E-ISSN 2149-0236
Journal of Aquaculture Engineering and Fisheries Research

REVIEW ARTICLE DERLEME MAKALE

A REVIEW: APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN MARINE AREAS

Şeyma Merve Kaymaz ORCID ID: 0000-0002-1936-0626, **Murat Yabanlı** ORCID ID: 0000-0002-9615-2222

Muğla Sıtkı Koçman University, Fisheries Faculty Department of Aquatic Sciences, Muğla, Turkey

Received: 17.04.2017

Accepted: 26.07.2017

Published online: 30.09.2017

Corresponding author:

Şeyma Merve KAYMAZ, Muğla Sıtkı Koçman University, Fisheries Faculty Department of Aquatic Sciences, 48000, Mentese, Muğla, Turkey

E-mail: seyma.merve87@gmail.com

Abstract:

In this review, the focus is the research of scientists which studied different GIS applications in marine areas. Based on literature review, the scientists stressed the use of GIS to assess and predict effects on marine environment. Marine spatial data are fundamental for a sustainable environmental management of marine areas, largely surrounded by countries with borders to the sea. In modern age, known as ‘’information age’’, data acquisition, analysis and management are essential for rapid, precise and economical resolutions. GIS applications were recommended to supply a principle from combining past and present circumstances in order to predict future for marine areas. This review provides an example to how GIS applications can be used in the monitoring, conservation, management, sustainable development and environmental protection stages of marine areas.

Keywords: GIS applications, Marine areas, Spatial data, Management, Decision support system

Introduction

Geographic Information Systems (GIS) for land usage were launched about 35 - 40 years ago, however it was only about 15 years that they were also applied to the sea (Goodchild, 2000). The assistance for study into universal Earth systems and the impacts of anthropogenic ecological change progressively increased, geographers started to develop their focus on research broader then previous traditional borders determined in the 1970 and 1980s. Marine GIS gained a substantial significance in the 1990s with the arrival and popularity of Earth System Science, an interdisciplinary initiative seeking to know the whole Earth system (atmosphere, oceans, seas, ice cover, environment, land etc.) world-wide (Nierenberg, 1992; Williamson, 1994).

Other factors boost the exposure of marine geography, and eventually marine GIS, comprise increasing global ecological understanding and apprehensions, increased comprehension of the part of marine life in preserving the global environment, new techniques for marine investigation beginning with the United Nations Convention on the Law of the Sea in 1994, and the designation of the International Year of the Ocean in 1998 (Psuty et al., 2002).

An understanding of the dynamics of marine area and living resources are essential for the explanation of the relationships between marine environment and species in any anthropogenic attempt to manage marine areas. Development of spatial thinking becomes very significant in several points throughout the study of methods in the marine environment using GIS, from collecting data to develop and to make decision by GIS. Many authors have studied spatial cognition in geographical environments (Slater 1982; Golledge and Stimson 1987; Blades 1991; Nyerges 1991; Golledge 1995; Nyerges and Golledge 1997; Lloyd 1997). Other main steps in developing spatial thinking are the understanding of various GIS data models (Blades 1991; Lloyd 1997) as well as the appreciation of spatial analysis in GIS (Cances et al. 2000).

Applications of GIS technology in several marine disciplines are versatile. Data acquired by different methods and integration of principles from different technological disciplines are joined with the aim to assist the determination of the changing aspects of the marine environment. GIS suggests solutions for an increasing number of problems in the marine environment and at the same time deliver different visions to the unknown depths of the seas. Marine troubles (in the coastal zone and pollution) have inherent spatiotemporal characteristics. By means of GIS, it is possible to collect and use several environmental parameters and understand their effects on the marine environment (Valavanis, 2002).

GIS among the several technologies is developed to enable an integrated management assisting data assembly, combination and analysis processes on these features.

Oceanographic GIS is used in a variety of ways, such as data distribution tools, mapping tools and monitoring analysis tools and in a variety of disciplines, such as coastal zone assessment and management, ocean surface processes, marine geology and geomorphology, marine eutrophication, environmental and bio-economic characterisation of coastal and marine systems, submerged marine habitats and marine habitat assessment, marine oil spill and pollution, ocean policy and management, climate change and sea-level rise, deep ocean mapping, flooding and natural hazard assessment and development of environmental sensitivity indices maps (Charlier, 2000; Valavanis, 2002).

The understanding of negative effects harming marine and coastal environments is required to intervene. By means of monitoring and modelling, it is possible to improve successful marine policy design and sustainable marine practices. The use of marine and coastal area information provides a helpful tool for generating planning procedures and more (Earle, 1999). Through the use of GIS it is possible to better identify and understand the threats affecting the areas. Authorities can simply understand marine and coastal areas conditions through reports supported by the data of statistics, tables and maps. GIS also serves to get immediate access to updated data on exceeding parameters, the whole sample details, parameter difference trends, and yearly summary of marine water quality status. Moreover GIS assists in making better-informed decisions and increasing awareness on problems correlated to marine water quality and besides to develop sustainability with the focus on the country (ESRI, 2014).

Short Literature Review

Several authors stressed the importance of the use of GIS in marine field for the growth of a sound marine GIS (Hamre, 1993) by describing some of the significant differences between terrestrial and marine applications of GIS, and presenting the results of an integrated system for the consideration and improvement of the protection area (Li and Saxena, 1993). Marine GIS evaluates important point of spatial data management for marine applications (Lucas et al., 1994) and it also joins time-dependent metadata with *in-situ* data for marine features and estimation of climate change (Wright et al., 1995). In the following years, development of new theoretical data model for sea bathymetry (Li et al., 1995), ocean discarding and monitoring of ecological impacts (Hall et al., 1995), finding of waste charging sites on the seafloor (Chavez Jr. and Karl, 1995), and new spatial data structure were included to marine GIS (Gold and Condal, 1995).

Beusen et al. (1995) developed a GIS-based model that integrated geohydrological data for the estimation of loads of nitrogen and phosphorus in the coastal seas of Europe.

Several authors have already introduced methods for the measurement of data uncertainity as well as that of model sensitivity analysis in studies using GIS (Hwang et al., 1998; Crosetto et al., 2000; Gahegan and Ehlers, 2000).

Li et al. (1998) created a monitoring and management GIS for Malaysia's shoreline together with an international and interdisciplinary team supported by the Asian Development Bank. The tool includes time series data (such as observations of wind and wave), spatial data (such as topography, shoreline and buoy locations, bathymetry, parcel) together with social and economic data and aerial photographs. The coastal GIS consists of three subsystems (coastal engineering management, shoreline erosion monitoring, coastal data inventory).

Van Zuidam et al. (1998) presented a research programme to the International Institute for Aerospace Survey and Earth Sciences, in which remote sensing, GIS, modelling and *in situ* measurements were used to develop and evaluate the scenarios for coastal zone management. Methodologies included hypothesis generation based on optimum remote sensing datasets, parameter estimation, evaluation and validation and calculation of the coastal landscape development influenced by both human impacts and natural processes.

Neilson and Costello (1999) introduced basic information on seabed types accessible on Ireland marine charts to label the high-tide mark shoreline in GIS according to the corresponding dominant seabed types. The application of this approach is suggested for all the coastal area for which basic seabed information exists and it could be used as basic information for research purposes and management.

Capobianco (1999) and Belfiore (2000) discussed the important role of new technologies in coastal management in Europe noting that many European Communities (EC) funded demonstration projects have reported the successful use of GIS for resource inventories, analysis and monitoring.

West (1999) developed a GIS-based decision support system for South Florida's coastal resources. The system uses a variety of datasets, GIS analyses and other embedded modelling and features a user interface for dynamic interaction. The tool was built for the Florida Department of Community Affairs to support a diverse set of decisions made by policy officials involved with Florida's coastal resources.

Stanbury and Starr (1999) developed a GIS for the Monterey Bay National Marine Sanctuary that allows manipulation of many terrestrial and marine datasets (land cover classification, benthic habitat types, fisheries, watersheds) aiming to create a broad spatiotemporal database for the evaluation of natural resources, permitting and monitoring coastal developments and assessing environmental impacts.

Garcia et al. (2000) incorporated the main physical components (marine processes, lithology, landforms and river discharge) with the main human-made components (population growth and urbanisation) in a GIS to develop a sensitivity index for the Costa del Sol coastline, Southern Spain.

MacDonald and Cain (2000) used GIS to rank the environmentally sensitive areas of the UK coastline based on assessments of pollution risks associated with shipping (description of different hazards, vessels routing patterns and historical frequencies of shipping accidents).

Li et al. (2001) applied various spatial modelling and analysis methods in high-resolution imagery to detect shoreline changes along the South shore of Lake Erie by representing the shoreline as a dynamically segmented linear model linked to a large amount of data describing shoreline changes.

The Use of Several GIS Applications in Marine Areas

Combined analyses of several datasets in a GIS environment provides meaningful information for natural processes. The depiction of the analysed data in some type of display such as maps, graphs, lists, reports or summary statistics provides for the communication media of GIS results or outputs.

Marine GIS is called upon to describe the intimate relations among the wind and sea currents that trigger certain oceanographic processes and explain the impact of these processes to the behaviour of marine organisms, behaviour of spatial temporal marine quality by taking species biology and ecology into consideration (Li and Saxena, 1993; Lockwood and Li, 1995).

GIS is also used for defining fish habitat and organising and executing living marine resources (the dynamics of marine objects), tracking marine mammals and analyzing their hunting and migrant lines, assessing the efficiency of marine protected areas, and answering to environmental ruins (Figure 1; Figure 2) (Meaden, 2000; NOAA, 2017).

Today, the integration of data within GIS is a routine task in marine GIS developments. The multidisciplinary data are used in GIS analysis in a variety of tasks and studies, such as global change, rectification and registration of satellite imagery, change detection of marine processes and visualisation of these processes (Figure 3) (Asrar, 1997; Ehlers, 1997; Faust and Star, 1997; Jensen et al., 1997).

Another integration between similar disciplines is represented by environmental modelling and GIS. Today, modelled output is routinely integrated into GIS applications, particularly for the study and forecasting of large-scale oceanographic, dynamic of ecological processes and atmospheric processes (Goodchild et al., 1993; Johnston et al., 1996).

GIS database enables the availability of data to achieve a synoptic status of the environment such as marine resources management, which includes the improvement of the productivity of marine ecosystems, the prevention of marine pollution, preservation of the quality of seafood and the protection of peculiar ecosystems like mangroves and corals (Aswathanarayana, 1999).

An interactive real time data delivery GIS system allowed the analysis and screening of satellite surface temperature (Figure 4) and visible imagery together with data overlays (for example gridded wind fields, bathymetry and observation data of marine) (Leshkevich and Liu, 2000).

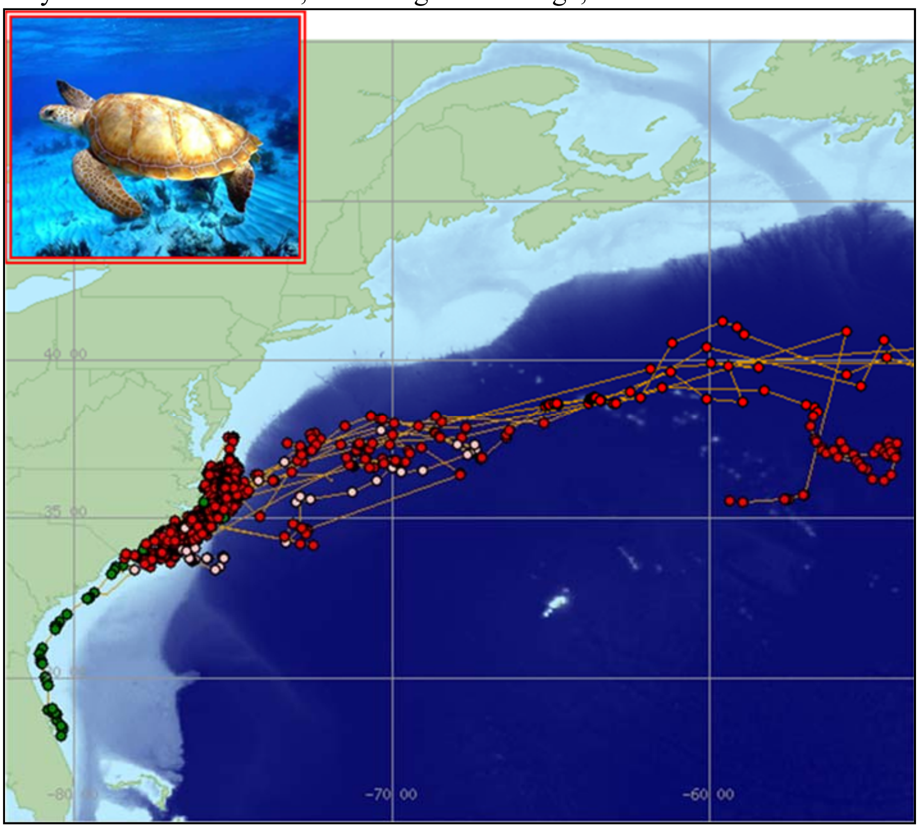

Figure 1. Sea Turtle Tracks (Caretta caretta) (McClellan et. al., 2011)

Figure 2. Marine Protected Areas (Alyssa, A., 2004)

The latest advances in remote sensing data uses GIS for estimating coastal and estuarine habitat conditions and trends. Latest advances in the application of GIS also assist in the integration of supplementary data layers to advance the accuracy of satellite images by providing to coastal planners and managers a tool to assess the impacts of alternative management practices (Klemas, 2001). GIS additionally had developed its capability in recent years to visualize and analyse spatio-temporal relations and problems. Several of the data models have dedicated problems related to multidimensional data which has been caused in different methods for the definition of the best path to store, query and present data solved by GIS and to visualize, spatio-temporal query and analysis are important for scientists and this interest provides collaboration between industry and academia in marine areas (Figure 5) (Wright et. al., 1997).

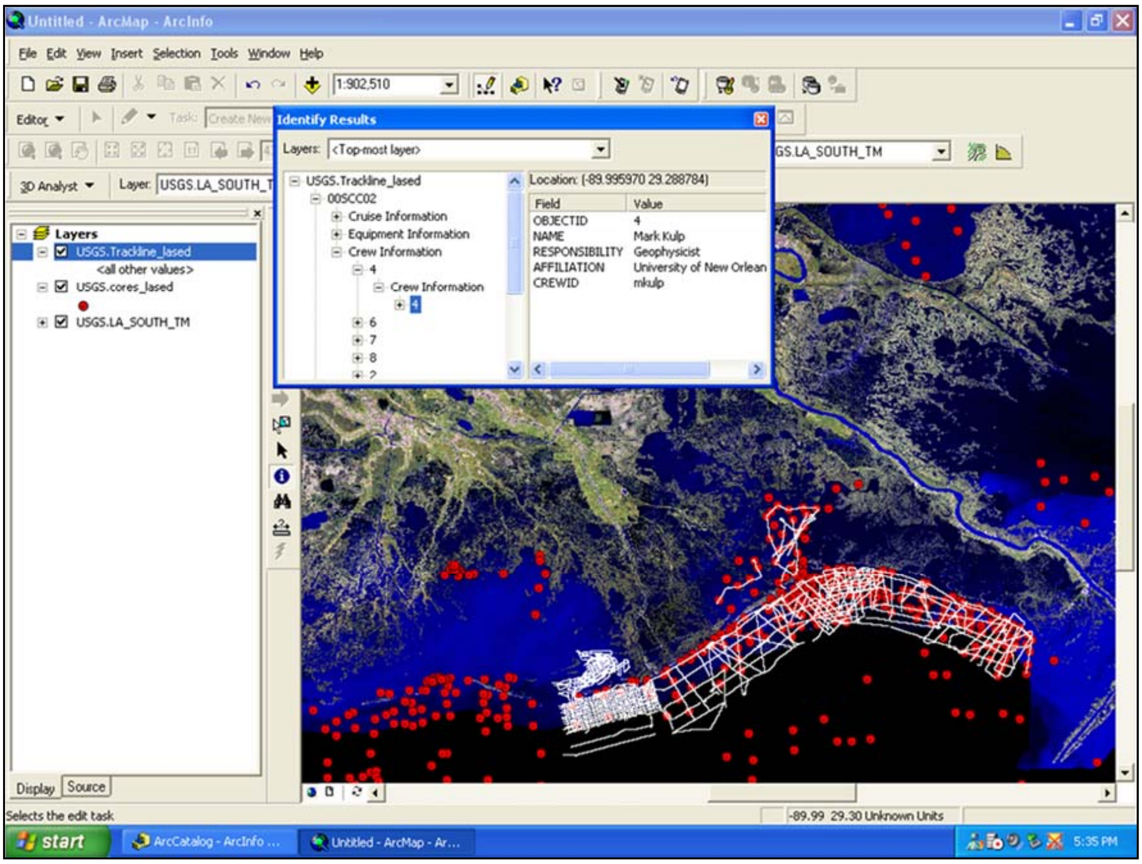

Figure 3. Implications of global warming, sea level rise by Heather Mounts (Wright et al., 2007)

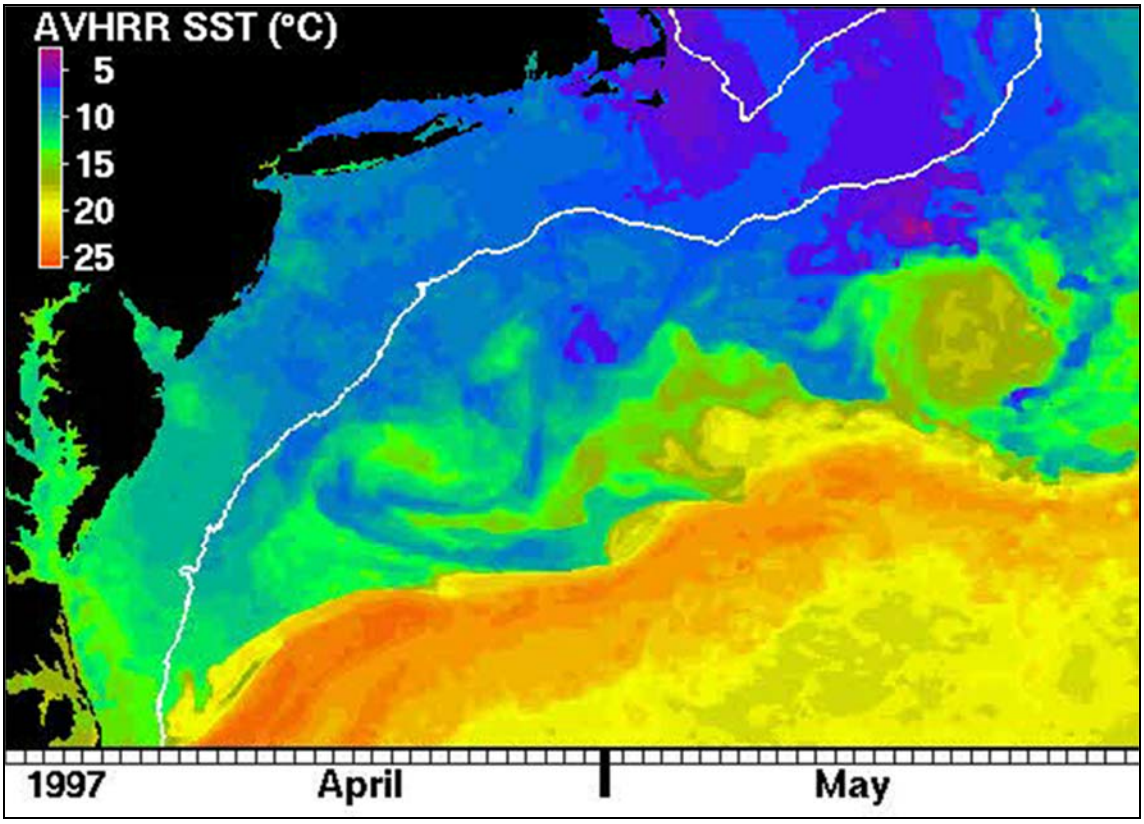

Figure 4. Sea Surface Temperature (http://www.po.gso.uri.edu/SST/)

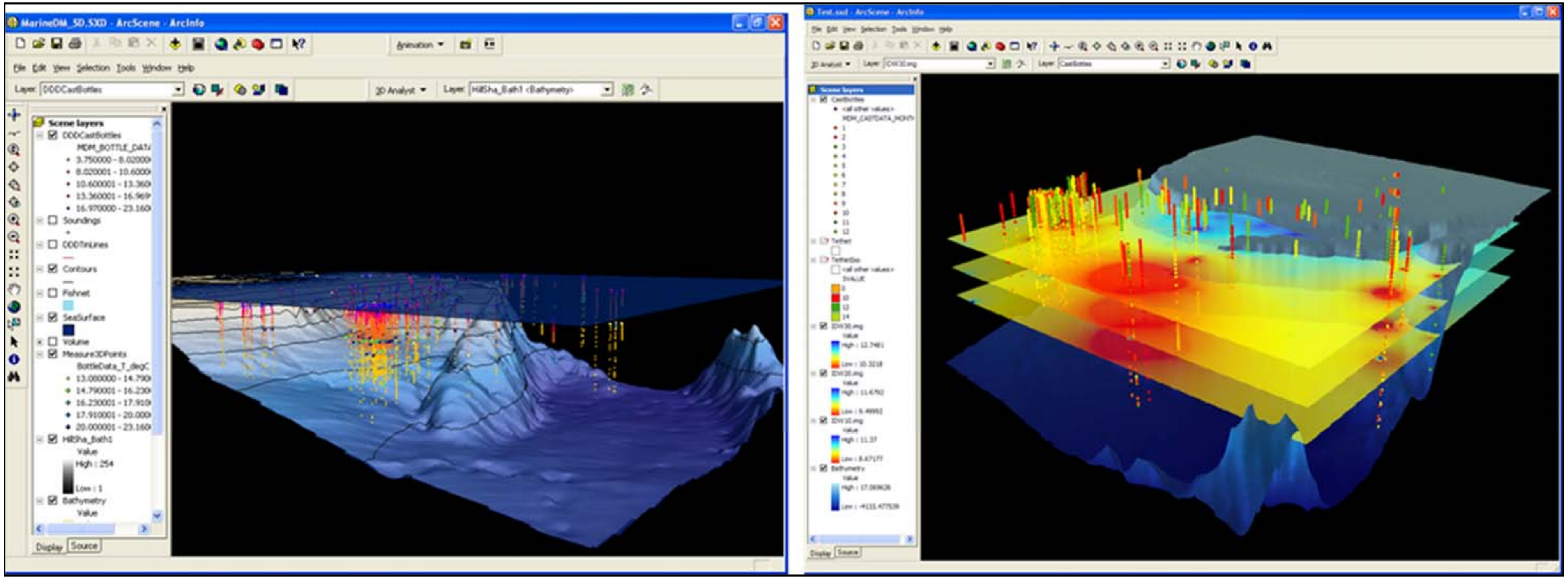

Figure 5. Multidimensional Visualisation (Wright et al., 2007)

Discussion and Conclusion

The use of GIS has long been a strong tool of government as well as business. Today, the marine geographical interpretation by means of GIS became a key tool in the field of marine policy making, planning and conservation. The important role that GIS plays to the cooperation of organisations in various international agreements for the management and the use of the marine areas include maritime transport, fisheries, recreation, disposal of waste, conservation and research. Additionally GIS as scientific discipline represents a significant tool for the management of coastal and marine areas particularly in providing the scientific basis for policy interventions through the development of integrated products that facilitate the lack of communication among decision makers and scientists. Carrying marine ecological data into GIS needs the understanding of causes related to these data and their features. The environmental spatio-temporal instability of the marine requirements obviously needs to be recognised and modelled. Applications of GIS technology in various oceanographic disciplines are multifaceted. They deal with data acquired with a variety of different methods and integration principles from different technological disciplines in an attempt to facilitate the resolution of the dynamics of the marine environment. GIS applications provide a significant opportunity in the management procedures, where the involvement of directors and administrators is essential for the use of GIS as a decision support system.

References

Alyssa, A. (2004). *Hawaiian Reef Fish and Marine Protected Areas* [Figure 2]. Testing the ArcGIS Marine Data Model: Using Spatial Information to Examine Habitat Utilization Patterns of Reef Fish along the West Coast of Hawaii, *Master of Science (MS) Thesis,* p.76.

Asrar, G.R. (1997). Global change research and Geographic Information Systems requirements. In J.L.Star, J.E.Estes and K.C.McGwire (Eds.), *Integration of Geographic Information Systems and Remote Sensing* (p.158-175). Cambridge: Cambridge University Press. ISBN: 9780521158800

Aswathanarayana, U. (1999). Functions and organisational structure of the proposed Natural Resources Management Facility in Mozambique. *Environmental Geology*, 37(3), 176-180. doi:10.1007/s002540050375

Belfiore, S. (2000). Recent developments in coastal management in the European Union. *Ocean Coastal Manage*, 43(1), 123–135.

Beusen, A.H.W., Klepper, O. & Meinardi, C.R. (1995). Modelling the flow of nitrogen and phosphorus in Europe: from loads to coastal seas. *Water Science Technology*, 31(8), 141–145.

Blades, M. (1991). The development of the abilities required to understand spatial representations. In D.M. Mark and A.U.Frank (Eds.), *Cognitive and Linguistic Aspects of Geographic Space: An Introduction* (p. 81-116), Dordrecht: Kluwer Academic Publishers. ISBN: 978-3-642-34358-2

Cances, M., Font, F. & Gay, M. (2000). Principles of Geographic Information Systems used for Earth Observation data. *Surveys in Geophysics*, 21(2), 187–199.

Capobianco, M. (1999). Role and use of technologies in relation to ICZM. European Commissio. Retrieved from http://europa.eu.int/comm/dg11/iczm/themanal.htm (Accessed 13.02.2017)

Charlier, R.H. (2000). Integrated Coastal Zone Management and GIS, BSOC Leadership Seminar Using Today's Scientific Knowledge for the Black Sea Areas Development Tomorrow", A.S. Bologa and R.H.Charlier (Eds.), Proceedings, 2000, p. 97-108. ISBN 973-99312-9-4

Chavez Jr. P.S. & Karl, H.A., (1995). Detection of barrels and waste disposal sites on the seafloor using spatial variability analysis on sidescan sonar and bathymetry images. *Marine Geodesy*, 18(3), 197-211.

Crosetto, M., Tarantola, S. & Saltelli, A. (2000). Sensitivity and uncertainty analysis in spatial modelling based on GIS. *Agricultural Ecosystem Environment*, 81(1), 71-79.

Earle, S. (1999). ESRI Special Ocean Exhibiton. Retrieved from http://www.esri.com/news/arcuser/1099/oceangis.html (Accessed 06.05.2016)

Ehlers, M. (1997). Rectification and Registration. In J.L.Star, J.E.Estes and K.C.McGwire (Eds.), *Integration of Geographic Information Systems and Remote Sensing* (p. 13-36), Cambridge: Cambridge University Press. ISBN: 9780521158800

ESRI (2014). Geoenabling Marine Water Quality Monitoring in Abu Dhabi. Retrieved from http://www.esri.com/esri-news/arcnews/spring14articles/geoenabling-marine-water-quality-monitoring-in-abu-dhabi (Accessed 10.01.2017)

Faust, N.L. & Star, J.L. (1997). Visualisation and the Integration of Remote Sensing and Geographic Information. In J.L.Star, J.E.Estes and K.C.McGwire (Eds.), *Integration of Geographic Information Systems and Remote Sensing* (p. 55-81), Cambridge: Cambridge University Press. ISBN: 9780521158800

Gahegan, M. & Ehlers, M. (2000). A framework for the modelling of uncertainty between remote sensing and geographic information systems. *ISPRS Journal Photogramme Remote Sensing*, 55(3), 176-188.

Garcia, G.M., Pollard, J. & Rodriguez, R.D. (2000). Origins, management, and measurement of stress on the coast of Southern Spain. *Coastal Management*, 28(3), 215-234.

Gold, C.M. & Condal, A.R. (1995). A spatial data structure integrating GIS and simulation in a marine environment. *Marine Geodesy*, 18(3), 213-228.

Golledge, R.G. (1995). Primitives of Spatial Knowlegde. T.L. Nyergers, M. Karwan, R. Laurini and M.J. Egenhofer (Eds.) *Cognitive Aspects of Human Computer Interaction for Geographic Information Systems*, Dordrecht: Kluwer Academic Publishers, p. 29-44. ISBN: 978-94-011-0103-5

Golledge, R.G. & Stimson, R.J. (1987). *Analytic Behavioural Geography*, Beckenham: Croom Helms, p. 355, ISBN: 1572300493

Goodchild, M. F. (2000). Foreword. In D. J. Wright and D. J. Bartlett (Eds.), *Marine and coastal geographical information systems* (p. 15), London: Taylor and Francis. ISBN: 9780748408627

Goodchild, M.F., Parks, B.O. & Steyaert, L.T. (1993). *Environmental Modelling with GIS*, New York: Oxford University Press, p. 230, ISBN: 0195080076

Hall, R.K., Ota, A.Y. & Hashimoto, J.Y. (1995). Geographical information systems (GIS) to manage oceanographic data for site designation and site monitoring. *Marine Geodesy*, 18(3), 161-171.

Hamre, T. (1993). User requirement specification for a marine information system, *Nansen Environmental and Remote Sensing Center*, Technical Report 74.

Hwang, D., Karimi, H.A. & Byun, D.W. (1998). Uncertainty analysis of environmental models within GIS environments. *Computer Geoscience*, 24(2), 119-130.

Jensen, J.R., Cowen, D., Narumalani, S. & Halls, J. (1997). Principles of change detection using digital remote sensor data. In J.L.Star, J.E.Estes and K.C. McGwire (Eds.), *Integration of Geographic Information Systems and Remote Sensing* (p. 37-54), Cambridge: Cambridge University Press. ISBN: 9780521158800

Johnston, C.A., Cohen, Y. & Pastor, J. (1996). Modelling of spatially static and dynamic ecological processes. In M.F.Goodchild, L.T.Steyaert, B.O. Parks, C.Johnston, D.Maidment, M.Crane and S.Glendinning (Eds.), *GIS and Environmental Modelling: Progress and Research Issues* (p. 149-154), Boulder: GIS World Books. ISBN: 978-0470236772

Klemas, V.V. (2001). Remote sensing of landscape level coastal environmental indicators. *Journal Environmental Management*, 27(1), 47–57.

Leshkevich, G.A. & Liu, S. (2000). Internet access to Great Lakes Coast Watch remote sensing information. *International Geoscience and Remote Sensing Symposium (IGARSS)*, 5, 2077-2079.

Li, R. & Saxena, N. K. (1993). Development of an integrated marine geographic information system. *Marine Geodesy*, 16(4), 293-307.

Li, R., Keong, C.W., Ramcharan, E., Kjerfve, B. & Willis, D. (1998). A Coastal GIS for Shoreline Monitoring and Management: Case Study in Malaysia. *Surveying and Land Information Systems*, 58(3), 157-166.

Li, R., Liu, J.K. & Felus, Y. (2001). Spatial modelling and analysis for shoreline change detection and coastal erosion monitoring. *Marine Geodesy*, 24(1), 1-12.

Li, R., Qian, L. & Blais, J. A. R. (1995). A hypergraph-based conceptual model for bathymetric and related data management. *Marine Geodesy*, 18(3), 173-182.

Lloyd, R. (1997). *Spatial Cognition: Geographic Environments*, Dordrecht: Kluwer Academic Publishers, p. 221, ISBN: 978-94-017-3044-0

Lockwood, M. & R. Li. (1995). Marine geographic information systems: What sets them apart, *Marine Geodesy*, 18(3), 157-159.

Lucas, A., Abbedissen, M.B. & Budgell, W.P. (1994). A spatial metadata management system for ocean applications: Requirements analysis. *In ISPRS Working Group II/2 Workshop on the Requirements for Integrated GIS* (New Orleans, Louisiana), p. 1-13.

MacDonald, A. & Cain, M. (2000). Marine environmental high risk areas (MEHRAs) for the UK. *International Maritime Technology*, 112(2), 61-70.

Meaden, G.J. (2000). Applications of GIS to Fisheries Management. In B. A. Megrey and E. Moksness (Eds.), *Marine and Coastal Geographical Information Systems*. Philadelphia: Taylor and Francis, p. 205-226, ISBN: 978-1-4020-8635-9

McClellan, C.M., A.J. Read, W.M. Cluse & M.H. Godfrey. (2011). *Sea Turtle Tracks (Caretta caretta)* [Figure 1]. Conservation in a complex management environment: the by-catch of sea turtles in North Carolina's commercial fisheries. *Marine Policy*, 35(2), 241-248.

Neilson, B. & Costello, M.J. (1999). The Relative lengths of seashore substrata around the coastline of Ireland as determined by digital methods in a Geographical Information System. *Estuarine Coastal Shelf Science*, 49(4), 501-508.

Nierenberg, W.A. (1992). *Encyclopedia of Earth System Science*, San Diego, California: Academic Press, pp. 2825, ISBN: 978-0122267192

NOAA (National Oceanic and Atmospheric Administration) (2017). Fisheries GIS. Retrieved from http://www.nmfs.noaa.gov/gis/ (Accessed 27.02.2017)

Nyerges, T.L. (1991). Analytical Map Use, Cartography and Geographic Information System, *Cartography and Geographic Information Systems*, 18(1), 22–28.

Nyerges, T. L. & Golledge, R. G. (1997) *NCGIA core curriculum in GIS*, National Center for Geographic Information and Analysis, University of California, Santa Barbara, Unit 007. Retrieved from http://www.ncgia.ucsb.edu/giscc/units/u007/u007.html (Accessed 12.03.2017)

Psuty, N.P., Steinberg, P.E. & Wright, D.J. (2002). Coastal and marine geography. Gaile, G.L. and Willmott, C.J. (Eds.), *In Geography in America at the Dawn of the 21st Century*, New York: Oxford University Press, p. 333. ISBN: 9780199295869

Sea Surface Temperature [Figure 4.]. Retrieved from, http://www.po.gso.uri.edu/SST/

Slater, F. (1982). *Learning through Geography*, Oxford: Heineman Educational Books, pp. 340, ISBN: 0435354108

Stanbury, K.B. & Starr, R.M. (1999). Applications of Geographic Information Systems (GIS) to habitat assessment and marine resource management. *Oceanology Acta*, 22(6), 699-703.

Valavanis, V. D. (2002). *Geographic Information Systems in Oceanography and Fisheries*, NewYork: Taylor and Francis Inc., pp.173, ISBN: 9780415284639

Van Zuidam, R.A., Farifteh, J., Eleveld, M.A. & Cheng, T. (1998). Developments in remote sensing, dynamic modelling and GIS applications for integrated coastal zone management. *Journal Coastal Conservation*, 4(2), 191-202.

West, L.A. (1999). Florida's Marine Resource Information System: A geographic decision support system. *Government Information Quartely*, 16(1), 47-62.

Williamson, P. (1994). Integrating Earth system science, *Ambio*, 23(1), 3. ISSN: 0044-7447

Wright, D. J., Haymon, R. M. & Fornari, D. J. (1995). Crustal fissuring and its relationship to magmatic and hydrothermal processes on the East Pacific Rise crest (9°12′ TO 54′N). *Journal of Geophysical Research*, 100(B4), 6097-6120.

Wright, D.J., Fox, C.G. & Bobbitt, A.M. (1997). A scientific information model for deepsea mapping and sampline. *Marine Geodesy*, 20(4), 367-379.

Wright, D.J., Blongewicz, M.J., Halpin, P.N. & Breman, J. (2007). *Implications of global warming, sea level rise by Heather Mounts.* [Figure 3]. Arc Marine: GIS for a Blue Planet, Chapter 3: Marine Survey (p. 21-44). USA: ESRI Press, p.202. ISBN: 9781589480179

Wright, D.J., Blongewicz, M.J., Halpin, P.N. & Breman, J. (2007). *Multidimensional Visual-ition.* [Figure 5]. Arc Marine: GIS for a Blue Planet, Chapter 8: Multidimensional GIS (p.163-175). USA: ESRI Press, p.202. ISBN: 9781589480179