VII.5. REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS

V.D.Valavanis[1], & Georgakarakos S.[2]

[1]Institute of Marine Biological Resources, HCMR, P.O. Box 2214, 71003, Heraklion, Hellas
[2]Fisheries Management and Sonar Laboratory, Aegean University Dept. of Marine Sciences, University Hill, 81100 Mytilini, Hellas

vasilis@her.hcmr.gr

INTRODUCTION

During the last three decades, the advancing new technologies of Remote Sensing (RS) and Geographical Information Systems (GIS) allow us to use spatial data such as satellite imagery, aerial photographs, and geo-referenced data layers and the necessary tools to comprehend ecosystem functioning and environmental change and more effectively monitor and manage our marine natural resources.

The combined use of RS and GIS technologies form an invaluable tool for the identification and spatiotemporal mapping of environmental processes and changes, fish population dynamics and fisheries-environment interactions. RS and GIS facilitate the decision-making process and promote the scenarios for geographic information use, the ecosystem approach to fisheries' management and the sustainable use of marine resources by the year 2015, principles evolved and agreed during the Earth Summits organized for the environment in Rio de Janeiro (1992) and Johannesburg (2002) (Figure 1).

Figure 1: AGENDA 21 (Rio Declaration on Environment and Development 1992) as well as the Fisheries Agreement (Johannesburg Earth Summit 2002) describe the commitment of the world's governments to use geographic information from established and new monitoring systems in order to develop information-based management polices for decreasing over-fishing, restoring depleted fish stocks and using natural resources under sustainable and development schemes.

In this unit, the basic concepts of RS and GIS are explained and their combined application to Hellenic marine environment and fisheries are presented (VALAVANIS, 2002).

MARINE SATELLITE REMOTE SENSING

Remote Sensing (RS) aims to develop and use knowledge of the optic properties of the components of the earth's surface in order to obtain algorithms, which can be used to draw charts expressing important properties of the earth's surface on the basis of measurements taken from a variety of earth-orbiting satellites and other airborne systems and their sensors. In Marine Sciences, RS data obtained from visible or thermal infrared and microwave sensors include the charting of a variety of important water properties, including sea surface temperature, chlorophyll, photosynthesis levels and sea level altimetry measurements along wide ocean areas. Current basic RS research focuses on the development of new sensors for the measurement of additional sea properties, such as salinity.

The ways satellites and their sensors orbit around the earth and measure sea surface parameters are multifaceted. Environmental satellites are launched in geostationary or polar orbits. Geostationary satellites follow the earth's rotation and they monitor the same area of the earth and constantly send back information about that area. Polar-orbiting satellites go around the earth from pole to pole and they monitor different areas during their orbit (Figure 2).

A geostationary (GEO for geosynchronous) orbit is one in which the satellite is always in the same position with respect to the earth's rotation. The satellite orbits at an elevation of approximately 36 000 km because that produces an orbital period (time for one orbit) equal to the period of rotation of the earth (approximately 24 h). By orbiting at the same rate, in the same direction as the earth, the satellite appears stationary (synchronous with respect to the rotation of the earth). Geostationary satellites provide a "big picture" view of the same part of the earth. Alternatively, polar-orbiting satellites provide a more global view of the earth, circling at near-polar inclination (the angle between the equatorial plane and the satellite orbital plane), orbiting at an altitude of approximately 900 km. A polar-orbiting satellite operates in a sun-synchronous orbit passing the equator and each latitude at the same local solar time each day, meaning the satellite passes overhead at essentially the same solar time throughout all seasons of the year. This feature enables regular data collection at consistent times as well as long-term comparisons. The orbital plane of a sun-synchronous polar-orbiting satellite rotates approximately one degree per day to keep pace with the earth's surface.

Satellites and their sensors monitor the earth's surface in two main ways (Figure 3). Sensors that provide their own source of energy are called active while sensors that rely on the sun's energy are called passive. Active sensors emit radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. Active sensors include radars, scatterometers, lidars, laser altimeters and sounders. On the other hand, passive sensors detect the sun's energy that is either reflected (visible wavelengths of the light spectrum) or absorbed and then re-emitted (thermal infrared wavelengths) by the earth's surface. Passive sensors include radiometers, spectrometers, spectroradiometers and hyperspectral radiometers. Both active and passive sensing provides a variety of measurements including both atmospheric and oceanic parameters (Table 1).

While satellite acquisitions are most often presented in the form of images, they are actually digital data. Acquired satellite data provide measurements of the sea surface temperature in °C, chlorophyll-a concentration in mg/m^3, ocean wind speed in m/sec, sea level altimetry in cm, etc. Examples of several satellite data are presented in Figure 4. Satellite measurements have three main characteristics that depend on the sensor's capacity to acquire data at a given detail. These characteristics are named spectral, spatial and temporal resolution and they depict the primary characteristics of each sensor. The spectral resolution of a sensor and its acquired data is a measure of its power to resolve features in a certain part of the electromagnetic spectrum (active sensors) or the spectrum of visible light (passive sensors). This is important because certain features are best monitored at certain parts of the spectrum. The spatial resolution of satellite data is a measure of the ability of a sensor to separate the images of closely adjacent objects, meaning the smallest area identified as a separate mapping unit is the picture element (pixel) of the satellite image. Objects that are smaller than the spatial resolution of an image are not monitored. Finally, temporal resolution is the frequency at which satellite data are recorded in a specific place on earth. The more frequently an

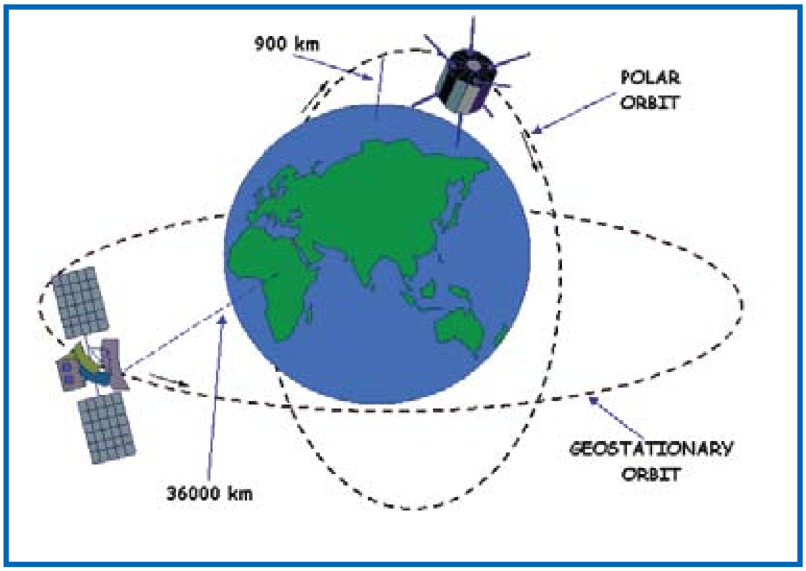

Figure 2: The geostationary and polar orbits of environmental satellites. Sensors in geostationary orbit constantly monitor the same area of the earth while sensors in polar orbit provide data for essentially all the earth's surface.

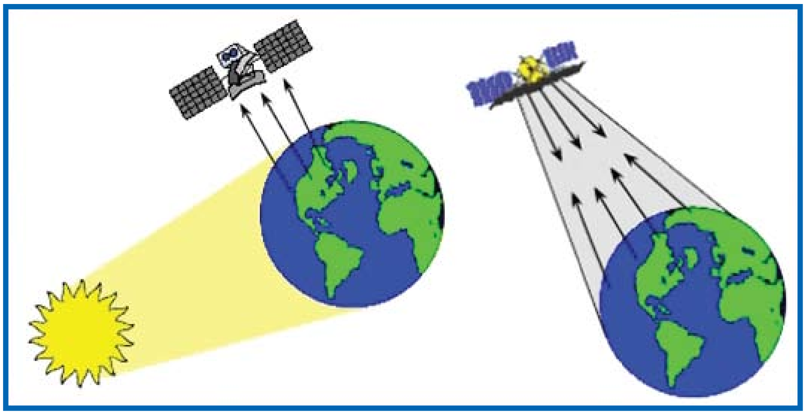

Figure 3: The passive and active Remote Sensing sensor systems. Sensors absorb either the sun's light reflectance to the earth (passive) or they transmit and absorb their own signal (active). Different environmental parameters are measured by each sensor system.

Table 1. Main environmental satellites, their sensors and measured environmental parameters applied in oceanographic and fisheries research.

SATELLITE	SENSOR	TYPE	PARAMETER
NOAA-POES Polar Operational Environmental Satellites	AVHRR Advanced Very High Resolution Radiometer	Passive, multispectral radiometer	Sea Surface Temperature
AQUA	MODIS Moderate Resolution Imaging Spectroradiometer	Passive, imaging spectrometer	Sea Surface Temperature and Chlorophyll
SeaStar ORBVIEW	SeaWiFS Sea viewing Wide Field-of-view Sensor	Passive, ocean colour sensor	Sea Surface Chlorophyll, Photosynthetically Active Radiation
QuikSCAT	SeaWinds	Active, radar scatterometer	Ocean Wind Speed and Direction
ERS-2 European Remote Sensing	WD Wind Scatterometer	Active, radar scatterometer	Ocean Wind Speed and Direction
ERS-2 European Remote Sensing	RA Radar Altimeter	Active, radar altimeter	Significant Wave Height, Surface Wind Speed
TOPEX-Poseidon	Doris Doppler Orbitography and Radiopositioning	Active, radar altimeter	Wind Speed, Wave Height

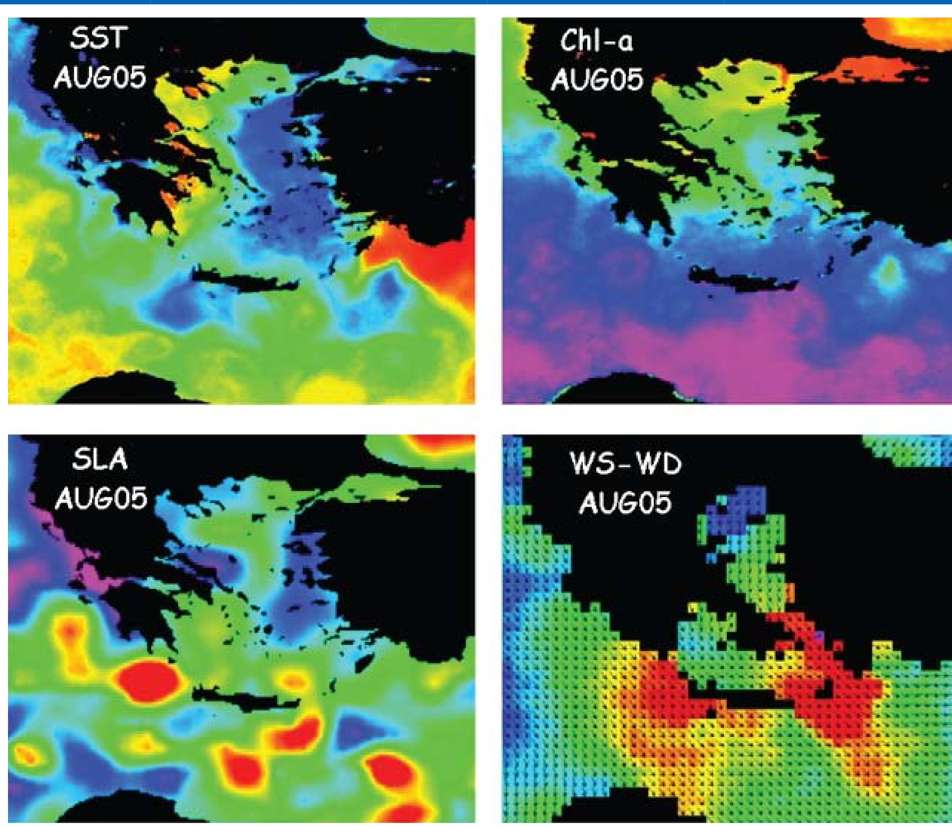

Figure 4: Examples of monthly-averaged satellite data for August 2005 in the SE Mediterranean. Main oceanic processes (e.g. gyres, eddies, fronts and upwelling) are visible in SST (sea surface temperature), Chl-α (chlorophyll), SLA (sea level altimetry) and WS-WD (wind speed and direction) satellite images. Colours depict real parameter values (purple/blue: low, green/yellow: medium, red: high).

area is monitored, the better or finer the temporal resolution is for that area.
Today, the combination of fine spectral, spatial and temporal resolutions characterizes most satellite sensors and acquired multi-parameter data that provide an enormous amount of information for the state of the sea surface. These data are widely processed through GIS to identify several ocean processes and marine species-environment interactions.

MARINE GEOGRAPHICAL INFORMATION SYSTEMS

Geographic Information Science (GI Science), the scientific context to Geographic Information Systems (GIS), which is the technical content of GI Science, are both emerging and coherent science and technology fields with two important research streams: research in basic GI Science (e.g. software integration, data scale and resolution, process models) and research using GIS (e.g. data modelling and integration, decision support). In Marine Sciences, GIS are widely applied to data modelling and integration producing analytical results in the form of charts that depict the condition of the marine environment and its living resources in spatiotemporal scales and effectively support information-based natural resource management schemes (Figure 5).
GIS is considered the main framework for geospatial data handling. The main two components of a GIS are its database and its analytical capacity. GIS has the ability to relate different data in a spatial context and to reach a conclusion about their relationship. Most of the information we have about our world contains a location reference, placing that information at some point on the globe. In GIS databases, two main data models are stored. These data models, raster (e.g. satellite data) and vector (Figure 6) represent the whole variety of marine data used in various analytical procedures. Because data in GIS are stored under a common geo-reference system, different types of data can be viewed through a map overlay (Figure 7). This technique allows the combined analysis of raster and vector data in order to identify any possible relations among different datasets.
The common geo-reference of different data types is the first step in GIS development. Given this uniform storage of various data, GIS analyses include a variety of data integration and statistical procedures that are applied to data according to specific questions to be answered. Such questions include six basic concepts that are inherently spatial and are used by geoscientists in studying spatial phenomena. These spatial concepts are location, distribution, region, association, movement and diffusion.

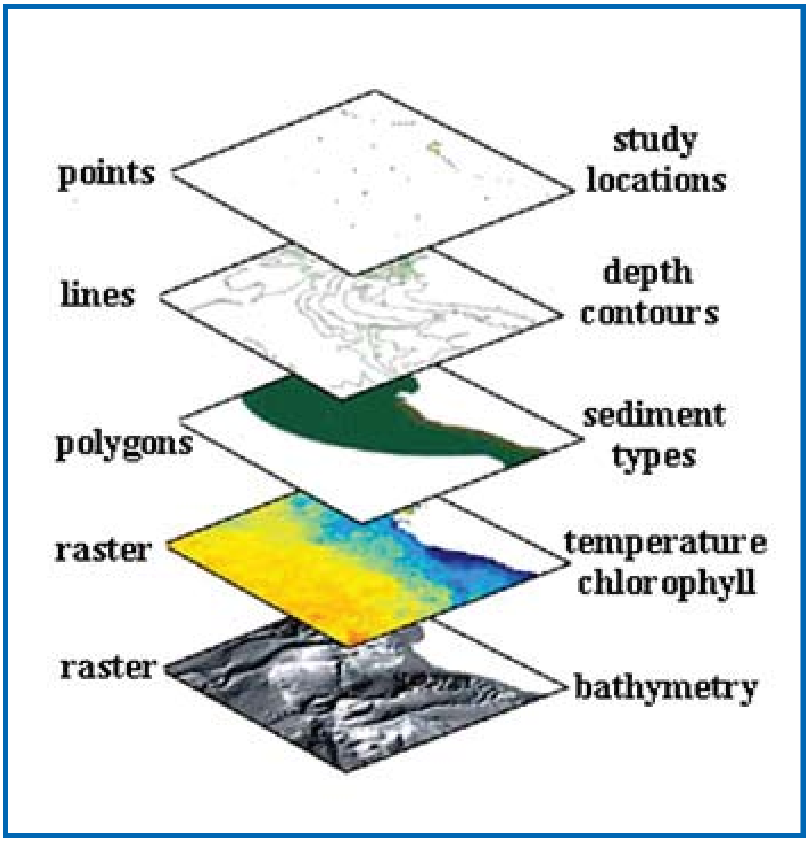

Figure 5: Examples of the variety of data types handled by Marine GIS. Points, lines and polygons are vector data type while satellite imagery and model output are raster data type. Under GIS databases, different data formats are uniformly stored and referenced through a common geo-reference system. Then, spatial integration and GIS analysis of different data formats is applied.

The most basic spatial concept is that of location. For example, the location of a meteorological station will give a spatial meaning to the associated dataset. Also, the first question, for example, that an oceanographer studying an upwelling event will typically ask is "where does it occur"? Distributions may be thought of as sets of individual locations of one or more datasets describing a part or the whole of an area. A region is an area that is distinguished from other areas by one or more characteristics. By creating a region a scientist is able to generalize and simplify. A region, for example, is an area where sea surface temperature (SST) is generally lower than in the surrounding area. If we have two different spatial distributions that appear to be similar, we have a spatial asso-

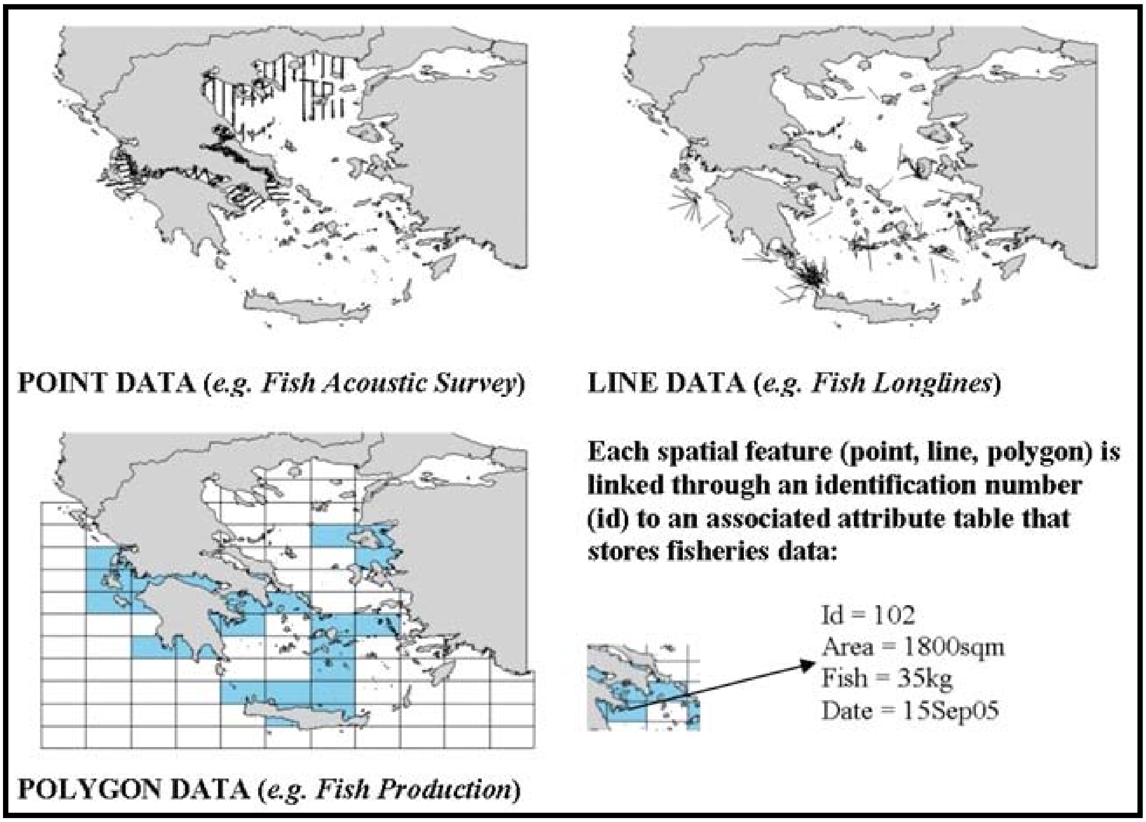

Figure 6: Examples of a vector GIS database including fisheries attribute data represented by points, lines and polygons. Here, research vessel acoustic surveys are represented by points and longline fishing activity is represented by lines. Polygons represent the official sampling units for the monitoring of Hellenic fisheries' resources (size: 1° x 0.5°).

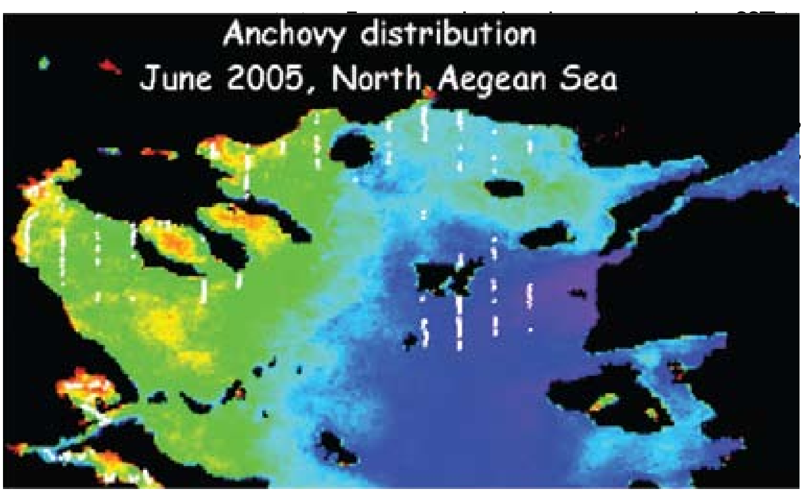

Figure 7: Overlay example of vector and raster GIS datasets including anchovy attribute data (vector-points) and sea surface temperature (raster-colours). The common geo-reference storage of different data models in GIS databases prepares data for further statistical and GIS analyses.

geoscientist may integrate the associated datasets and explain, for example, how the distribution of wind data from several locations of meteorological stations affects a region where a spatial association between SST and Chl-a does exist and how movements of fish populations correspond to this process, and finally, how this process is diffused in space and time.

Spatial analysis in GIS refers to a large number of modelling data operations including a variety of techniques, such as classification and aggregation, proximity analysis, adjacency analysis, connectivity analysis, optimum path analysis, statistical analysis, interpolation and outlining as well as other data integrations.

Classification involves reassigning a data value to a descriptive attribute of a polygon according to the values taken by other attributes. Classification can be followed by aggregation, which involves grouping two or more adjacent reclassified units by dissolving boundaries between polygons and then reconstructing new data topology. For example, an SST image can be classified based on certain data ranges and then aggregated to areas of low, medium and high temperature values (e.g. identification of upwelling areas). Proximity analysis involves the determination of several spatial features (points, lines, polygons) located within a maximum distance from a given spatial feature. Proximity analysis introduces the concept of a 'buffer zone', which can be of a fixed or variable size. For example, proximity analysis may be used to locate fishing ports that are within 100 miles from a given fishing area (e.g. spatial relation between catches and landings). Adjacency analysis involves reassigning to a given data value a new value, which depends on that of neighbouring data values. In raster data, such as satellite images and aerial photographs, adjacency analysis might employ a filter, such as a summation, mean or gradient filter. For example, adjacency analysis may be used for the computation of slope (e.g. the rate of change in data values) in a Chl-a image (e.g. identification of Chl-a fronts). Connectivity analysis consists of determining the boundaries of an area by starting from a certain data value and moving in every direction in order to locate the points verifying a given data value (e.g. threshold value). For example, connectivity analysis may be used for the identification of areas where SST is between 20 and 23 °C.

Optimum path analysis consists of determining the optimum path between two points or areas considering distance, cost, time and other factors. For example, when combining fish migration habits and environmental data, this type of analysis applies well to seasonal fish migrations. Impedance, which is defined by characteristics such as certain data values, is assigned to each data value revealing, e.g. the difficulty of a species to pass through certain data values of SST (according to species-preferred living environmental conditions). Statistical analysis supplies basic statistics on the descriptive data such as mean, standard deviation, minimum, maximum and median values and histograms of data distribution. More sophisticated analyses such as regression, classification and Principal Component Analysis (PCA) provide valuable information, for example in relations between fisheries' populations and oceanography. These calculations are common in image processing software packages and are widely used in GIS. However, current GIS packages often do not include extensive statistical tools but do provide data exchange with such tools. Interpolation techniques provide an estimate of a value at a point where the value is unknown, within a region covered by a number of known values of sampled points. The choice among the many interpolation methods depends on the spatial model, which is best fitted to the sampled values. Two commonly used interpolation methods are local interpolation (spline, weighted mobile mean), and kriging. These methods are based on the hypothesis whereby two points, which are close to each other are more likely to have similar values for a given property than two distant points are. They take into account the fact that space is not necessarily isotropic (e.g. the bottom sediment values from a point sonar survey are more likely to vary through the whole of a study area than between two close together and parallel transect lines).

During the process of marine GIS development, often multiple inputs are required. For example, the explanation of why a mobile cephalopod species (e.g *Loligo vulgaris*) is found 200 km offshore at certain times of their life cycles, requires the input of species life history data into their migration habits (fisheries' biologists), wind and current patterns, and the identification of food supply upwelling events in the region at that specific time (physical and biological oceanographers) as well as expert GIS developers for the integration of this knowledge. From the GIS point of view, the ultimate aim is to join all required knowledge and develop a model of the marine environment in order to understand what and where things are and how and why they are where they are.

MARINE GEOGRAPHIC INFORMATION SYSTEMS IN HELLENIC SEAS

Over the last two decades, there has been increasing recognition that problems in fisheries and related marine areas are nearly all manifest in the spatial and temporal domain. The combination of oceanographic and fisheries' GIS applications and tools provides the opportunity to identify the dynamic relations between species populations and ocean processes in spatial and temporal scales. The need for the identification of interactions between environment and fisheries becomes crucial in the fisheries management process.

For these reasons, an integrated approach to the management of Hellenic fisheries' resources includes the development of a multi-component management system by the Institute of Marine Biological Resources (IMBR) of the Hellenic Centre for Marine Research (HCMR). IMAS-Fish (Development of an Integrated Management System to support the sustainability of Hellenic Fisheries' resources: IMAS-Fish) delivers data and analytical information to fisheries' policy makers and supports the decision process towards new and effective management schemes. The system includes all the components of past and current monitoring systems of the Hellenic fisheries' resources and in-

tegrates latest developments in statistical, GIS and RS applications in fisheries' management promoting the ecosystem and precautionary approaches.
The components of IMAS-Fish are multifaceted. The system operates on a 3-fold technological setting, including an Oracle database, a GIS database and an Internet server. Databases include a variety of fisheries and oceanographic datasets (e.g. fisheries' effort and production, survey data, satellite imagery and other environmental data) while its analytical functions are accessible through the Internet. RS and GIS developments for the Hellenic Seas over the last decade are incorporated into this system. The IMAS-Fish tool is accessible at: http://efterpi.ncmr.gr/imasfish (ZERVAS *et al.,* 2004; DAMALAS, 2005; DAMALAS *et al.,* 2006).
A variety of marine and fisheries' GIS research applications aim to identify the spatial component of ocean processes, fisheries' resources and their relations. From the oceanographic perspective, several studies deal with the classification of sea surface waters (DRAKOPOULOS, *et al*., 1999, 2000, 2002) and the mapping of ocean processes, namely fronts, gyres, marine productivity hotspots and upwelling (VALAVANIS *et al.,* 1999, 2004, 2005; KATARA *et al.,* 2005). From the fisheries' perspective, several studies deal with the mapping of fish population distributions (VALAVANIS *et al.,* 2002, 2004), mapping of essential fish habitats (VALAVANIS *et al.,* 2004; GIANNOULAKI *et al.,* 2006) and species-environment relationships (VALAVANIS *et al.,* 2002; KAPANTAGAKIS *et al.,* 2002). These GIS-based research applications use satellite environmental data and surveyed fisheries' data combined with various GIS, statistical and geostatistical techniques.
The classification of surface waters based on their temperature, chlorophyll and salinity characteristics provides an insight into the state of the sea surface environment and explains why fish population distributions are concentrated in more productive areas in the north and central Aegean Sea while gradually diminishing in numbers in less productive waters in the south Aegean and the Cretan Sea. In fact, 60-70% of total fisheries' production comes from the north/central Aegean Sea that is characterized by productive waters, river run-off and Black Sea water input. Four classes of water are identified through Principal Component Analysis (PCA) and unsupervised classification of combined satellite and model data. Classified water bodies in the Hellenic Seas have the following characteristics (Figure 8): 16-24°C, 0.20-3.80 mg/ m^3 and 37.9-38.3 psu (red), 18-23°C, 0.10-0.27 mg/

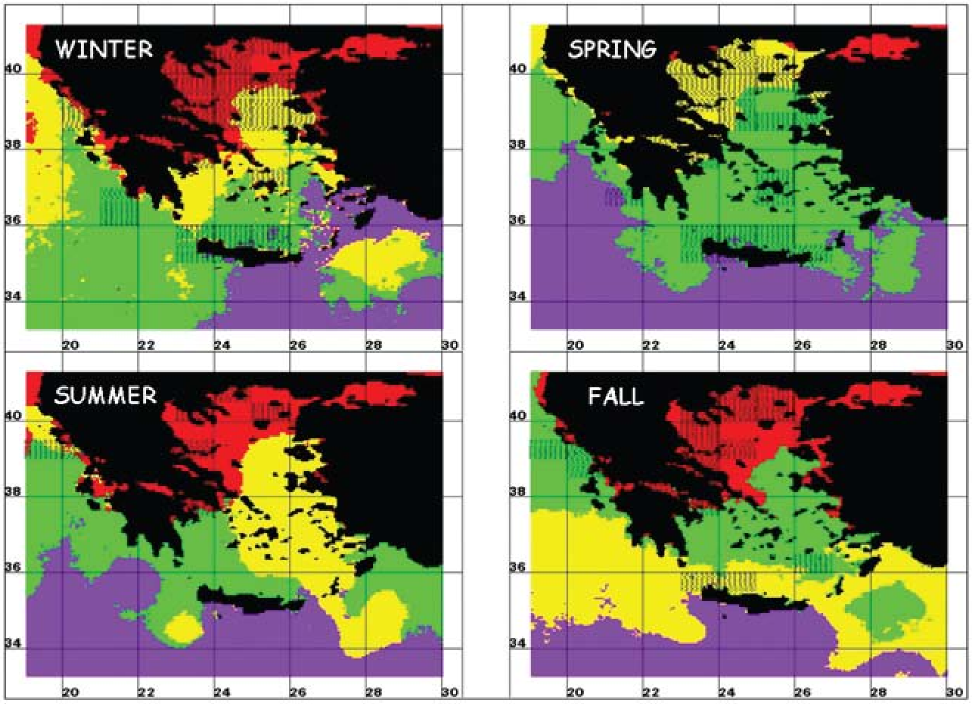

Figure 8: Seasonal classification of surface waters based on their temperature, chlorophyll and salinity content for the period 2000-2005. General distribution of *Loligo vulgaris* (short-finned squid) is also shown for the same period. Four classes of water are identified (see text for colour-scale description). Monitored squid production is mostly associated to colder, less saline and more productive water bodies, a pattern that is observed in most commercial fish species in Hellenic Seas.

m^3, 38.2-38.6 psu (green), 18-25°C, 0.08-0.14 mg/m^3, 38.3-39.7 psu (yellow) and 19-25°C, 0.05-0.08 mg/m^3, 38.6-38.8 psu (purple).

The mapping of major ocean processes provides invaluable knowledge on the identification of certain marine areas that affect fish population distributions, either passively or actively (Figure 9). For example, a productive thermal front (an area where different water masses converge) is an area where many fish species actively aggregate for their feeding. Marine productivity hotspots and upwelling have similar fish aggregation effects while productive gyres and their surrounding currents often function as natural barriers where fish are passively trapped inside these productive areas. Depending on species' life stage (egg/larvae, juvenile, adult), these ocean processes create favourable environmental conditions and habitats that are used by various fish species for spawning/nursery, feeding and mating purposes.

For example, the spatial distributions of *Engraulis encrasicolus* (European anchovy) acoustic survey data and mesoscale thermal fronts in the north Aegean Sea during June 2004 present strong associations. Accompanied GIS and Generalized Additive Model (GAM) analysis reveals the distribution of fronts and trends in anchovy presence and its distributional abundance. In the Thracian Sea (permanent anticyclones and fronts) results indicate that anchovy is distributed within the continental shelf (depths <200m), an area dominated by chlorophyll-a concentrations around 0.45 mg/m^3. Anchovy abundance is higher in areas of less than 300m, around 22.75°C and 0.58 mg/m^3. In the Thermaikos Gulf (extended continental shelf), anchovy is present in areas less than 60m. In both areas, anchovy abundance is within 5.55 nautical miles minimum distance from fronts (total study area 160x105 nautical miles). Alternatively, ocean gyres function as natural barriers between different life stages of the same species. A typical example of this pattern is the distribution of European anchovy larvae inside a gyre while adults are distributed around the gyre boundary.

Such multi-parameter GIS spatial associations are very important for the management of marine fisheries' resources. The over exploitation of fisheries' resources is a worldwide spatial problem. Previously rich areas in marine resources and favourable habitats have been either over fished or destroyed by certain fishing gears. The need to design and protect over exploited regions and identify alternative fishing grounds is growing rapidly. Thus, GIS applications dealing with this important subject produce integrated map products that aim to facilitate this important issue. For example, the mapping of marine productivity hotspots reveals both known fishing grounds and potential alternative fishing activity areas (Figure 10). This trend may be used for the design of seasonal and spatially-variable marine protected areas that will help the natural conditioning of traditional fishing grounds in regenerating themselves. On the other

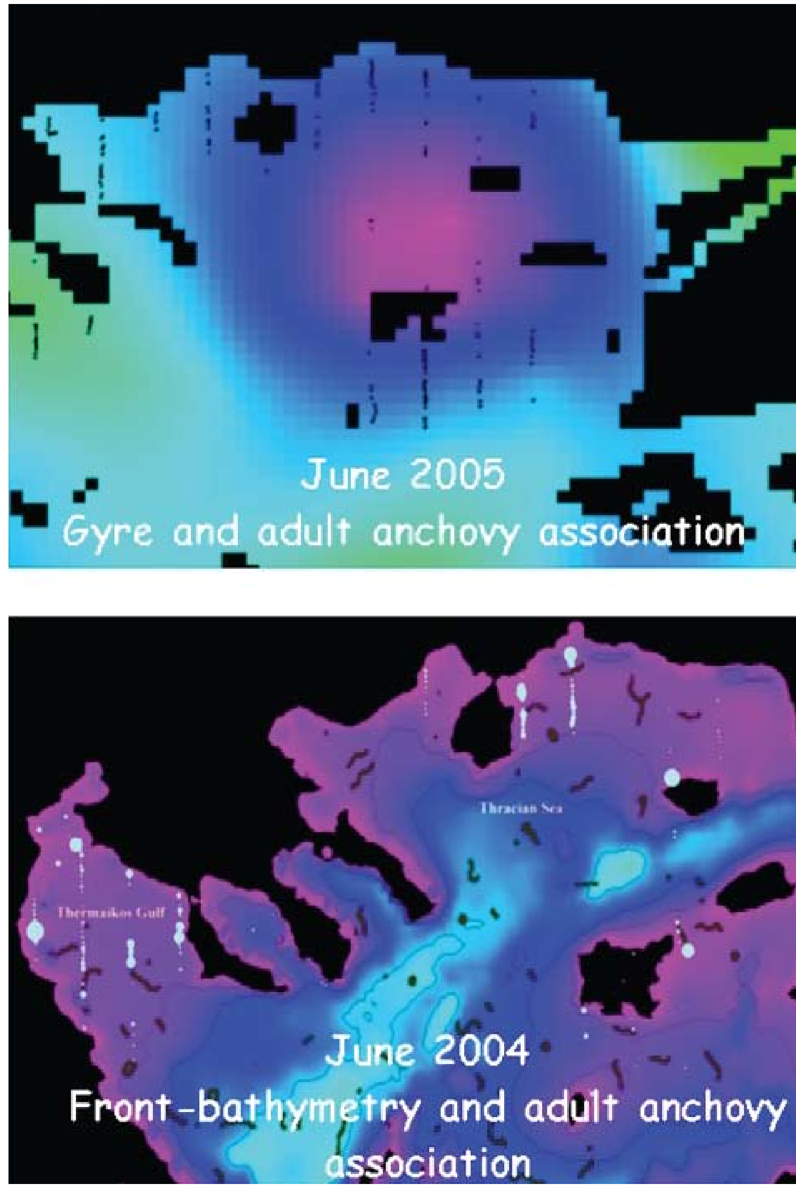

Figure 9: Spatial associations of adult *Engraulis encrasicolus* (European anchovy) acoustic survey data in the north Aegean Sea to gyre formation (June 2005) and mesoscale thermal fronts (June 2004). Shaded bathymetry (purple to light blue for shallow to deeper waters) and isobaths of -100m, -300m and -1 000m are also shown.

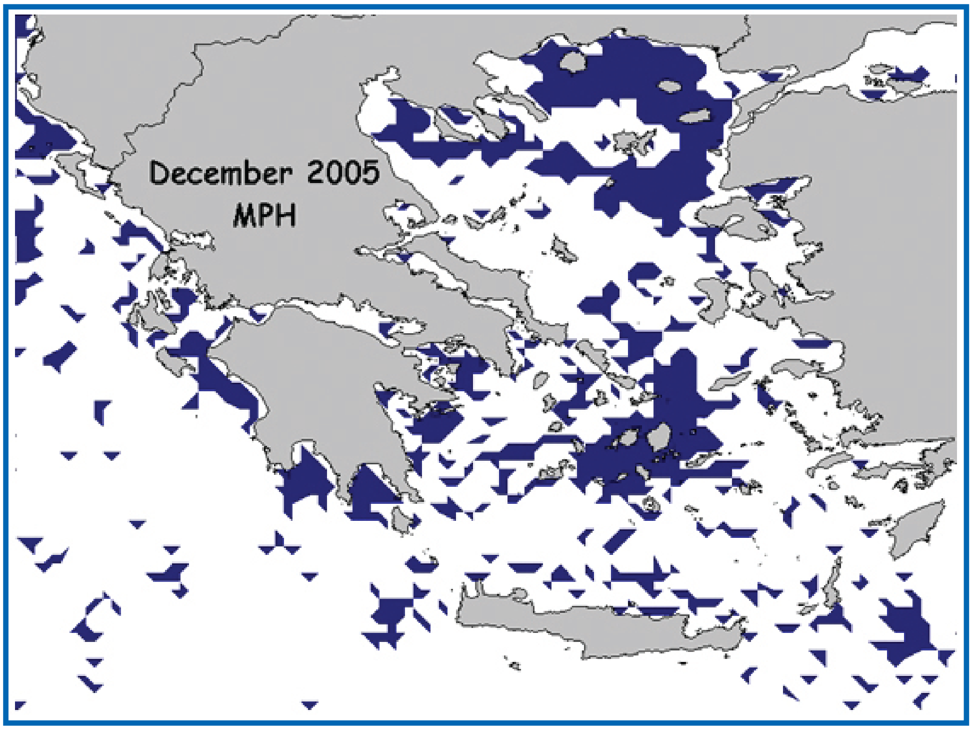

Figure 10: Marine Productivity Hotspots (MPH) in Hellenic Seas in December 2005. MPH are characterised by negative SST and positive Chl-α anomalies and reveal known fishing grounds as well as potential alternative fishing activity areas. Such GIS products may facilitate the spatial component of the fisheries' management process.

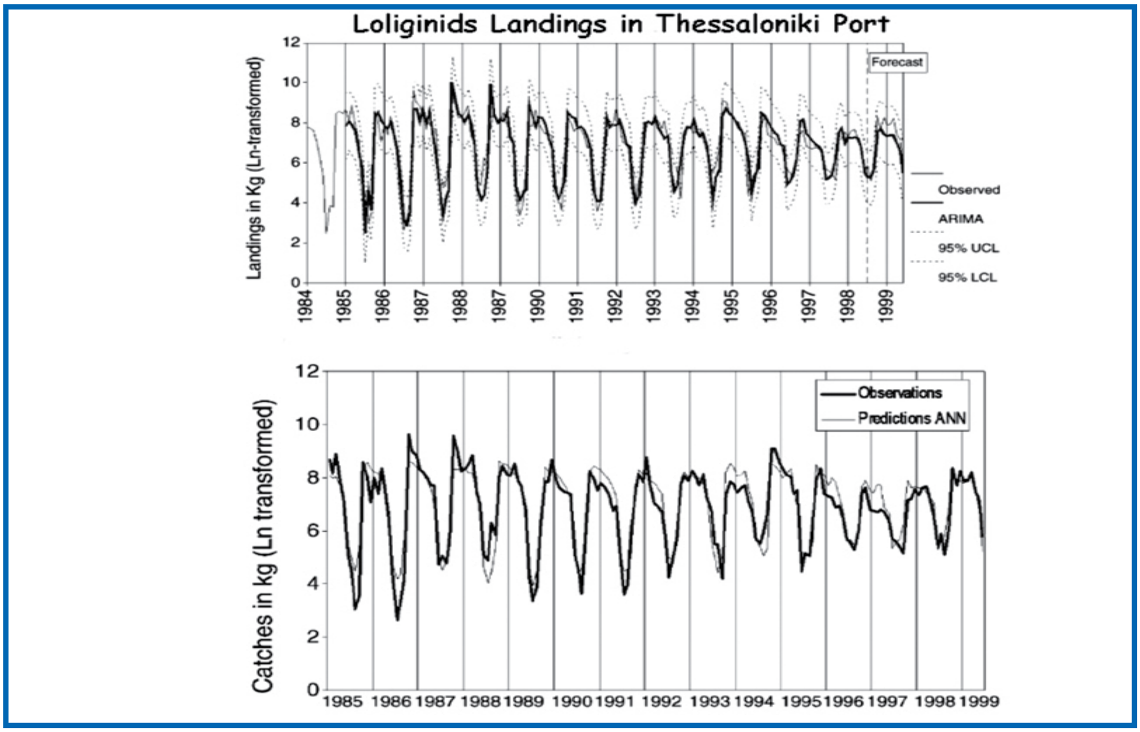

Figure 11: The use of environmental parameters for fisheries' forecasting and prediction using Auto-Regressive Integrated Moving Average (ARIMA) model and Artificial Neural Networks (ANN) for Loliginids landings in Thessaloniki port (1985-1999). Sea Surface Temperature (SST) may be used as environmental descriptor for the prediction of landings at high confidence limits.

hand, fishing activities could be led to new unexploited areas.

In association with this, fisheries' forecasting becomes important (Figure 11). Modelling fish production and distribution in short and medium terms greatly facilitates the management process. GIS and statistical applications on this subject provide important outputs on the identification of those environmental factors that may be used as indicators of fish production and distribution (GEORGAKARAKOS *et al.,* 2002, 2006).

In a spatial context, combined RS/GIS/statistical applications aim to facilitate the complex fisheries' management process by providing products that are based on scientific knowledge and analysis in order new management schemes could be based on analyzed monitored information and eventually become more effective than current policies.

REFERENCES

DAMALAS, D., 2005. Development of advanced statistical analysis and modelling of fisheries and environmental data using S-Plus. *Proceedings of the 12th Pan-Hellenic Ichthyologists Conference*. Oct. 13-16, 2005, Drama Greece.

DAMALAS, D., KAVVADAS, S., ZERVAS, T. & VACHLAS, N., 2006. Development of advanced statistical analysis and modelling of fisheries and environmental data through the Internet-based tool IMAS-Fish using S-Plus. *Proceeding of the 8th Pan-Hellenic Oceanography-Fisheries Symposium*. June 4-8, Thessaloniki Greece.

DRAKOPOULOS, P., VALAVANIS, V.D. & GEORGAKARAKOS, S., 2000. Spatial and Temporal Distribution of Chlorophyll-a in the Aegean Sea According to SeaWiFS Imagery. *Proceedings of the Sixth Hellenic Conference on Oceanography and Fisheries*. May 23-26, 2000, Chios, Greece, p.206-210.

DRAKOPOULOS, P.G., PETICHAKIS, G., VALAVANIS, V., NITTIS, C. & TRIANTAPHYLLOU, G., 2002. Optical variability associated with phytoplankton dynamics in the Cretan Sea during the years 2000 and 2001. *Proceedings of the 3rd EuroGOOS Conference*, Dec. 3-6, Athens Greece.

DRAKOPOULOS, P., VALAVANIS, V.D. & GEORGAKARAKOS, S., 1999. An Information System for the Identification and Measurement of Upwellings. *Proceedings of the Fifth Hellenic Geographic Conference,* Nov. 10-12, 1999, Athens, Greece.

GEORGAKARAKOS, S., HARALABUS, J., VALAVANIS, V.D., ARVANITIDIS, C., KOUTSOUBAS, D. & KAPANTAGAKIS, A., 2002. Loliginid and Ommastrephid Squids Prediction in Greek waters using Time Series Analysis Techniques. *Bulletin of Marine Science* 71(1): 269-287.

GEORGAKARAKOS, S., KOUTSOUBAS, D. & VALAVANIS, V.D., 2006. Time series analysis and forecasting techniques applied on loliginid and ommastrephid landings in Greek waters. *Fisheries Research* 78(1): 55-71.

GIANNOULAKI, M., MACHIAS, A., VALAVANIS, V.D., SOMARAKIS, S. & PAPACONSTANTINOU, C., 2006. Estimating the potential habitat of the European anchovy in the Eastern Mediterranean basin using GIS. *Proceedings of the 136th Annual Meeting of the American Fisheries Society: Fish in the Balance*, Sep. 10-14, 2006, Lake Placid, NY.

KAPANTAGAKIS, A., VALAVANIS, V.D., GEORGAKARAKOS, S., PALIALEXIS, A. & KATARA, I., 2002. Analysis of fisheries catch data in relation to temperature anomalies in SE Mediterranean using GIS. *Proceedings of the Second International Symposium on GIS/Spatial Analyses in Fishery and Aquatic Sciences,* Sep. 3-6, Brighton UK.

KATARA, I., PALIALEXIS, A., KAVVADIA, A. & VALAVANIS, V.D., 2005. Oceanographic GIS: Mapping of marine productivity hotspots and mesoscale thermal fronts. *Proceedings of the Third International Symposium on GIS/Spatial Analyses in Fishery and Aquatic Sciences,* Aug. 22-26, Shanghai, China.

VALAVANIS, V.D., 2002. *Geographic Information Systems in Oceanography and Fisheries*. Taylor & Francis, London, p240.

VALAVANIS, V.D., DRAKOPOULOS, P. & GEORGAKARAKOS, S., 1999. A Study of Upwellings Using GIS. *Proceedings of CoastGIS99 International Conference GIS and New Advances in Integrated Coastal Zone Management,* September 9-11, 1999, Brest, France. IFREMER.

VALAVANIS, V.D., GEORGAKARAKOS, S., KAPANTAGAKIS, A., PALIALEXIS, A. & KATARA, I., 2004. A GIS Environmental Modelling Approach to Essential Fish Habitat Designation. *Ecological Modelling* 178(3-4): 417-427.

VALAVANIS, V.D., GEORGAKARAKOS, S., KOUTSOUBAS, D., ARVANITIDIS, C. & HARALABOUS, J., 2002. Development of a Marine Information System for Cephalopod Fisheries in the Greek Seas (Eastern Mediterranean). *Bulletin of Marine Science* 71(2): 867-882.

VALAVANIS, V.D., KAPANTAGAKIS, A., GEORGAKARAKOS, S., KATARA, I. & PALIALEXIS, A., 2002. GIS mapping of marine species feeding grounds through analysis of satellite imagery. *Proceedings of the Second International Symposium on GIS/Spatial Analyses in Fishery and Aquatic Sciences,* Sep. 3-6, Brighton UK.

VALAVANIS, V.D., KAPANTAGAKIS, A., KATARA, I. & PALIALEXIS, A., 2004. Critical regions: A GIS-based model of marine productivity hotspots. *Aquatic Sciences* 66(1): 139-148.

VALAVANIS, V.D., KATARA, I. & PALIALEXIS, A., 2002. Spatiotemporal relations between anomalies in sea surface temperature and chlorophyll concentration in Hellenic Seas (SE Mediterranean). *Proceedings of the SPIE Nineth International Symposium on Remote Sensing: Remote Sensing for Environmental Monitoring, GIS Applications, and Geology,* 23-27 September 2002 Crete, Greece. pp. 651-658.

VALAVANIS, V.D., KATARA, I. & PALIALEXIS, A., 2005. Marine GIS: Identification of mesoscale oceanic thermal fronts. *International Journal of Geographical Information Science* 19(10): 1131-1147.

ZERVAS, T., PAPACHRISANTHOU, A., FOURLANOS, G. & COSMOPOULOS, Y., 2004. The Internet-based tool IMAS-Fish GIS. *Proceedings of the 14th Hellenic ArcGIS ArcInfo User Conference.* Nov. 1-3, 2004, Athens Greece.