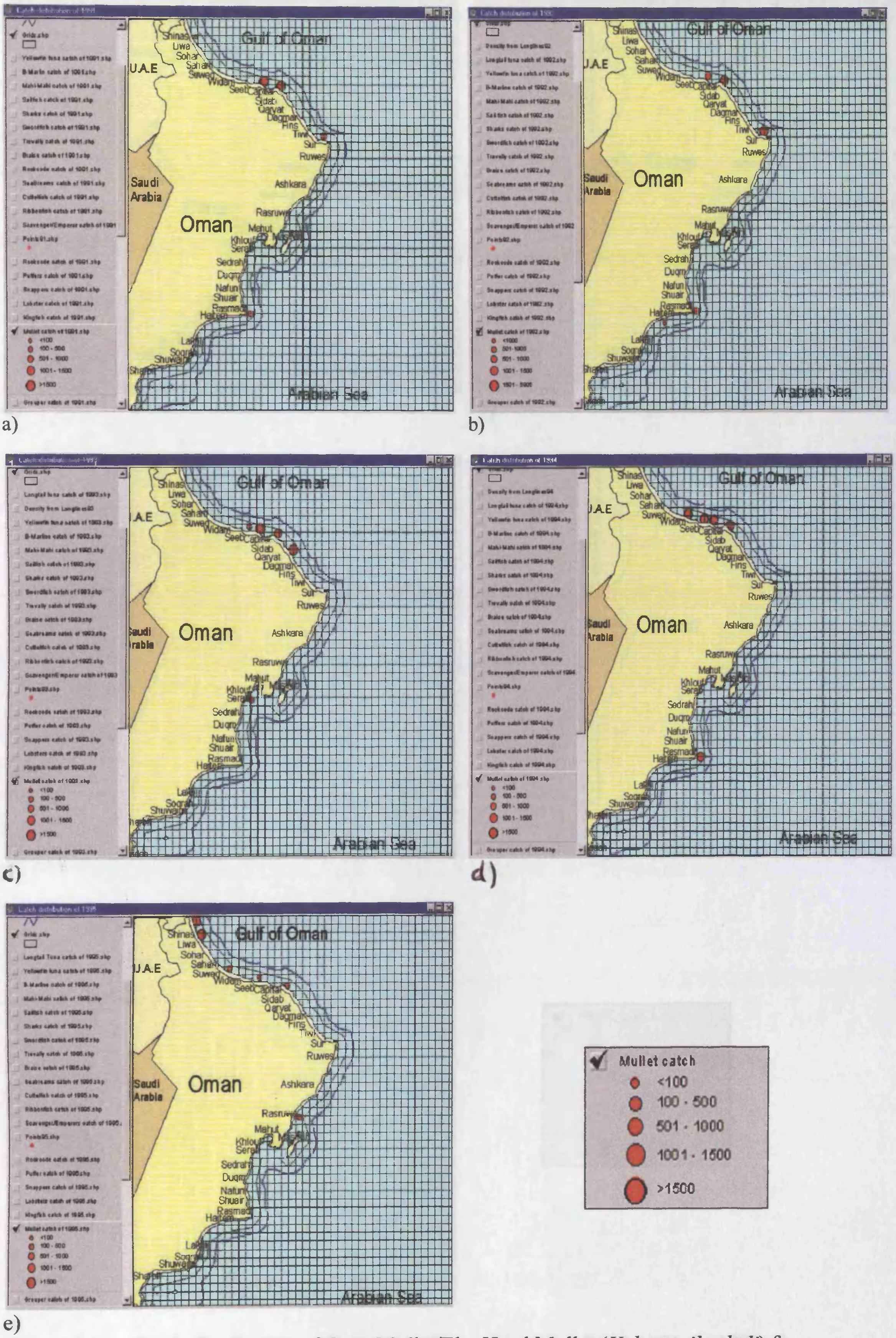


Figure B.12. Catch distribution of Grey Mullet/Flat Head Mullet (*Valamugil seheli*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

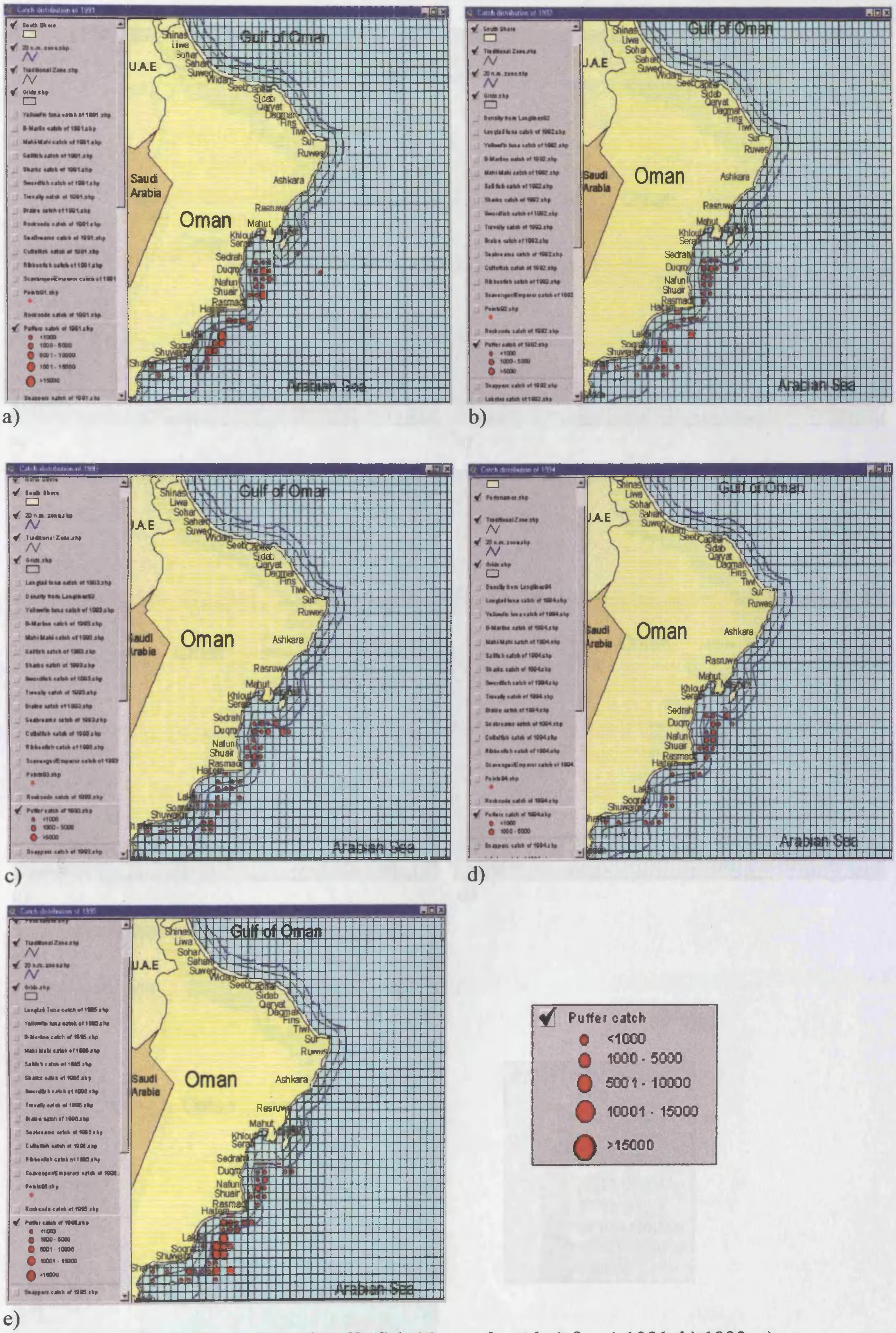


Figure B.13. Catch distribution of Pufferfish (*Tetraodontidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

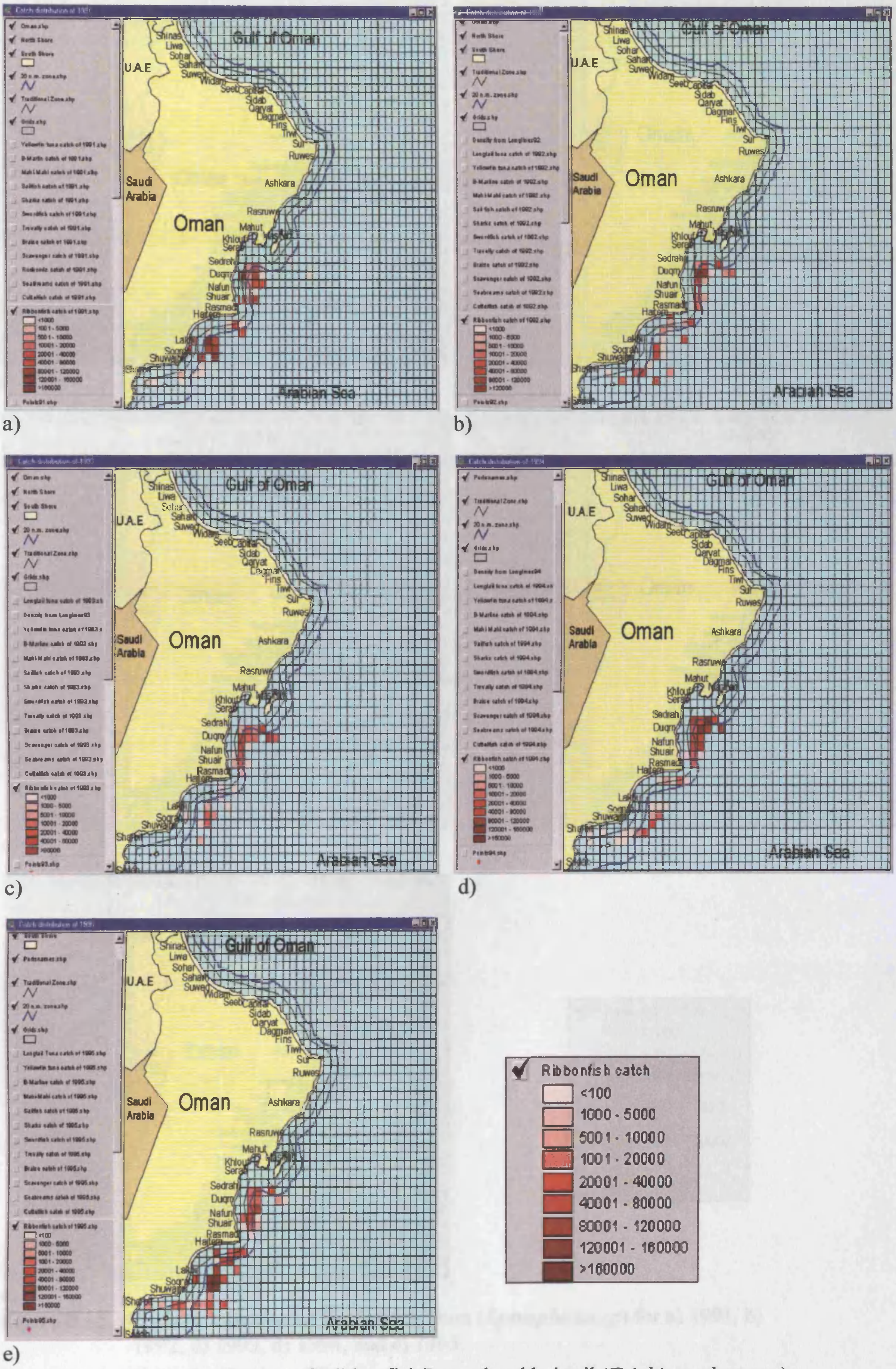
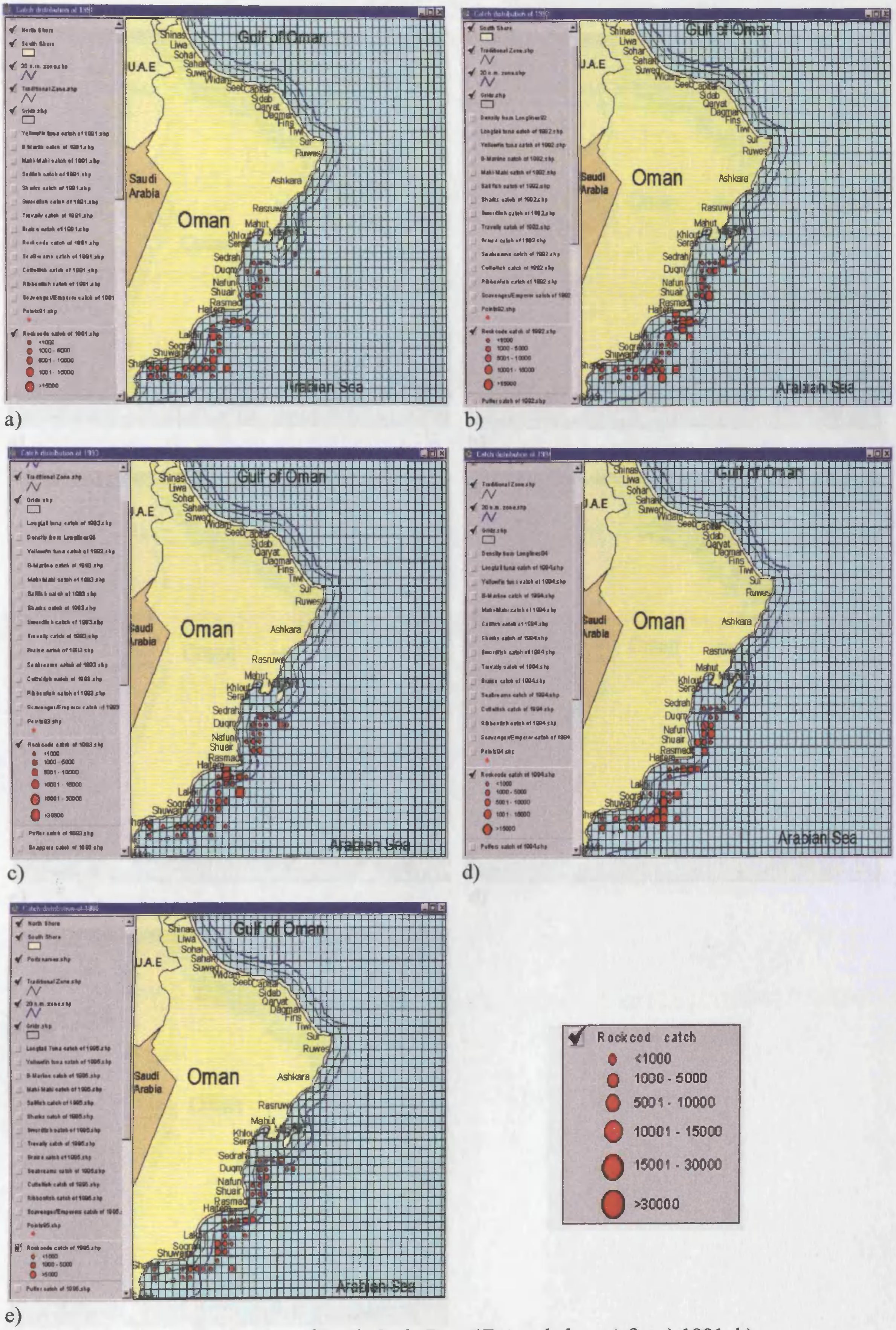


Figure B.14. Catch distribution of Ribbonfish/Large head hairtail (*Trichiurus lepturus*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995



a)

b)

c)

d)

e)

Figure B.15. Catch distribution of Rock Code Bass (*Epinephelus sp*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

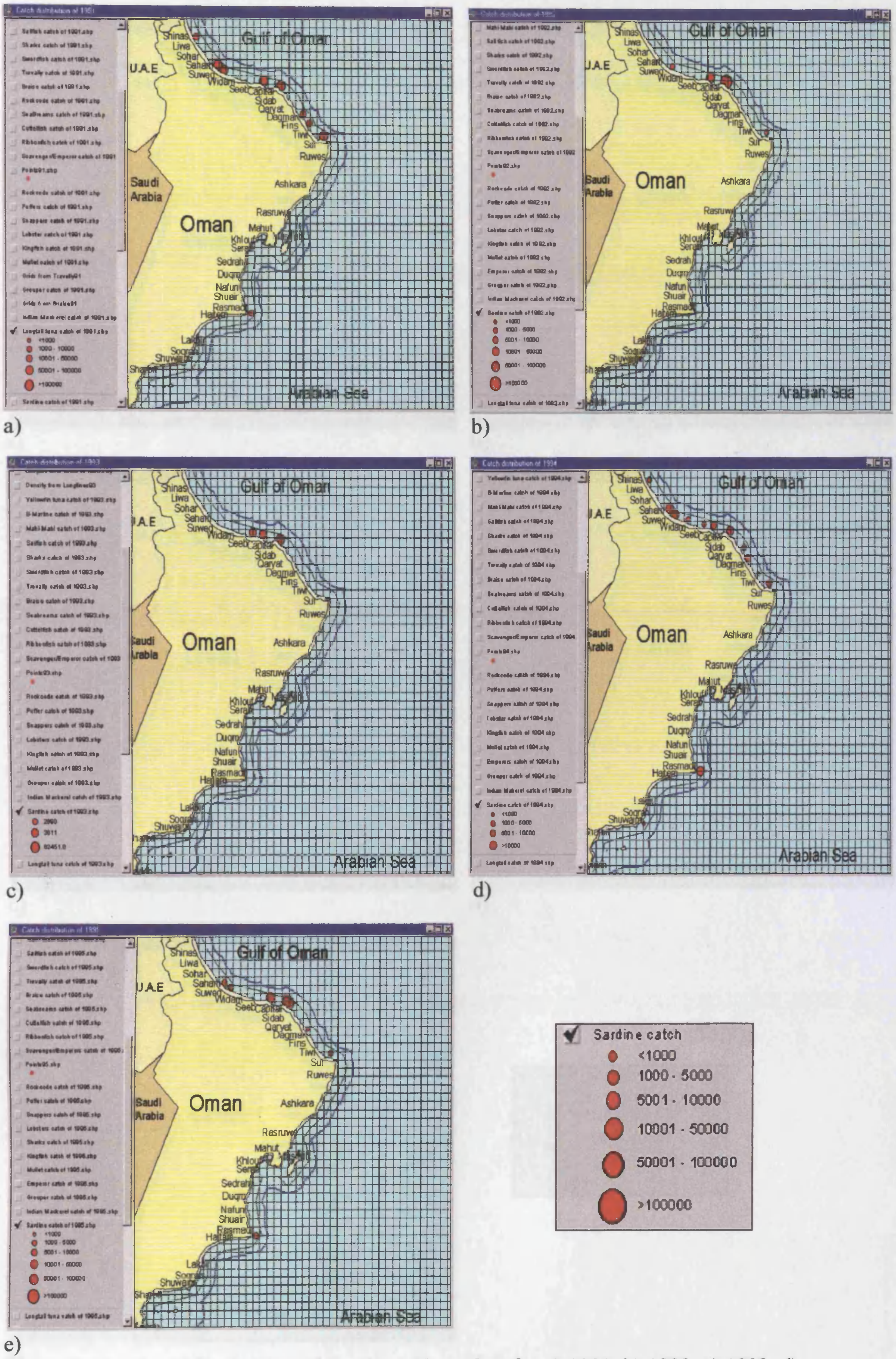


Figure B.16. Catch distribution of Sardine (*Clupeidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

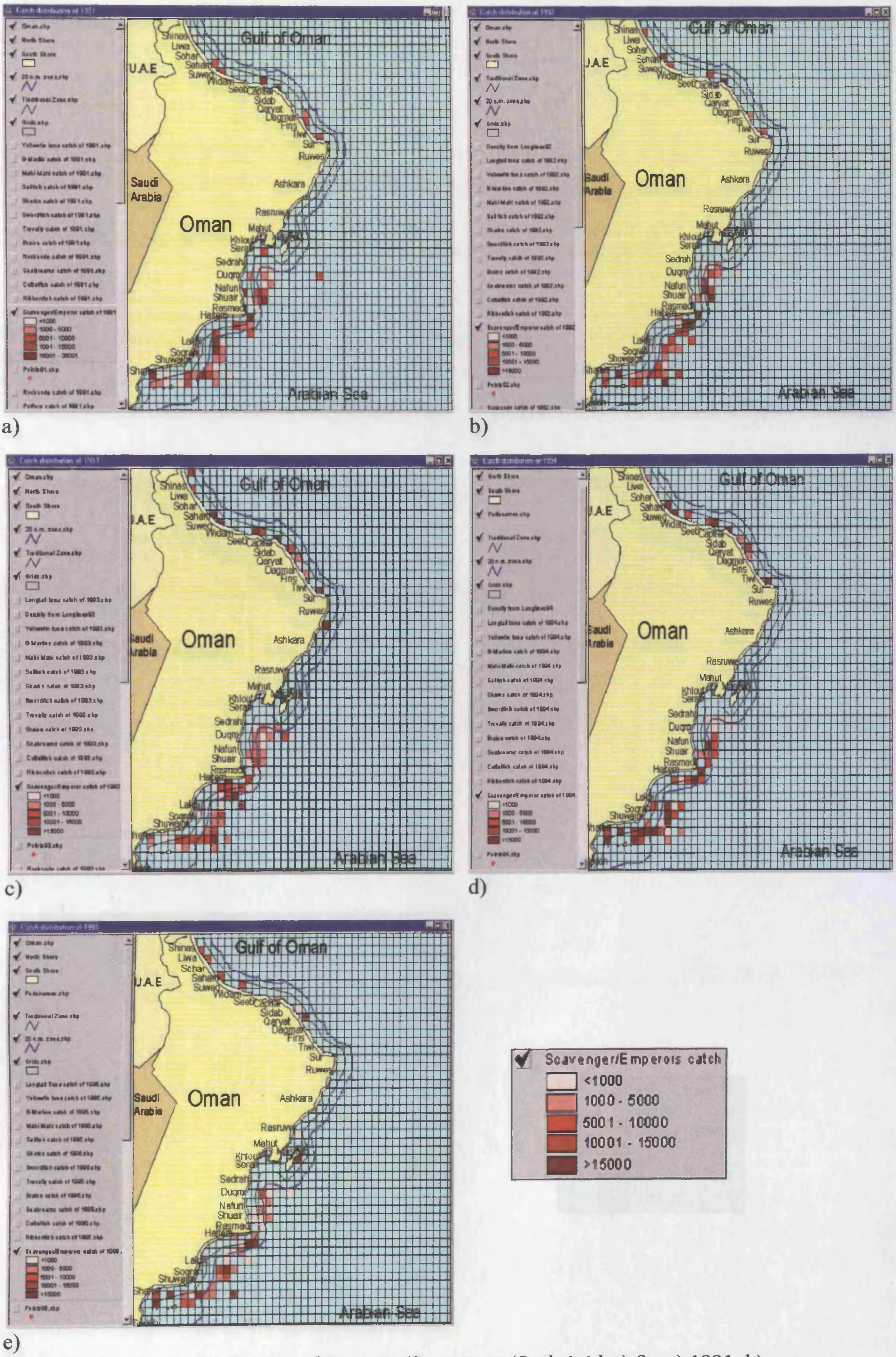


Figure B.17. Catch distribution of Emperor/Scavenger (*Lethrinidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

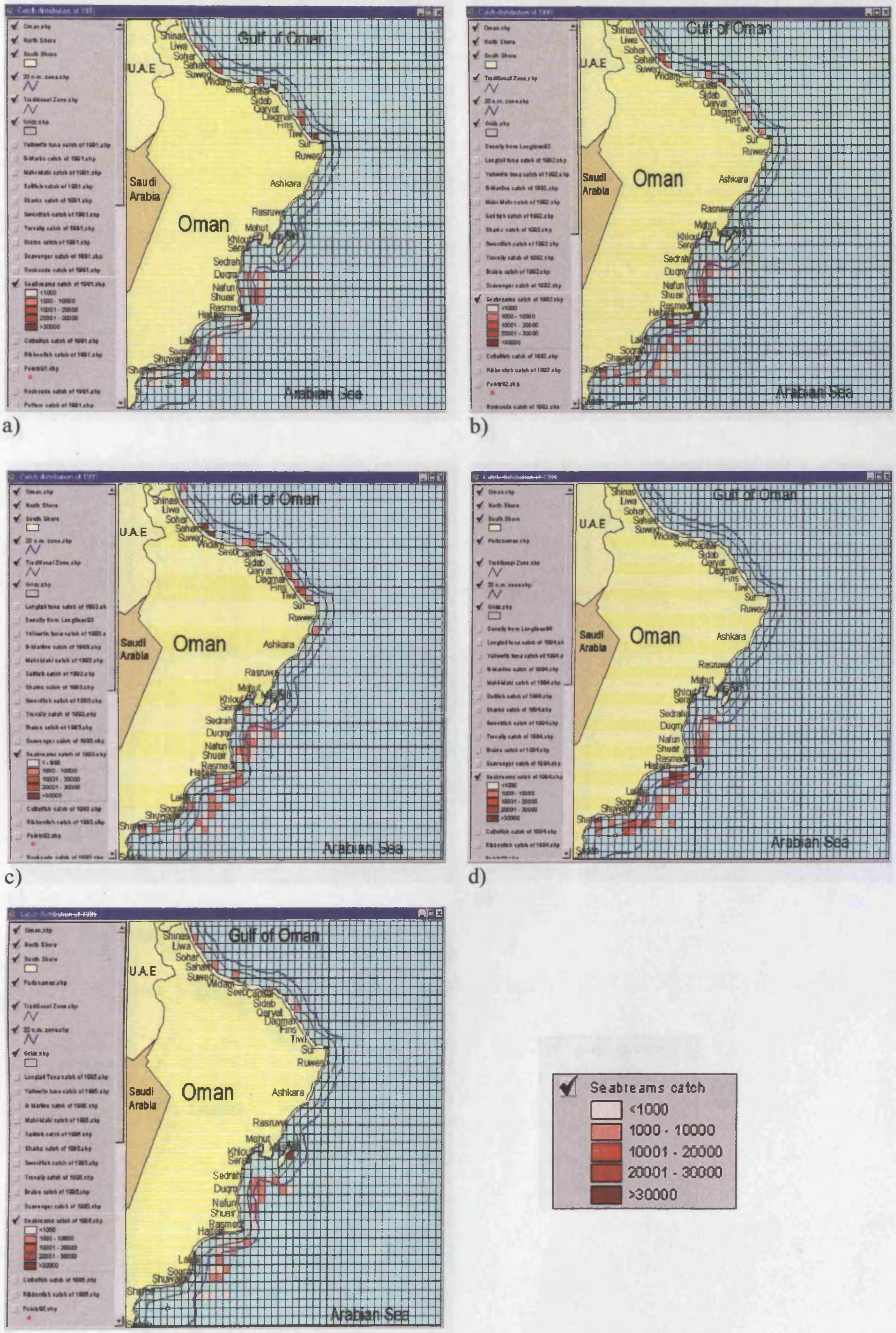


Figure B.18. Catch distribution of Seabreams (King Soldierbream) (*Argyrops spinifer*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.

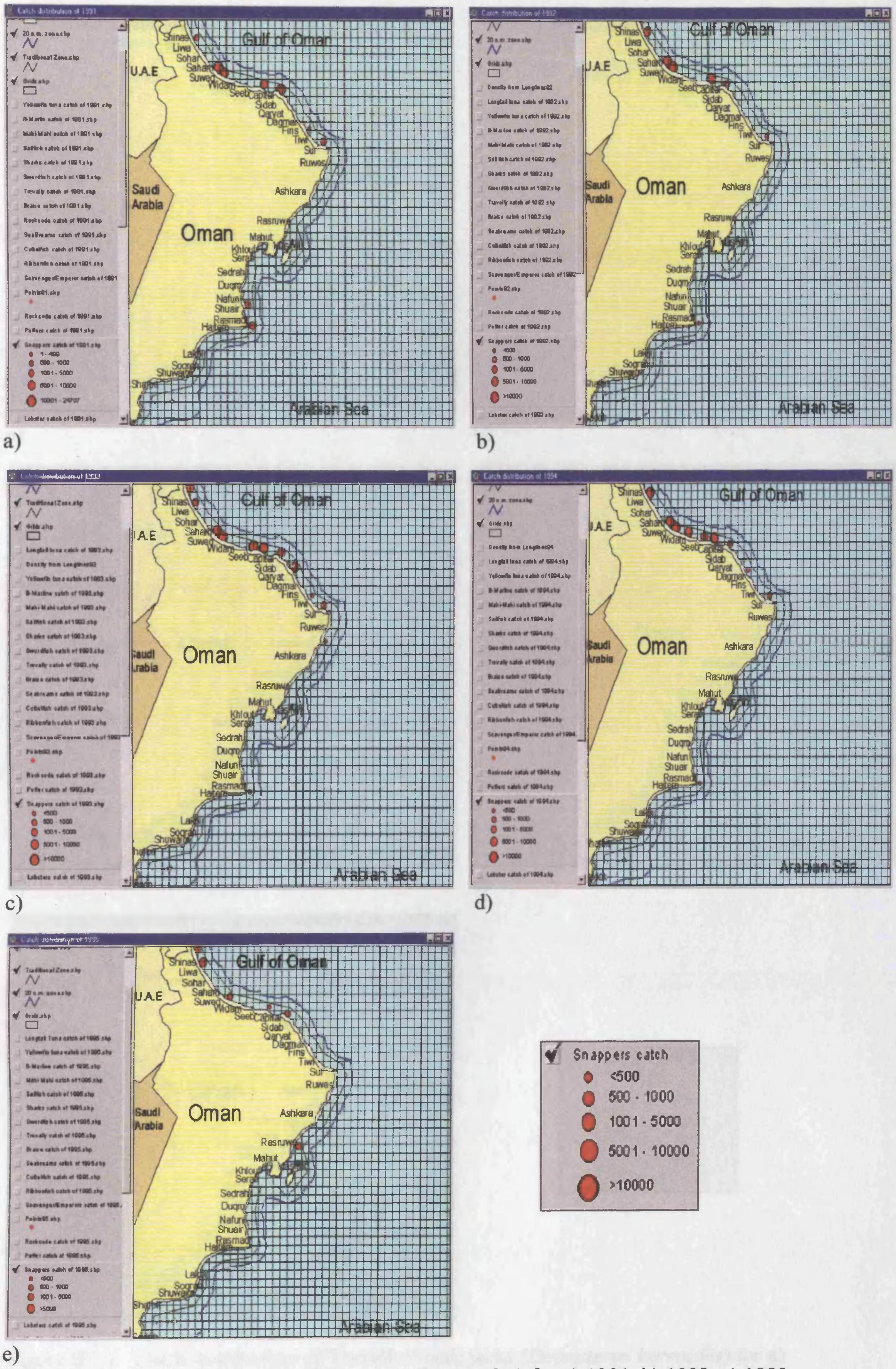
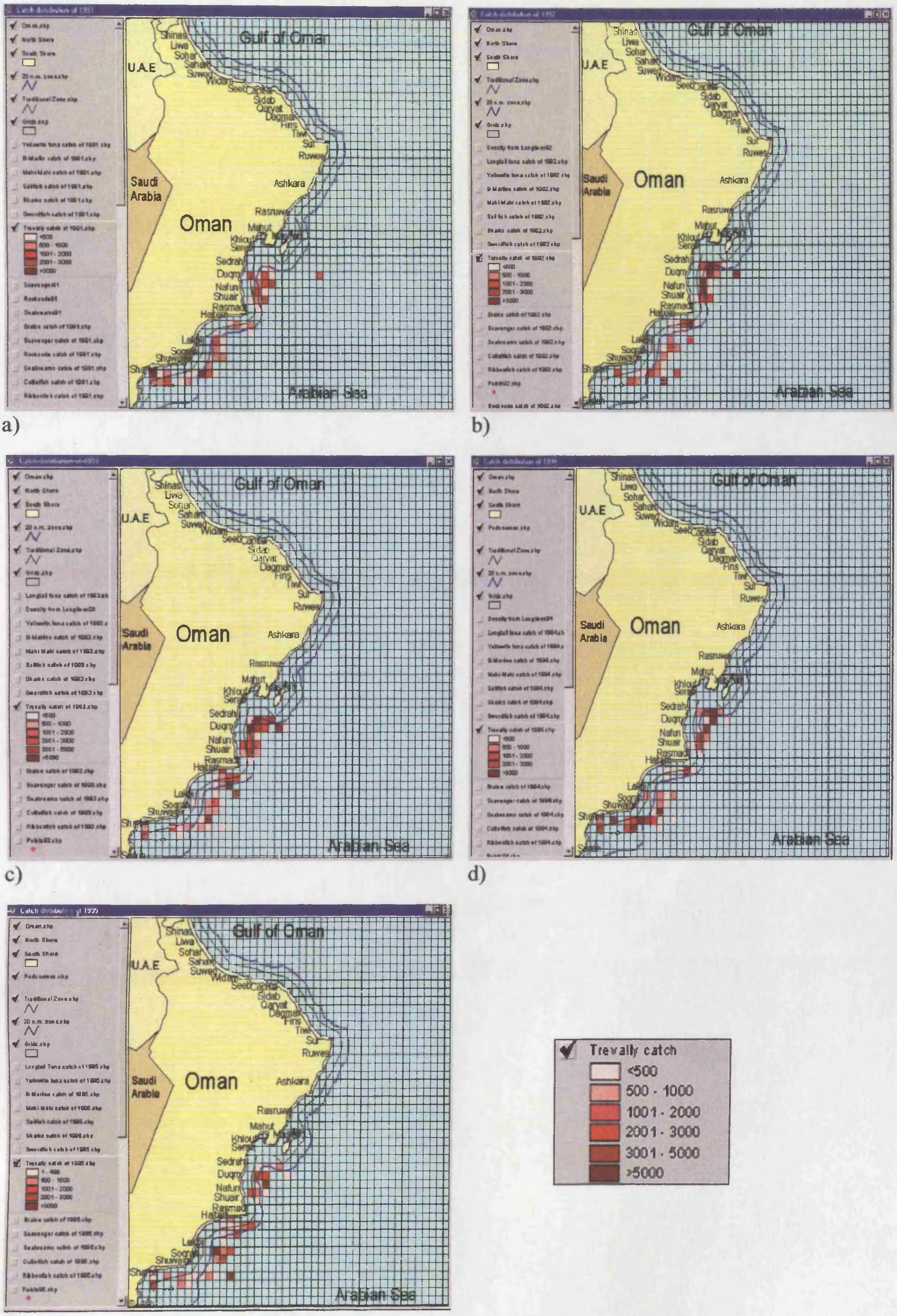


Figure B.19. Catch distribution of Snappers (*Lutjanidae*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.



e)

Figure B.20. Catch distribution of Travelly/Small jacks (*Decapterus kurroides*) for a) 1991, b) 1992, c) 1993, d) 1994, and e) 1995.