

ABSTRACT

JASON, ALLYSON LYNNE. Geographic Modeling of El Niño Southern Oscillation Influence on Remotely Sensed Global Nutrient Distribution Patterns – Applications to Science and Geographic Information Systems Education (Under the Direction of Dr. Hugh A. Devine)

The objective of the study was to geographically model the effects of the El Niño Southern Oscillation (ENSO) influence on remotely sensed global nutrient distribution patterns. The result was a system of digital maps communicating the impact of ENSO on the physical and biological components of the ocean. These maps compare modeled phytoplankton biomass distribution over the ENSO extremes. Chlorophyll *a*, Aerosol Optical Thickness, and Sea Surface Temperature data, all obtained from remotely sensed sources, were used to develop these predictions. Areas of iron deposition and phytoplankton presence (chlorophyll *a* < 0.1 $\mu\text{g l}^{-1}$) were combined with nutrient distributions (based on the temperature-nutrient relationship) to create a sixteen-category composite phytoplankton ecological factor distribution map for each month in the study. The months included in the study were January, February, March of 1998, an El Niño year, and January, February, March of 1999, a La Niña year. Finally, an educational multimedia tool (CD-ROM) was created based on the research in the study for use in grades 7-16 classrooms. The tool was designed and tested to utilize Geographic Information Systems and the Internet to apply inquiry-based learning to science education.

GEOGRAPHIC MODELING OF EL NIÑO SOUTHERN OSCILLATION
INFLUENCE ON REMOTELY SENSED
GLOBAL NUTRIENT DISTRIBUTION PATTERNS – APPLICATIONS TO
SCIENCE AND GEOGRAPHIC INFORMATION SYSTEMS EDUCATION

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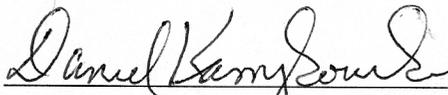
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DEDICATION

This work is dedicated to my extended family, without their love and support this would not have been possible. It is also dedicated to my best friend who always made me laugh, especially when I did not want to smile.

BIOGRAPHY

Allyson Jason was born in New Jersey and has lived in North Carolina since 1994. While attending North Carolina State University, she became interested in the sciences, particularly oceanography and environmental science. An internship during the summer of her junior year, with the National Marine Fisheries Service and the Marine Mammal Stranding Network, introduced her to GIS. In 1998 the author received a Bachelor of Science in Natural Resources with a concentration in Marine and Coastal Resources from North Carolina State University. Following her graduation, Allyson attended graduate school at North Carolina State University, pursuing a Master of Science in the Marine Sciences. The author's interests have always included earth system science, environmental science, and the utilization of computers in the sciences.

Remembering her initial introduction to GIS, the author took the introductory graduate course in the subject and immediately realized its broad applications and extensions in her field of interest. She transferred to the Center for Earth Observation at NCSU to complete her graduate studies as a Master of Science student in Natural Resources with a concentration in the area of spatial information systems. There she worked with remotely sensed marine data in conjunction with GIS on phytoplankton distribution modeling. As a graduate teaching assistant with the Center for Earth Observation, the author became a co-instructor of the Introductory GIS course at the university. She developed a love for teaching as well as community outreach while working at the center. This led

her to incorporate the need for scientist participation in education into her Marine Science GIS research. Among the author's future research interests are the emerging applications of GIS and remote sensing in the marine environment. She also has a major research interest in the importance of "real world" examples of cutting edge scientific research to secondary education and to students' understanding of scientific principles. The author also would like to work in the development of new technologies for use in traditional as well as distance learning education applications, particularly those dealing with spatial analysis.

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Personally, the author would like to thank everyone who supported her even when she did not know what she wanted to do. Thank you Sheldon for always being there and being you. Thanks to her parents, Raymond and Laraine, for being her foundation throughout her life and always encouraging her to ask questions and to her sister Janine for listening.

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1. INTRODUCTION

Nutrient compositions of the ocean can be used to predict the type and amount of phytoplankton present. For example, where nitrate is in excess, there tends to be more carbonaceous (carbonate-based skeletons) plankton, while where silicate is in excess, there tends to be more diatoms (silicate-based skeletons). In the past, oceanographers have only been able to view the concentrations of nitrate, phosphate, silicate, iron and chlorophyll *a* from a few sample points obtained via expensive cruises. Moreover, traditional measurements collected by these oceanographic cruises, costing \$10,000-25,000 per day, cannot create spatially contemporaneous coverage of even the limited area under investigation. They can, therefore, only provide a sketchy scientific description of the world's oceans (Barale, 2000). Furthermore, integration of the historical record, created by combining all recorded oceanographic cruises as archived by the National Oceanographic Data Center, can only generate a climatology of nutrient variability (Conkright et al., 1998). The prohibitive cost of increased cruise effort, combined with concerns involved in covering large areas with *in situ* sensors, has resulted in a lack of data sets with the large spatial coverage and repetition necessary to connect the physical and biological processes of the world ocean.

As an alternative to traditional ship-based methods, remote sensing satellites can be used to link physical, chemical, and biological factors in the world ocean to estimate primary productivity. Today, satellites can provide frequent, global scale, near surface views of selected oceanographic variables (Kamykowski, Zentara, Morrison, & Switzer, In Review). To sample each pixel in a two-minute satellite scene (contains two million pixels) covering an area of two million square kilometers would take a ship traveling at 20 km/hr more than 11 years (Yoder, Lewis, & Blanchard, 2002). Some of the variables now obtained through remote sensing satellites, such as sea surface temperature, aerosol optical thickness and chlorophyll *a*, are important to the physical and biological processes in the ocean. However, compiling the data necessary to study oceanographic processes can be difficult, especially when the data come from different sources. The varying temporal, spatial and spectral resolution of remotely sensed data within and between satellites limits the ability of many oceanographers to study changing oceanographic phenomena beyond qualitative comparisons.

Relationships between the physical and biological processes in the world ocean continue to be expanded in recent marine research (Switzer, 1999). At the forefront of this research is the application of new technologies, formerly used in other disciplines. When coupled with remotely sensed data, Geographic Information Systems (GIS) (originally designed for terrestrial use) have the ability to provide a view of whole ecological systems and/or a regional perspective of oceanographic phenomena (Lucas, 2000). GIS provides a framework for more

easily compiling satellite data from varying sources as well as those measuring different phenomena. In this study, data were obtained from two different NASA/NOAA satellites, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) on board the SeaStar satellite and the 5-channel Advanced Very High Resolution Radiometers (AVHRR) on board the NOAA -7, -9, -11 and -14 polar orbiting satellites. To be combined, these differing sources required manipulation of the spatial data through reprojection, interpolation, and data format conversion. But after this manipulation, a quantitative, geographic model that merged the physical and biological relationships in the world ocean could be constructed. This enabled the characterization of biomass based on a nutrient availability classification of phytoplankton in the world ocean.

A climatological phenomenon that has a significant impact on phytoplankton in the ocean's ecosystems is the El Niño Southern Oscillation (ENSO) phenomena (Turk, McPhaden, Busalacchi, & Lewis, 2001). The dominant source of inter-annual ocean variability (Chavez et al., 1999), ENSO is a complex and interrelated phenomenon that benefits from a multidisciplinary marine GIS/remote sensing approach. The ENSO phenomena is a global event arising from large-scale ocean-atmosphere interaction (Thomas, 2000) characterized by a cycling between two extremes-- El Niño and La Niña. In this study, comparable time periods of ENSO influence on the world ocean were examined to investigate the influence of ENSO on nutrients important to phytoplankton ecology. To examine ENSO influence, scientists must study it as a

set of interconnected phenomena occurring on the entire earth (Earth System Science).

A major increase in marine geographic recognition occurred with the advent of Earth System Science (Wright, 2000), an interdisciplinary systems approach that views the Earth, including the geosphere, atmosphere, hydrosphere and biosphere, as a synergistic physical system of interrelated phenomena, governed by complex processes (Johnson, Ruzek, & Kalb, 2000). Johnson et al. (2000) challenged researchers and educators to use the Earth System Science framework to address the scientific dimensions of global change in order to expand the understanding of various interdisciplinary topics. Earth System Science curriculum development can attack the challenge by providing fundamental knowledge, stimulating interest, and creating an informed society (Johnson et al., 2000).

Communication and resource sharing are important to connecting the various disciplines incorporated in Earth System Science research and education (Johnson et al., 2000). The importance of scientists' involvement, as experts with access to data and facilities, in science education is well documented (Bray, 1998; Bruce, Bruce, Conrad, & Huang, 1997; Bybee, 1998; National Research Council, 1990, 1996a, 1996b). According to Bybee & Morrow (1998) scientists can play many roles in science education with varying degrees of involvement, including the development of educational materials. Earth System Science is in need of quality, adaptable, interdisciplinary educational materials, not merely a few

pictures (Johnson et al., 2000). GIS education has the potential to provide these types of educational materials to Earth System Science.

Two of the fourteen interdisciplinary topics selected as a theme to be incorporated into Earth System Science educational materials are remote sensing and the ENSO phenomena (Johnson et al., 2000). Quality peer-reviewed Earth System Science materials that have a well-described content presented in an orderly sequence are needed at all levels (Johnson et al., 2000). The purposes of this study are to geographically model the El Nino Southern Oscillation influence on remotely sensed global nutrient distribution patterns and to communicate to others the relationship between the physical and biological components of the ocean via creation of an educational multimedia tool employing GIS.

2. LITERATURE REVIEW

2.1 MARINE GEOGRAPHIC INFORMATION SYSTEMS

One of the major impediments to the utilization of Geographic Information Systems (GIS) in the marine environment has been a lack of data (compared to that available for terrestrial applications). From accurate geodetic control networks for surveying to detailed maps of vegetation, mineral resources, and population distribution derived from remotely sensed images, the application of computers and GIS to the temporally less variable terrestrial environment has

occurred for decades (Goodchild, 2000). This quantity of terrestrial surface geographic data has a much more limited equivalent, however, for the remaining two thirds of the Earth's surface which is covered by the world ocean (Goodchild, 2000).

Compared to land-based systems, marine systems tend to be sampled sparsely and infrequently (Lucas, 2000). The only fixed features in the marine ecosystem are found on the ocean floor, and ocean depth is one of the few static elements in the marine environment that can be measured (Goodchild, 2000). Furthermore, the ocean is continuously moving, therefore significant changes in environmental conditions can occur over very short time (Lucas, 2000). Reconciling the ocean's natural temporal scale variability across merged data sets requires the harmonization of attribute values and/or spatial distributions from diverse sources, each with their own inherent sampling structure and characteristics. Therefore, to use marine data in a GIS, the ocean's natural spatial and temporal variability must be acknowledged and modeled explicitly (Lucas, 2000).

Utilization of GIS in the marine environment began in the early 1960's with the National Oceanographic Survey's use of computers for nautical chart creation. Sophisticated oceanographic data collection technologies were developed in the 1970's and 80's while computer costs were high, creating a proliferation of information to be analyzed by researchers in the 1990's (Wright, 2000). As the cost of processing the collected information declined, marine GIS

began to evolve from potential (Manley & Tallet, 1990) to reality (Keller, Gowan, & Dolling, 1991; Robinson, 1991).

Marine GIS began appearing in various conference proceedings as early as 1991 (Keller et al., 1991). The first known American graduate thesis on marine GIS was written in 1992 (Hatcher, 1992). Li and Saxena (1993) published one of the first peer-reviewed journal articles in *Marine Geodesy*. The first American doctoral dissertation was completed in 1994 (Wright, 1994). Emerging issues that have increased the exposure of marine GIS include new techniques for marine exploration, rising global environmental awareness and concerns, and a heightened understanding of the role of marine life in maintaining the global ecosystem (Wright, 2000). Interest in the marine applications of GIS only continues to expand (Goodchild, 2000).

2.2 REMOTELY SENSED GLOBAL NUTRIENT DISTRIBUTIONS

Phytoplankton play a key role in the ecology of the marine ecosystem and changes in their patterns and abundance have significant impact on the entire ocean ecosystem. Phytoplankton are thought to play a major role in the global carbon cycle. They account for approximately 50% of the photosynthesis on the planet and play an important role in regulating the amount of carbon in the atmosphere (Feldman, 2002). The health and economics of many countries and their citizens depend upon the productivity of the oceans (King, 1999). Therefore,

phytoplankton type and the conditions that affect their growth and development are important to the stability and health of the world ocean and to those that benefit from it. Nutrient distribution and iron affect the type of phytoplankton that are present in a given location in the world ocean. The research described in this study defines the distribution of sixteen categories of nutrient availability by differential presence/absence of nitrate, phosphate, silicate, and iron in the world ocean and compares it to the global distribution of chlorophyll *a* concentrations exceeding $0.1 \mu\text{g l}^{-1}$.

Estimates of world ocean regional primary productivity exhibit high variance compared to *in situ* measurements because the latter are limited to occasional movements at widely separated locations (Dr. D. Kamykowski, personal communication, Dec 2000). Further research into nutrient variability has the potential to improve estimates of primary productivity. However, the nutrient fertility (and therefore variability) of the ocean is not routinely monitored via satellite. Seasonal averages of nutrient fertility for nitrate, phosphate and silicate can be produced regionally. Monthly mean climatologies were produced at the global scale for the first time in 2000, however they were based on the static, and historical databases of nutrients in the world ocean available from the National Oceanographic Data Center (Louanchi & Najjar, 2000). However, Louanchi & Najjar (2000) only used a few temperature-nutrient relationships with each representing large areas of the ocean. This coarse resolution climatological

approach does not adequately support other temporal nutrient variation, especially at a global scale.

The satellite-based comparisons in this study provide a finer spatial resolution means for dynamically monitoring the temporal variability of nutrients in the world ocean. The satellites allow direct comparison of remotely sensed nutrient availability over similar time periods (Kamykowski et al., In Review). Nutrients and temperature are highly correlated in the surface ocean (Kamykowski & Zentara, 1985; Louanchi & Najjar, 2000). Therefore, this physical-biological link in the ocean can be used to provide a representative, temporally varying view of nutrient distribution at sea surface (Kamykowski & Zentara, 1986; Kamykowski et al., In Review; Switzer, 1999). One way to determine the presence or absence of nutrients with satellite data is to use Sea Surface Temperature (SST) to derive nutrient distribution.

The temperature-nutrient relationship developed by Kamykowski and Zentara (1986) can be used to generate time varying estimates of the availability of nitrate, phosphate and silicate in the world ocean. The distribution of nitrate, silicate (Levitus, Conkright, Reid, Najjar, & Mantyla, 1993), and seasonal global averages of phosphate (Conkright, Gregg, & Levitus, 2000) were used in the derivation of Nutrient Depletion Temperatures (NDT) from the temperature-nutrient relationship. The NDT is defined as the temperature above which a specific nutrient is no longer detectable by wet chemistry techniques. In mid and lower regions of the world ocean, nutrients are depleted from the water column as

temperature increases during the seasonal cycle. Therefore, as SST increases nutrients tend to be depleted from the water column. A global set of the NDTs for nitrate, phosphate, and silicate can be used in conjunction with AVHRR derived SST to estimate nutrient availability.

The global annual distribution of nitrate, silicate (Levitus et al., 1993) and seasonal global averages of phosphate (Conkright et al., 2000) are available based on the historical record. In Switzer (1999) the temperature-nutrient relationship was applied at the global scale to generate near-surface patterns for nitrate in the world ocean using the nitrate Nutrient Depletion Temperature (NDT), in the form of a NDT matrix, in conjunction with AVHRR derived SST. Switzer (1999) determined positive versus negative (SST-NDT) differences graded by size for each month from 1987 to 1996 to estimate the degree of nitrate replete/deplete status in the world ocean. Most recently, basin scale estimates of surface nitrate and new production were created in 2000 using remotely sensed SST and chlorophyll data (Goes et al., 2000).

Kamykowski, et al. (In Review) compared the temperature-nutrient relationship research based on the availability of nitrate, phosphate, silicate with the availability of iron based on aerosol abundance and precipitation in the world ocean. Phytoplankton community structure was inferred from patterns in nutrient availability. The analysis began with an examination of positive versus negative values of a less subjective set of NDTs than those used by Switzer (1999) to estimate the presence and absence of nitrate, phosphate and silicate for sixteen

representative months from March 1999 through June 2000. Kamykowski, et al. (In Review) then used satellite-derived Aerosol Optical Thickness and precipitation data to estimate the amount of dry versus wet iron deposition. The resulting data were formed into an eight category map that was then combined with chlorophyll *a* data. The final data manipulations resulted in a sixteen category contour map that displayed the presence/absence of nitrate, phosphate, silicate, iron and chlorophyll *a*. The sixteen category maps were used to infer possible phytoplankton taxonomic composition and cell size. The analytical process employed default interpolation procedures at a 1° by 1° resolution for all data in the study.

Manu Datta's MS research at North Carolina State University expanded the temperature-nutrient relationship beyond simple presence/absence. The research explored the use of a new set of linear regression equations for each temperature (*x*) and nutrient (*y*) to derive the NDTs for nitrate, phosphate and silicate. The main focus of the research is on the estimation of nutrient concentrations in the Indian Ocean during the monsoon/inter-monsoon cycle (Dr. D. Kamykowski, personal communication, March 2002).

2.3 GLOBAL DISTRIBUTION OF NITRATE, PHOSPHATE, SILICATE AND IRON

Nitrate is seasonally depleted (unmeasurable by normal spectrophotometric methods) from most of the oceanic surface waters of the world ocean except for high latitudes and the eastern tropical Pacific Ocean (Levitus et al., 1993). The highest surface concentrations are typically found in the region of the Subantarctic Convergence. The Eastern Equatorial Pacific has high nitrate with concentrations decreasing with distance from shore to about 180°W (Levitus et al., 1993). Nitrate utilization is iron-dependent (Chisholm, 1995; De Baar, 1994) and a region's nitrate-temperature relationship may change with iron availability. The potential for iron limitation is well-documented in the Southern Ocean, Equatorial Pacific and Subarctic Pacific (Hutchins & Bruland, 1998; Pondaven, Ruiz-Pino, Druon, Fravallo, & Treguer, 1999; Takeda, 1998).

The distribution of phosphate is similar to that of nitrate since their pathways through the water column are similar. Phosphate regeneration occurs somewhat faster at shallower depths than nitrates. Phosphate is most abundant in the surface waters surrounding the Antarctic continent. High phosphate is also found in the Pacific subpolar gyres and the Eastern Equatorial Pacific (Levitus et al., 1993).

The distribution of silicate in the world ocean is slightly different from nitrate and phosphate since its pathway through the water column is different. Silicate is an essential nutrient to siliceous-bearing plankton such as radiolarians

and diatoms (Levitus et al., 1993). Near depletion of this nutrient will occur where these plankton bloom, primarily in cold waters (Dugdale, 1972; Levitus et al., 1993). Generally, silicate shows a similar distribution to nitrates and phosphates in surface water (Levitus et al., 1993), but varies in association with the differences between bacterial regeneration (N, P) and chemical dissolution kinetics (Si). The Weddell Sea, near Antarctica, exhibits the highest silicate content of any of the surface waters of the world ocean while the northwest north Pacific exhibits high levels. Silicate is generally depleted in mid and lower latitude surface waters of the Atlantic, Indian and Pacific Oceans (Levitus et al., 1993).

There is no temperature-iron relationship for near-surface waters to parallel those for nitrate, phosphate, and silicate. Therefore, the oceanic source of iron is not calculable by the same techniques used for the other oceanic nutrients (Kamykowski et al., In Review). When iron is present, larger phytoplankton cells are present and when iron is absent, smaller phytoplankton cells are present. This pattern of control by the absence or presence of iron has been observed in the equatorial Pacific in that large diatoms are present after a week of iron enrichment (Cavender-Bares, Mann, Chisholm, Ondrusek, & Bidigare, 1999).

Atmospheric iron availability to the ocean depends on delivery to the ocean, seawater solubility and reactivity, and biological assimilation (Archer & Johnson, 2000; Fung et al., 2000; Moore, Doney, Glover, & Fung, 2002). Husar *et al.* (1997) and Prospero (2000) showed that temporal and spatial iron distribution patterns based on at-sea atmospheric mineral dust concentrations are consistent

with satellite observations of Aerosol Optical Thickness (AOT). Within limitations, satellite data was used in the present study to monitor iron deposition as indexed by AOT. Since subsurface iron sources are small as compared to that required for the utilization of nitrate (Fung et al., 2000), they were excluded from the present study.

2.4 EL NIÑO SOUTHERN OSCILLATION PHENOMENA

Since climatology is so important to nutrient availability in the ocean, a perturbation of normal conditions, the El Niño Southern Oscillation (ENSO) phenomena, was examined by this study. The ENSO phenomena is a global event arising from large-scale interaction between the ocean and the atmosphere (Thomas, 2000) that is characterized by a cycling between two extremes: warming or El Niño event and cooling or La Niña event.

The terms El Niño and La Niña cover a wide range of conditions. Therefore, the definitions are general and qualitative in nature (Philander, 1990). Although the definitions vary, the most common characteristics of the El Niño phase are anomalous warming of surface water, sea surface temperature increases in the eastern and central Pacific, linkage to pressure changes at sea level, and a slackening of westward-flowing equatorial trade winds (Glantz, 2001). The La Niña phase, which frequently follows El Niño episodes, is characterized by cold sea surface temperature in the central and eastern tropical Pacific for several

months. The more common characteristics of La Niña are westward winds blowing stronger than normal along the equator, sea level rise in the eastern Pacific with a concurrent drop in the western Pacific, and a thermocline depression in the western Pacific while rising to the surface in the eastern Pacific (Glantz, 2001).

According to Glantz (2001) during the 1997-2000 period, there had been a spectacular demonstration of climatic variability. In the first part of that period, El Niño ended and in the second part, La Niña began. The 1997-1998 El Niño severely disrupted global weather patterns and Pacific marine ecosystems (McPhaden, 1999) causing an estimated 23,000 deaths and at least 33 billion dollars in property damage worldwide (Kerr, 1999).

The Southern Oscillation has been monitored by the Southern Oscillation Index (SOI) since the 1870's. The SOI is a measure of the difference in sea level pressure between Darwin, Australia and Tahiti converted into an index, with the negative phase representing El Niño and the positive, La Niña. Recently, despite the long SOI record, researchers have been moving away from reliance on the SOI as the primary indicator of ENSO phase and are relying on global monitoring of a broader set of variables (Glantz, 2001). An intensity classification is produced by the Climate Prediction Center to provide a season-by-season breakdown of conditions in the tropical Pacific (NOAA-NWS, 2000). Another ENSO phase indicator is the Multivariate ENSO Index (MEI) (Wolter, 2002). The MEI is based on the six main observed variables over the tropical Pacific: sea-level pressure,

zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. The MEI is computed separately for each of twelve sliding bi-monthly seasons (e.g. Dec/Jan, Jan/Feb) (Wolter, 2002).

2.5 GEOGRAPHIC INFORMATION SYSTEMS EDUCATION

Geographic Information Systems (GIS) is “a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes” (Burrough, 1986). Research both *on* and *with* GIS is known as Geographic Information Science (GISc). Goodchild (1992) defined GISc as “the generic issues that surround the use of GIS technology, impede its successful implementation, or emerge from an understanding of its potential capabilities.” The present study focuses on the use of GIS and GISc in education. Clarke (2001), DeMers (2000), and Goodchild (1992) provide a more in depth treatment of GIS and GISc.

GIS education is comprised of several disciplines including geography, education, and instructional/educational technology. GIS applications and developments have been viewed separately as both a science and an application, typically found in both peer-reviewed literature and in trade publications. The majority of GIS education literature generally comes from the applications and is comprised of anecdotal, non-peer-reviewed accounts of projects or experiences

(Kerski, 2000). The discipline of instructional technology, which designs and evaluates processes and resources for learning, pays little attention to GIS (Anglin, 1995). Joseph Kerski (2000) noted the minimal treatment of GIS in education literature. However, this literature includes books introducing new technology to teachers (Bazeli & Heintz, 1997; Morrison, Lowther, DeMeulle, & Stollenwerk, 1999), reviews of electronic learning tools (Menges, 1994), and evaluations of educational technology (e.g. CD-ROMs) (Barron & Orwig, 1997). Kerski (2000) estimates only 1% of GIS research addresses education. However, this GIS education research either minimally raises awareness of the applications of GIS or provides overviews (e.g. Alibrandi, 1998; Deal, 1998; Michelsen, 1996; Tinker, 1992), instead of an in depth educational evaluation (Kerski, 2000).

GISc's effect on society is beginning to be addressed (Pickles, 1995). To encourage more research, the University Consortium for Geographic Information Science (1996) placed "GIS and Society" as one of the top ten areas of needed research. GIS and Society research area includes the effect of GIS on large social structures, of which schools are an important component. Another indication GIS education is becoming more mainstream among GIS users is the increase in GIS education conferences. The First National Conference on the Educational Applications of Geography Information Systems was held in Washington, DC in 1994. In 2001 Environmental Systems Research Institute (ESRI) founded the annual *Education* User Conference, which is held prior to the annual International ESRI User Conference.

The participants of that first national GIS education conference named lesson development as the top research priority (Barstow, Gerrard, Kapisovsky, Tinker, & Wojtkiewicz, 1994). The need still existed in 2000 when Kerski appealed for an expanded library of GIS-based lesson modules that would utilize GIS software capable of performing robust spatial analysis and problem solving. Kerski (2000) stated, “Educators need research that results in lesson modules that they can use in their curricula, and data about the difference that GIS makes in teaching and learning.” Other recommendations call for the development of GIS-based curriculum materials for a range of subject areas and grade levels (Rita Hagevik, personal communication, 2001, Kerski, 2000; Thompson, 1987; Winn, 1997).

Through its ability to analyze phenomena across space and time from local to global scales, GIS offers the ability to identify the interconnections of isolated sets of facts or observations (Maynard, 1991). Interweaving connections through an interdisciplinary approach is a more effective means of helping students solve problems than teaching subjects in isolation (Jacobs, 1989). The U.S. Secretary of Labor’s Commission on Achieving Necessary Skills stated that the most effective way to teach skills is “in context” through resource use and identification, group work, information use and acquisition, and use of complex interrelationships (U.S. Department of Labor, 1991). As an inquiry-based learning tool, GIS education has the potential to teach these necessary lifelong skills (in addition to interdisciplinary connections). Bednarz (1995) demonstrated the linkages between GIS and

inquiry-based learning, where students construct knowledge and explore spatial relationships through building databases and creating maps.

GIS allows students to pose questions and propose answers about the real world, which are then tested with real-world data (Kerski, 2000). The National Science Education Standards define inquiry as a step beyond “science as a process,” where students learn skills such as observation, inference and experimentation in order to become independent inquirers about the natural world (National Research Council, 1996a). The content standards for science (National Research Council, 1996a), geography (Geography Education Standards Project, 1994), and technology (International Society for Technology in Education, 2000) are leading education toward a multidisciplinary, inquiry-based instructional model. Furthermore, GIS is regarded as a tool which can address the standards’ emphasis on inquiry and investigation (International Society for Technology in Education, 2000; National Research Council, 1996a), as well as the integrative use of technology for communication, research, and for solving real-world problems (Kerski, 2000).

Real-world problems involve gathering information, analyzing all relevant information, and identifying satisfactory outcomes from among several possible solutions (Kohn, 1982). This problem-based method of education presents students with an ill-structured and open-ended problem that emulates real-world situations requiring them to take an active role as problem solver (Finkle & Torp, 1995). Students need more information than is initially provided; there is no fixed

formula or right way to investigate. The unique problem evolves as new information is discovered and often there is no single right answer (Stepien, Gallagher, & Workman, 1993). GIS technology allows students to guide their own spatial relationship exploration while constructing knowledge from real-world data through map creation (Kerski, 2000).

Instructors and school district administrators can easily justify the implementation of GIS through local, state, and national standards (Ramirez, 1995). Teachers need and have requested lesson materials illustrating how to implement educational standards in the classroom. GIS-based lesson modules are a clear way to incorporate these standards into the classroom, yet few of these modules exist (Kerski, 2000). Currently individual teachers create most of the GIS-based lesson modules, which slows the adoption of GIS in the classroom given that before a teacher can create lessons s/he must first know the basics of GIS, as well as the essentials of the software, and few have the time to do both simultaneously (Kerski, 2000).

According to Kerski the need to connect schools to the GIS applications used in business, government, and universities, identified at the 1992 NCGIA GIS in the Schools workshop (Palladino, 1992), still exists; and the connection should be made through information on GIS for teachers and students, instructional materials, and easy to use software (Kerski, 2000). Scientists can contribute to GIS educational multimedia by translating their expertise and research into

practical examples that explain complex and interrelated phenomena (Krygier, Reeves, DiBiase, & Cupp, 1997).

2.6 INTERNET AND GEOGRAPHIC INFORMATION SYSTEMS EDUCATION

Kerski (2000) found that teachers who use GIS also use a variety of other multimedia in the classroom. Although over 90% of schools have access to the Internet (Bednarz, 1999), to be effective in the classroom sufficient goals and guidance are required (Serim & Koch, 1996). The same is true for GIS utilization in the classroom. Kerski (2000) went on to note:

The Internet is another new educational tool with tremendous potential for inquiry-oriented education, particularly with its accessibility to real-time, real-world data that can be input directly into a GIS. . . . Internet technology has become mainstreamed partly because it requires little time to implement, unlike GIS. Studies on Internet technology have shown that without sufficient goals and guidance, students use the tools as entertainment or to simply fill time. This random browsing may familiarize them with the tools, but not with the process of research or with the subject matter for which the tool is being used. Similar concerns have been voiced with GIS, particularly if the goal is to use it to teach a content area. The difference between random clicking and a goal-focused method is that the latter becomes pointed inquiry with an educational purpose.

Active inquiry and problem-based learning are increasingly used as models for GIS-based learning (Kerski, 2000). This study created a student-centered, interdisciplinary lesson where the teacher acts as a guide and motivator to change students from passive receivers of knowledge to explorers of existing knowledge

and creators of their own knowledge (Harmin, 1994; Silberman, 1996). Active learning transforms the subject being learned from fact-centered to problem-centered in an open-ended process that includes critical reflection (Moser & Hanson, 1996). Student-centered GIS lessons, where a student learns the content by doing, foster cooperative learning by using teams of students who construct their own analyses and geographic representations of real-world data (Ramirez, 1995).

2.7 EARTH SYSTEMS SCIENCE CURRICULUM AND GEOGRAPHIC INFORMATION SYSTEMS EDUCATION

Earth System Science began as a multidisciplinary approach to understanding the Earth as a system including the atmosphere, oceans, biosphere, lithosphere, and interior on a global scale (Nierenberg, 1992). Earth System Science education aligns with the benchmarks for science literacy established by the American Association for the Advancement of Science's Project 2061 (1993) which includes systems, models, constancy and change, and scale as common themes found throughout science, mathematics and technology. To develop a sustainable Earth System Science education program consistent with education standards, the National Aeronautic and Space Administration (NASA) created the Earth Science Enterprise (ESE) Education Strategy (NASA, 1996). The largest ESE precollege activity is the Global Learning and Observations to Benefit the

Environment (GLOBE) Program (NASA, 1996). GLOBE is an international program that allows hands-on science through measurements of the atmosphere, hydrosphere, and biosphere and data input and sharing. Feedback is provided to the students so that they can see rapid results of their findings, correlated with data from students around the world (*The GLOBE Program*, 2002). However, this program has only recently begun using visualization and GIS to examine the data.

The American Geological Institute (AGI) has developed inquiry-based curriculum for K-12 earth science through funding from the National Science Foundation and the AGI Foundation (American Geological Institute, 2001a), most notably the *EarthComm* (high school) (American Geological Institute, 2001b) and *Investigating Earth Systems* (middle school) curriculum programs (American Geological Institute, 2001c). The AGI curriculum is designed to utilize guided inquiry and to be a complete curriculum system including books, software, and professional development. However, the software offered by the AGI program, which most closely relates to Earth System Science, is curriculum specific. That is, the AGI curriculum (and similar curricula) employs a specific type of software that must be relearned with each new application. Correspondingly the Exploring the Environment (ETE) program, supported by the NASA Classroom of the Future at Wheeling Jesuit University, is developing an Internet accessible environmental earth science course modules for high school level students (*Exploring the Environment*, 2000). While the ETE project involves open-ended real-world problems utilizing satellite images, the software program is specific to remote

sensing applications and the project, again not giving students adaptable advanced computer skills.

Utilizing GIS to gather and analyze real-world data teaches students skills that are directly applicable to the workplace environment, where multidisciplinary approaches are frequently necessary. Although GIS education has the ability to teach basic and advanced computer skills, its primary purpose is to aid in the acquisition of concepts and content area skills in multiple disciplines including Earth System Science. GIS software can be utilized by Earth System Science education in the same manner that Earth system scientists implement the technology, to visualize and model earth processes and their complex interrelationships including the relationship between the physical and biological components of the ocean.

3. OBJECTIVES

The objective of this study is to geographically model the El Niño Southern Oscillation (ENSO) influence on remotely sensed global nutrient distribution patterns in order to communicate to others the relationship between the physical and biological components of the ocean through the following tasks:

- Selection of spatial data necessary to estimate phytoplankton distribution patterns in the world ocean.
- Compilation of spatial data needed to compare the cycles of the ENSO phenomena.
- Comparison of phytoplankton distribution patterns between resulting El Niño and La Niña time periods.
- Build and test a transferable model of the nutrient distribution patterns important to phytoplankton for use in grade levels 7-16 science education.

4. DATA AND METHODS

The central calculation of the present study utilized the same algorithm as Kamykowski et al. (In Review) and Switzer (1999). This algorithm, displayed in Equation 1, uses the physical-biological link in the ocean to determine the presence or absence of nutrients.

Equation 1: Algorithm to Determine Nutrient Presence/Absence

Sea Surface Temperature (SST) - Temperature at which the Nutrient Depletes (NDT)

The data used in this study were acquired from a variety of sources (Table 1) and preprocessed to enable the various formats to be combined. To communicate the relationship between the physical and biological components of the ocean an educational CD-ROM multimedia tool was created to facilitate the guided inquiry of the complex and interrelated ENSO phenomena using GIS. The multimedia tool was tested on a focus group of targeted educators using a follow-up evaluation instrument at a GIS teacher workshop held at North Carolina State University.

4.1 OVERVIEW

4.1.1 STUDY AREA SPATIAL AND TEMPORAL SCALE DEFINITION

This study was conducted at the global scale focused on the world ocean.

The data sources used in the study are found in Table 1.

Table 1: Data Summary

<i>Phytoplankton Ecological Factor</i>	<i>Resolution</i>	<i>Data Model</i>	<i>Data Source</i>
Sea Surface Temperature (SST) for Jan., Feb., March 1998 and Jan., Feb., March 1999	54km (0.5° x 0.5°)	Vector/Point ASCII matrix	AVHRR Oceans Pathfinder Descending & Best monthly data
Nutrient Depletion Temperature (NDT) for Nitrate, Silicate, and Phosphate	10° x 10° Canadian squares	Vector/Point ASCII matrix	Dr. Daniel L. Kamykowski (Derived from NODC data)
Iron Deposition for Jan., Feb., March 1998 and Jan., Feb., March 1999	9 x 9 km (0.09° x 0.09°)	Standard Mapped Image Hierarchical Data Format (HDF)	SeaWiFS Aerosol Optical Thickness Level 3 monthly data
Chlorophyll <i>a</i> Concentration for Jan., Feb., March 1998 and Jan., Feb., March 1999	9 x 9 km (0.09° x 0.09°)	Standard Mapped Image Hierarchical Data Format (HDF)	SeaWiFS Ocean Color Level 3 monthly data

Specific months were selected to compare the chlorophyll biomass distribution maps over time scales that represent extremes of the El Niño Southern Oscillation (ENSO) phenomena, El Niño and La Niña. The selection was based on the intensity classification created by the Climate Prediction Center (2000) and the Multivariate ENSO Index (MEI) (Figure 1). Negative values of the MEI represent La Niña, while positive MEI values represent El Niño (Wolter, 2002).

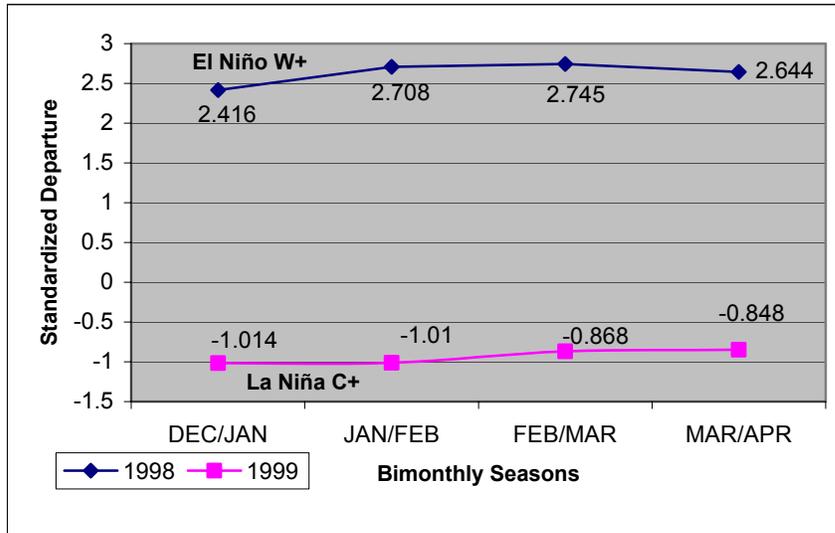


Figure 1: Multivariate ENSO Index for Months of Interest

Adapted from: (Wolter, 2002) Note: MEI values for the two ENSO phases are not directly comparable, each ENSO phase must be evaluated individually.

Based on the criteria described in Table 2, the months selected were January, February, March of 1998, an El Niño year classified as W+ (NOAA-NWS, 2000), and of 1999, a La Niña year classified as C+ (NOAA-NWS, 2000).

Table 2: Month of Interest Selection Criteria

<i>Data Selection Criteria</i>	<i>Reasoning</i>
From the same season	Temporal scale preservation
From comparable values of ENSO index	Avoidance of comparing a strong ENSO event with a weak ENSO event
Availability across the data sources	The data needed to be obtainable for the selected time period from all sources required for the study

4.1.2 DATA SELECTION AND PREPROCESSING

4.1.2.1 SEA SURFACE TEMPERATURE

The NOAA/NASA AVHRR Oceans Pathfinder Monthly Sea Surface Temperature (SST) data product was selected as the SST source for this study. Other satellites measure SST (e.g. MODIS). Additionally, there are other derivations of remotely sensed AVHRR SST (e.g. Reynolds Optimal Interpolation). However, this study selected the Pathfinder data product to allow direct comparison with the methods used by Switzer (1999) and Kamykowski et al (In Review).

Monthly averaged SST Pathfinder data used in the study were derived from the NOAA AVHRR data using the Pathfinder Version 4.1 algorithm (NASA/JPL PO.DAAC, 2000). The SST point data matrices (vector model) were obtained from the “Best” quality and “descending” data measurements. A sample SST matrix is illustrated in Figure 2. The “Best” quality data had to pass a series of retrieval quality tests administered before being added to the data product. The selection of descending (night-time) data improved representation by reducing clouded areas and avoided temporary day-time “hot spots” (Switzer, 1999). The SST matrices for the months of interest were obtained at 54 kilometer resolution, or 0.5 x 0.5 degree squares, from the NASA Physical Oceanography Distributed

Active Archive Center at the Jet Propulsion Laboratory, California Institute of Technology (NASA/JPL PO.DAAC, 2000).

Removing the NO DATA values, headers, and extraneous fields from the SST matrices was accomplished by using JMP 4 (SAS Institute Inc., 2001a). The data were then converted to a text file for export to ESRI's ArcView 3.2 desktop GIS software (ESRI, 1996b). The text file was imported utilizing ArcView's Add Event Theme function and the point data was converted to a shapefile (SHP file), ArcView's native file format.

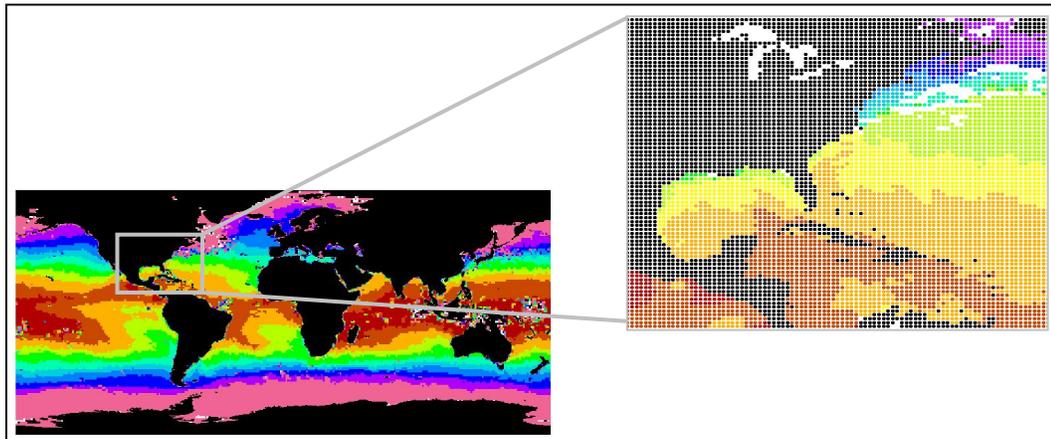


Figure 2: Example of SST Point Data Matrices

4.1.2.2 NUTRIENT DEPLETION TEMPERATURE

The nutrient depletion temperature or NDT is not constant over the world ocean. The NDT point data matrices (vector model) used in this study were based on scatter plots of the specific nutrient availability versus temperature for 10°

latitude by 10° longitude Canadian Squares (International Oceanographic Data and Information Exchange, 2001) in the world ocean. The point data matrices are based on a 30 year historical data set from the National Oceanographic Data Center archive (Kamykowski & Zentara, 1985, 1986). The method for creating the matrices is described by Kamykowski and Zentara (1985; 1986) and Switzer (1999) and Kamykowski et al. (In Review). The NDT matrices for the three nutrients important to phytoplankton selected for inclusion in the study (nitrate, phosphate, and silicate) were obtained from Dr. Daniel L. Kamykowski (personal communication, Jan 2000) (Figure 3).

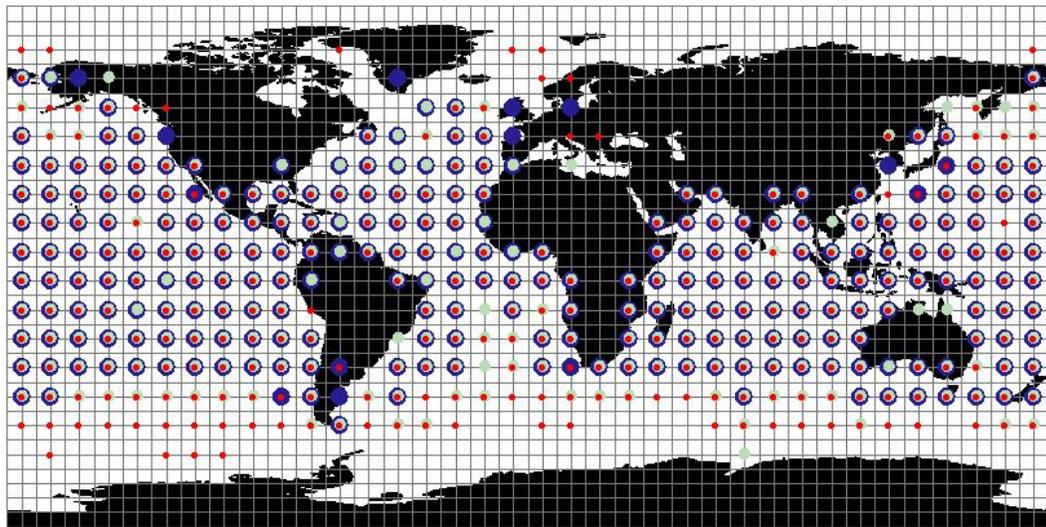


Figure 3: Nutrient Depletion Temperature Data Points

Color Key: red denotes silicate; green denotes phosphate; blue denotes nitrate

The NO DATA values and unnecessary fields were removed from the NDT matrices using Microsoft Excel leaving latitude, longitude, and NDT values in the matrices. The data were then converted to a text file for export to ESRI's

ArcView software. The text file was imported utilizing the Add Event Theme function and converted to a point shapefile.

4.1.2.3 OCEAN COLOR AND AEROSOL OPTICAL THICKNESS

The NASA/NOAA remotely sensed Sea-viewing Wide Field of view Sensor (SeaWiFS) Level 3 Standard Mapped Image (SMI) products were selected as the source for Ocean Color and Aerosol Optical Thickness (AOT) for this study. The SMI product for Ocean Color can be used as a measure of chlorophyll *a* concentration and the AOT product can be used as a measure of iron deposition. The SMI products for the months of interest for Ocean Color and AOT were obtained via Dr. John M. Morrison of North Carolina State University from the Goddard Distributed Active Archive Center at the Goddard Space Flight Center.

Both Level 3 SMI products are global gridded data that have been statistically collected into monthly grid cells corresponding to 0.09 x 0.09 degree squares, or 9 kilometer resolution (Acker, 2000). An example of the Chlorophyll *a* Concentration SMI and the Aerosol Optical Thickness SMI are illustrated in Figure 4 and Figure 5, respectively. The Chlorophyll *a* Concentration SMI contains information derived from ocean color measurements by SeaWiFS's spectroradiometer, which measures radiance in specific bands of the visible light spectrum (Acker, 2000). In this study, phytoplankton above background will be considered present in areas where chlorophyll *a* concentrations exceed $0.1 \mu\text{g l}^{-1}$

(low level) in the world ocean (Kamykowski et al., In Review). The AOT SMI contains information derived from radiance measurements made by SeaWiFS at the 865nm center wavelength (Acker, 2000).

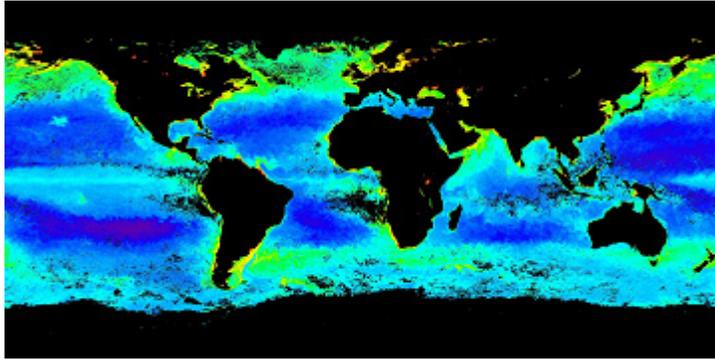


Figure 4: Chlorophyll *a* Concentration: SeaWiFS Mapped Image
From: (SeaWiFS Level-3 Standard Mapped Images, 2002)

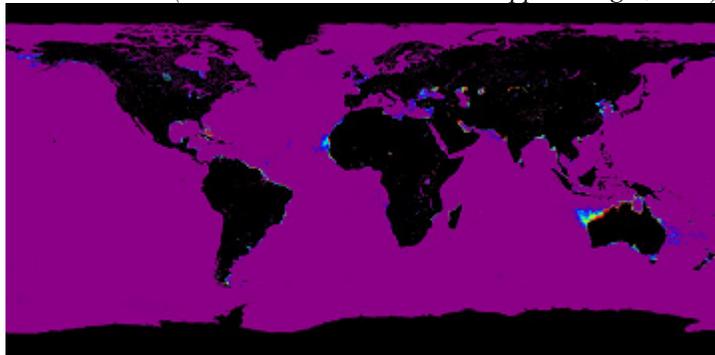


Figure 5: Aerosol Optical Thickness: SeaWiFS Mapped Image
From: (SeaWiFS Level-3 Standard Mapped Images, 2002)

All SeaWiFS data are distributed in the Hierarchical Data Format (HDF), which was developed by the National Center for Supercomputing Applications as a self-describing, platform independent format (Acker, 2000). ENVI Spectral Image Processing software (Research Systems Inc., 2001) was used to extract each SMI product from the HDF file for each month into a file format importable by ERDAS IMAGINE Image Processing software (ERDAS, 2001) (the interchange

format LAN). The header file information for each HDF file was missing and therefore the projection information contained within the header file had to be defined using the Layer Information dialog in the IMAGINE software. The LAN files were imported into IMAGINE using a block size of 256 and output data type of unsigned 16 bit to match the nutrient grid data, and saved as IMG files, ERDAS IMAGINE's native file format.

4.1.3 *EDUCATIONAL CD-ROM MULTIMEDIA TOOL*

The final objective of the study was not to create a commercially available curriculum aid, but rather to examine the ability and usefulness of GIS to facilitate Earth Systems Science education. More specifically, this effort was to utilize the results of a scientific research study of the complex ENSO phenomena to provide a means of communicating oceanographic and Earth systems science principles. While Earth System Science education is emerging, oceanography and marine science are not common core science subjects in secondary education. It was assumed that the teachers who would implement the materials would have had some experience with GIS and ArcView, as well as a general science background. The CD-ROM multimedia tool contains a GIS project with all necessary data, background information for the teacher, instructional materials, student instructions, and an annotated informational hyperlink list indexed by keywords (Table 3).

Table 3: GIS Educational Multimedia CD-ROM Contents

<i>Global Ocean Ecosystem Investigations Educational Multimedia CD-ROM</i>	
A. Teacher Materials	
1. CD Contents & Metadata (ReadMe File) (Appendix I)	
2. Instructional Materials (Appendix J)	
a. Background Content Paper	
b. What's on the CD	
c. Unit Plan	
d. GIS Spatial Analyst Project Procedure	
e. Discussion Questions and Extensions	
3. GIS in the Marine Environment PowerPoint	
4. Global Ocean Ecosystem Investigations PowerPoint	
5. Teacher Hyperlinks (Appendix K)	
B. Student Materials	
1. Student Instructions (Appendix L)	
2. Student Hyperlinks	
C. ArcView Example Project – January 1998 Composite Nutrient Grid	

4.1.3.1 BACKGROUND MATERIALS

To assist the teacher with their understanding of the scientific research study, background materials were compiled (Table 3; Appendix J). The purpose of the background content paper was to explain the basic scientific principles employed by the research study and the GIS project, and to give a general overview of the organization of the CD-ROM multimedia tool. This background paper included information on how the data was obtained, how nutrients relate to temperature, why it is important to study ENSO, how nutrients are related to phytoplankton, and why phytoplankton are important to the Earth system. Also included in the background material is a brief overview of the procedures used in the GIS Spatial Analyst Project. A section entitled “Discussion” describes how the teacher can address the results that the students have found using the GIS project

from a scientific and a social perspective. A few suggestions for optional extensions of the project are included, for example obtaining SST temperatures for other months of interest.

To illustrate the research methods in greater detail two presentations were included in PowerPoint, Adobe PDF and HTML formats to provide the teacher with several implementation options. The presentations included extensive notes to explain the content of each slide. A large number of images were included in the presentations to allow the teacher to use or adapt the presentations in the classroom.

The first presentation “Global Ocean Ecosystem Investigations: GIS in Science Education” describes the scientific research study as well as some of the impacts and consequences of the ENSO phenomena. This presentation was adapted from a presentation given in July 2001 at the International ESRI Education Users Conference to show how the GIS/Spatial Analyst project could be used to investigate the relationship between the physical, chemical, and biological factors in the world ocean. The second presentation “GIS in the Marine Environment” provides the background information on the use of GIS and remote sensing technologies in oceanographic research. This presentation was designed for use as an introduction to the project or as a stand-alone explanation of the applications of GIS in oceanography.

Finally, a description of the CD-ROM contents and metadata was included in a ReadMe file (Appendix I). The section entitled “What’s on the CD” contains

a brief description of each component included on the CD-ROM multimedia tool along with the file name, format and location. The section entitled “Metadata” contains a description of the data used in the project. The final component of the ReadMe file is a brief overview of how the data was manipulated to create the grids used in the GIS project including data processing, and SST and NDT surface creation.

4.1.3.2 INSTRUCTIONAL MATERIALS

To facilitate a student-centered, guided inquiry of the complex and interrelated ENSO phenomena, a Unit Plan was created that synthesized the use of the Internet and GIS. The teacher “sets the stage” by introducing the marine environment and the use of GIS in oceanographic research. The students are then broken into the research groups found in Table 4. The student research teams perform a background investigation of their respective topics on the Internet using the annotated list of informational hyperlinks (See Section 4.1.3.3 Annotated Informational Hyperlinks). The students then share this background research with the entire class via a method determined by the teacher such as class presentations, written reports, and mini “research” fairs.

Table 4: Student Research Groups used in the Unit Plan

<i>Group Name (keyword)</i>	<i>Example Group Purpose/Study Area</i>
• Why Care	Why care about the oceans?
• Space	Why study the ocean from space?
• Ocean Color	What color is the ocean?
• Phytoplankton	Why are phytoplankton important?
• Remote Sensing	How do satellites work?
• SST	What is sea surface temperature (SST)?
• ENSO-Climate	How do atmospheric climatic events affect the ocean?
• Nutrients	How do organisms in the ocean use nutrients?

Following the information exchange, the teacher moderates a brainstorming session to create a list of questions or problem statements that the students would like to investigate further. The teacher must guide these questions to determine which ones can be investigated using the GIS project. Some example problem questions are included in Table 5. Other problem questions can be investigated by adding data to the GIS project or in other ways such as a guest speaker or additional lessons (Table 5).

Table 5: Example Problem Questions Created in a Brainstorming Session

<i>GIS Project Questions</i>	<i>Questions Requiring Additional Information</i>
How does the SST affect the distribution of nutrients in the ocean?	Where are volcanoes located (ESRI sample data) and how might volcanoes affect nutrients in the ocean?
What is the connection between nutrients and phytoplankton that could be found there?	How are people affected by the El Niño Southern Oscillation phenomena and where on Earth can these effects be found? (Internet Research)
How does climate affect the living things in the ocean?	If the El Niño Southern Oscillation phenomena occur in the Pacific how can it affect America?
Where are more nutrients found in the ocean?	What is the global carbon cycle and why do phytoplankton play an important role in it?

After the brainstorming session the teacher demonstrates the ArcView example project (See Section 4.1.3.4 ArcView Example Project) illustrating the

eight category composite nutrient presence/absence grid for the month of January 1998 to facilitate a classroom discussion of the problem questions/statements they have created and to generate potential “plans of attack”. The teacher can then either demonstrate how to recreate the example GIS project with the students following along with the student instructions or the students could use the student instructions to recreate the example project on their own. The student instructions include visual as well as written directions of how to create the example project to accommodate different learning styles (Appendix L).

While many questions can be addressed by merely examining one month of nutrient distribution, several months must be examined in order to study the ENSO phenomena. Therefore, the students should create the eight category nutrient presence/absence grids for all months included in the GIS project. With all six months of interest the students can examine how the nutrient distributions change between the two extremes of the ENSO phenomena-- El Niño and La Niña. As a further extension ESRI’s Image Analyst can be used to perform change detection analyses to determine the amount of change from month to month. This allows additional questions to be addressed. An example research question might be “when and in what part of the world ocean did the largest amount of change occur and how might this change affect the phytoplankton that live there?”

4.1.3.3 ANNOTATED INFORMATIONAL HYPERLINKS

Although the Internet is mainstream, students need guidance and goals to reduce random browsing, wasted time and frustration (Kerski, 2000). To offer guidance during the Internet research, an intensive Internet search was conducted in order to compile an annotated list of hyperlinks to educate both the teacher and student on background concepts and provide information necessary to understand the scientific principles utilized in the research study (Appendix K). The relevant Internet research objectives were determined by the research groups, which are found in Table 4.

The annotated informational hyperlink list was designed as a resource that could be utilized with or without the GIS project to allow the greatest degree of adaptability for the teacher. Every hyperlink was annotated to offer an overview of the subject content found on the website. Wherever possible, links were provided to the relevant topical areas housed on the particular website. To facilitate the student usage, each hyperlink was assigned keywords that were identical to the research group names (Table 4). A separate teacher version was included that contains not only the student list but also several additional sites for the teacher to use in their curriculum implementation (Appendix K).

4.1.3.4 ARCVIEW EXAMPLE PROJECT

To facilitate the use of GIS to explore the ENSO phenomena, a GIS project was created that would give students the opportunity to recreate the research process used to create the composite nutrient distribution maps from the study via inquiry-based learning. Although the original study used several brands and types of software, ESRI's ArcView (ESRI, 1996b) was selected as the GIS software with which the project would be created and implemented. ArcView was selected primarily because the portion of the study selected for inclusion in the CD ROM multimedia tool was originally analyzed using ArcView and ArcView Spatial Analyst.

The research selected for inclusion in the GIS project was the creation and analysis of the eight category composite nutrient presence & absence grids (See Section 4.2.3.1 Composite Nutrient Presence/Absence Grids). Table 6 lists the contents of the GIS project consisting of the included data set and an example project. The data has already been interpolated and was left as unprojected latitude/longitude so the ESRI sample data could be added to the project as the students were creating hypotheses.

Table 6: Educational Multimedia GIS Project Contents

<i>GIS Project Contents</i>			
Data (in oceans.apr for display purposes)			
	<i>Phytoplankton Ecological Factor</i>	<i>Data Model</i>	<i>Purpose</i>
	Sea Surface Temperature for Jan., Feb., March 1998 and Jan., Feb., March 1999	Surfaces/Grids	Calculation and Analyses
	Nutrient Depletion Temperature (NDT) for Nitrate, Silicate, and Phosphate	Surfaces/Grids	Calculation and Analyses
	Latitude/Longitude Graticule	Vector Shapefile	Reference
	Countries of the World	Vector Shapefile	Reference
ArcView Example Project – Nutrient Composite Grid (example.apr)			
	a. ArcView project containing the completed composite nutrient presence/absence grid for the month of January 1998		
	b. The data necessary to view the example project		

Using the GIS project, students recreate the construction of the composite nutrient presence/absence grids. The students use the principles of map algebra to apply the algorithm (Equation 1) to the Sea Surface Temperature (SST) and the Nutrient Depletion Temperature (NDT) surfaces. The students can examine the individual presence/absence grids for each nutrient they created for the month(s) of interest. The students then reclassify the individual presence/absence grids and add them together to create the eight-category composite nutrient presence/absence grid(s). To facilitate the examination of the ENSO phenomena, the data included in this project spans two years January, February, and March 1998 (El Niño) and January, February, March 1999 (La Niña) (Table 6). Creation of the eight category nutrient presence/absence grids allows the investigation of how the nutrient distributions change between the two extremes of the ENSO phenomena-- El Niño and La Niña.

Several extensions to the GIS project are included in the instructional materials. ArcView Image Analyst can be used to perform change detection analyses to determine the amount of change from month to month. Additional data can be added to the project as students generate their own questions and projects that investigate how climatic events affect the physical (SST), chemical (NDT), and biological (phytoplankton) composition of the world oceans. For example, a layer representing volcanoes could be added for the investigation of their potential influence on nutrient distribution patterns. Information about the location of the SeaWiFS standard map image products is included to facilitate the qualitative comparison between the nutrient distribution patterns for a specific month and the corresponding chlorophyll *a* concentration, an indicator of primary productivity. Finally, a description of the SST acquisition and interpolation process was included to allow the investigation of any month of interest thereby allowing the GIS project to remain up to date.

4.2 METHODOLOGY

4.2.1 *STATISTICAL ANALYSES OF STUDY DATA*

Histograms of the Nutrient Depletion Temperature (NDT) data, as well as a parametric regression model of the Sea Surface Temperature (SST) data, were created in SAS Statistical Analysis software (SAS Institute Inc., 2001b) to

determine the best interpolation models. A representative SST Histogram (Figure A-1), the SST Parametric Regression (Figure A-2), and the NDT histograms for nitrate, phosphate, and silicate (Figure A-3, Figure A-4, and Figure A-5, respectively) can be found in Appendix A. Both the NDT and SST data were found to be continuous and statistically homogenous. The NDT data displayed a right skewed trend. The SST data had a second order (quadratic) trend (Figure A-2).

4.2.2 *GEOSTATISTICAL ANALYSES*

Table 1 illustrates the data model for each phytoplankton ecological factor. The data used in this study were acquired from a variety of sources, each with a different projection. To utilize the data conjunctively, a common projection was selected. There are only a few projections available for use with the raster data model at the global scale. The projection of the SeaWiFS data was an Equidistant Cylindrical projection. In this projection, scale is true along all meridians and the standard parallels and is constant along any parallel and along the parallel of opposite sign, although distortion of both shape and area increase with distance from the standard parallels (Weisstein, 1999). The Equidistant Cylindrical projection was selected for this study as it retains scale well along the equator, the major area of ENSO phenomena. Also, the majority of the distortion in the

projection occurs at the poles, an area that will be ignored due to lack of data observations and ice cover.

The SeaWiFS data were in a raster format with a resolution of 0.09 degrees, while the SST and NDT data were in a vector (point) data model with resolutions of 0.5 degrees and 10 degrees, respectively. In order to perform any map computations, the raster data model was chosen as the common data model for this study. Raster data models or grids, are defined as geographic space is partitioned into rectangular cells with each cell containing a numeric data value (ESRI, 1996c). These are typically used to represent geographic phenomena that vary continuously over space (ESRI, 1996a). Using map algebra, new data layers are derived from existing data layers through combination and transformation (Allen, 1998a). By utilizing the raster data format, the input and output layers all have the same geometry, (e.g., number of rows/columns, spatial extent represented, pixel size/resolution) but the attribute values for some or all of the cells in the output raster are altered by the transformation applied (Allen, 1998b). In this study, the algorithm (Equation 1) was applied to the SST and NDT data in order to create the nutrient presence/absence grids and to combine the reclassified grids into the composite presence/absence grids.

As noted, the SST and NDT data obtained for use in this study are point features, or a vector data model. To convert the vector point data to a raster data model, spatial interpolation was used to create the grids. In spatial interpolation input points can be either randomly or regularly spaced and these points represent

magnitude measurements, such as temperature. The resulting raster grid is the estimate of the quantity on the actual surface for each cell location. Different interpolators are used to produce better estimates of the actual values. Selection of interpolation method is based on the phenomena that the values represent and how the sample points are distributed. No matter which interpolator is selected, the more input points and the greater their distribution, the more reliable the results. The interpolation methods make different assumptions about how to determine the best estimated values (ESRI, 1996a). It is therefore very important to select the interpolator that best describes the data. Using a statistical analysis of the study data (see section 4.2.1 Statistical Analyses of Study Data) and a qualitative examination of the various interpolation methods, kriging was selected to interpolate the surfaces in this study. Kriging allows some quantification of prediction quality. Kriging can also be used to remove trends from data and is one of the few interpolators that can be used with non-normally distributed data.

4.2.2.1 KRIGING INTERPOLATION METHOD

Kriging is used on continuous data that is statistically homogeneous. It involves an interactive investigation of the spatial behavior of the phenomenon represented by the z values before selection of the best estimation method for generating the output surface. Kriging is an advanced interpolation procedure for

spatial data that generates an estimate of the surface from a scattered set of points (Shibli, 1997). This study utilized both ordinary and universal kriging methods.

When ordinary kriging is used a semi-variogram is modeled by fitting a theoretical mathematical function to the sample semi-variogram. The spatial variation is quantified by the semi-variogram. The semi-variogram is estimated by a sample semi-variogram that is computed from the input point data set. The value of the sample semi-variogram for a separation distance of h (referred to as the lag) is the average squared difference in z value between pairs of input sample points separated by h (ESRI, 1996d). The distance at which the data was collected determined the lag distance. In this study, when ordinary kriging semi-variograms were examined, the model with the lowest root mean square error (RMSE) was chosen.

Universal kriging assumes that the spatial variation in values is the sum of a structural component (drift), a random but spatially correlated component, and random noise representing the residual error. The structural component represents a constant trend over the surface. Universal kriging uses polynomial orders to approximate this drift. The random noise is assumed to be normally distributed and spatially independent. After accounting for the structural effect, the remaining variation is spatially homogeneous such that the z -value difference between input sample points is merely a function of the distance between them as with ordinary kriging (ESRI, 1996d). Kriging is then performed from the residuals (Shibli, 1997).

4.2.2.2 SST AND NDT DATA INTERPOLATION

ESRI ArcView and the extensions Spatial Analyst (ESRI, 1996b) and Kriging Interpolator 3.2 (Boeringa, 2001) were used to interpolate the Sea Surface Temperature (SST) point data matrices and the Nutrient Depletion Temperature (NDT) point data matrices. Before the interpolation, a latitude/longitude grid, in decimal degrees (map units), from ESRI sample data (ESRI, 1996b), was used to set the Analysis Extent.

Universal Kriging with quadratic drift was selected as the surface interpolator for the SST data in this study because it best described the second order trend of the data described in the parametric regression model in Figure A-2. Ordinary Kriging was selected as the surface interpolator for the NDT data for this study. Semi-variograms for several different ordinary kriging functions were generated for each nutrient. The spherical function was chosen for each nutrient because it explained more of the variation in the data as indicated by the lowest overall RMSE. The semi-variograms for nitrate, phosphate and silicate (Figure B-1, B-2, and B-3) are found in Appendix B. The interpolation parameters can be found in Appendix C.

Finally, the nutrient presence/absence grids and the SST grids had to be projected from an unprojected (geographic) projection for alignment with the SeaWiFS data. ESRI's ArcInfo Workstation GIS software (ESRI, 2001) was used to define the projection for the nutrient grids created in ArcView as Geographic

with the Clarke 1866 Spheroid with decimal degrees (DD) as the unit. ArcInfo was then used to reproject each grid into Equidistant Cylindrical, which is a subtype of the Equirectangular projection, using the PROJECT GRID command.

4.2.3 *SPATIAL MODELING*

4.2.3.1 COMPOSITE NUTRIENT PRESENCE/ABSENCE GRIDS

ArcView Spatial Analyst's Map Calculator was used to subtract the individual nutrient depletion temperatures (NDT) from the SST for each month of interest (Equation 1). With negative numbers representing presence and positive numbers representing absence, the values were used to interpret the resulting nutrient availability categories (Figure 6). The NDT must be higher than the SST in order for the nutrients to remain in the water column and to be available to living organisms.

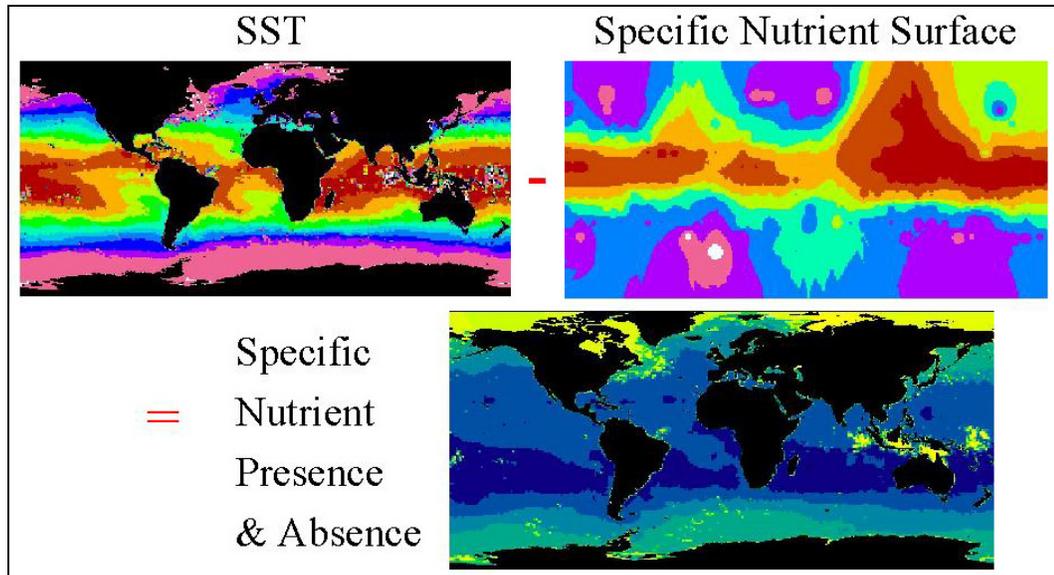


Figure 6: Nutrient Presence/Absence Determination

The nutrient presence/absence grids for each nutrient for each month were reclassified. All values less than or equal to zero were considered absent and assigned a value of two (2) while all values greater than zero were considered present and assigned a value of one (1). To distinguish the different nutrients, a reclassification scheme was created to keep track of the relative values for each of the three nutrients using the mathematical concept of place value. The three nutrients, nitrate, phosphate, and silicate, were designated by the ones, tens and hundreds place values, respectively. For an example of the nutrient availability reclassification scheme see Table 7.

ArcView Spatial Analyst's Map Calculator was then used to add the three reclassified nutrient grids for each month together, creating a composite nutrient presence/absence grid for each month. Each cell in the monthly nutrient presence/absence grids was therefore represented by one of eight categories of

specific nutrient presence/absence (Table 7; Figure E-1). A cell value of 222 indicated all three nutrients were absent; a cell value of 111 indicated all three nutrients were present; any other cell value indicated that one or more than one nutrient was either present or absent (Table 7).

Table 7: Nutrient Availability Reclassification

<i>Nutrient Presence/ Absence Category</i>	<i>Abbreviation</i>	<i>Reclassification Scheme</i>
All Nutrients Absent	Abs	222
Silicate Only	S	122
Phosphate Only	P	212
Nitrate Only	N	221
Phosphate and Silicate	PS	112
Nitrate and Silicate	NS	121
Nitrate and Phosphate	NP	211
Nitrate, Phosphate and Silicate	NPS	111

4.2.3.2 COMPOSITE ECOLOGICAL INDICATOR PRESENCE/ABSENCE GRIDS

The final step involved the creation of the sixteen-category composite distribution map for each month to include iron and chlorophyll *a*. The Aerosol Optical Thickness and Chlorophyll *a* grids were reprojected and resampled to the same resolution as the nutrient presence/absence grids using the method described in Appendix D. The Aerosol Optical Thickness and Chlorophyll *a* grid cell values, digital numbers ranging between 0 and 255, were compared to actual data values to determine the range of presence and absence for these factors. Initially, the digital numbers in the image were analyzed using the inquire cursor to represent

the values for each data layer received from SeaWiFS. Values that represented land or no data were noted (255). Mapped images accessed at the SeaWiFS web site (*SeaWiFS Level-3 Standard Mapped Images*, 2002) were used to analyze the digital numbers over multiple locations (a minimum of 50) for each monthly image (Figures 4 and 5) to help verify the interpretation (Table 8). Then, the numbers were inserted into a conditional statement that was a part of a spatial model built in IMAGINE Spatial Modeler (Appendix E) and the numbers were reclassified (Table 8; Appendix E-2).

IMAGINE Spatial Modeler was used to reclassify the cell (pixel) values of the Chlorophyll *a* grids and the AOT grids for each month of interest so that all values indicated absence or presence. The reclassification scheme that was created to keep track of the relative values for each of the three nutrients of interest using the place value was continued with the chlorophyll *a* and aerosol optical thickness (iron). Chlorophyll *a* and aerosol optical thickness were designated by the thousands and ten thousands place values, respectively. Table 8 includes a description of the digital numbers and the values used to reclassify the chlorophyll *a* and AOT SMI products.

Table 8: SeaWiFS Standard Mapped Image Product Classification

<i>Data Layer</i>	<i>Digital Number</i>	<i>Actual Data Values</i>	<i>Reclassification Scheme</i>
Chlorophyll <i>a</i>	255	Land	2000
	> 60	< 0.1 $\mu\text{g l}^{-1}$ Absent	2000
	≤ 60	$\geq 0.1 \mu\text{g l}^{-1}$ Present	1000
Iron	255	Land	20000
	> 25	Absent	20000
	≤ 25	Present	10000

The reclassified iron image was added to the reclassified chlorophyll image. A pixel with a reclassified value of 11000 contained both iron and chlorophyll *a* while a value of 21000 represented chlorophyll present and iron absent. All values not representing categories of interest were reclassified to thirty thousand (30000) and removed from the final image. For example, a cell value of 31211 could be removed. Each reclassified iron – chlorophyll image was then combined with each eight category nutrient grid for the El Niño and La Niña months (Figure 7). There were 64 possible combinations of the five ecological factors examined that were reclassified into 16 categories (Table 9; Appendix E). Each cell in the composite ecological factor presence/absence grids for each month was represented by one of sixteen categories of specific ecological factor presence/absence (Table 9). A cell value of 22222 indicated all factors of interest were absent; a cell value of 11111 indicated all factors of interest were present; any other cell value indicated that one or more than one ecological factor was either present or absent. Therefore, a cell value of 21112 indicated that silicate, phosphate, and chlorophyll *a* were present

while nitrate and iron were absent. The process was completed for the months of January, February, March 1998 (El Niño) and January, February, March 1999 (La Niña) in order to compare the El Niño Southern Oscillation events on the same temporal scale (Figure E-2).

Table 9: Phytoplankton Ecological Factor Classification

<i>Representative impacts of nutrient availability on phytoplankton community cell size</i>				
<i>Nutrient Presence/ Absence Category</i>	<i>Abbreviation</i>	<i>Iron (F) Absent (smaller cells)</i>	<i>Abbreviation</i>	<i>Iron (F) Present (larger cells)</i>
All Nutrients Absent	Abs	1	FAbs	9
Silicate Only	S	2	FS	10
Phosphate Only	P	3	FP	11
Nitrate Only	N	4	FN	12
Phosphate and Silicate	PS	5	FPS	13
Nitrate and Silicate	NS	6	FNS	14
Nitrate and Phosphate	NP	7	FNP	15
Nitrate, Phosphate and Silicate	NPS	8	FNPS	16

4.2.4 EDUCATIONAL MULTIMEDIA TOOL EVALUATION

Assessment of GIS-based lesson modules is necessary to understand the effect of the technology (Kerski, 2000). Therefore, the multimedia tool was beta-tested with evaluation instrument at a GIS teacher workshop held at North Carolina State University in August 2001. The evaluation instrument was designed to assess both the content and the usability of the CD-ROM multimedia tool, as well as the quality of communication concerning the relationship between

the physical and biological components of the ocean using GIS. The results were analyzed to determine the overall usefulness of the CD-ROM multimedia tool and its effectiveness in this communication.

The evaluation instrument, in the form of a survey/questionnaire, was designed to assess each component of the CD-ROM multimedia tool (Appendix M). First, demographic information was obtained including the grade level(s) and subject(s) taught, years of teaching, level of marine science education experience, and the level of comfort with and amount of GIS use in the classroom. The remainder of the survey was designed to lead the evaluator through each component of the CD-ROM beginning with the background information. Evaluators were instructed to open the ReadMe file to obtain a better understanding of the content and layout of the Global Ocean Ecosystems Investigation CD-ROM multimedia tool. The evaluators then assessed the quality of the Background and Instructional Materials.

First, the organization, usefulness, and potential implementation of the background content paper were assessed followed by the Teacher Instructional materials, including the Unit Plan, the GIS Project procedure overview, and the Discussion section. Then the detailed Student Instructions, the Presentations, and the Informational Hyperlink WebPages were assessed. In addition to the aforementioned assessment, the evaluators were asked to answer several questions by utilizing the WebPages, for example: “How would you define/describe EI

Niño?” and “What are phytoplankton and why are they so important?” and to determine the level of difficulty involved in researching the answers.

To assess usefulness, organization, and implementation potential of the GIS project, evaluators were instructed to follow the Student Instructions (Appendix L) in performing the GIS lesson using the data for the month of January 1998. The evaluators were asked several content questions (Appendix M) that could be answered upon successful completion of the GIS project. The evaluators were also asked to list three hypotheses. Both these hypotheses and a separate assessment were used to assess the level of usefulness in using the overall multimedia tool.

5. RESULTS

5.1 CHLOROPHYLL CLASSIFICATION

The chlorophyll *a* classification of the world ocean for the months January, February, March 1998 and January, February, March 1999 showed the greatest amount of nutrients found in the world ocean to be: NPS (category 8), followed by absent (Abs, 1), and finally NP (7) (Figure 7, Table 9). Moderate nutrient amounts included FP (11), FN (12), and FNPS (16) and small amounts were found of the categories FNS (14), FPS (13), NS (6), FS (10), and S (2).

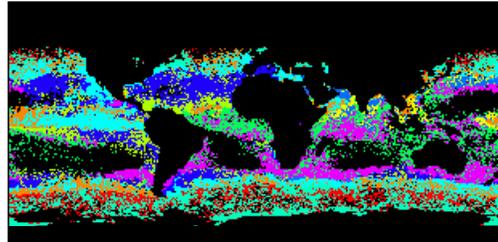
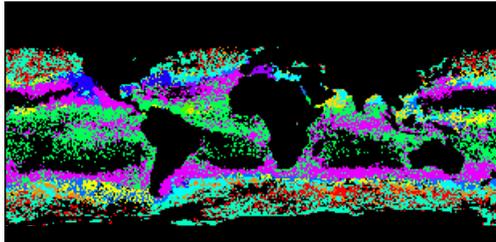
Generally, phosphate was commonly found throughout the world ocean, except south of 45° S where nitrate was more common. Large diatoms associated with FNPS could be found in the upper or lower latitudes (north of 60°N and south of 60°S). Ignoring iron, note that the eastern Pacific equatorial region and the higher latitudes of the world ocean were dominated by NSP (8). The central region of the ocean is dominated by absent (1) and phosphate (3). The major aerosol source regions of northern Africa, the Arabian Peninsula, eastern Asia, Patagonia and southern Africa (Moore et al., 2002) show plumes that were associated with iron presence and the categories of FNS, FPS, and FS (Figure 7).

El Niño Conditions

La Niña Conditions

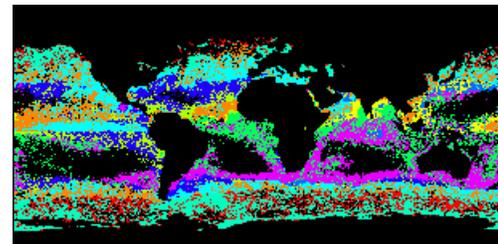
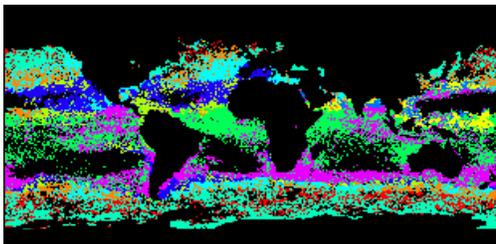
January 1998

January 1999



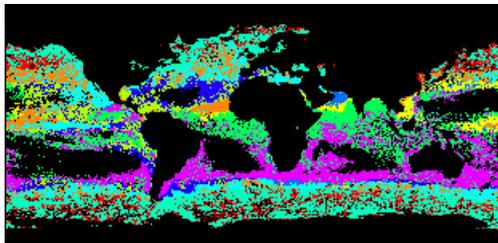
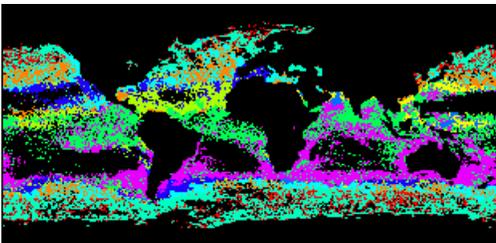
February 1998

February 1999



March 1998

March 1999



Iron Absent			Iron Present		
No Data 0	P 3	NS 6	Abs 9	N 12	NP 15
Abs 1	N 4	NP 7	S 10	PS 13	NPS 16
S 2	PS 5	NPS 8	P 11	NS 14	

Figure 7: Composite Phytoplankton Ecological Factor Distribution Images

Figure 8 and Figure 9 illustrate the variation in the percentage of phytoplankton ecological indicator categories present for each month. January 1998 shows the greatest variation from the other months and the highest percentages of absent (1) and F (9). The phosphate categories of P (3) and FP (11) for January 1998 show the least variation as compared to the other months (Figure 8). In January 1998, most of the nutrients were very low as compared to the other months except for the categories of absent (1), F (9), NPS (8) and FNPS (16). It is also noteworthy that 5% of the January 1998 categories was NS. The NS category was not found in any of the other months analyzed by this study. In February 1998, a high percentage of phosphate (3) was found (Figure 9).

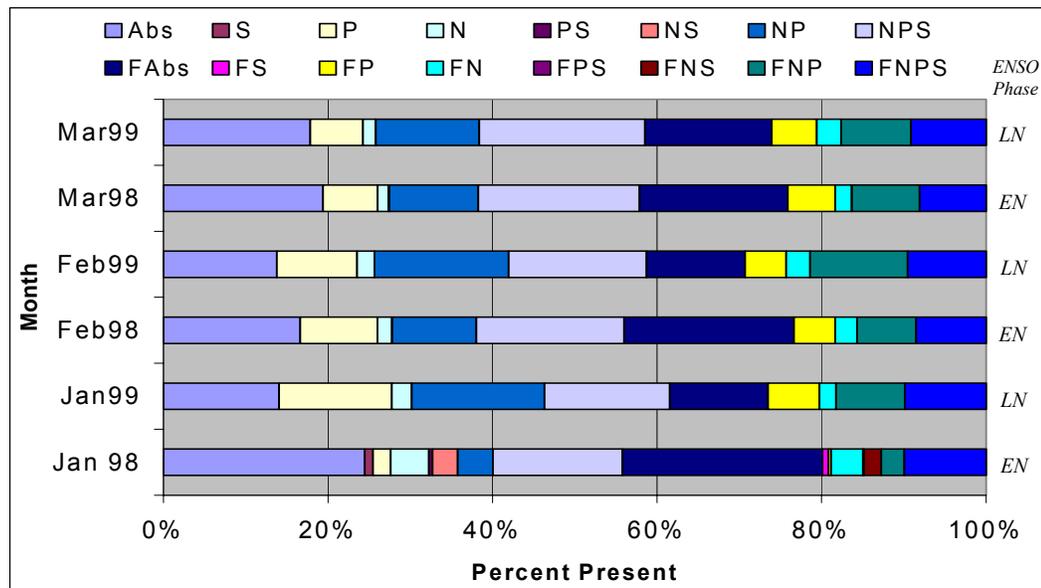


Figure 8: Phytoplankton Ecological Indicator Percent Present per Category

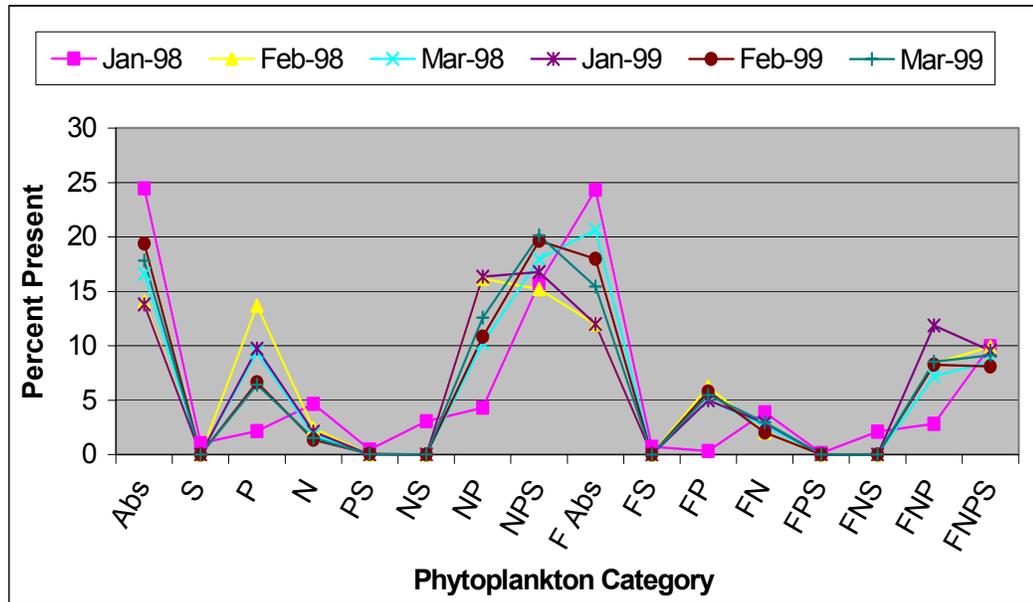


Figure 9: Categories of Phytoplankton Ecological Indicators Present

The percentage change was calculated by percent of pixels that were changed or unchanged throughout the world ocean (Figure 7). Between January 1998 and January 1999 a 43% change occurred in the world ocean, February 1998 and February 1999 a 37% change, and in March 1998 and March 1999 a 34% change. The intra-annual changes were lower, as expected, with the January 1998 to February 1998 percentage change being 39.45%, the February 1998 to March 1998 change was 32.7%. The January 1999 to February 1999 change was 32.4%, and the February 1999 to March 1999 change was 34%.

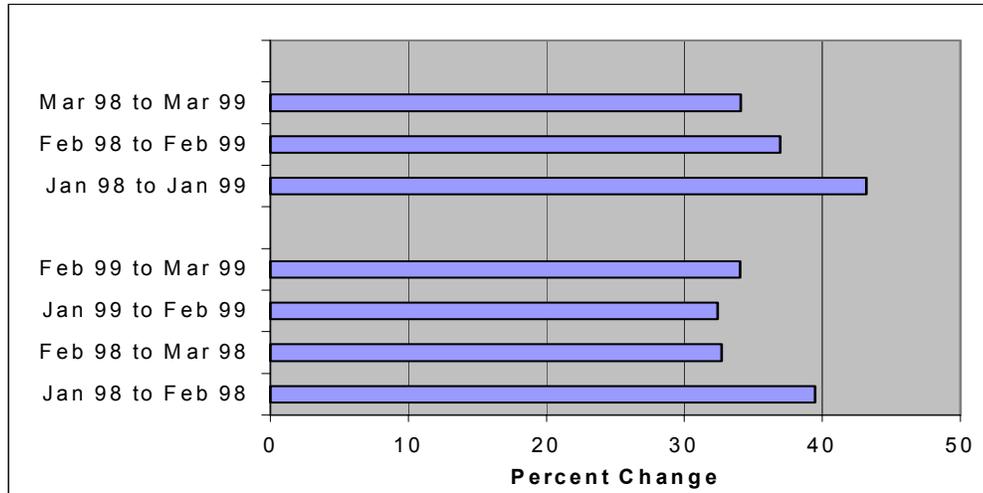


Figure 10: Inter- and Intra-Annual Percent of Pixels that Changed Categories

5.2 EVALUATION INSTRUMENT

The evaluation results were analyzed quantitatively in spreadsheets and qualitatively by utilizing the ATLAS.ti software program (Muhr, 1996). The ATLAS.ti program is designed for qualitative analyses of large bodies of textual data, which cannot be analyzed by formal, statistical approaches in meaningful ways (*The Knowledge Workbench*, 1999).

Twelve teachers participated in the evaluation with 75% coming from middle schools and 25% coming from high schools (Figure N-1). The gender distribution consisted of 3 males (25%) and 9 females (75%) (Figure N-2). The amount of teaching experience, measured by years of service, ranged from 2 to 30 with an average of 17.1 years of service (Figure N-3). The gender distribution fell across the years of experience with one male in each of the following years of

experience categories, 7 –12, 13-18, and 26+ (Figure N-4). One teacher frequently used GIS in the classroom while the remaining 11 teachers only used GIS in the classroom very infrequently (Figure N-5). However, there was a range in comfort level of using GIS to explain a topic with 3 teachers feeling comfortable or very comfortable (25%), 6 teachers feeling uncomfortable or very uncomfortable (50%), and 3 teachers being neutral (25%) (Figure N-6). The majority of the teachers had very little marine science experience.

Overall, the mean and median level for organization and quality of usefulness of the educational CD-ROM multimedia tool, including each of its components, were at or above neutral (Figure N-7, Figure N-8). The most useful components for the CD-ROM multimedia tool were the WebPages, the Teacher Instructions, and the Student Instructions (Figure N-7). The most organized components of the CD-ROM multimedia tool were the WebPages, the Student Instructions, and the Presentations (Figure N-8). The overall educational CD-ROM multimedia tool received ratings of useful and well organized from the evaluators (Figure N-7, Figure N-8).

The difficulty level of using the CD-ROM was rated as neutral (Figure N-9). The difficulty level of utilizing the WebPages component to answer several questions received a neutral rating. The difficulty of using the GIS project and the background materials to answer several project-specific questions was also rated neutral. Finally, the evaluators gave a neutral rating to the level of difficulty

associated with developing three hypotheses that could be tested with the CD-ROM multimedia tool.

The evaluators were asked if the CD-ROM addressed their need to teach local, state and national standards in science and geography (Figure N-10). The mean and median of the evaluators agreed that the CD-ROM multimedia tool did address their need to teach science standards. The median of the evaluators agreed that the CD-ROM addressed geography standards, while the mean of the evaluators agreed to a slightly lesser degree.

Finally, the mean and median levels of quality of communication of the physical and biological components in the ocean through the educational CD-ROM multimedia tool were above neutral. The evaluators were asked if the Global Ocean Ecosystems Investigations CD-ROM multimedia tool communicated the relationship between the physical and biological components in the ocean (Figure N-11). The mean and median of the evaluators agreed that the CD-ROM multimedia tool communicated the physical-biological relationship in the ocean. The evaluators were then asked if they gained a better understanding of the relationship between the physical and biological components in the ocean. The median of the evaluators agreed that they gained a better understanding of the biological-physical link in the ocean, while the mean of the evaluators agreed to a slightly lesser degree. Finally, the evaluators were asked if they believed that students could use the Global Ocean Ecosystems Investigations CD-ROM multimedia tool to gain a better understanding of the relationship between the

physical and biological components in the ocean. The mean and median of the evaluators agreed that students could use the tool to gain a better understanding of the physical-biological link in the ocean.

6. DISCUSSION

6.1 ENSO INFLUENCE

The basic pattern of nitrate, phosphate, and silicate were compared for January, February, March 1998 (an El Niño year) to January, February, March 1999 (a La Niña year). A major advantage of this approach is that the nutrient distribution differences were responsive to the actual physical forces occurring in the world ocean. In this multi-nutrient approach, patterns begin to emerge that represent the types of phytoplankton that could be found in these areas. Changes and various comparisons were analyzed as a result of this satellite-based approach. When comparing January 1998 to January 1999, scattered regions from 40°S to 0° were in a state of iron flux (Figure 7). Change occurred between categories F (9) and absent (1). In this region of the world ocean, there is generally very little chlorophyll and change between similar classes can easily occur based on the near depletion state of all categories of nutrients. Another example was the coastal upwelling zone of South America in which the category of F (9) was present during El Niño and the category P (3) was present during La Niña (Figure 7). This

could possibly be due to enhanced convection during El Niño and upwelling during La Niña episodes.

When comparing February 1998 to February 1999, the pattern of iron enrichment once again becomes important in scattered areas from 40° S to 0° latitude because category F (9) changed to absent (1) and visa versa. Greater change was also observed in the Southern Ocean as category NPS (8) changed to FNPS (16) and visa versa (Figure 7). This pattern of iron flux was also present during the March 1998 to March 1999 months, although to a lesser degree. Additionally, category FP (11) changed to P (3) and visa versa (Figure 7). This may be due to the iron dust that is deposited in the Atlantic from the northern coast of Africa.

The northern Atlantic Ocean did not change as much as other areas of the world ocean in this study, which is expected as the major region of ENSO influence is the Pacific Ocean. Throughout the study area as a whole, the stronger the ENSO episode the larger the differences in phytoplankton categories observed between the years. January 1998 was the strongest El Niño month in this study and thus the differences were greater (Appendix G).

It was found that some change occurred within the same season but more change occurred when comparing two different years. Some of the change within seasons could be attributed to data modeling but, more importantly, the ocean is a dynamic system that exhibits constant change and it is reasonable that there would

be a large amount of inter-annual change between two very opposite climatic events (Appendix G and H).

The top three phytoplankton ecological indicator categories found in this study were NP, which exhibited very little annual change, the absent category, which exhibited change and was found 40°S to 0° around the areas of no chlorophyll *a* in austral summer, and the category NPS, which changed to FNPS depending on the sources of iron. The FNPS category also changed and was found in moderate amounts and is related to the major aerosol source regions of northern Africa, the Arabian Peninsula, eastern Asia, Patagonia and southern Africa. It should also be noted that El Niño causes a change in terrestrial precipitation patterns, which may increase the amount of wind blown dust in some regions (e.g. Australia). These plumes are also associated with changes in the moderate amount categories of FP and FN. Very little of the categories FNS, FPS, NS, FS, and S were found, however this was expected as silicate is a limiting factor in regions of the world ocean.

The greatest changes between January 1998 and January 1999 were in categories P (3), NP (7), FNP (15), absent (1), and F (9) (Appendix G). Shifts between category F (9) and absent (1) as well as category NPS (8) and FNPS (16) were common between the January and February months but not as common between the March months (Appendix G). In general there were fewer changes between the March months. The results show the importance of iron availability

to the composition of phytoplankton communities and how climatic changes can affect them.

The upper and lower latitudes (north of 60°N and south of 60°S) are cold and concurrently nutrient rich and contain more NPS and FNPS categories. In contrast, there are areas in the open ocean, in the lower middle latitudes that are strongly nutrient limited and contain small amounts of chlorophyll *a* and therefore, few phytoplankton. These areas are referred to as ‘wet deserts.’

6.2 EDUCATIONAL MULTIMEDIA TOOL EFFECTIVENESS

The evaluation was conducted at a GIS teacher workshop held at North Carolina State University in August of 2001, where teachers were learning to implement a specific GIS project in the classroom. The teachers were asked to evaluate the educational CD-ROM multimedia tool on the final day of the workshop as a supplement to the workshop agenda. The potential exists that the results might have varied from those collected if the teachers had been given the CD-ROM multimedia tool to evaluate at their leisure without time constraints.

The Global Ocean Ecosystem Investigations CD-ROM multimedia tool was comprised of six components (Table 3) each of which was evaluated. The only component to receive a mean and median ratings lower than very well to well organized and very useful to useful was the GIS project component (Figure N-7, Figure N-8). However, 91% of the teachers utilized GIS very infrequently in the

classroom (Figure N-5) and only 25% felt comfortable using GIS to explain a topic (Figure N-6). The rating of the GIS project component may be directly related to the level of GIS experience of each evaluator. The neutral GIS project ratings may also be due to the lack of time to freely investigate the projects before evaluating them. It is also not surprising to find teachers still learning to implement GIS projects in the classroom to find the other components, with which they may be more familiar, to be more useful (Figure N-7). Overall, the Global Ocean Ecosystem Investigations CD-ROM multimedia tool was determined to be well organized and useful.

The evaluators determined that using the Global Ocean Ecosystem Investigations CD-ROM multimedia tool to answer questions about the physical and biological components in the ocean was neither difficult nor easy (Figure N-9). This neutral rating suggests that the CD-ROM multimedia tool contained the information necessary to investigate the El Niño Southern Oscillation phenomena as well as the physical and biological link in the ocean. All answers given to the questions were correct; as well as all hypotheses developed had the potential to be answered using the Global Ocean Ecosystem Investigations CD-ROM multimedia tool. The quality of the answers suggests that the teachers were able to use the CD-ROM multimedia tool to inquire about an ill-structured Earth System Science related problem.

Overall, the evaluators agreed that the Global Ocean Ecosystem Investigations CD-ROM multimedia tool addressed their need to teach local, state

and national standards in science and geography (Figure N-10). However, no assessment was made of either the evaluators' familiarity with the standards, or to qualify what their standard implementation needs were.

Overall, the evaluators agreed that the Global Ocean Ecosystem Investigations CD-ROM multimedia tool communicated the relationship between the physical and biological components of the ocean. The correct answers given by the evaluators suggesting the teachers learned about ENSO and the physical-biological link in the ocean. Finally, the evaluators believed that students could use the CD-ROM multimedia tool to gain a better understanding of the relationship between the physical and biological components in the ocean.

7. CONCLUSIONS

This study demonstrated that the distribution of nitrate, phosphate, silicate, and iron in the world ocean could be compared to the global distribution of chlorophyll *a* as measured by SeaWiFS to compare changes in phytoplankton community structure during El Niño and La Niña years. Six digital maps depicting distribution patterns for physical, biological and chemical factors important to phytoplankton ecology were successfully created. In addition, a spatial model of the geographic distribution of the phytoplankton ecological indicators, nitrate, phosphate, silicate, iron, and chlorophyll *a*, was created. The geographic model has the potential to be applied to future research efforts in

oceanography and Earth System Science. The distribution maps for a specific temporal scale were successfully compared to facilitate the analyses of the influence of the El Niño Southern Oscillation (ENSO) phenomena on the phytoplankton ecological indicators. Inferences were drawn as to the level of the ENSO influence on the nutrients and chlorophyll *a* examined by the study.

El Niño and La Niña affect the phytoplankton composition of the world ocean because of the temperature shifts that are associated with these conditions. These temperature shifts alter the types of nutrients present, their proximity and accessibility to surface water, and their associated phytoplankton compositions. This results in trophic shifts in the world ocean and ecosystem changes during these episodes. Determining the worldwide phytoplankton ecological indicator distribution patterns is important to the study of primary productivity in the world ocean.

The Global Ocean Ecosystem Investigations CD-ROM multimedia tool was designed to facilitate the communication of an oceanographic application of Earth System Science via inquiry-based and problem-based learning. The CD-ROM multimedia tool addressed the ability of an ill-structured, guided inquiry GIS curriculum to align with teachers' need to meet the local, state and national education standards. Teachers using the CD-ROM were able to communicate the systems approach to oceanography and ENSO without external assistance, as evidenced by a rating of neutral difficulty for successful answer location and hypotheses development.

8. FURTHER STUDY

Further development toward improving the accuracy of the NDT fields as better nutrient information becomes available is needed. Research toward the application of AOT and precipitation data to iron availability at the ocean surface may improve the estimation of iron availability. Analyzing more months with the geographic model would allow a better calibration of the model than could be achieved by the study data set. Analysis of more ENSO and non-ENSO time periods would facilitate the comparison of normal versus extreme condition influence on nutrient distributions and phytoplankton community structure. Other types of data that affect phytoplankton ecology and are climatically variable, such as sea surface height, surface winds and ice cover, could be added to the geographic model. Other approaches to phytoplankton community cell size and taxonomic composition based on ratios or amounts of nutrients present need to be explored. The use of multispectral satellites such as MODIS may be able to achieve a continuous higher resolution classification while offering the opportunity to use alternate techniques such as optical analyses based on phytoplankton accessory pigments. Finally, the use of other software, including ENVI and IBM's Open DX, could result in a more refined model. A better model and the use of ecological modeling principles have the potential to create predictions of phytoplankton community structure, or at the least presence/absence, which could enhance resource management options.

Progress toward the development of GIS lesson modules coupled with scientific research studies should continue through collaborative partnerships between scientists and educators. Those unique professionals who have the background in education, GIS, and the sciences are best suited to contribute to the aforementioned partnerships. There are many ways that scientific professionals can assist in reforming science education. The scientist can be a resource via e-mail or a chat room on the Internet, or the scientist can call a local school and ask to become involved. The scientist can also partner with a teacher, school system, or university. These relationships have the potential to create unique experiences, not only for the teacher and student but for the scientist as well. Partnerships that result in exemplary educational materials have the potential to reach a much larger audience.

Further assessment of the Global Ocean Ecosystem Investigations CD-ROM multimedia tool would potentially improve the quality. To improve assessment a larger sample size of teacher-evaluators should be used. The teachers need to be given time to examine the multimedia tool at their leisure. This would remove potential time pressure bias and would help to improve the qualitative and quantitative effectiveness assessments. An assessment of students and/or implementation of the CD-ROM multimedia tool in a classroom would increase the quality of the assessment and subsequently the tool. Potential improvements include alignment with one or several curriculums available or in use across the country. Easier to use instructions could be created utilizing video tutorial creation

software that would demonstrate some of the procedures. Using tutorials for each month would provide a mechanism for teaching the project in those classrooms with limited or no access to ArcView Spatial Analyst. More sea surface temperature data could be obtained, interpolated, and included with the CD-ROM multimedia tool to allow the investigation of additional time periods. Additional extensions to the GIS projects could be created and other data sets could be included to augment the inquiry process (e.g. ocean circulation or ice cover). Continued updates of the Global Ocean Ecosystem Investigations CD-ROM multimedia tool would keep the data and research current. Finally, continued technical support such as troubleshooting and/or “ask-a scientist” would help to ensure the continued use of the Global Ocean Ecosystem Investigations CD-ROM multimedia tool.

9. REFERENCES

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Appendix A: STUDY DATA STATISTICAL ANALYSIS

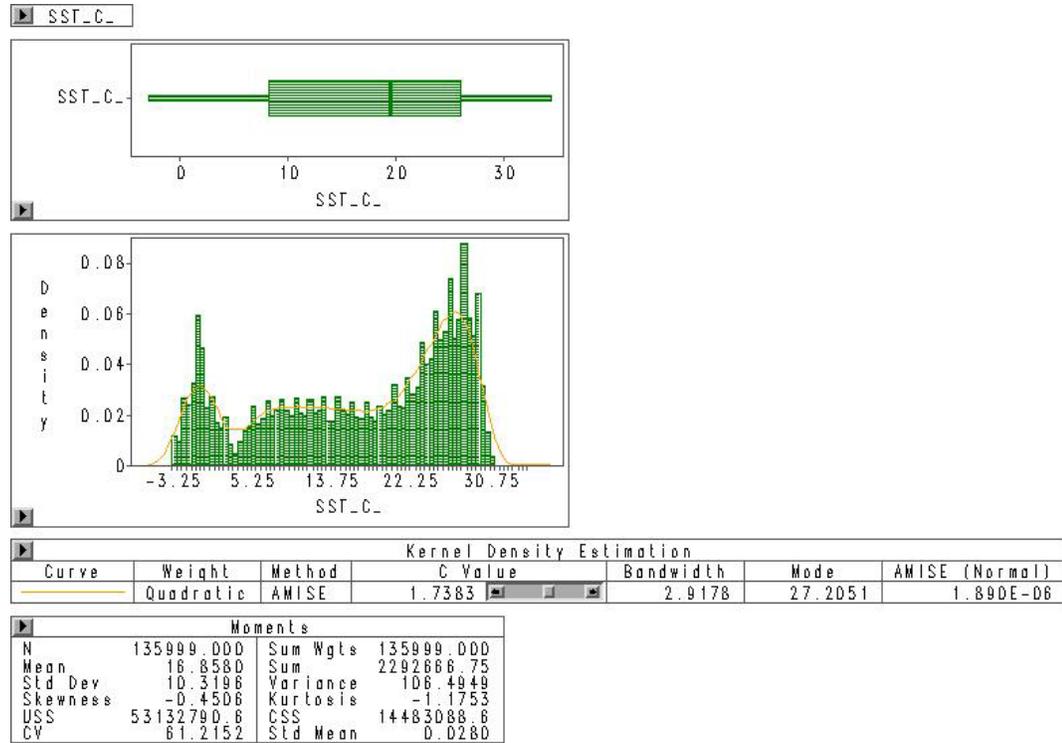
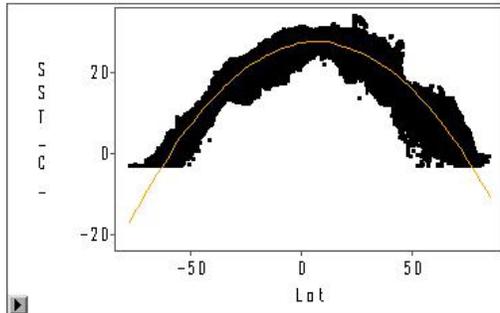


Figure A-1: Representative Sea Surface Temperature Histogram Distribution

SST_C_ = Lat
 Response Distribution: Normal
 Link Function: Identity

Model Equation
 $SST_C_ = 16.9535 + 0.0393 \text{ Lat}$



Parametric Regression Fit										
Curve	Degree(Polynomial)	Model			Error			R-Square	F Stat	Pr > F
		DF	Mean Square	DF	Mean Square					
	2	2	6741808.90	1.E+05	7.3493	0.9310	917344.5	<.0001		

Polynomial Equation, Specified Deg = 2
 $SST_C_ = 27.1768 + 0.0966 \text{ Lat}^{++1} - 0.0062 \text{ Lat}^{++2}$

Parameter Estimates, Specified Deg = 2					
Variable	DF	Estimate	Std Error	t Stat	Pr > t
Intercept	1	27.1768	0.0106	2560.18	<.0001
Lat ++ 1	1	0.0966	0.0002	515.24	<.0001
Lat ++ 2	1	-0.0062	4.631E-06	-1337.24	<.0001

Figure A-2: Parametric Regression Fit of SST (°C) Versus Latitude

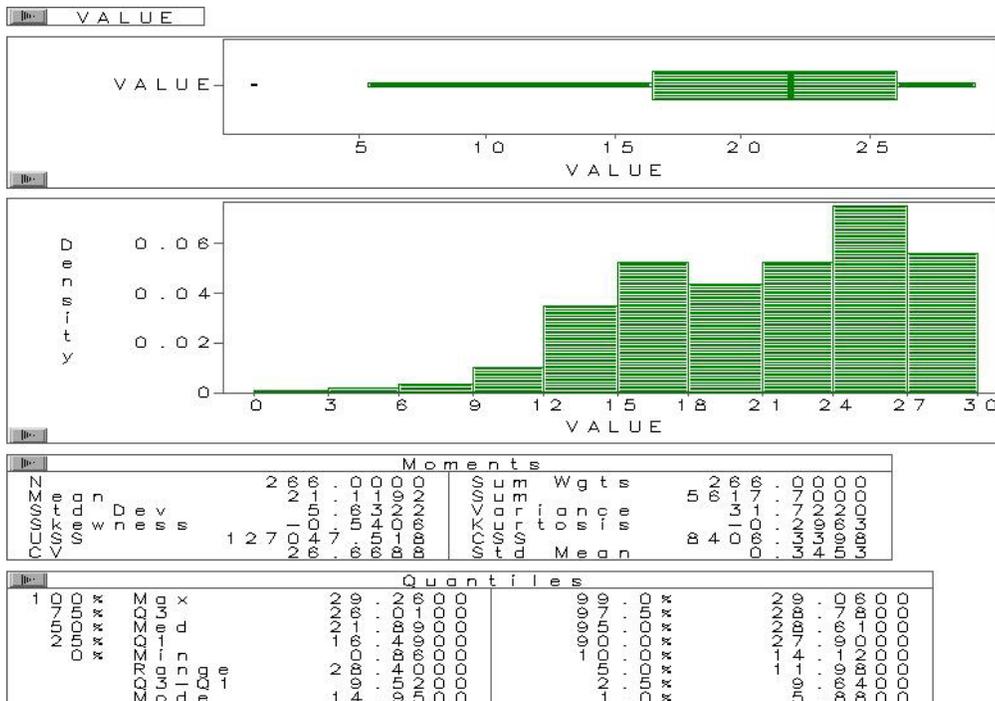


Figure A-3: Nitrate Nutrient Depletion Temperature Histogram Distribution

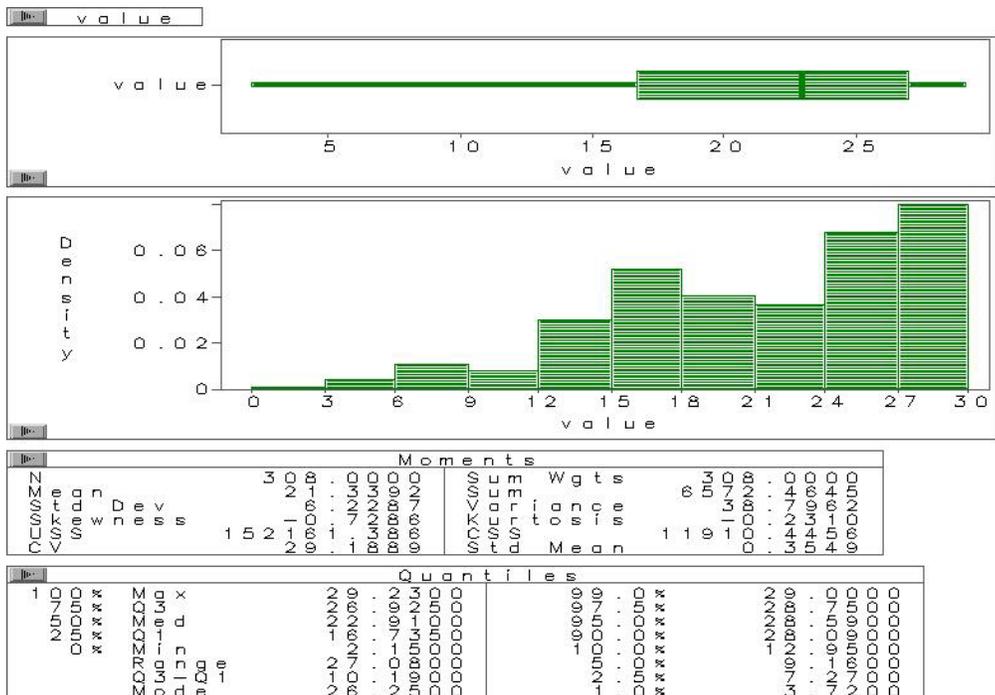


Figure A-4: Phosphate Nutrient Depletion Temperature Histogram Distribution

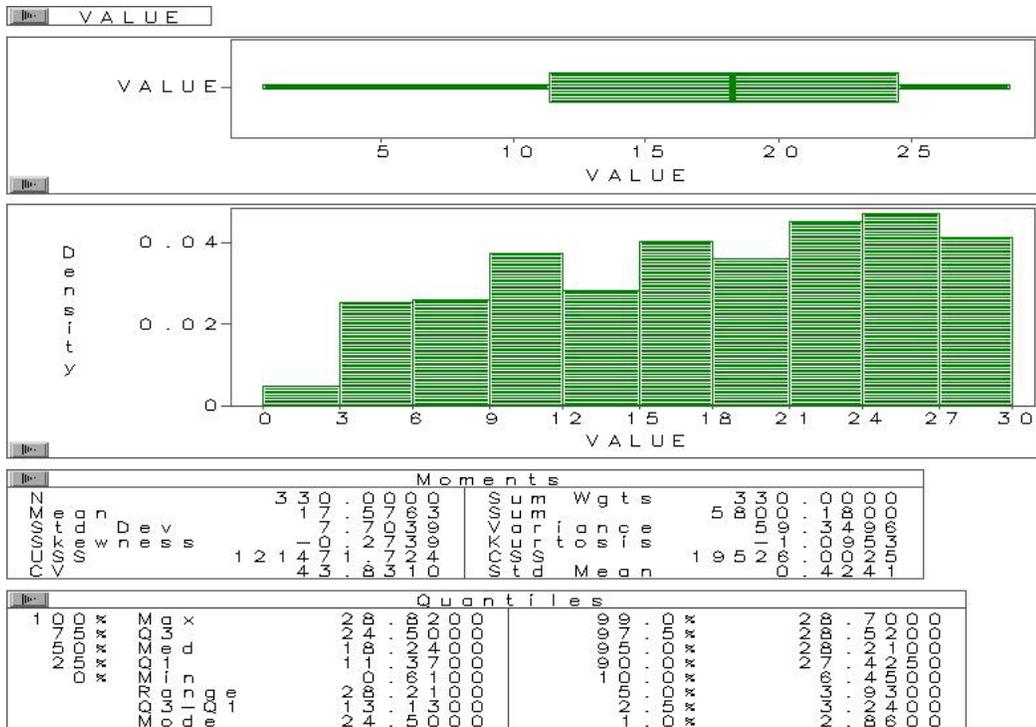
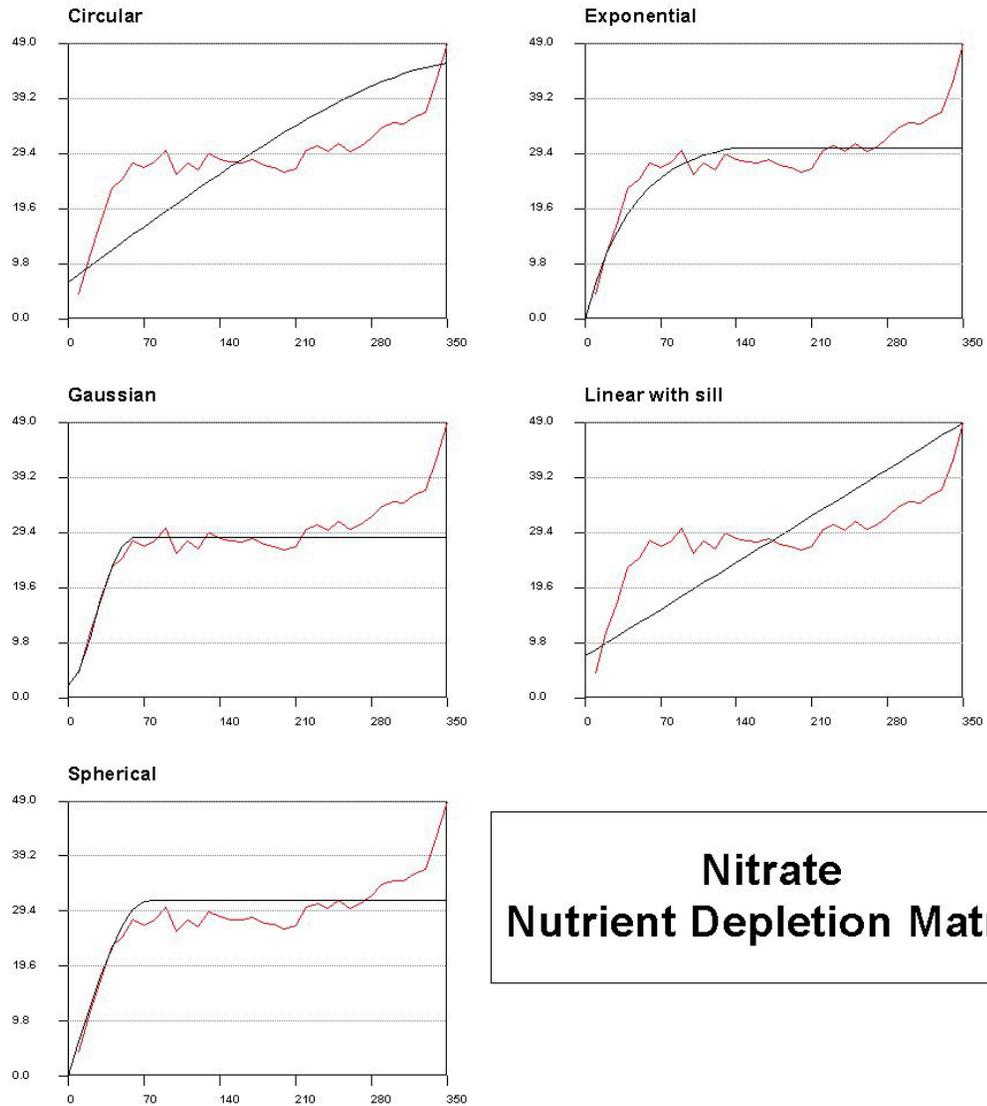


Figure A-5: Silicate Nutrient Depletion Temperature Histogram Distribution

Appendix B: NDT SEMI-VARIOGRAM MODELING

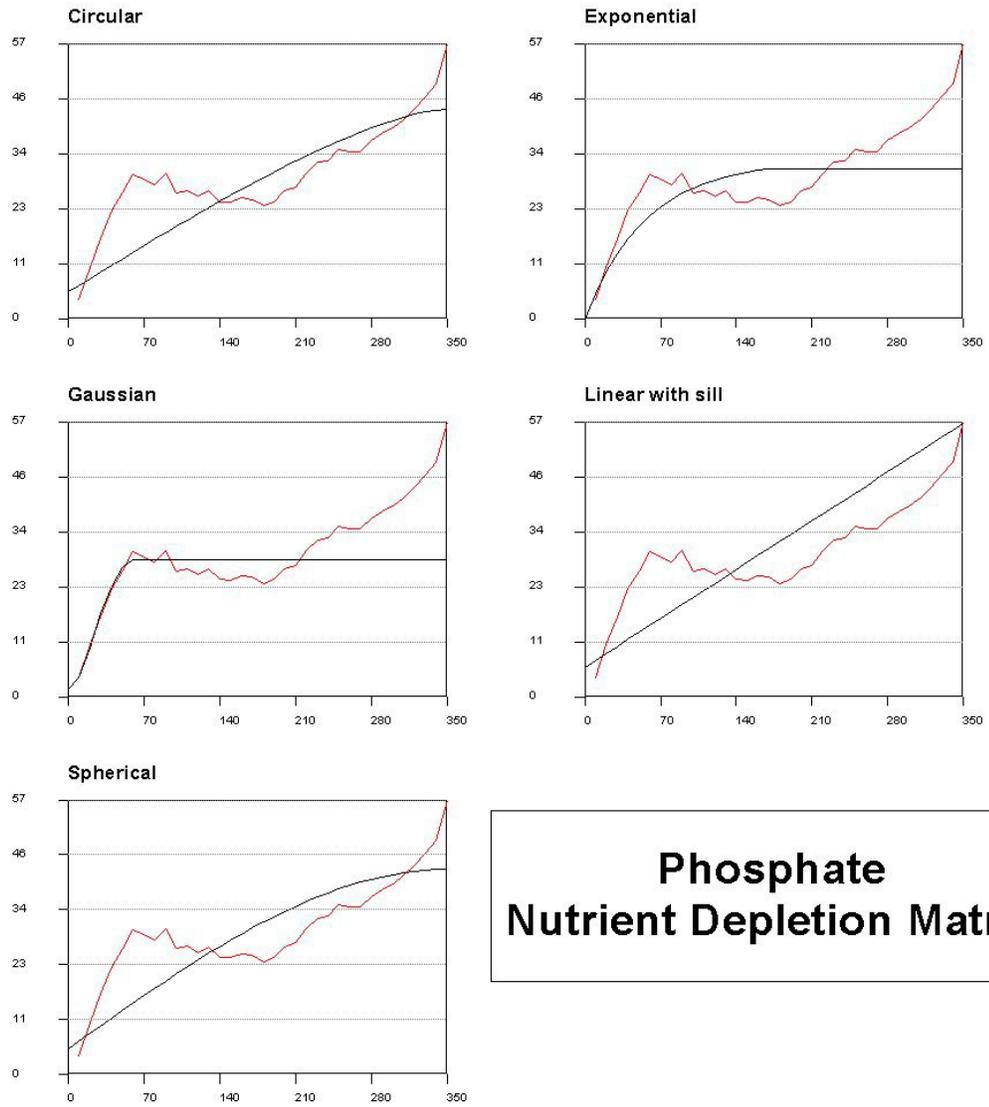


**Nitrate
Nutrient Depletion Matrix**

Model	AIC	BIC	SSE	RMSE	n
Circular	269.68	274.34	1870	7.77	35
Exponential	239.14	243.80	781	5.02	35
Gaussian	244.63	249.30	914	5.43	35
Linear with sill	269.94	274.61	1884	7.80	35
Spherical	238.19	242.85	760	4.95	35

LAG INTERVAL = 10

Figure B-1: Semi-variograms Computed for Nitrate Nutrient Depletion Temperatures



**Phosphate
Nutrient Depletion Matrix**

Model	AIC	BIC	SSE	RMSE	n
Circular	265.91	270.58	1679	7.36	35
Exponential	276.07	280.73	2245	8.51	35
Gaussian	280.76	285.43	2567	9.10	35
Linear with sill	278.49	283.15	2405	8.81	35
Spherical	267.07	271.73	1736	7.48	35

LAG INTERVAL = 10

Figure B-2: Semi-variograms Computed for Phosphate Nutrient Depletion Temperatures

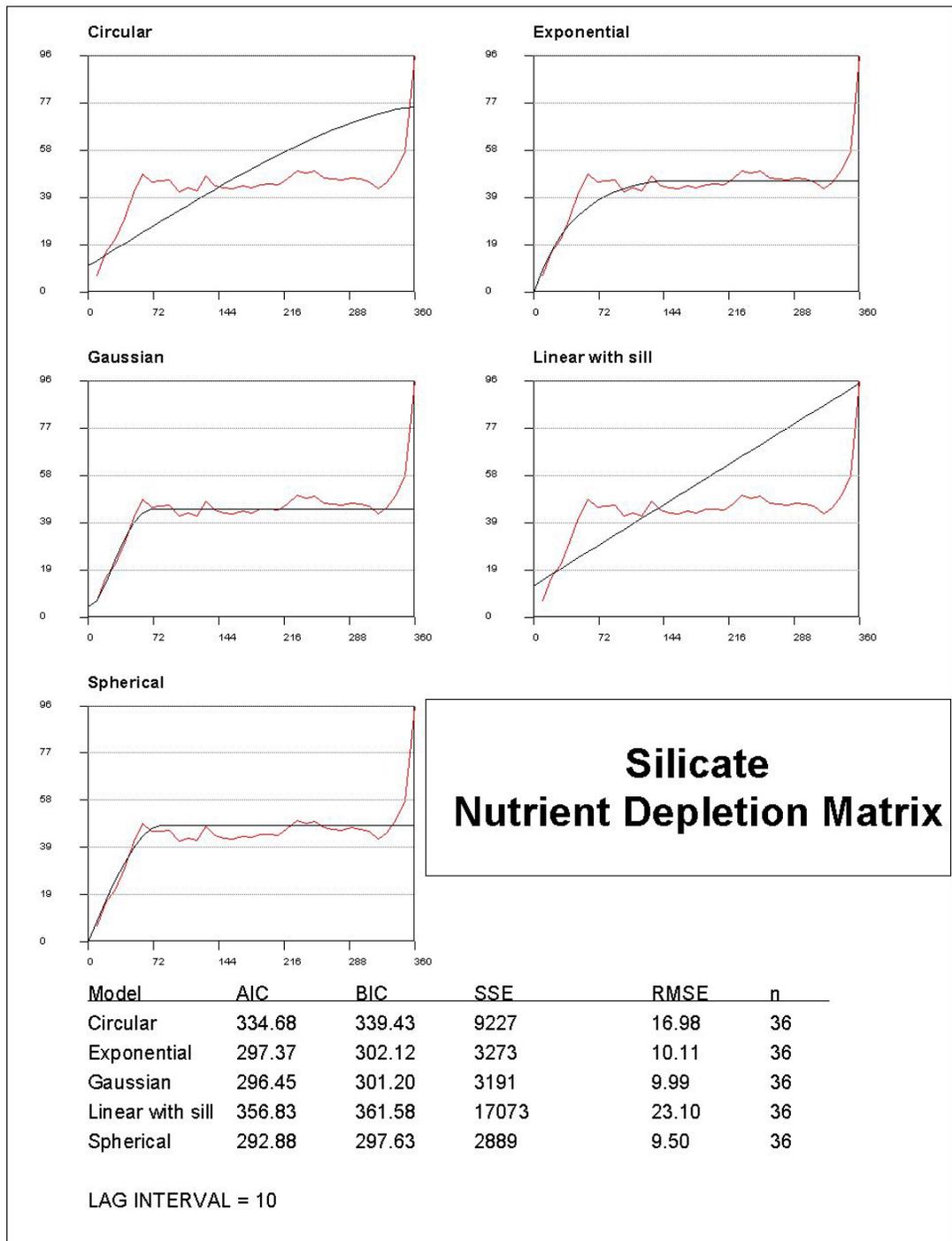


Figure B-3: Semi-variograms Computed for Silicate Nutrient Depletion Temperatures

Appendix C: SST & NDT SPATIAL INTERPOLATION PARAMETERS

ESRI ArcView and the extensions Spatial Analyst (ESRI, 1996b) and Kriging Interpolator 3.2 (Boeringa, 2001) were used to interpolate the Sea Surface Temperature (SST) point data matrices and the Nutrient Depletion Temperature (NDT) point data matrices. Before the interpolation, a latitude/longitude grid, in decimal degrees (map units), from ESRI sample data (ESRI, 1996b), was used to set the Analysis Extent.

Universal Kriging with quadratic drift was selected as the surface interpolator for the SST data in this study because it best described the second order trend of the data described in the parametric regression model in Figure A-2. The search distance was set to one degree because it was the lowest search distance at which the data would interpolate. The z value was set to variable radius type. The sample count was set to the value 12 as suggested by the software, but a variety of sample counts larger and smaller made little difference in the interpolation results.

Ordinary Kriging was selected as the surface interpolator for the NDT data in this study to obtain the best representation of the variation in the data. Semi-variograms for several different ordinary kriging methods, circular, exponential, gaussian, linear with sill, and spherical were generated for each nutrient using a lag distance of 10. Semi-variograms for nitrate, phosphate and silicate (Figure B-1, B-2, and B-3, respectively) can be found in Appendix B. The method of

spherical with a lag distance of 10 was chosen for each nutrient because it explained more of the variation in the data, indicated by the lowest overall RMSE, and the data were collected at 10 degree intervals. Each nutrient was then interpolated using the spherical method with a variable radius type. The search distance was set to 120 with the sample count set to the value 12 as suggested by the software. Following interpolation, a variance grid was examined for each nutrient of interest and little variation was found.

Finally, the nutrient presence/absence grids and the SST grids had to be projected from an unprojected (geographic) projection for alignment purposes. ESRI's ArcInfo Workstation GIS software (ESRI, 2001) was used to define the projection for the nutrient grids created in ArcView as Geographic with the Clarke 1866 Spheroid with decimal degrees (DD) as the unit. ArcInfo was then used to reproject each grid into Equidistant Cylindrical, which is a sub type of the Equirectangular projection, using the PROJECT GRID command.

Appendix D: OCEAN COLOR & AOT PROJECTION PARAMETERS

As described in 4.1.2.3 Ocean Color and Aerosol Optical Thickness, the projection information had to be defined using the Layer Information dialog in the IMAGINE software. After the LAN files were imported, the Map Model was changed from undefined to Equirectangular with units in meters. The upper left (X, Y) was set to (-9959479.13772564, 9951942.04485359) in order to be

identical with the coordinate system of the nutrient grid. The pixel size was rescaled to the new coordinate system (9723.260). The Map Projection was set to the nutrient grid parameters with a spheroid (Sphere of Radius 6370997m) and an undefined datum. Image Geometric Correction was used with reproject as the model, and a first order polynomial. The image (4096 width by 2048 height) was then resampled to the nutrient grid (360 width by 180 height) because it had the lowest resolution. Cubic convolution was used with the settings in Table D-1 to match the parameters of the nutrient grid. Cubic convolution was selected because it uses a weighted average to help smooth the image (*Geometric Correction Tutorial*, 2000) and it retains spatial accuracy (Oetter, 2000).

TableD-1: Reprojection Parameters

<i>Parameters</i>	<i>X</i>	<i>Y</i>
Upper Left	-19959479.13772564	9951942.04485359
Lower Right	19959480.73047490	-9951940.45210434
Pixel Size	111194.87428468	111194.87428468

Appendix E: METHODOLOGY FLOWCHARTS

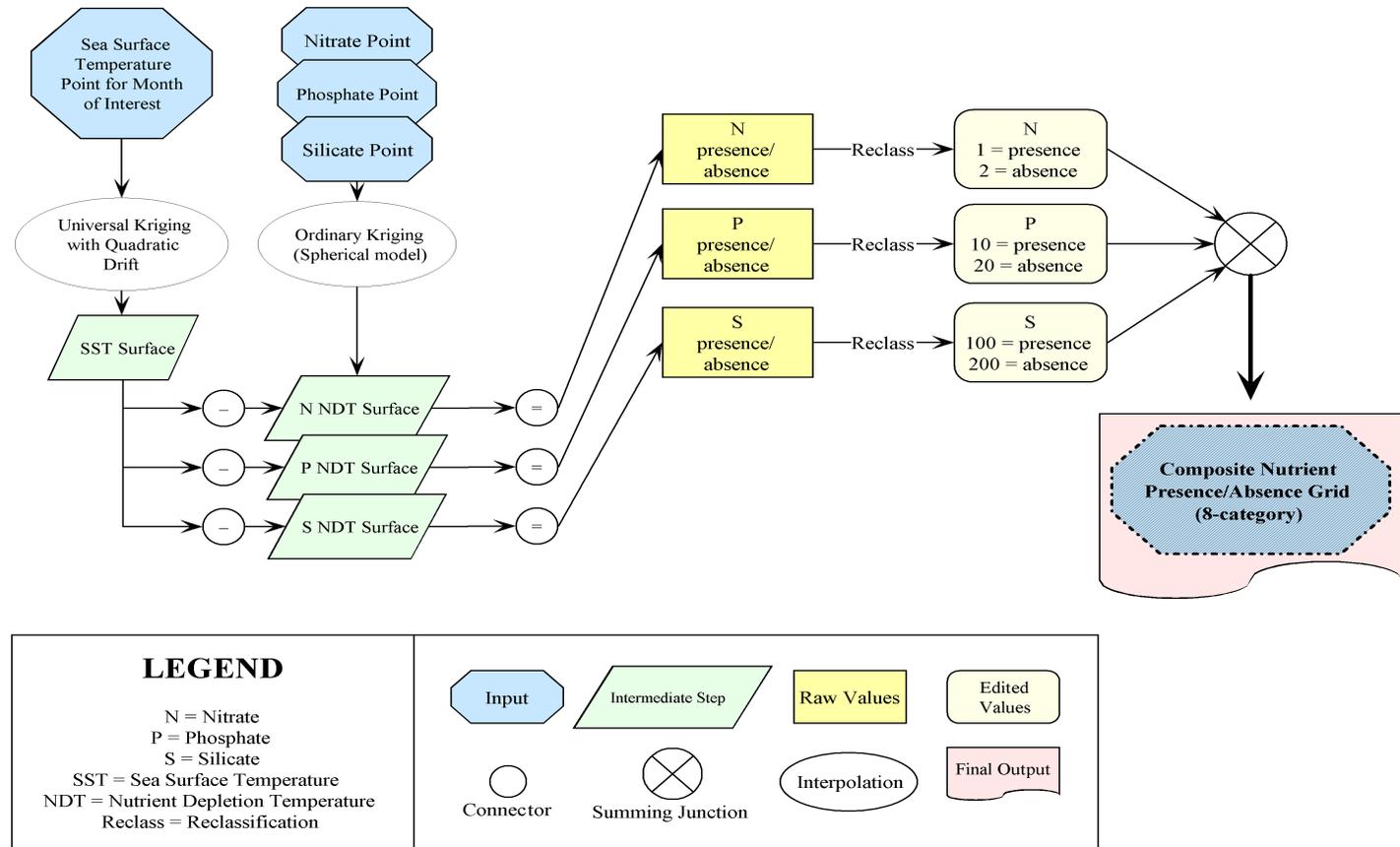


Figure E-1: Eight Category Composite Nutrient Presence/Absence Grid Creation Process Flowchart

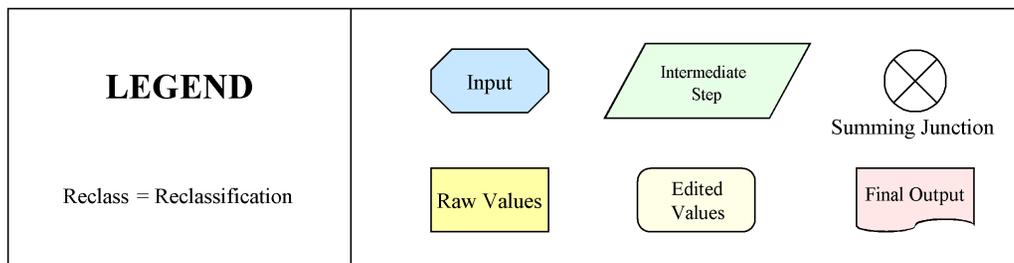
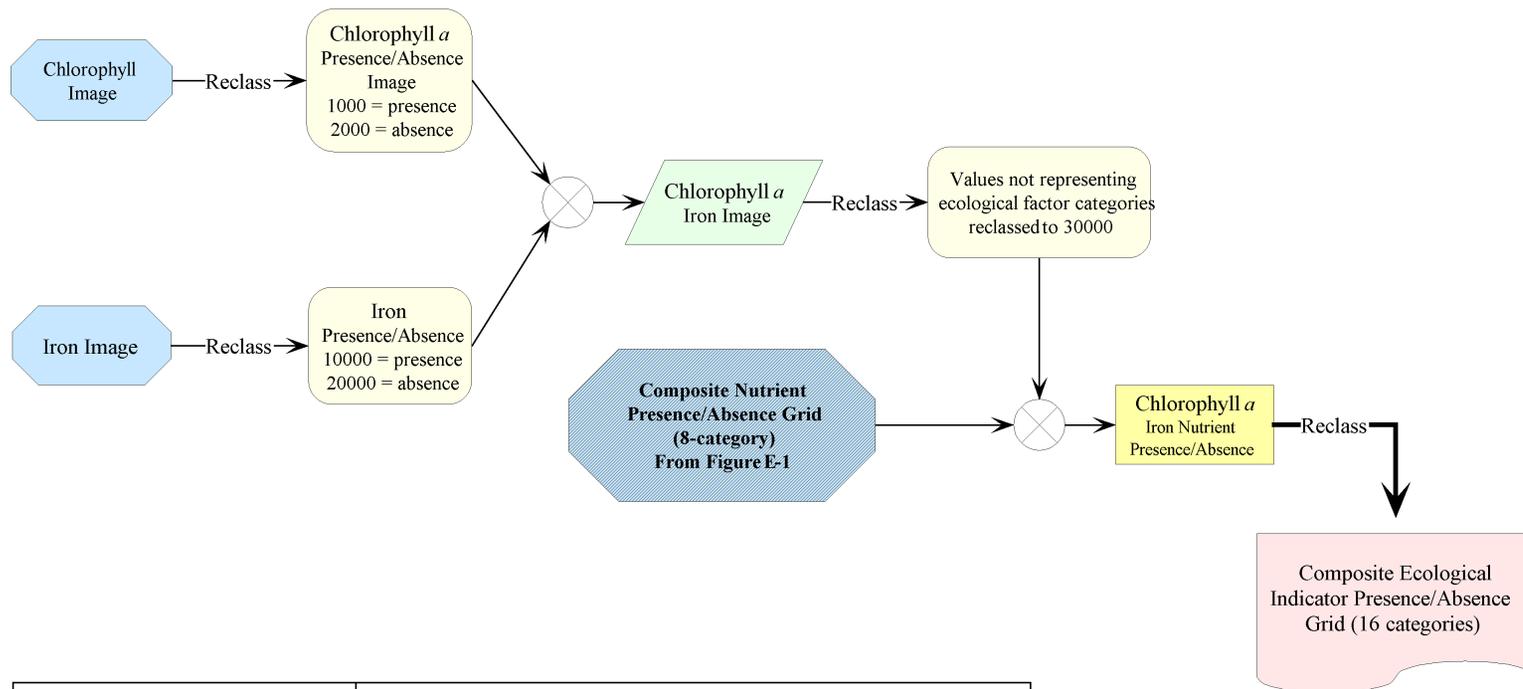
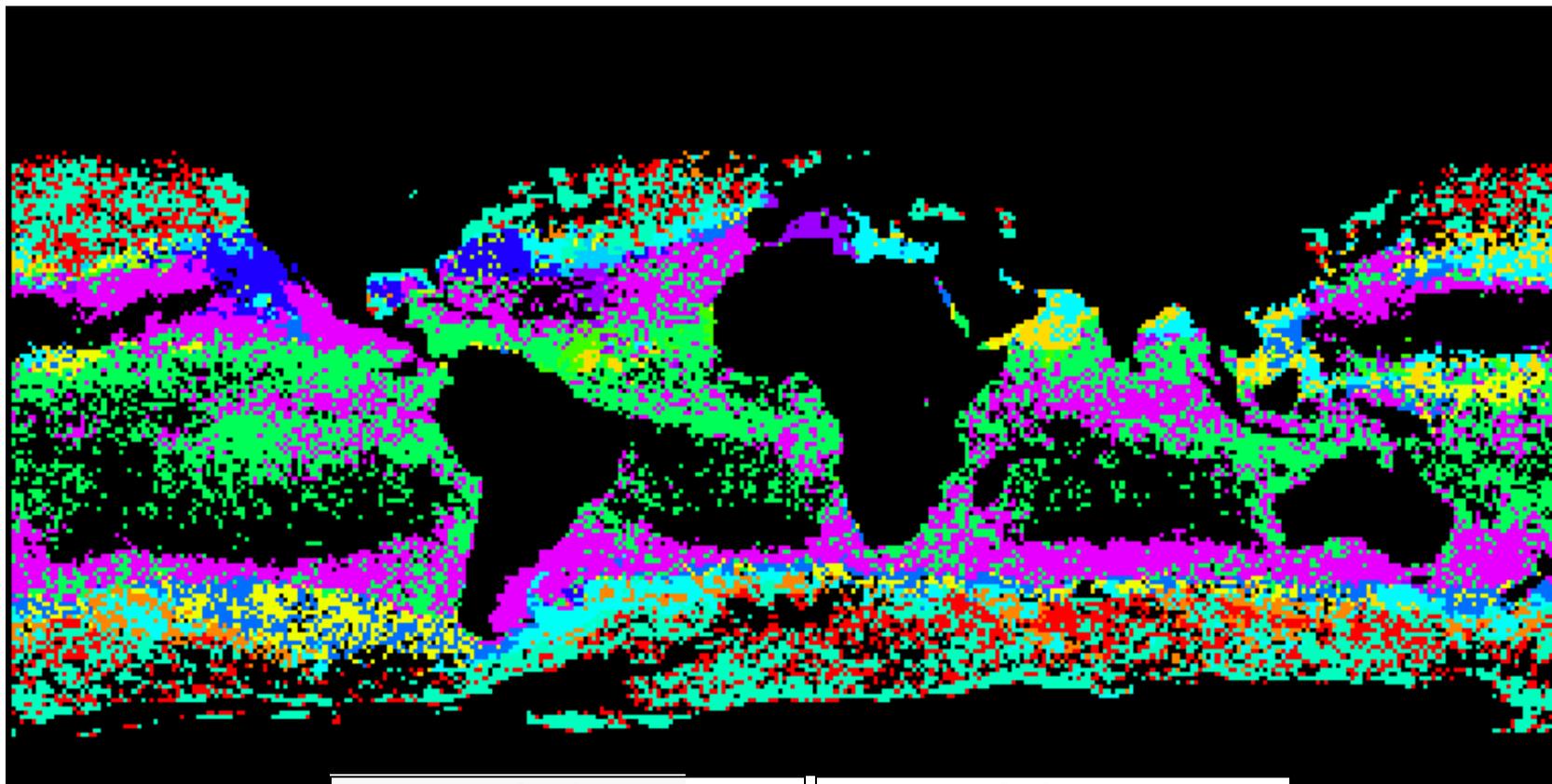


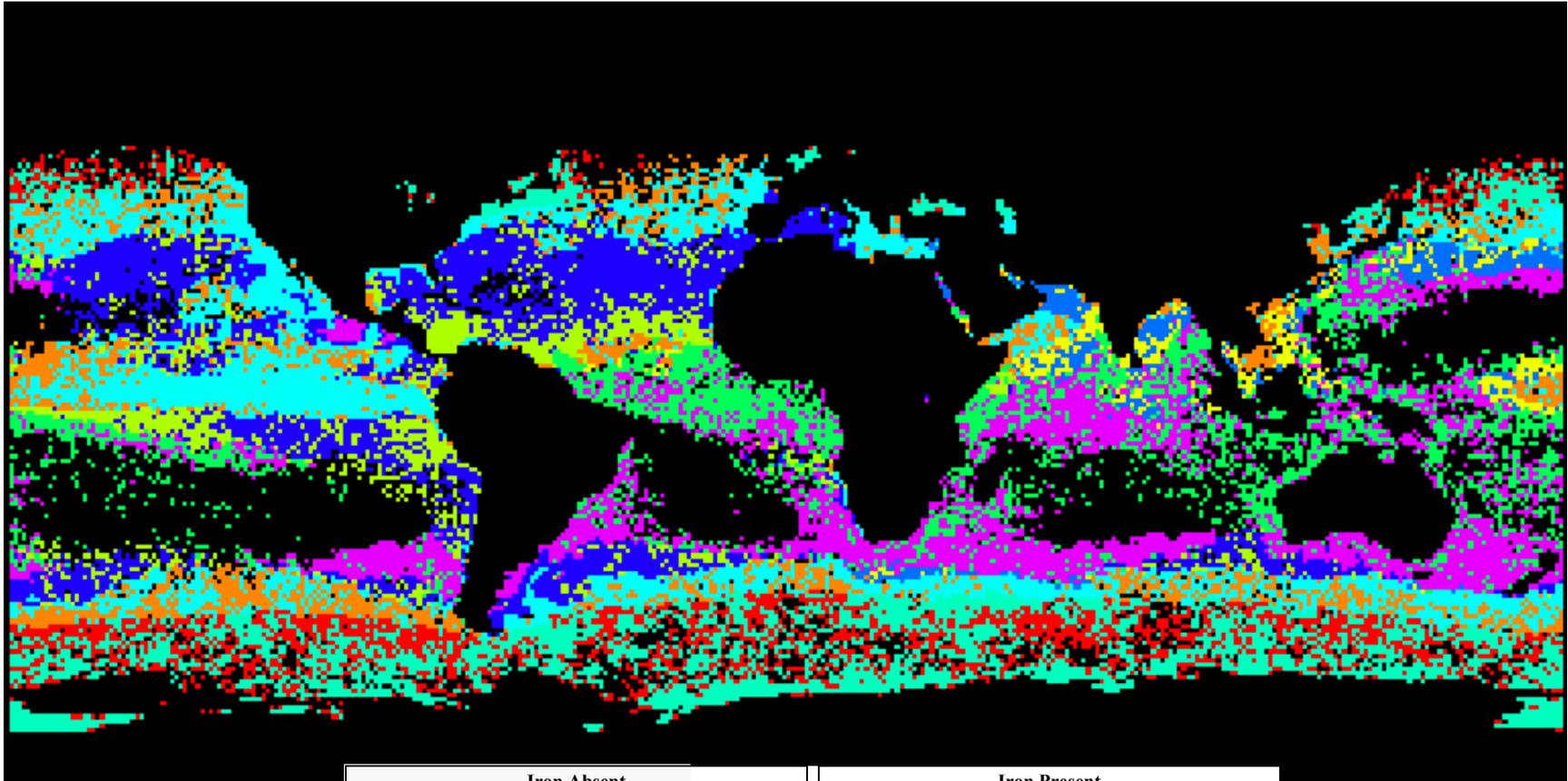
Figure E-2: 16 Category Composite Ecological Indicator Presence/Absence Grid Creation Process Flowchart

Appendix F: 16 CATEGORY COMPOSITE PHYTOPLANKTON PRESENCE/ABSENCE MAPS



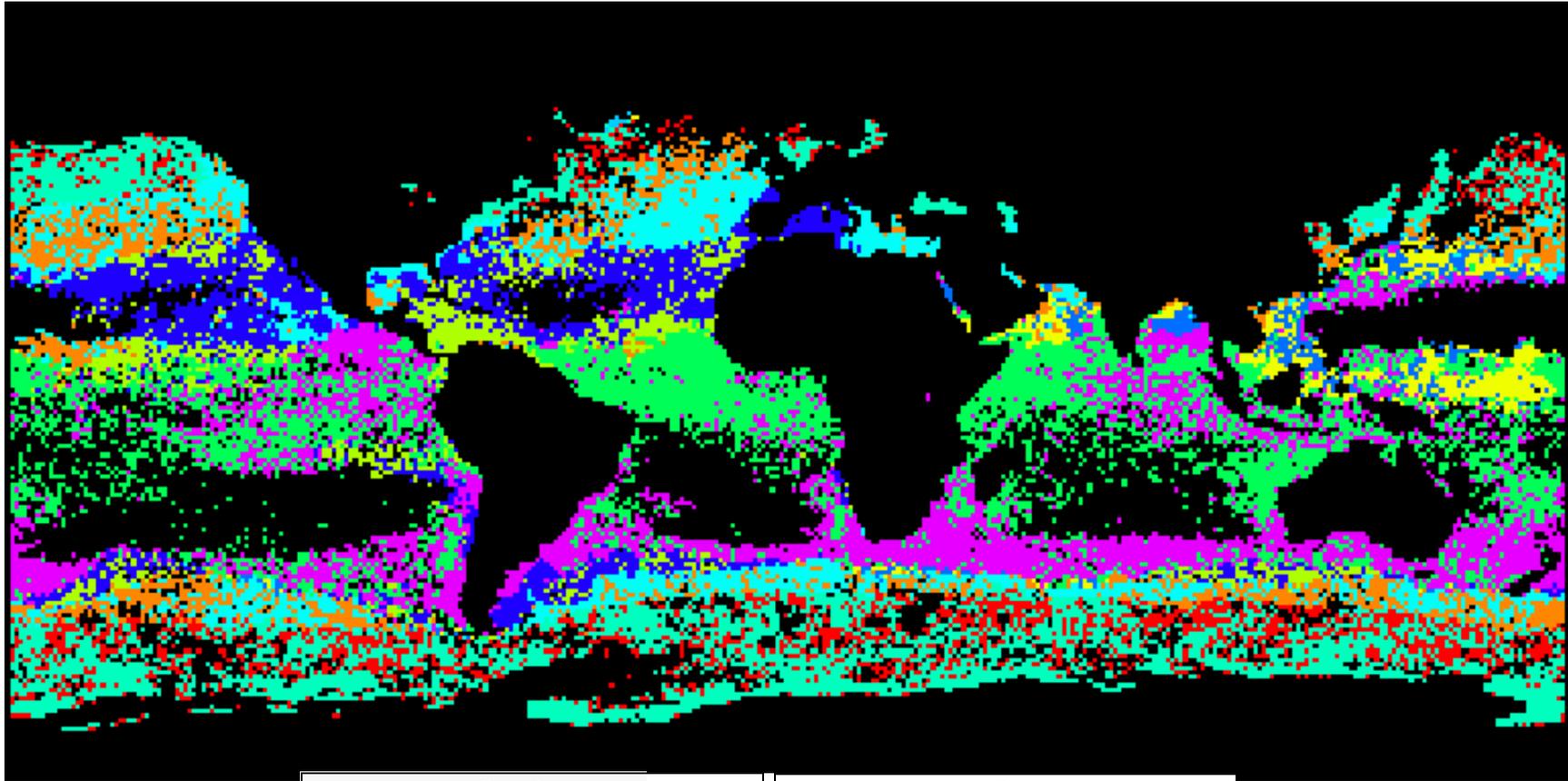
Iron Absent			Iron Present		
No Data 0	P 3	NS 6	Abs 9	N 12	NP 15
Abs 1	N 4	NP 7	S 10	PS 13	NPS 16
S 2	PS 5	NPS 8	P 11	NS 14	

Figure F-1: Phytoplankton Ecological Indicators Presence/Absence Categories for January 1998



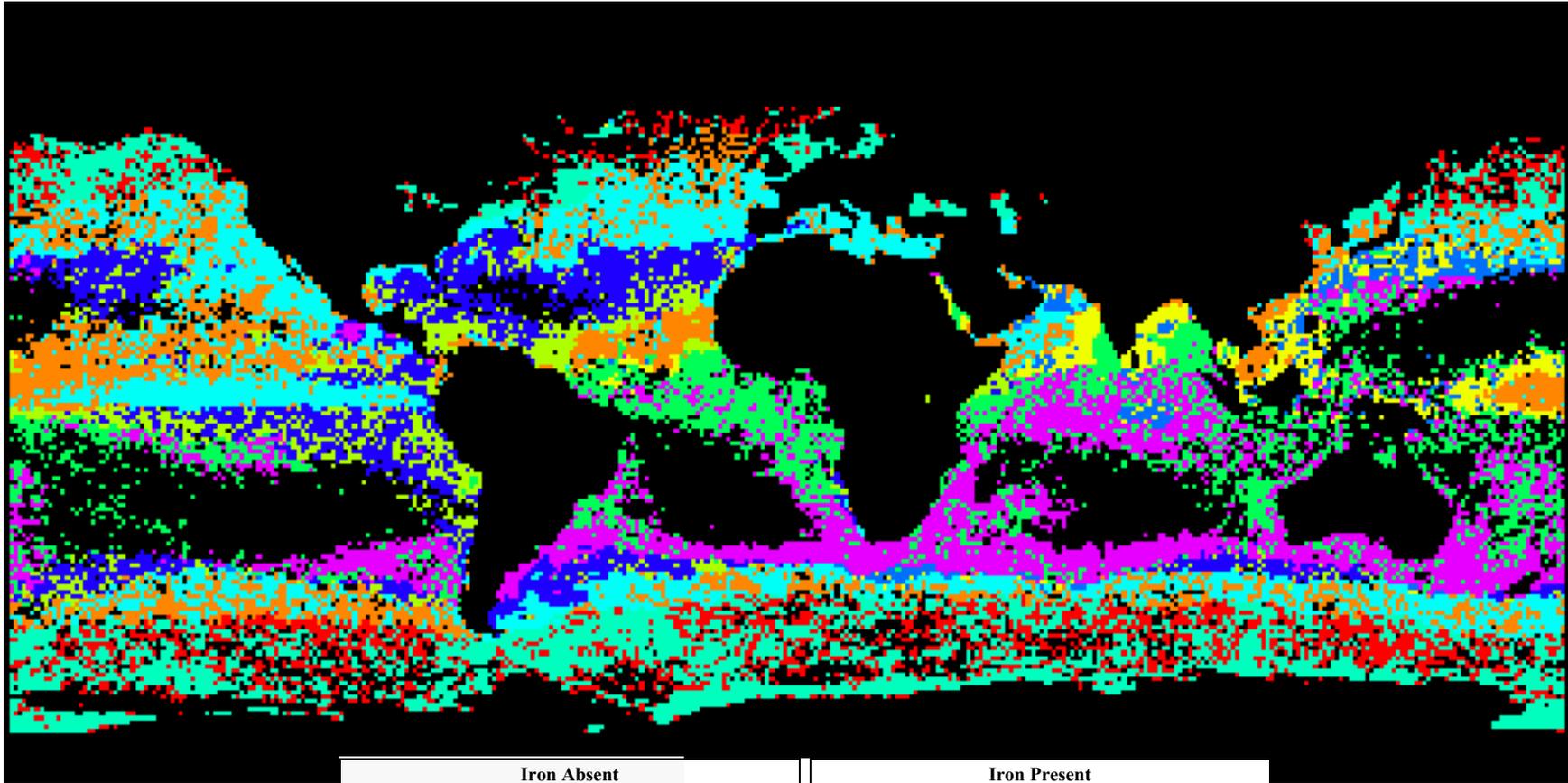
Iron Absent			Iron Present		
No Data 0	P 3	NS 6	Abs 9	N 12	NP 15
Abs 1	N 4	NP 7	S 10	PS 13	NPS 16
S 2	PS 5	NPS 8	P 11	NS 14	

Figure F-2: Phytoplankton Ecological Indicators Presence/Absence Categories for January 1999



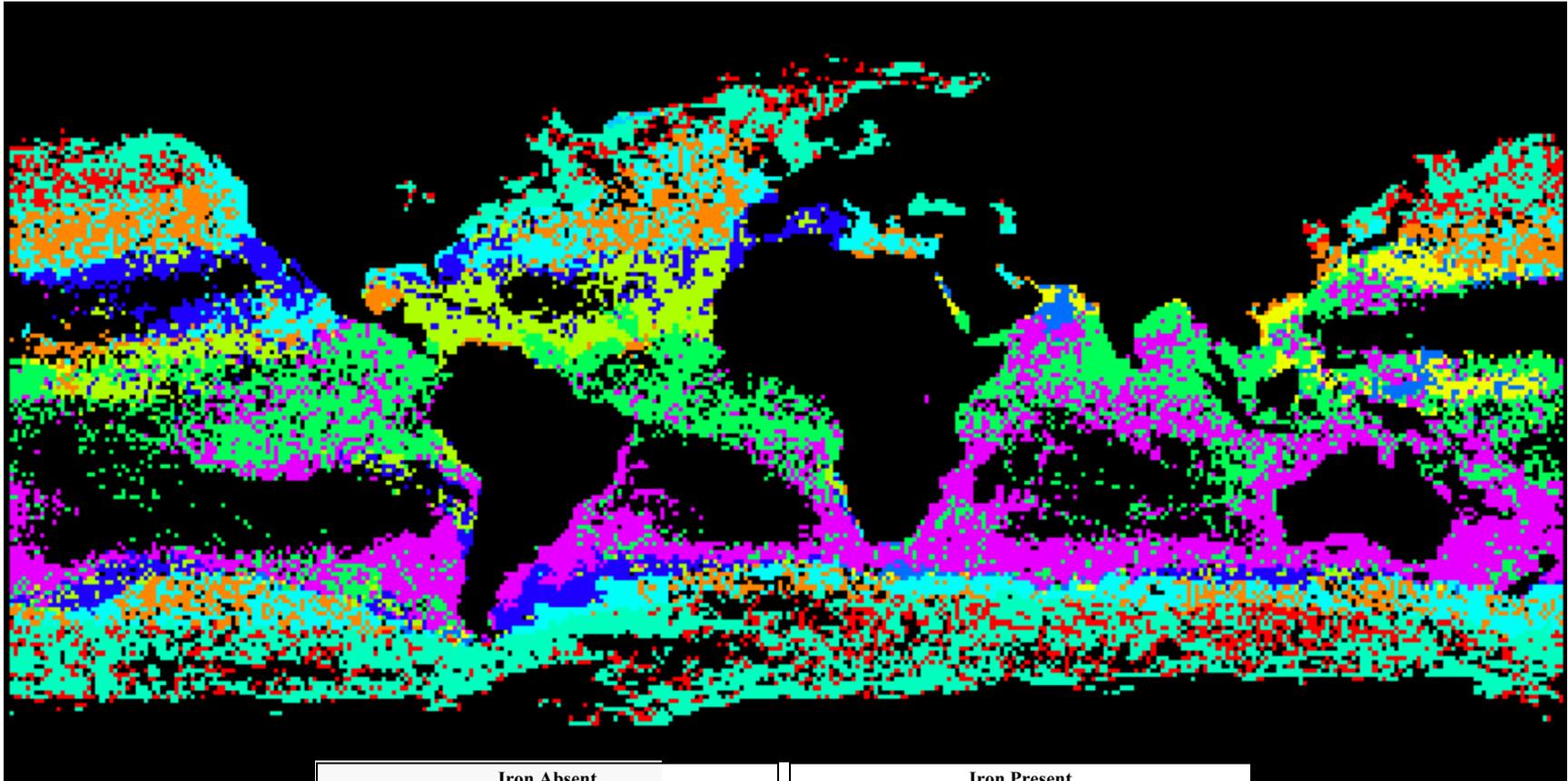
Iron Absent			Iron Present										
No Data	0		P	3		Abs	9		N	12		NP	15
Abs	1		N	4		S	10		PS	13		NPS	16
S	2		PS	5		P	11		NS	14			
			NS	6									
			NP	7									
			NPS	8									

Figure F-3: Phytoplankton Ecological Indicators Presence/Absence Categories for February 1998



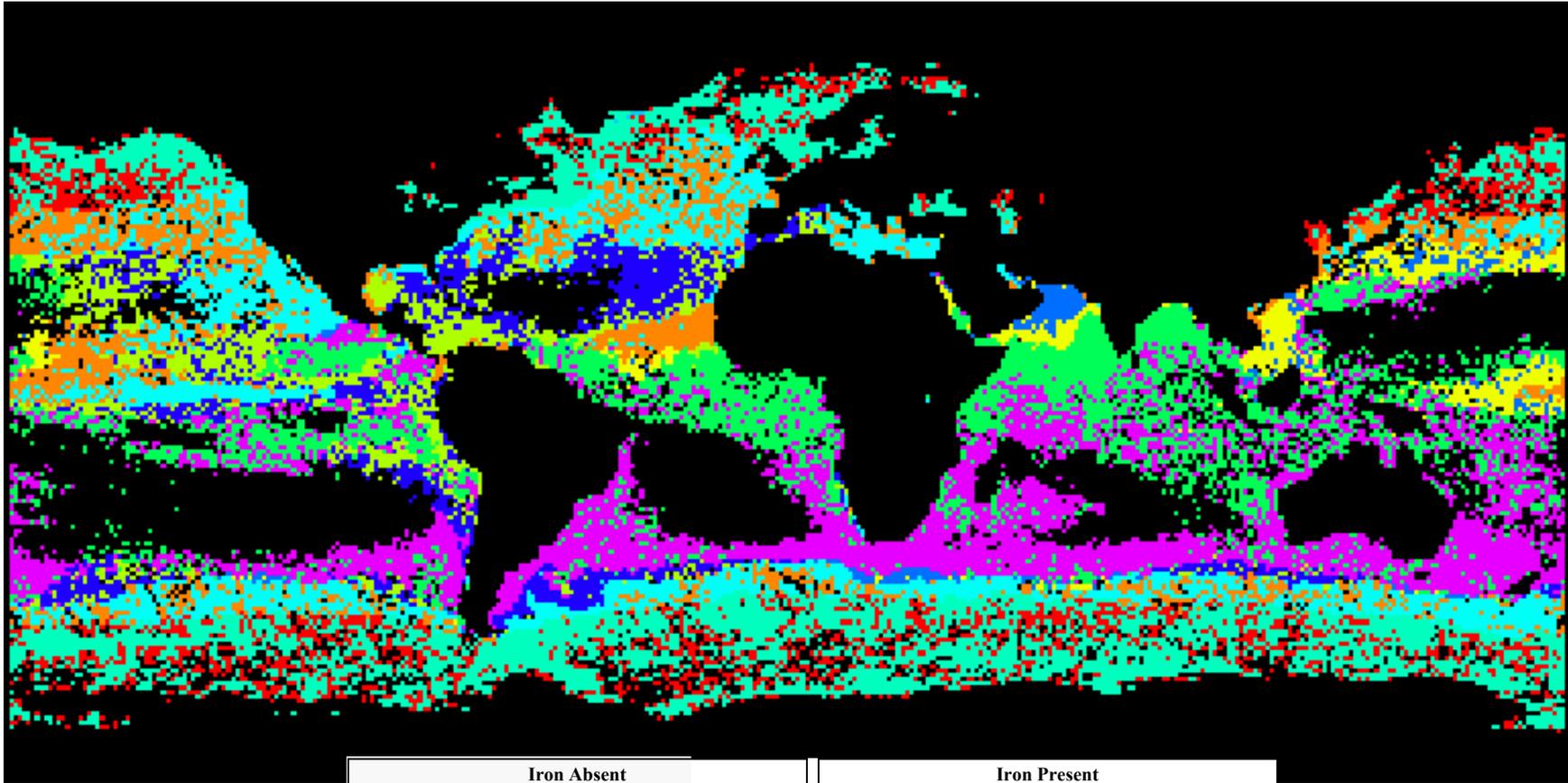
Iron Absent			Iron Present								
No Data	0	P	3	NS	6	Abs	9	N	12	NP	15
Abs	1	N	4	NP	7	S	10	PS	13	NPS	16
S	2	PS	5	NPS	8	P	11	NS	14		

Figure F-4: Phytoplankton Ecological Indicators Presence/Absence Categories for February 1999



Iron Absent			Iron Present		
No Data 0	P 3	NS 6	Abs 9	N 12	NP 15
Abs 1	N 4	NP 7	S 10	PS 13	NPS 16
S 2	PS 5	NPS 8	P 11	NS 14	

Figure F-5: Phytoplankton Ecological Indicators Presence/Absence Categories for March 1998



Iron Absent			Iron Present								
No Data	0	P	3	NS	6	Abs	9	N	12	NP	15
Abs	1	N	4	NP	7	S	10	PS	13	NPS	16
S	2	PS	5	NPS	8	P	11	NS	14		

Figure F-6: Phytoplankton Ecological Indicators Presence/Absence Categories for March 1999

Appendix G: MONTHLY PHYTOPLANKTON PRESENCE

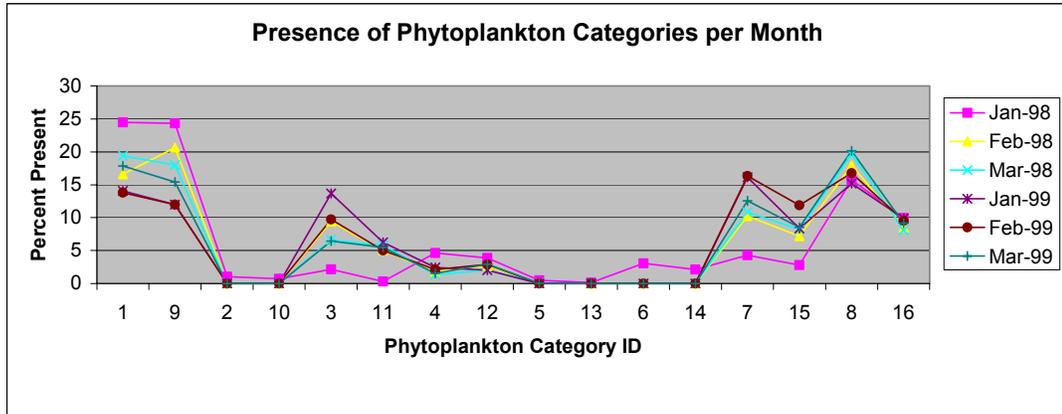


Figure G-1: Collective Phytoplankton Categories per Month

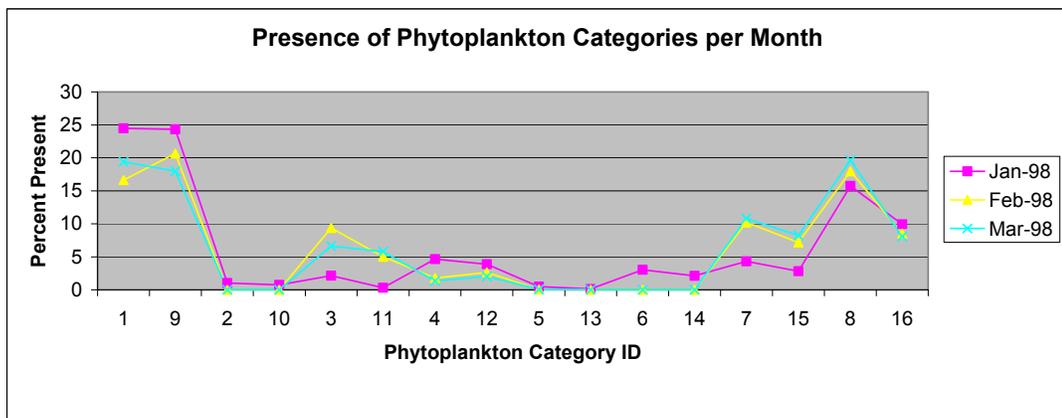


Figure G-2: Collective Phytoplankton Categories 1998 (El Niño)

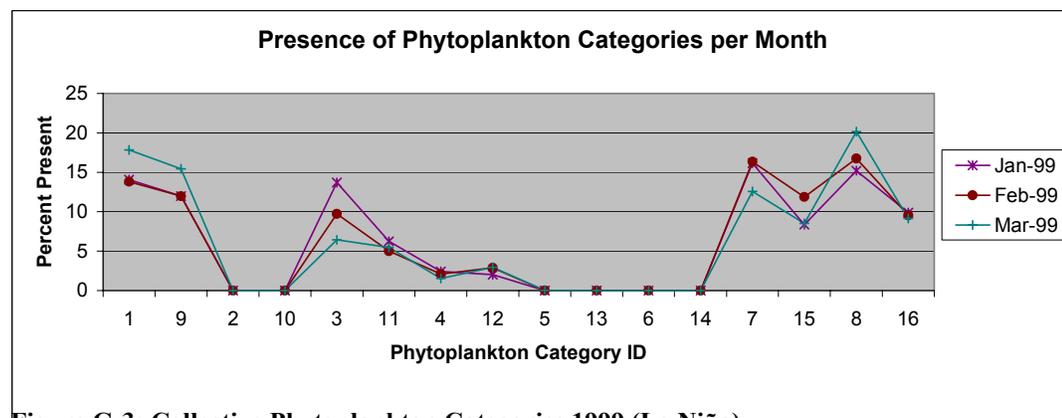


Figure G-3: Collective Phytoplankton Categories 1999 (La Niña)

Appendix H: INTER-ANNUAL & INTRA-ANNUAL VARIATION

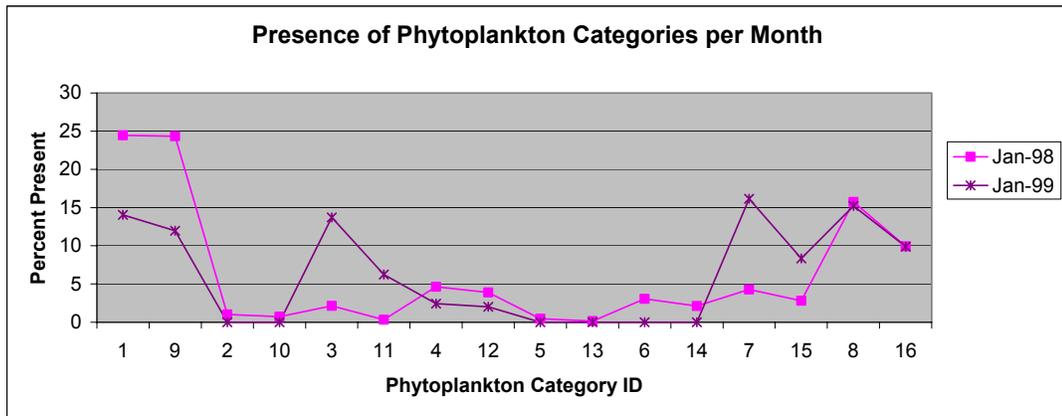


Figure H-1: Inter-Annual Variation January

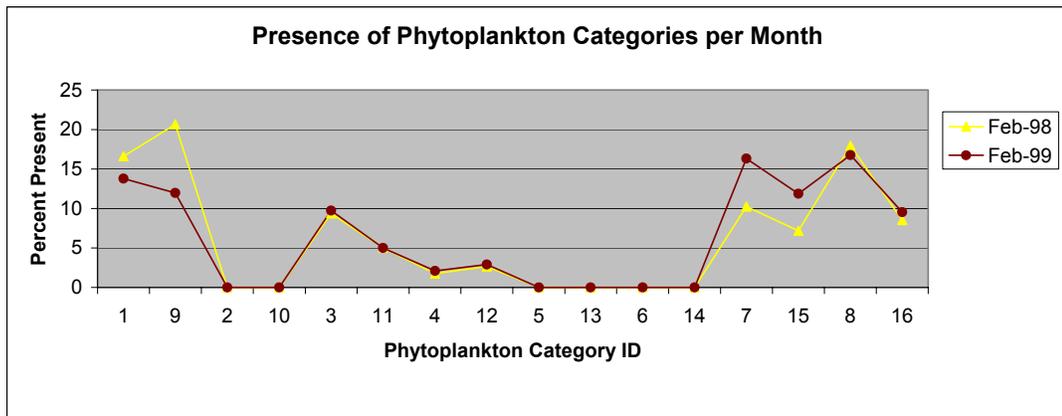


Figure H-2: Inter-Annual Variation February

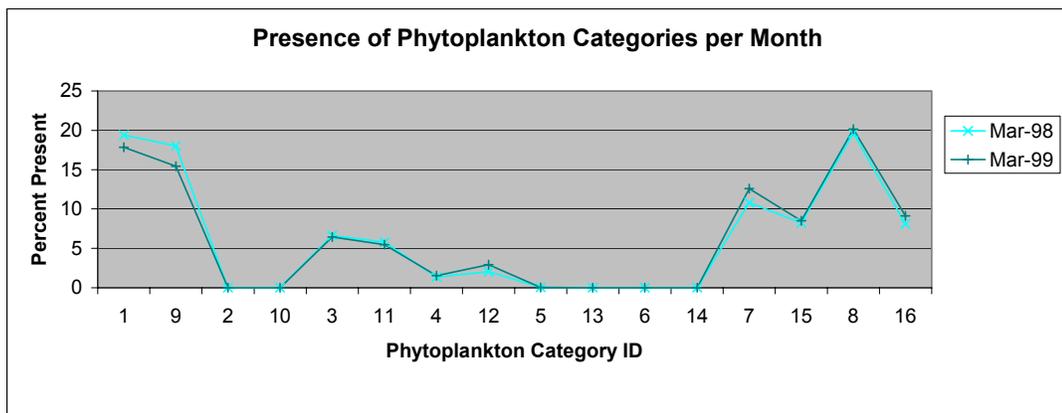


Figure H-3: Inter-Annual Variation March

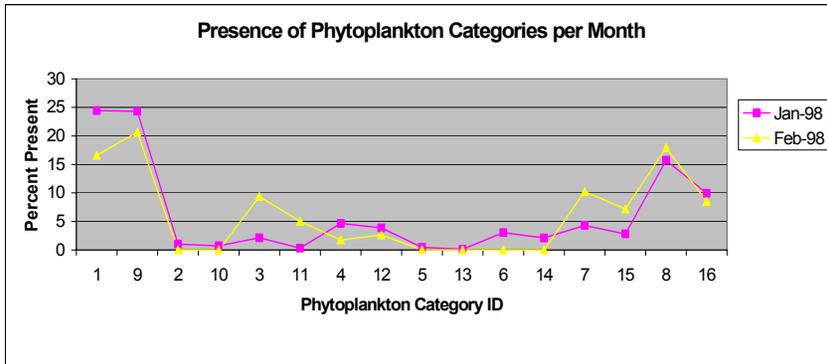


Figure H-4: Intra-Annual Variation January to February 1998

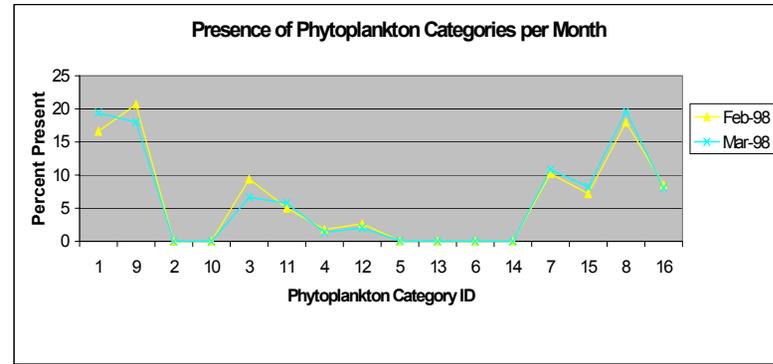


Figure H-5: Intra-Annual Variation February to March 1998

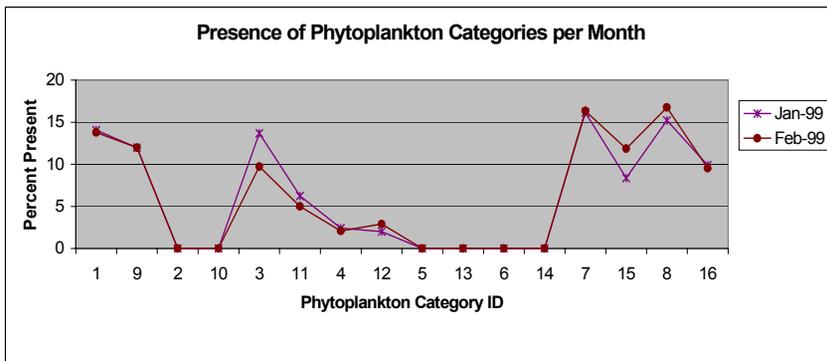


Figure H-6: Intra-Annual Variation January to February 1999

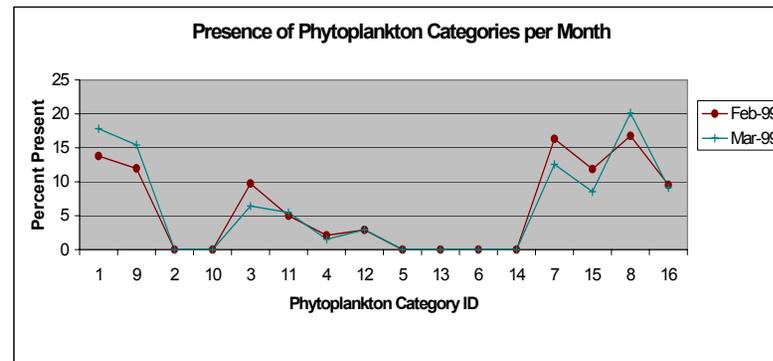


Figure H-7: Intra-Annual Variation February to March 1999

Appendix I: CD-ROM README FILE

What's on the CD & Metadata

- **Global Ocean Ecosystem Investigations: GIS in Science Education Presentation – PowerPoint, Adobe PDF and Webpage**
This presentation given in July 2000 at the International GIS in Education conference shows how a new technique using AVHRR remote sensing data can be used to analyze the nutrients in the ocean. This GIS/Spatial Analyst project can be used to investigate the relationship between the physical, chemical, and biological characteristics in the World Ocean. Impacts and consequences of the climatic events El Niño and La Niña are also discussed. (ESRI_95_97_2000.ppt, html or pdf)
- **GIS in the Marine Environment Presentation – PowerPoint, Adobe PDF and Webpage**
Introductory information on new GIS techniques in oceanographic research. It provides the background for this project and can be used as an introduction. (Background_Marine_95_97_2000.ppt, html or pdf)
- **Web research pages for background research: Teacherlinks and Studentlinks**
This is a resource for teachers and students to use to provide background information for this project. A separate teacher page is included. Keywords are used to indicate which website meets the needs of each group. The groups are: Why care?, Space, Ocean Color, Phytoplankton, Remote Sensing, SST, ENSO (climate), and Nutrients
- **Example GIS/Spatial Analyst project with analyses**
This project (example.apr) shows how to analyze the grids to create a grid of nutrient presence and absence. Eight categories are represented (none, S, P, N, NS, NP, PS, NPS). January 1998 data was used to create this example. The grids are saved as permanent grids and as a further extension, Image Analyst can be used to perform change detection analyses.
- **GIS/Spatial Analyst project: SST and Nutrient grids**
This project (ocean.apr) has two views; one view contains the Sea Surface Temperature grids (av_project\data\sst\grid\specific month for January, February, and March 1998 (El Niño) and for January, February, March 1999 (La Niña) and the other view contains the nitrate, phosphate, and silicate grids (av_project\data\ndt\grid\nutrient name). This project and these shapefiles can be used by students to generate their own questions and projects that investigate how climatic events affect the physical (SST), chemical (NDT), and biological (phytoplankton) composition of the World Oceans.
- **Teacher and Student pages: Word Documents**
Background, lessons, and procedural instructions for this unit (teacher) and a separate word file that contains the directions for the students (student).

Metadata

Data Summary

DESCRIPTION	FILE NAME	DATA MODEL	DATA SOURCE
SST for Jan., Feb., March 1998 and Jan., Feb., March 1999	199801, 199802, 199803, 199901, 199902, 199903	Vector/Point Converted to: Raster/Surface See Figure 1.	AVHRR Oceans Pathfinder
Nutrient Depletion Temperature (NDT) for Nitrate, Silicate, and Phosphate	Nitrate, Silicate, Phosphate	Vector/Point Converted to: Raster/Surface See Figure 2.	Matrices from Dr. Kamykowski

1. The AVHRR derived Sea Surface Temperature (SST) data was obtained from the Physical Oceanography Distributed Active Archive Center (<http://podaac.jpl.nasa.gov/sst/>).
2. The NDT matrices were prepared from a global data set obtained from the National Oceanographic Data Center (NODC). Twenty magnetic tapes in Station Data II format containing 230,202 oceanographic stations with at least one plant nutrient (nitrate, phosphate or silicic acid) represented were obtained from NODC. Each ocean area was processed successively through a sequence of programs including OCEAN, SCATTER, REGRESC, COMBINE, TABLE, WMSYM, and WORLDMAP. These matrices were developed by Dr. Dan Kamykowski (1986) and are reliable over a broad geographic area and can be used for comparisons.

DATA MANIPULATION OVERVIEW

1. Removing no data values and unnecessary fields using JMP properly formatted the SST point data and the NDT matrices for import as text files into ArcView.
2. ArcView's Add Event theme function was used to import the text files, converting the point data to shapefiles.
3. A latitude/longitude grid, in decimal degrees (map units), from ESRI sample data, was used to set the Analysis Extent with a cell output size of one degree.
4. Kriging was then used to interpolate the data into a surface. An extension was downloaded from ESRI called Kriging Interpolator 3.2 (<http://gis.esri.com/arcscrippts/scripts.cfm>) or you can use ArcView/Spatial Analyst 8.1.
5. Universal Kriging was used for all of the SST data.
6. Integer grids were used throughout this study.

CREATING THE SEA SURFACE TEMPERATURE (SST) SURFACE

1. JMP was used to strip off the header and delete extraneous columns and no data records. The data was then converted to a text file that contained latitude, longitude, and sea surface temperature (SST). JMP was required because of the data set size (300,000 points), as the data was collected for every 1.0 degree in the World Ocean (Figure 1).

2. ArcView Spatial Analyst and Kriging Interpolator 3.2 were loaded and the Analysis Extent was set to match the latitude/longitude grid. A cell size of 0.5 decimal degrees was set to match the distance at which the data was collected.
3. Universal Kriging with quadratic drift was chosen as the model because it best described the second order trend of the data, according to the parametric regression fit.
4. The z value field was set to SST with a variable radius type. The search distance was 1.0 degree because it was the lowest search distance at which the data would interpolate. The sample count was set to the 12 suggested by the software, but a variety of sample counts larger and smaller proved to make no difference in the interpolation.

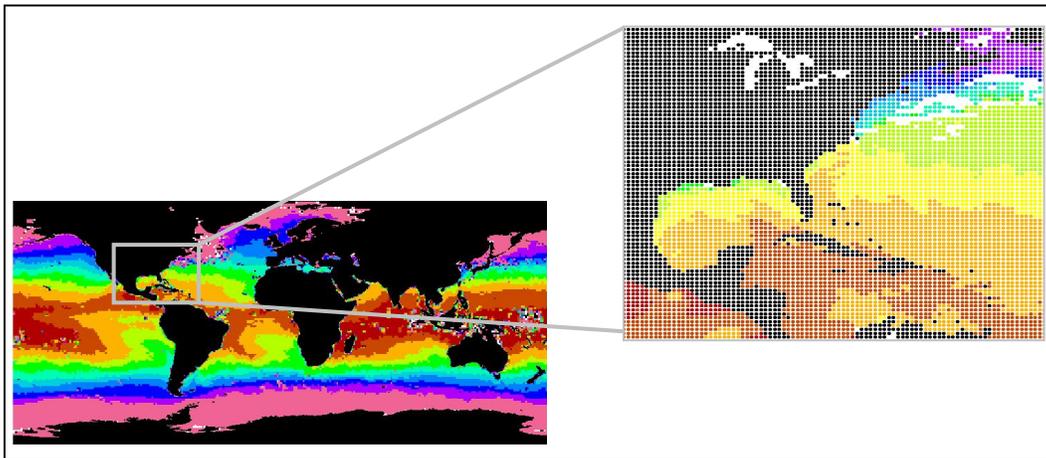


Figure 1: SST Point Data

CREATING THE NUTRIENT SURFACES

1. Dr. Dan Kamykowski provided the nutrient matrices used in this study.
2. JMP was used to remove no data records. The data was then converted to a text file that contained latitude, longitude, and nutrient depletion temperatures (NDTs) (Figure 2).
3. To determine the kriging method that best represented the data statistically, several semi-variograms were generated for each nutrient. The method of spherical with a lag interval of 10 was chosen for each nutrient because it explained more of the variation in the data (lower RMSE) and the data were collected at 10 degree intervals.
4. Each nutrient was then interpolated using Ordinary Kriging by the spherical method with a variable radius type and a search distance of 120 and a sample count of 12 (value suggested by software).
5. A Variance Grid was examined for each nutrient grid and little variation was found.

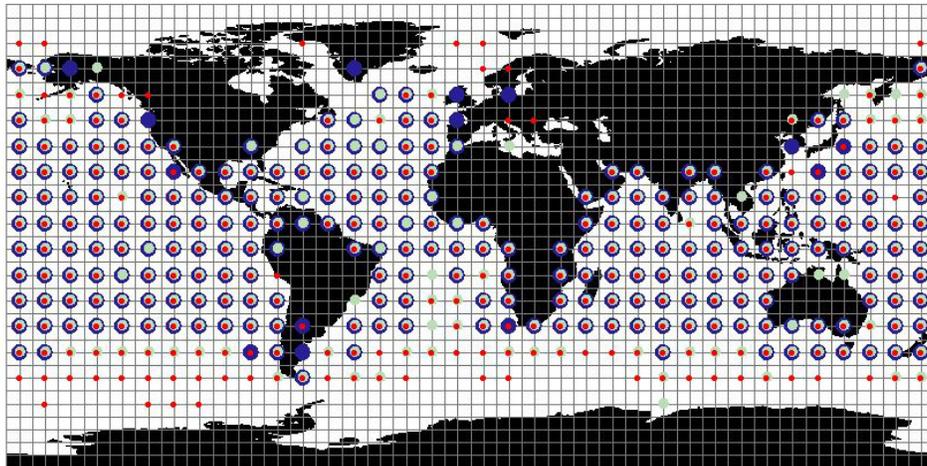


Figure 2: Nutrient Data Points: *Color key: red denotes silicate; green denotes phosphate; blue denotes nitrate*

Appendix J: TEACHER BACKGROUND INFORMATION

Teacher Background Information

Ocean Productivity During El Niño and La Niña Months Allyson Jason, August 2001

As a result of marine research, the connections between the physical and biological processes in the ocean continue to expand (Kamykowski, 1986). This expansion has been facilitated by satellites, which are able to provide frequent, large scale, near surface views of selected oceanographic variables. For example, a two-minute satellite scene containing 2 million pixels that cover an area of 2 million square kilometers would take a ship more than 11 years traveling at 20 km/hr to sample each pixel (<http://seawifs.gsfc.nasa.gov/>). Some of the variables that are important to phytoplankton ecology such as wind speed, surface height, sea surface temperature, incident radiation, water column attenuation and chlorophyll *a* are obtainable through remote sensing. Therefore, satellites have enabled oceanographers to estimate regional productivity of the World Ocean. However, these estimates are highly variable and exhibit high variance compared to *in situ* measurements.

Knowledge of the nutrient availability might further constrain the variance of the estimates, but monitored nutrient fertility of the ocean is not routinely performed. A solution, and one way to provide a representative view of nutrient distribution at sea surface and at depth that is comparable with satellite data, is to use sea surface temperature, in conjunction with the distribution of nitrate, silicate (Levitus *et al.*, 1993) and seasonal global averages of phosphate (Conkright *et al.*, 2000). Seasonal averages for all three nutrients can be produced regionally. This climatological approach does not support other measures of temporal nutrient variation, especially at a global scale. The resulting satellite-based comparisons are between dynamic satellite fields that can change daily and nutrient fields that represent a generic year or possibly a generic season such as a month as represented by this project.

Nutrient compositions of the ocean can be used to predict the type and amount of phytoplankton present. For example, where nitrate is in excess, there tends to be more carbonaceous (carbonate based skeletons) plankton, while where silicate is in excess, there tends to be more diatoms (silicate based skeletons). Where there are no detectable nutrients, there tends to be less primary production. In the past, oceanographers have only been able to view the presence and absence of nitrate, phosphate, and silicate from a few sample points obtained via expensive cruises. Today, remote sensing satellites can be used to link physical, chemical, and biological factors in the World Ocean to determine phytoplankton composition. An algorithm was developed which uses the physical-biological link in the ocean to determine the presence or absence of nutrients (Equation 1).

Equation 1: Algorithm

Sea Surface Temperature (SST) - Temperature at which the Nutrient Depletes (NDT)

In mid and lower regions of the world ocean, nutrients are depleted from the water column as temperature increases during the seasonal cycle. The nutrient depletion temperature or NDT is not constant over the World Ocean and matrices have been created for every 10 degrees of latitude and longitude. Latitude is primary among the reasons for this NDT variation (Kamykowski, 1987), due to the solar radiation gradient. For example, in equatorial waters where there is relatively constant heating, the water temperature through a relatively thick upper water column is high, with an upper limit primarily determined by evaporation rate (Pickard, 1963). The NDT temperatures for nitrate, phosphate, and silicate were created from 30-year averages of data obtained from the National Oceanographic Data Center or NODC. Each ocean area was processed according to 10-degree Canadian square designations to provide plots (For an image of Canadian Squares visit: <http://ioc.unesco.org/oceanteacher/resourcekit/M3/images/MCSBlocks.pdf>).

Each ocean area was processed successively through a sequence of programs (Kamykowski & Zentara, 1986).

Since climatology is so important to nutrient availability in the ocean, two extreme episodes, El Niño and La Niña were compared. El Niño episodes are characterized by a large-scale warming event that causes changes in atmospheric winds across the tropical Pacific, including reduced easterly (east-to-west) winds across the eastern Pacific in the lower atmosphere and reduced westerly (west-to-east) winds over the eastern tropical Pacific in the upper atmosphere. These conditions block the normal upwelling that occurs along North and South America. The 1997-1998 event killed an estimated 2,100 people and caused at least 33 billion dollars in property damage worldwide (Suplee, 1999). La Niña episodes, the opposite of El Niño, frequently follow El Niño episodes. La Niña, a cooling event, results in nearly absent rainfall across the eastern equatorial Pacific and at the same time enhances rainfall across the western equatorial Pacific, Indonesia and the Philippines. Wetter than normal conditions tend to be observed during December-February over northern South America and southern Africa, and during June-August over southeastern Australia. Drier conditions are generally observed along coastal Ecuador, northwestern Peru and equatorial eastern Africa during December-February, and over southern Brazil and central Argentina during June-August. In general, during a La Niña episode, nutrients become more plentiful as a result of enhanced upwelling in the Eastern Pacific and evaporation decreases (Suplee, 1999).

As we attempt to monitor these coupled oceanic-atmospheric events, a Multivariate ENSO Index (MEI) has been developed. The MEI can be understood as a weighted average of the main ENSO features contained in the following six variables: sea-level pressure, the east-west and north-south components of the surface wind, SST, surface air temperature, and total amount of cloudiness. It can be used to characterize which month represents a stronger occurrence of either La Niña or El Niño years (<http://www.cdc.noaa.gov/~kew/MEI/>). Each La Niña or El Niño year has its own unique signature. The sea surface temperatures for the months January, February, and March 1998 in this project represent one of the strongest El Niño events

in the last 40 years with February and March 1998 representing the peak of intensity for that year. The sea surface temperatures for the months January, February, and March 1999 represent a La Niña year in which conditions were every bit as dramatic as the rise towards the El Niño conditions in 1997. However, the months of January 1999 represent the stronger month as compared to the months of February and March 1999. Therefore to compare months that represent the two extremes of the data provided would mean comparing March 1998 to January 1999. The MEI indices for each month are listed in Table 1. The farther the number is from 0, the stronger the occurrence of the event during that year.

Table 1: Multivariate El Niño /Southern Oscillation (ENSO) Index for 1998 El Niño and 1999 La Niña Months

El Niño		La Niña	
January 1998	+ 2.4	January 1999	- 1.2
February 1998	+ 2.7	February 1999	- 1.0
March 1998	+ 2.8	March 1999	- 0.75

Additional derived sea surface temperature months from the satellite Pathfinder (AVHRR) can be downloaded from the Physical Oceanography Distributed Active Archive Center (<http://podaac.jpl.nasa.gov/sst/>). Be careful to strip off the header and delete the extraneous columns and no data records first. Convert the latitude, longitude, and sea surface temperature (SST) fields to a text file. This is a large data set and you will need to use a program such as JMP to prepare the data set. Then use the Kriging Interpolator in Spatial Analyst 8.1 to interpolate the data. A quadratic drift model with a variable radius type and a search distance of 1.0 degree with a sample count of 12 was used in the interpolations.

This project allows you to analyze the distribution of eight categories of nutrient availability by presence or absence of nitrate, phosphate, and silicate in the World Ocean. Differences in atmospheric events such La Niña and El Niño and their effect on the SST and nutrient distribution in the World Ocean can be inferred.

Nutrient availability can also be used to consider the type of phytoplankton that could occur in an area and how shifts in climate can cause shifts in the chemical and biological characteristics of the ocean.

Phytoplankton play a key role in the ecology of the marine ecosystem and changes in their patterns and abundance have significant impact on the entire ocean ecosystem. Phytoplankton are thought to play a major role in the global carbon cycle. They account for approximately 50% of the photosynthesis on the planet and play an important role in regulating the amount of carbon in the atmosphere. The health and economics of many countries and their citizens depend upon the productivity of the oceans (<http://seawifs.gsfs.nasa.gov/cgibrs/level3>). Therefore, phytoplankton type and abundance and the conditions that affect their growth and development are important to the stability and health of the World Ocean and to those that benefit from it.

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What's on the CD

- **Global Ocean Ecosystem Investigations: GIS in Science Education Presentation – PowerPoint, Adobe PDF and Webpage**

This presentation given in July 2000 at the International GIS in Education conference shows how a new technique using AVHRR remote sensing data can be used to analyze the nutrients in the ocean. This GIS/Spatial Analyst project can be used to investigate the relationship between the physical, chemical, and biological characteristics in the World Ocean. Impacts and consequences of the climatic events El Niño and La Niña are also discussed. (ESRI_95_97_2000.ppt, html or pdf)
- **GIS in the Marine Environment Presentation -- PowerPoint, Adobe PDF and Webpage**

Introductory information on new GIS techniques in oceanographic research. It provides the background for this project and can be used as an introduction. (Background_Marine_95_97_2000.ppt, html or pdf)
- **Web research pages for background research: Teacherlinks and Studentlinks**

This is a resource for teachers and students to use to provide background information for this project. A separate teacher page is included. Keywords are used to indicate which website meets the needs of each group. The groups are: Why care?, Space, Ocean Color, Phytoplankton, Remote Sensing, SST, ENSO (climate), and Nutrients
- **Example GIS/Spatial Analyst project with analyses**

This project (example.apr) shows how to analyze the grids to create a grid of nutrient presence and absence. Eight categories are represented (none, S, P, N, NS, NP, PS, NPS). January 1998 data was used to create this example. The grids are saved as permanent grids and as a further extension, Image Analyst can be used to perform change detection analyses.
- **GIS/Spatial Analyst project: SST and Nutrient grids**

This project (ocean.apr) has two views; one view contains the Sea Surface Temperature grids (av_project\data\sst\grids\specific month for January, February, and March 1998 (El Niño) and for January, February, March 1999 (La Niña) and the other view contains the nitrate, phosphate, and silicate grids (av_project\data\ndt\grids\nutrient name). This project and these shapefiles can be used by students to generate their own questions and projects that investigate how climatic events affect the physical (SST), chemical (NDT), and biological (phytoplankton) composition of the World Oceans.
- **Teacher and Student pages: Word Documents**

Background, lessons, and procedural instructions for this unit (teacher) and a separate word file that contains the directions for the students (student).
- **READ ME file: Instructions**

This Word file contains the directions for what is on the CD (CD organization) and a Metadata file.

Introductory and Background Procedure

1. Introduce the project and “set the stage” by showing students the **GIS in the Marine Environment PowerPoint**. Tell the students that they will be breaking up into groups to complete additional background research and that they should look for themes in the presentation that interest them. Encourage them to record information that might help them with their research and presentations.
2. Break students up into the following research groups:
 - **Why Care** (Why care about the oceans?)
How are the oceans different from the land and why are they so important to us?
 - **Space** (Why study the ocean from space?)
How did we study the ocean in the past and how have techniques for studying them changed and why?
 - **Ocean Color** (What color is the ocean?)
What is the principle behind ocean color and how do we use it to study the ocean?
 - **Phytoplankton** (Why are they so important?)
What are phytoplankton and what key roles do they play in the ecology of the ocean?
 - **Remote sensing** (Pathfinder and SeaWiFS – how do they work?)
What can satellites tell us about the ocean? How are they used in oceanography?
 - **SST** (What is sea surface temperature (SST) and why is it so important?)
What do temperature patterns tell us about the ocean and how do climatic events relate to SST?
 - **ENSO-Climate** (How do atmospheric climatic events affect the ocean?)
How would you describe El Niño and La Niña? What is an oscillation and why is it important? How are scientists trying to forecast these cycles?
 - **Nutrients** (How are temperature and chemical composition of the ocean related?)
What is nutrient depletion temperature (NDT)? How do nitrate, phosphate and silicate affect the life found in the ocean? Where do they come from and how are they used plants and animals in the ocean?

Use the **Web research pages** to help students research their topics. Determine how the students will share the information with each other. Some suggestions are:

- they could present to the class
- create written reports for each other
- break up into jigsaw groups and teach each other

- create museum displays of their topics and one member each group would present and answer questions as the rest of the class rotates through each display area
3. After the groups have shared their information, have the class brainstorm a list of questions or problem statements that they would like to further investigate. Circle the problems that can be investigated using the **GIS/Spatial Analyst project: SST and Nutrient grids**. Some problem questions might be: How does the SST affect the distribution of nutrients in the ocean? What is the connection between nutrients and phytoplankton that could be found there? How does climate affect the living things in the ocean? Where are more nutrients found in the ocean? Other problem questions can be investigated by adding additional data to the GIS project or in other ways such as a guest speaker or additional lessons.
 4. Allow the students to use the example project to discuss some of the problem questions/statements they have created and to generate possible options. The teacher could then demonstrate how to recreate the example project, **example GIS/Spatial Analyst project with analyses**, and the students could follow or the students could use the student pages to recreate the example. The student pages for the project are found in the word file student.

GIS/Spatial Analyst project: SST and Nutrient grids procedure

1. Engage ArcView and load the Spatial Analyst extension.
2. Create a new view.
3. Add the Sea Surface Temperature (SST) month or months of interest from the ocean.apr project or CD (av_project\data\sst\grids\specific month). Remember that January, February, and March 1998 represent El Niño months and January, February, March 1999 represent La Niña months. Check the ENSO Index to determine how strong the effect was in each month (see background information).
4. Name your new view after the SST month or each theme after the month(s) you have added. Be careful to keep track of the month(s) and year(s) you added.
5. Add the three Nutrient Depletion Temperature Grids: Nitrate, Phosphate, and Silicate (av_project\data\ndt\grids\nutrient name).
6. From the Analysis menu use the map calculator to create the expression (SST month – Nutrient Depletion Temperature Grid) and rename the calculation so that you can identify it later.
7. We are only interested presence or absence so open the legend editor of the map calculation from step 6 and change the classes to two. Then change the values in the legend editor for each class so that there is a break at zero. For example: -29.0 to -9.1 becomes -29.0 to 0 and -9.1 to 10.0 becomes 0 to 10.0.

8. Turn on this grid. Notice that -29.0 to 0 , for example, represents Presence and 0 to 10.0 represents absence (notice the switch – if it is negative it is PRESENT and if it is positive it is ABSENT).
9. From the Analysis menu select reclassify the same grid as in number 8. Reclassify the values from the default of 9 to 2.
10. Change the values from each class so that there is a break at zero again as in step 7. The 1's represent Presence and the 2's represent absence. Reclassifying is important because it takes the number values and creates a yes/no grid of 1's and 2's.
11. When you reclassify you will set up a numbering system for each nutrient. Use 1 and 2 for Nitrate, 10 and 20 for Phosphate, and 100 and 200 for Silicate.
12. Repeat each step for each nutrient.
13. Use the map calculator to create an expression for EACH SST month that adds the reclass of each nutrient together (reclass of silicate available + reclass of phosphate available + reclass of nitrate available).
14. Your final results will be a map calculation that contains the following 8 categories for that particular SST month. This grid could be called the nutrient composition grid for a particular month and year.
 - 222 = Absence of S, P, and N
 - 221 = Absence of S and P but presence of N
 - 212 = Absence of S, presence of P, absence of N
 - 211 = Absence of S, presence of P and N
 - 122 = Presence of S, absence of P and N
 - 121 = Presence of S, absence of P, presence of N
 - 112 = Presence of S, presence of P, absence of N
 - 111 = Presence of S, P, and N
15. For each month represented look at the nutrient composition grid. How does it change from month to month? How have El Niño and La Niña contributed to these changes?
16. Use the Phytoplankton Taxonomic Classification (Table 1 on page 9) to determine the possible phytoplankton compositions of certain areas of the World Ocean. How does this change over time? How would these changes affect the food webs found in certain parts of the oceans?
17. Convert the temporary grid to a permanent grid by using Theme – Save Data Set.
18. Image Analyst can now be used to determine the amount of change from month to month. In what part of the World Ocean did the largest amount of change occur and during which months? How might this change affect the phytoplankton that live there?
19. For step by step directions with images see **STUDENT PAGES** (student.doc).

Discussion

Students should now return to their problem questions and the options they generated in the beginning of the project. What answers have they found? Do they have any new questions? What are the assumptions made by this project? For example the highly fluctuating nutrient values near continents are not represented in this project.

How might this information be used in coastal areas that depend on the ocean for their livelihood? Are any parts of the World Ocean affected more than others and in what months? Remote-sensing techniques are becoming a routine part of the way we monitor the ocean and our environment. Why is this important to us?

For further investigation, SST temperatures can be downloaded from the Physical Oceanography Distributed Active Archive Center at <http://podaac.jpl.nasa.gov/sst/>. Why is ocean temperature so important and what does it tell us? What other physical and chemical factors are important to phytoplankton productivity and the fertility of the World Ocean and what remote sensing techniques are being used to obtain this information?

For example, when atmospheric iron is available, larger phytoplankton cells are present. Iron is not affected by temperature but instead is determined by temporal and spatial patterns of at-sea atmospheric mineral dust. Satellites are measuring Aerosol Optical Thickness or AOT to study and monitor deposition. In addition, world distribution of chlorophyll *a* concentrations which are used monitor phytoplankton blooms are available online at Images and datasets: <http://seawifs.gsfc.nasa.gov/SEAWIFS.html>.

Table 1: Phytoplankton Classification Schemes

<i>Representative impacts of nutrient availability on phytoplankton community cell size and taxonomic composition</i>				
CATEGORY		-F (smaller cells)		+F (larger cells)
Absent: all	1	Prochlorococcus, ultraplankton, nanoplankton	9	ultraplankton, nanoplankton
S: Silicate Only	2	Prochlorococcus, ultraplankton, nanoplankton, small diatoms	10	ultraplankton, nanoplankton, diatoms
P: Phosphate Only	3	Prochlorococcus, ultraplankton, nanoplankton	11	ultraplankton, nanoplankton, cyanobacteria (N-fixation), small diatoms
N:Nitrate Only	4	Synechococcus, ultraplankton, nanoplankton	12	ultraplankton, nanoplankton, coccolithophores (SST>10), Phaeocystis (SST<10)
PS: Phosphate & Silicate	5	Prochlorococcus, Synechococcus, ultraplankton, nanoplankton, small diatoms	13	cyanobacteria (N-fixation), diatoms with N-fixing symbionts
NS: Nitrate & Silicate	6	Synechococcus, ultraplankton, nanoplankton, small diatoms, flagellates	14	small diatoms, flagellates
NP: Nitrate & Phosphate	7	Synechococcus, ultraplankton, nanoplankton, coccolithophores (SST>10), Phaeocystis (SST<10)	15	dinoflagellates
NPS: Nitrate, Phosphate & Silicate	8	Prochlorococcus, Synechococcus, ultraplankton, nanoplankton, small diatoms	16	large diatoms
<i>Representative impacts of nutrient availability on phytoplankton community cell size</i>				
<i>Category</i>	<i>Abbreviation</i>	<i>Iron (F) Absent (smaller cells)</i>	<i>Abbreviation</i>	<i>Iron (F) Present (larger cells)</i>
All Nutrients Absent	Abs	1	FAbs	9
Silicate Only	S	2	FS	10
Phosphate Only	P	3	FP	11
Nitrate Only	N	4	FN	12
Phosphate and Silicate	PS	5	FPS	13
Nitrate and Silicate	NS	6	FNS	14
Nitrate and Phosphate	NP	7	FNP	15
Nitrate, Phosphate and Silicate	NPS	8	FNPS	16

Appendix K: ANNOTATED HYPERLINKS-- TEACHER VERSION

Global Ocean Ecosystem Investigations

Informational Hyperlinks Teacher Section

Educational Materials Associated with the *Ocean Planet* - A large number of educational materials have either been developed specifically for the *Ocean Planet* Exhibition, or have been developed for other purposes but are a good complement to the materials presented in the Exhibition. If the materials are available in electronic form, you can retrieve them for use in your classroom. We will continue to add new materials as they become available.

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/search_educational_materials.html

Education Resources For Oceanography And Earth Sciences - a lot of links that you need to investigate.

<http://podaac.jpl.nasa.gov/edu/edudoc.html>

Resource Room - A continually expanding list of resources to help you explore the *Ocean Planet* including: [Links to Compilations of Oceanographic Resources on the Internet](#), [Questions and Answers about the Ocean and Environment](#), [Scientific Journals on the Internet](#), [Oceanography from Space](#), [Aquariums on the Internet](#), [Ocean-related Events and Activities at Other Institutions](#), [Other Online Exhibitions](#), [Educational Resources Available on the Internet](#), and [Ocean Planet Photo/Illustration/Artifact Archive](#)
http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/ocean_planet_resource_room.html

Exploring Satellite Oceanography - A set of lesson plans for high school science students including: Introduction to Satellite Oceanography.

<http://dcz.gso.uri.edu/amy/avhrr.html>

Satellite Shows La Niña's Impact on Ocean Biology - An article from Space.com.

http://www.space.com/scienceastronomy/planetearth/el_nino_991214.html

Pumping of nutrients to ocean surface waters by the action of propagating planetary waves - An article from *Nature*.

http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v409/n6820/full/409597a0_fs.html

COAST - Physical Parameters Activities - Nutrients in the Ocean - This is a Lesson plan website: Sonar technology is used by oceanographers and topographers to discover the appearance of the sea floor. This information helps us better understand the geologic features of the deep ocean and allows us to travel the oceans more safely.

http://www.coast-nopp.org/resource_guide/elem_mid_school/physical_param_acts/

IODE Resource Kit - In particular look at the [Training Module on the Applications of Geographic Information Systems \(GIS\)](#) which is a truly well done tutorial about GIS.

<http://ioc.unesco.org/oceanteacher/resourcekit/>

Geo 222 Resources - Look at the New Sets of Review Questions for Exam 3 if it is still there. There are study questions about: Ocean Productivity, Atmospheric and Surface Ocean Circulation, and El Nino and Plankton.

<http://www-personal.umich.edu/~vmckenna/geo222-resources01.html>

Student Section

Monitoring the Earth from Space with SeaWiFS - An overview of the importance of the oceans, oceanography, and ocean color from the SeaWiFS program. Contains the following sub-pages: [Why should we care about the oceans?](#), [Why study the oceans from space?](#), [What color is the Ocean and why do you need a satellite to tell you?](#), [Phytoplankton - All things great and small](#), [SeaWiFS background](#), [Show and Tell](#), [Putting it all together](#). Each sub-page contains links with "More Information."

http://seawifs.gsfc.nasa.gov/SEAWIFS/sanctuary_1.html

Groups: Why Care, Space, Ocean Color, Remote Sensing, Phytoplankton

SeaWiFS Science Focus - The SeaWiFS "Science Focus" pages are intended to highlight a notable event or remarkable image. The SeaWiFS images are displayed and the underlying scientific principles that create or are illustrated by the observed phenomena are briefly discussed. Of particular interest are [The North Atlantic Bloom](#), [SeaWiFS and Global Warming](#), and [SOIREE: A Phytoplankton Party in the Southern Ocean](#)

http://eosdata.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/science_focus.html

Groups: Phytoplankton, Why Care

Ocean Color From Space - A list of links from SeaWiFS with the following sub-pages: [Introduction](#), [History And Other Background Info](#), [Ocean Meanders, Mediterranean](#), [Global Seasonal Change](#), [Coastal Features](#), [North Atlantic Productivity](#), [Upwelling Dynamics](#), [Indian Ocean Monsoon](#), [Western Boundary Currents](#), [Polar Productivity](#), [Image Compositing](#), and [Global Biosphere](#).

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/ocean_color_from_space.html

Groups: Why Care, Space, Ocean Color, Remote Sensing, Phytoplankton

SeaWiFS Project - The Living Ocean Teacher's Guide - An overview of the purpose and importance of the SeaWiFS project including the following sub-pages: [Studying Global Ocean Color Form Space](#), [What We See From Space](#), [Phytoplankton](#), [Carbon](#)

http://seawifs.gsfc.nasa.gov/SEAWIFS/LIVING_OCEAN/

Groups: Ocean Color, Space, Phytoplankton, Nutrients, Why Care

PODAAC Links to Oceanography and Earth Science Resources - A varied list of links sorted by the following categories: [Oceanography Resources](#), [In Situ Ocean](#)

[Data](#), [Climate and Weather Resources](#), [Earth Science Resources](#), [Remote Sensing Resources](#), [NASA's Earth Observing System](#), also check out the education links: [General Information](#), and [Kid's Stuff](#) for young adults and the young at heart.

<http://podaac.jpl.nasa.gov/info/links.html>

Groups: ENSO-Climate, Remote Sensing, Space, Why Care, SST

Ecosystems of Our World - An overview of why everything is connected

<http://library.thinkquest.org/11353/text/ecosystems.htm>

Groups: Why Care

El Niño: The Child Returns - El Niño. Regional or global consequences?

<http://www.cotf.edu/ete/modules/elnino/elnino.html>

Groups: ENSO-Climate, Remote Sensing, Space, Why Care

Earth System Science - In the phrase "Earth system science (ESS)," the key term is "system." A system is a collection of interdependent parts enclosed within a defined boundary.

<http://www.cotf.edu/ete/ESS/ESSmain.html>

Groups: Why Care

Oceans - A great overview website including Datasets, Reference ([La Nina Fact Sheet](#), [What is a Coccolithophore? Fact Sheet](#), [What are phytoplankton? Fact Sheet](#), [Ocean and Climate Fact Sheet](#), [What is El Nino? Fact Sheet](#)), Features ([Watching Plants Dance to the Rhythms of the Ocean](#), [Polynyas, CO2, and Diatoms in the Southern Ocean](#), [Tracking Eddies that Feed the Sea](#), [Illuminating Photosynthesis in the Arabian Sea](#), [Searching for Atlantic Rhythms](#), [Questioning Convection](#), [Global Temperature Trends](#), [Eye on the Ocean](#), [El Nino's Extended Family Introduction](#), [The Color of El Niño](#))

<http://earthobservatory.nasa.gov/Topics/oceans.html>

Groups: Why Care, Space, Phytoplankton, SST, Ocean Color, ENSO-Climate

Remote Sensing - Introduction and History as well as more information links.

<http://earthobservatory.nasa.gov/Library/RemoteSensing/>

Groups: Remote Sensing, Space

Space-based Observations of the Earth - By David Herring and Michael King
Reprinted here with permission of the Encyclopedia of Astronomy and Astrophysics.

<http://earthobservatory.nasa.gov/Library/Observing/>

Groups: Remote Sensing, Space

Global Change Master Directory Oceans- Links to a large array of oceanographic variables and topics, Look specifically at the main topics: [OCEAN CHEMISTRY](#), [OCEAN OPTICS](#), [OCEAN TEMPERATURE](#).

http://gcmd.gsfc.nasa.gov/md/param_search/OCEANS.html?homepage

Groups: Phytoplankton, SST, Ocean Color, Remote Sensing, Nutrients

Oceanography from the Space Shuttle - is a pictorial survey of oceanic phenomenon visible to the naked eye from space.

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/shuttle_oceanography_web/oss_cover.html

Groups: Remote Sensing, Space

Ocean Chemistry- The Basics of Ocean Chemistry: Carbon, Circulation, and Critters

<http://seawifs.gsfc.nasa.gov/SEAWIFS/TEACHERS/CHEMISTRY/>

Groups: Nutrients

Ocean Biology - Phytoplankton in biospheric processes.

<http://seawifs.gsfc.nasa.gov/SEAWIFS/TEACHERS/BIOLOGY/><http://seawifs.gsfc.nasa.gov/SEAWIFS/TEACHERS/BIOLOGY/>

Groups: Nutrients, Phytoplankton, Why Care

Spaceborne Ocean Color Instruments - Spaceborne instruments, designed to make precise measurements of ocean color, are the best method available to estimate ocean productivity on the global scale. Contains an overview of the sensors that have been and are available.

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/instruments.htmlhttp://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/instruments.html

Groups: Space, Ocean Color, Remote Sensing

Partnership for Observation of the Global Oceans - Contains many links to other information about global ocean work. Be sure to look at the purpose of the organization on the homepage.

<http://www.oceanpartners.org/links.html>

Groups: All

CDC Map Room: Sea Surface Temperature - SST TOTALS, SST ANOMALIES, and SST TIME-LONGITUDE PLOTS.

<http://www.cdc.noaa.gov/map/clim/sst.shtml>

Groups: SST

ELEMENTS OF THE OCEAN OBSERVING SYSTEM FOR CLIMATE- Surface Temperature and the Sea Surface Salinity, SST measurement methods, SSS measurement methods, Observing system requirements for SST and SSS.

<http://www-ocean.tamu.edu/OOSDP/FinalRept/05a.html>

Groups: SST

Offshoreweather.com - Marine weather forecasts, tide charts & tide tables, buoy reports, and more! Type in your zipcode or latitude/longitude and receive information about SST near your home.

<http://www.offshoreweather.com/>

Groups: SST

NOAA Websites - Ocean Sciences websites.

<http://www.websites.noaa.gov/guide/sciences/ocean/ocean.html>

Groups: All

NOAA West Network - Satellite data access page to the latest sea surface temperature composite images for the Northwest Region and the World.

http://www.pmel.noaa.gov/data_rescue/satellite/intro.html

Groups: SST

PO.DAAC AVHRR OCEANS PATHFINDER - The NOAA/ NASA AVHRR Oceans Pathfinder sea surface temperature data.

<http://podaac.jpl.nasa.gov/sst/>

Groups: SST

Product Systems Branch SST Information - Sea Surface Temperature Images.

http://140.90.207.25:8080/PSB/EPS/SST/sst_anal_fields.html

Groups: SST

Sea Surface Temperature Changes - Earth Space Research Group description of SST during ENSO.

<http://www.ices.ucsb.edu/geos/125.html>

Groups: ENSO-Climate, SST

Sea Surface Temperature Definition - What is the Sea Surface temperature?

<http://www.csc.noaa.gov/crs/definitions/SST.html>

Groups: SST

NOAA/PMEL/TAO - What is an El Niño (ENSO)? - El Niño is a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe.

<http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html>

Groups: ENSO-Climate

Global Sea Surface Temperature - Educational Background about SST.

<http://www.teacherlink.usu.edu/TLresources/longterm/NASA/html/lithos/globalsea/>

Groups: SST

Global Biosphere - Discusses the patterns of plant life both on the land and in the oceans as observed from space. An illustration was produced by combining data from two different satellites and shows Earth as a complex system, teeming with life.

<http://teacherlink.ed.usu.edu/TLresources/longterm/NASA/html/lithos/globalbio/index.html>

Groups: Ocean Color, Why Care, Space

El Niño Sea Surface Temperatures: a look at the El Niño event from 1982-83

[http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/elni/sst.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/elni/sst.rxml)

Groups: ENSO-Climate

<http://www-personal.umich.edu/%7Evmckenna/geo222-schedule01.html> **ENSO Monitor** - El Niño-Southern Oscillation (ENSO) is a coupled ocean-atmosphere phenomena that has a worldwide impact on climate.

<http://ingrid.ldgo.columbia.edu/SOURCES/.Indices/ensomonitor.html>

Groups: ENSO-Climate

El Niño and the Current state of the Tropical Pacific - On these pages, you will find information about the state of the tropical Pacific Ocean as viewed from space as well a multi-lingual primer on ENSO and its teleconnections to world-wide weather patterns. Also included are links to visualizations of the ENSO phenomenon, related ENSO research at Goddard Space Flight Center and other selected facilities around the globe.

<http://nsipp.gsfc.nasa.gov/enso/index.html><http://nsipp.gsfc.nasa.gov/enso/index.html>

Groups: ENSO-Climate, SST

Sea surface temperatures impact weather in Amazon basin - 12/24/1999 - ENN News - Environmental News Network - Your leading news source on the environment.

http://www.enn.com/news/enn-stories/1999/12/122499/sstamazon_8414.asp

Groups: SST, ENSO-Climate

UNIT4 - Global Climate Systems: Ocean/Atmospheric Coupling; Climate Change and El Nino. Montreal and Kyoto

<http://darwin.bio.uci.edu/~sustain/state/chapter2.htm>

Groups: ENSO-Climate, Why Care

Image Library - Thumbnail search interfaces are available to browse AVHRR sea surface temperature (SST); SeaWiFS chlorophyll imagery and SeaWinds wind vectors.

<http://wavy.umeoce.maine.edu/sorry.html>

Groups: ENSO-Climate, SST, Ocean Color

Earth from Space - The NASA Space Shuttle Earth Observations Photography database of over 375,000 images is a national treasure.

<http://earth.jsc.nasa.gov/>

Groups: Space, Why Care

El Niño Theme Page - distributed information on ENSO - Very Informative.

http://www.pmel.noaa.gov/tao/el_nino/nino-home.html

Groups: ENSO-Climate

Exercise 13 Marine Ecosystems - Objective: To examine the conditions leading to the abundance and distribution of life in the sea.

<http://geosun1.sjsu.edu/~dreed/105/exped9/1.html>

Groups: Nutrients, Phytoplankton

Ocean Ecology - Marine Ecology/Plant Productivity. Now that you know who's who in the oceans, we can look at how they fit together into communities.

<http://www-class.unl.edu/geol109/ecology.htm>

Groups: Nutrients, Phyttoplankton

Light and nutrients - Where phytoplankton live in the water column and why

<http://www-ocean.tamu.edu/Quarterdeck/QD5.2/pariente-light.html>

Groups: Nutrients, Phytoplankton

Marine Habitat - Information from the USGS. So, how do we describe something as abstract as habitat? One way is to look closely at some of its contents. We study the lower links in the marine food chain by measuring phytoplankton and zooplankton. We look at factors that affect the food web including nutrients, ocean temperature, and salinity. We also consider bathymetry (the topography of the ocean floor), and ocean depth in our area of study.

<http://www.absc.usgs.gov/research/seabird&foragefish/marinehabitat/home.html>

Groups: Nutrients, Phytoplankton, SST, Why Care

Welcome to the Remarkable Ocean World - Be sure to examine the Online Library including: Main Branch, Historical Oceanography, Geological Oceanography, Physical Oceanography, Chemical Oceanography, Biological Oceanography, Ocean Science, Humans and the Sea, Space Science. A Very Important Site!

<http://www.oceansonline.com/index.htm>

Groups: All

Satellite Oceanography - From the Remarkable Ocean World.

<http://www.oceansonline.com/satellites.htm>

Groups: Space, Remote Sensing, Ocean Color

OCNG 251-502, Fall 2001: Chapter 15 - Biological Productivity and Energy Transfer.

<http://www-ocean.tamu.edu/~duce/chapter15.html>

Groups: Nutrients, Phytoplankton, Why Care

Character of Ocean Water - LECTURE NOTES: Character of Ocean Water. See the [Lecture Schedule](#) for more information.

<http://www-personal.umich.edu/~vmckenna/lec-222/lec-salinity01.html>

Groups: Nutrients, Phytoplankton, Why Care

Biology Learning Center Online Science Courses - Please enjoy these marine science educational resources brought to you by the Marine Biology Learning Center, a nonprofit organization dedicated to providing insight and leadership to the stewardship of our ocean planet. Especially look at: General Ecology, Marine Ecology, and Oceanography.

<http://www.marinebiology.org/science.htm>

Groups: Nutrients, Phytoplankton, Why Care

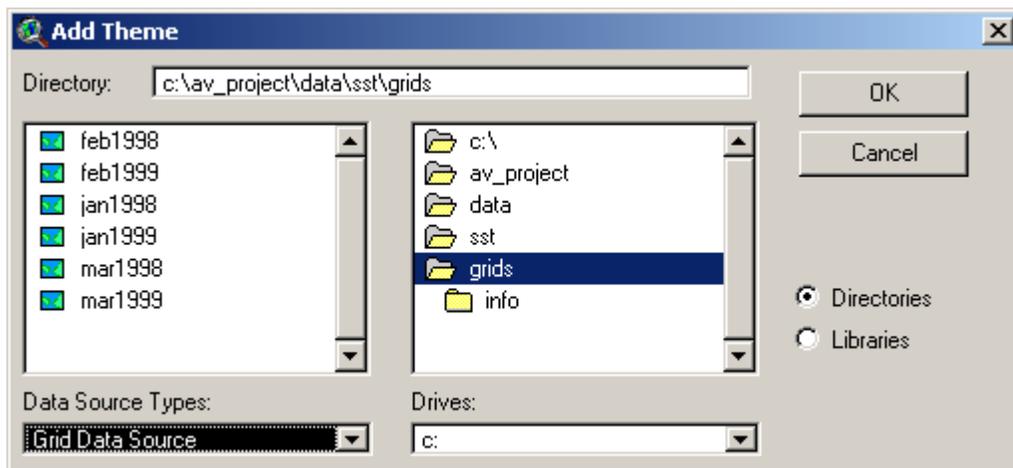
Appendix L: STUDENT INSTRUCTIONAL PAGES

STUDENT PAGES

These directions will guide you through the process of determining the absence and presence of nitrate, phosphate, and silicate from Sea Surface Temperature (SST) for the World Ocean during El Niño (January, February, March 1998) and La Niña (January, February, March 1999) months. The types of nutrients present in the ocean are one determining factor in the type of phytoplankton and other living things that might be found there.

Directions for Creating Nutrient Presence and Absence Grids

1. Open a new view adding:
 - a. The Sea Surface Temperature (SST) for the month of interest (ex jan1998)
 1. Change “Data Source Types:” to Grid Data Source
 2. /av_project/data/SST/grids



b. The three Nutrient Depletion Temperature Grids

1. Nitrate

- /av_project/data/NDT/grids/nitrate

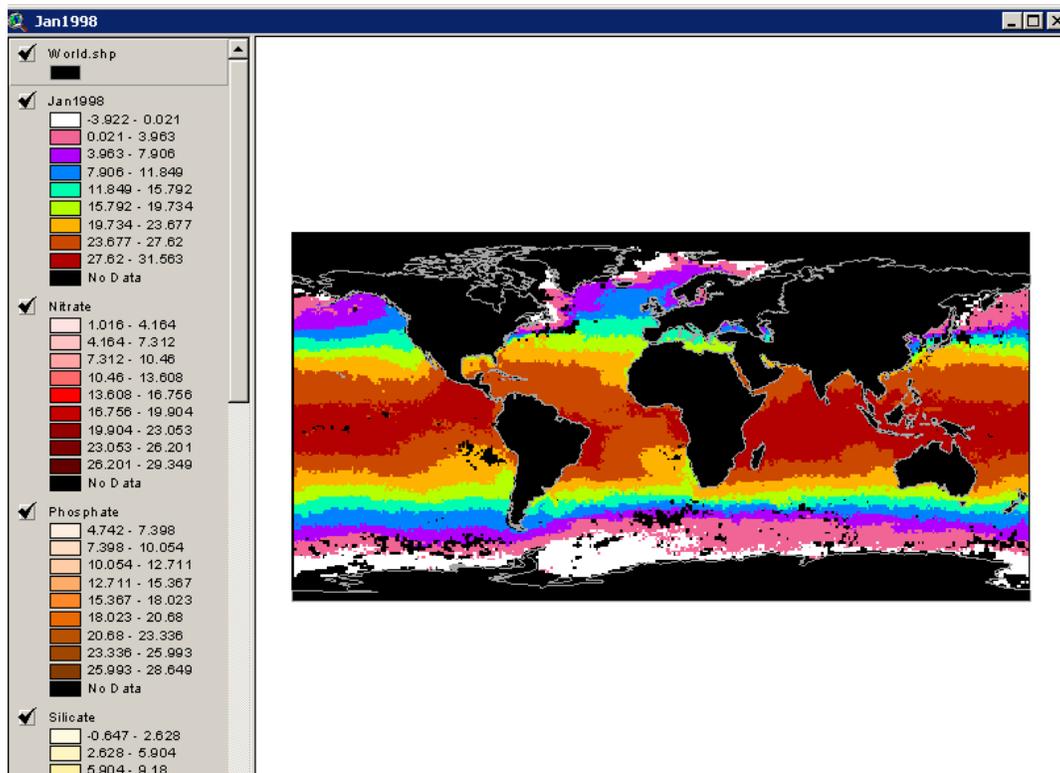
2. Phosphate

- /av_project/data/NDT/grids/phosphate

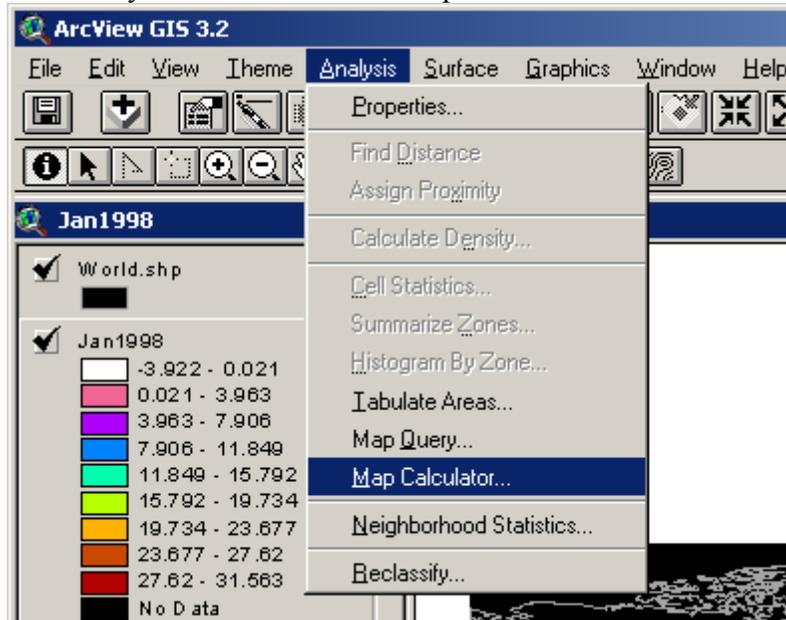
3. Silicate

- /av_project/data/NDT/grids/silicate

Hint: Name your new view for the SST month of interest to keep track.



2. From the Analysis Menu Select the Map Calculator.



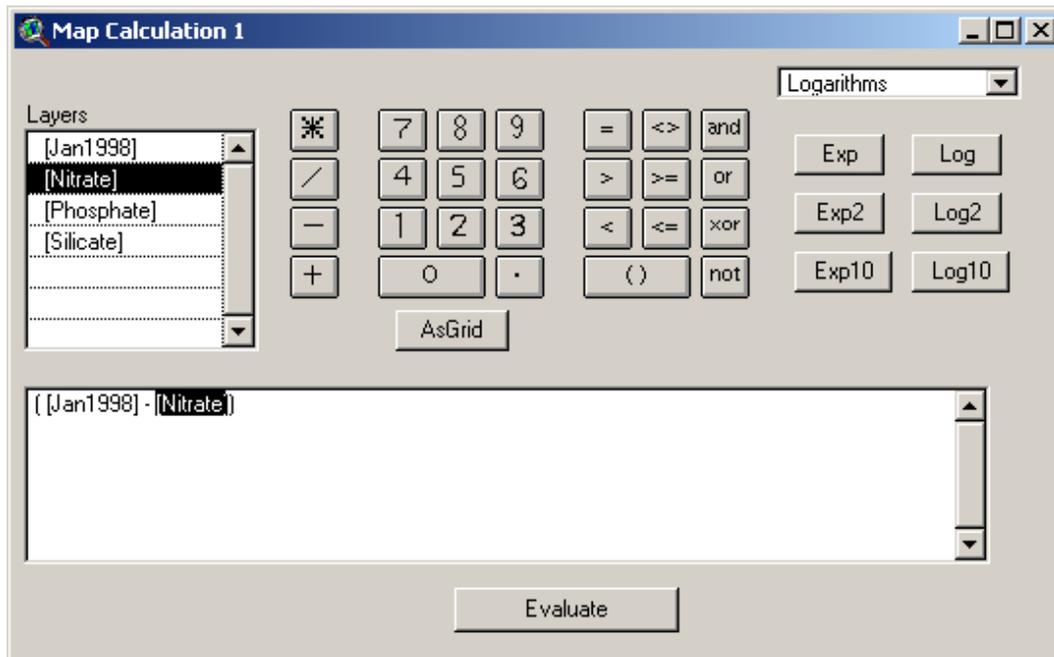
3. Using the Map Calculator create the expression $([Jan1998] - [Nitrate])$.

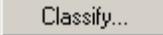
1. Under Layers - Double click on Jan1998

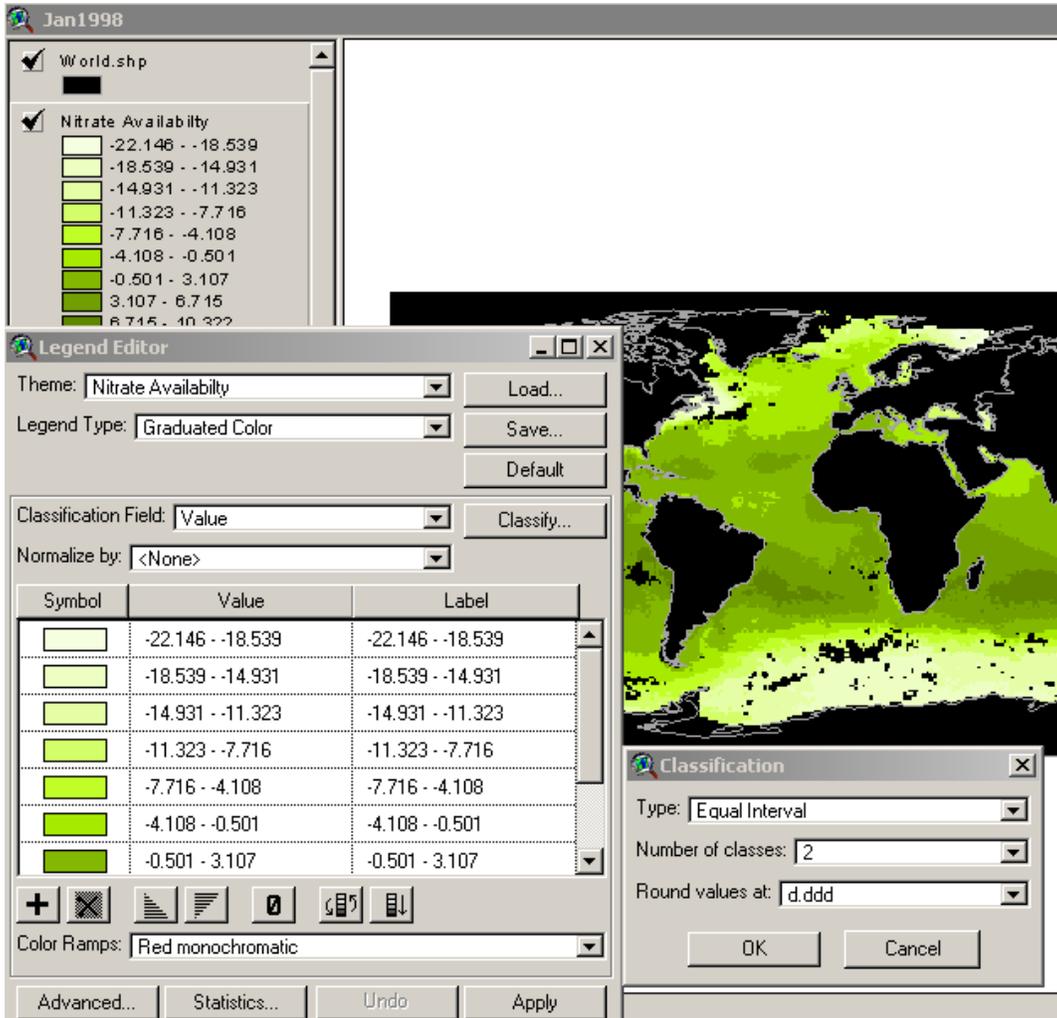
2. Click on the subtract button 

3. Under Layers - Double click on Nitrate

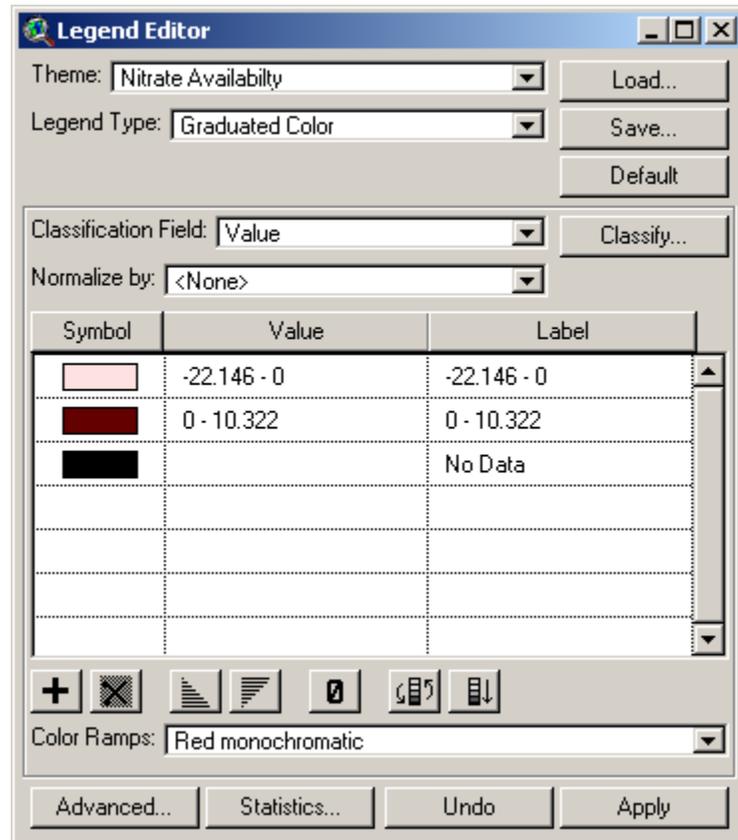
4. Click on the Evaluate Button 



4. Rename the Map Calculation 1 with an appropriate name so that you can identify the Nitrate Availability Theme. (Hint: Theme Properties)
5. We are only interested in two classes -- present or absent. Open the legend editor to change the classes from the default of 9 to 2.
 1. Open the legend editor
 2. Click on classify 
 3. Change the number of classes to 2
 4. Click Ok 

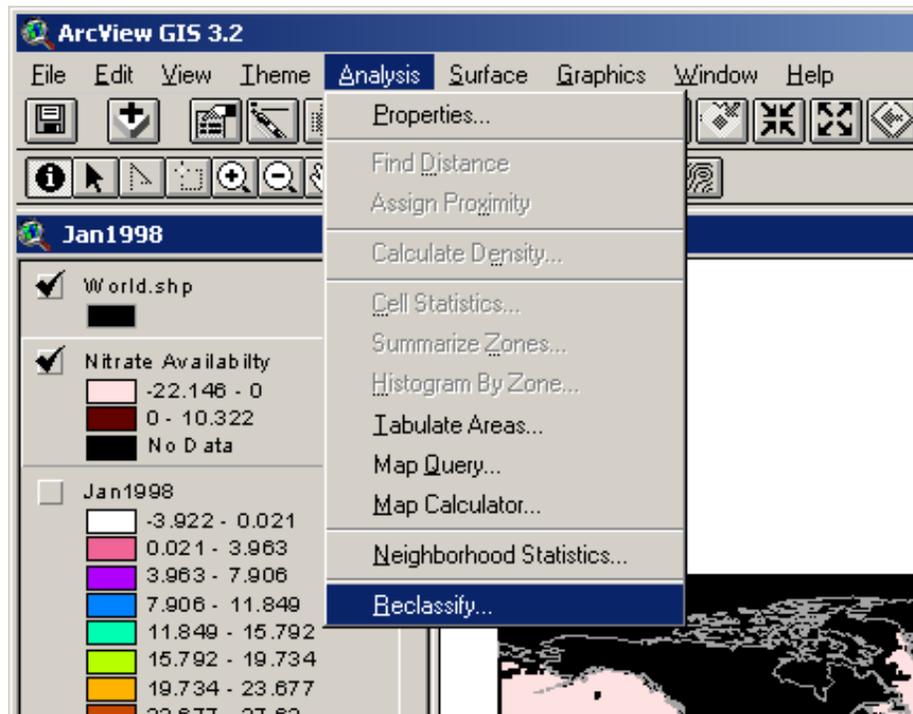


6. Change the values for each class so that there is a break at zero.
 1. Under Value change the class so it goes from the lowest value to zero (0)
 2. Under Value change the class so it goes from zero (0) to the highest value

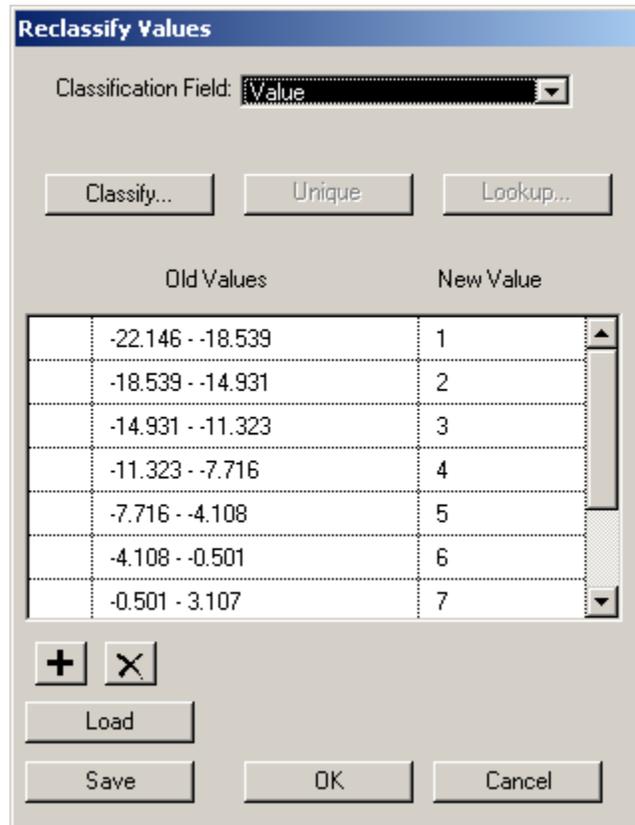


According to the ESRI Virtual Campus reclassification is the process of changing the values in a theme from one value to another. When you changed the values in the Legend Editor you only changed the display, not the actual Grid Theme. Performing reclassification creates a new grid theme using only the categories that you selected.

7. From the Analysis Menu Select Reclassify.



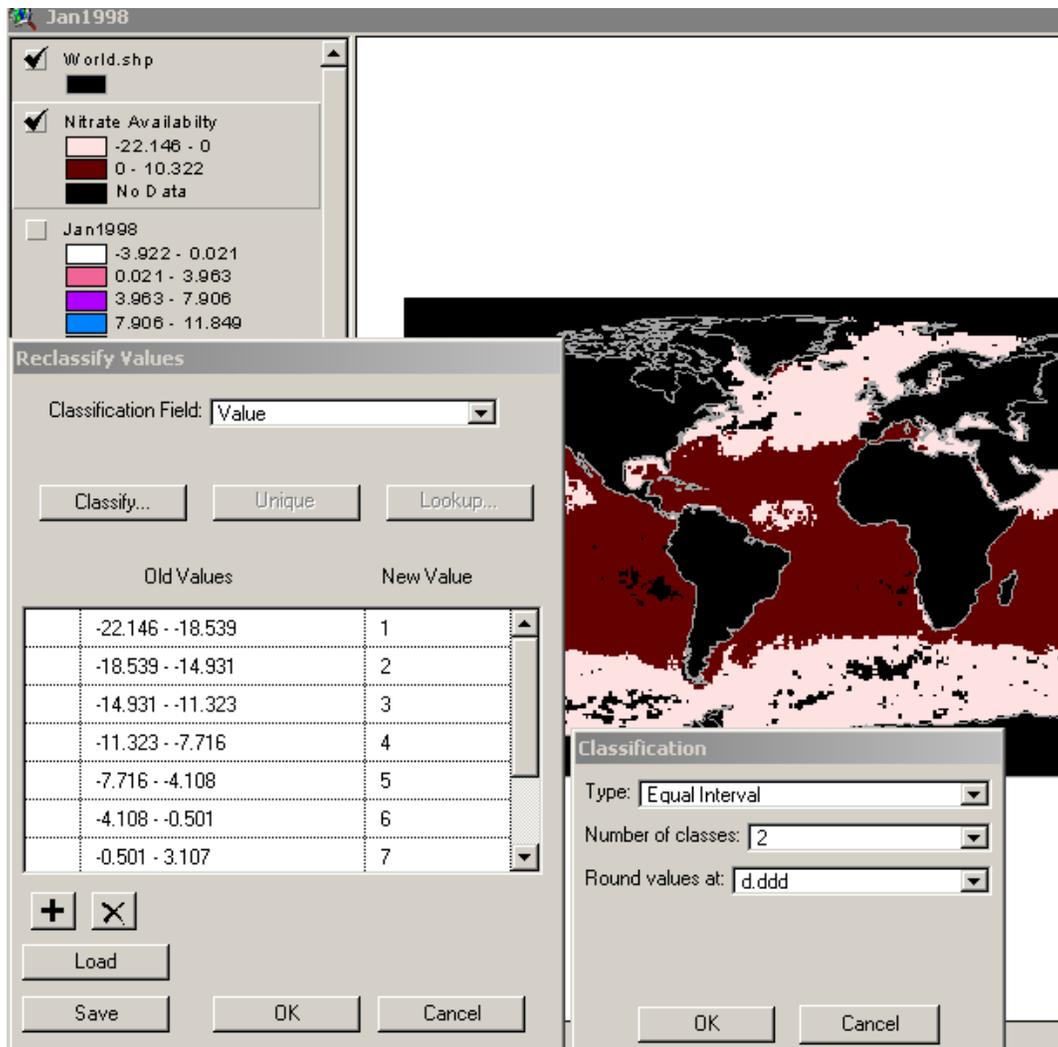
8. The Reclassify Values Dialog Box Will Open.



We are only interested in two classes present or absent.

9. In the Reclassify Values Dialog Box change the classes from the default of 9 to 2.

1. Click on classify
2. Change the number of classes to 2
3. Click Ok



10. Change the values for each class so that there is a break at zero.
 1. Under Old Values change the class so it goes from the lowest value to zero (0).
 2. Remember that a **NEGATIVE** value indicates the **PRESENCE** of the specific nutrient. Change New Values depending on the nutrient to:
 - a. 1 for Nitrate
 - b. 10 for Phosphate
 - c. 100 for Silicate
 3. Under Old Values change the class so it goes from zero (0) to the highest value
 4. Remember that a **POSITIVE** value indicates the **ABSENCE** of the specific nutrient. Change New Values depending on the nutrient to:
 - a. 2 for Nitrate
 - b. 20 for Phosphate
 - c. 200 for Silicate

Reclassify Values

Classification Field: Value

Classify... Unique Lookup...

Old Values	New Value
-22.146 - 0	1
0 - 10.322	2
No Data	No Data

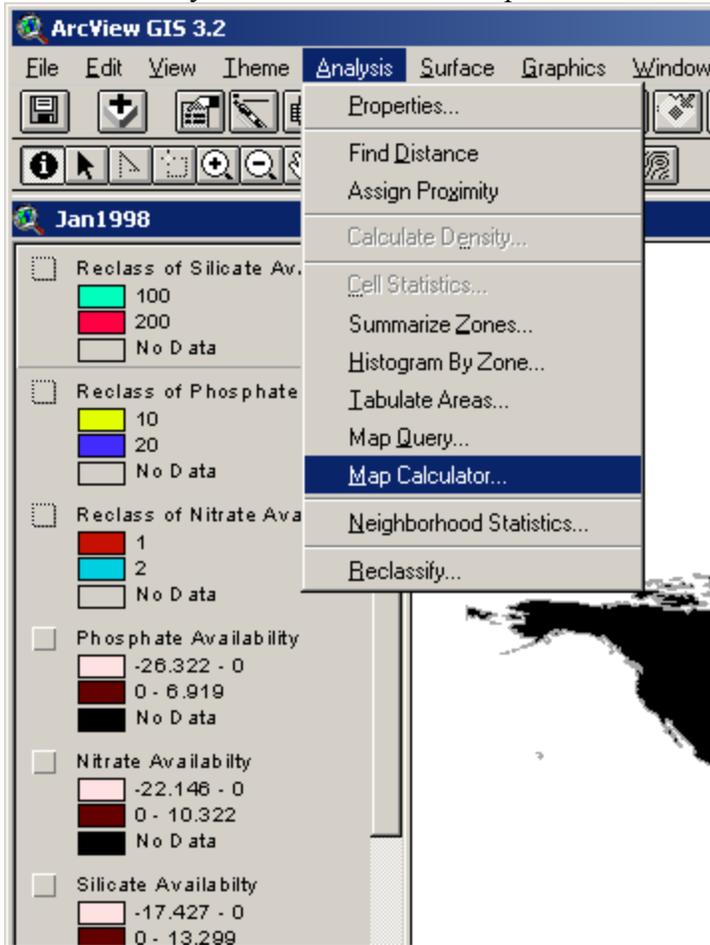
+ X

Load

Save OK Cancel

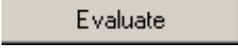
Repeat Steps 2 through 10 for each nutrient (Nitrate, Phosphate and Silicate).

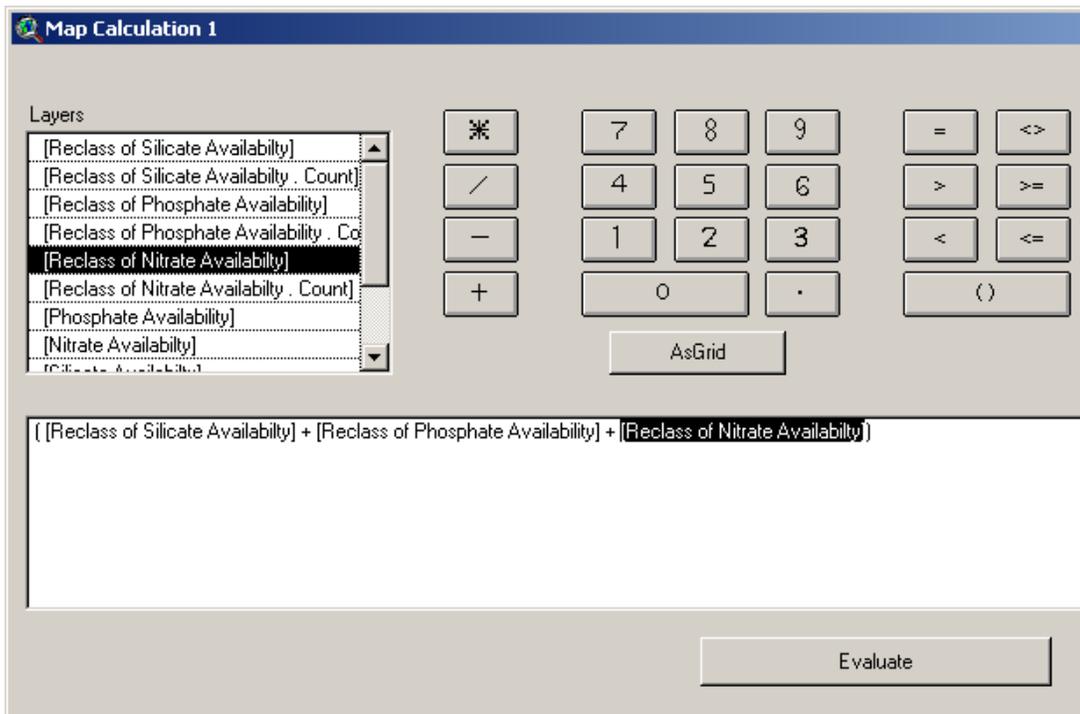
11. From the Analysis Menu Select the Map Calculator.



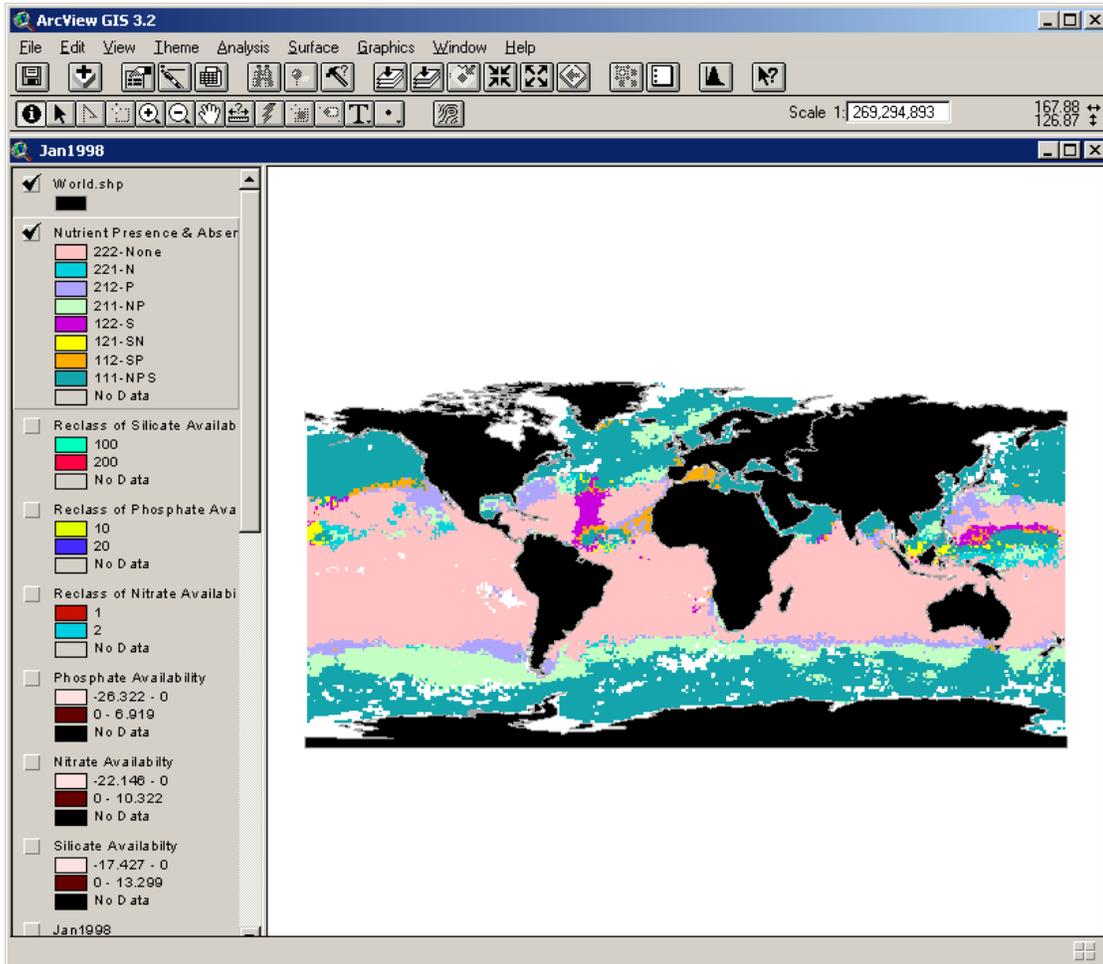
12. Using the Map Calculator create the expression:

$$([\text{Reclass of Silicate Availability}] + [\text{Reclass of Phosphate Availability}] + [\text{Reclass of Nitrate Availability}])$$

1. Under Layers - Double click on [Reclass of Silicate Availability]
2. Click on the Add button 
3. Under Layers - Double click the [Reclass of Phosphate Availability]
4. Click on the Add button 
5. Under Layers - Double click the [Reclass of Nitrate Availability]
6. Click on the Evaluate Button 

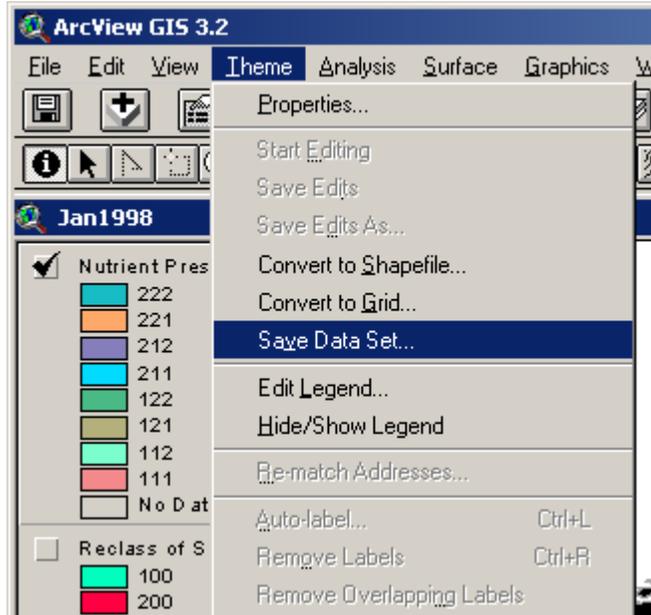


The final results of the nutrient composition grid should have a legend that contains 8 Categories. What does each of the 8 categories represent? Do you see any patterns from month to month? How might this affect the living things found there? How do climatic differences affect the living things found there?

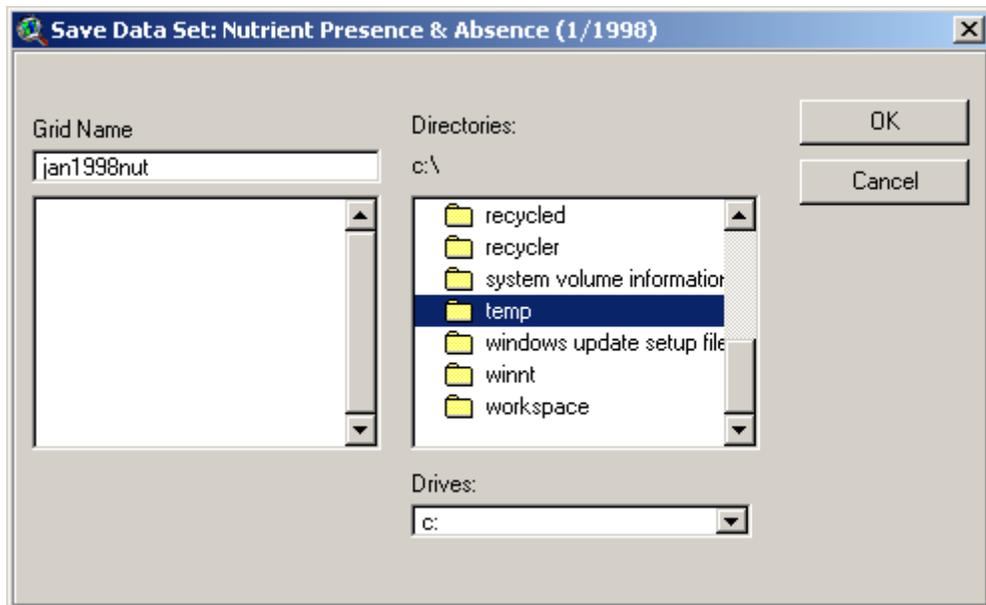


EXTENSION

1. Save your temporary grids as permanent grids and give them representative names. You can then use your permanent grids and Image Analyst to investigate change from month to month within the same year and between months in different years. When doing change detection, determine the question you want to investigate and the procedure before doing the calculations.



2. Name your grid and save it in a place that you will remember.



Appendix M: EVALUATION INSTRUMENT

EVALUATION

Thank you for completing the evaluation of the GIS Oceanography CD. Your detailed input will help to improve GIS educational materials in the future.

1. Demographic Information

1. Are you Male or Female? Type your answer here:

2. How many years have you been teaching? Type your answer here:

3. What grades are you currently teaching?

K 1 2 3 4 5 6 7 8 9 10 11 12 12+

Type the grade(s) you are currently teaching from the above list.

Grade(s):

4. I teach:

Geography Life Science Physical Science Earth Science Social Science Other: _____

Type all that apply:

5. How much Marine Science do you teach? In terms of time spent per year.

Type your answer here:

6. Describe the past experiences you have with Marine Science?

Type your answer here:

7. How much GIS do you teach and/or use in your classroom?

Use Very Infrequently

Use Quite Often

1

2

3

4

5

Type your answer here:

8. How comfortable do you feel using GIS to explain a topic?

Not Comfortable

Very Comfortable

1

2

3

4

5

Type your answer here:

Directions: Open the ReadMe file found in the Teacher Folder and read the METADATA to get a better understanding of what is on the GIS Oceanography CD before continuing with the evaluation.

2. Teacher Background – Read the Section “Teacher Background Information” in Teacher.doc

1. Rate the **Teacher Background** section in terms of organization.

Not Well Organized

Very Well Organized

1

2

3

4

5

Type your answer here:

2. Rate the **Teacher Background** section in terms of usefulness.

Not useful

Very useful

1

2

3

4

5

Type your answer here:

3. Describe how you would use this background information:
-

4. Describe how this information would help you communicate the relationship among nutrients, temperature, and phytoplankton in the ocean to your students:
-

5. Comments? Changes?
-

4. Student Instructions– Read the Student Instructions in Student.doc

1. Rate the **Student Instructions** in terms of organization.

Not Well Organized

Very Well Organized

1

2

3

4

5

Type your answer here:

2. Rate the **Student Instruction** section in terms of usefulness.

Not useful

Very useful

1

2

3

4

5

Type your answer here:

3. How well do you think a student could follow these instructions?

4. Comments? Changes?

5. PowerPoint Presentations– Examine the PowerPoint presentations in the Teacher folder looking at the slides as well as the notes.

1. Rate the **Presentations** in terms of organization.

Not Well Organized

Very Well Organized

1

2

3

4

5

Type your answer here:

2. Rate the **Presentations** in terms of usefulness.

Not useful

Very useful

1

2

3

4

5

Type your answer here:

3. What, if anything, would you like to see added to the presentations?
-

4. Describe how you would use these presentations in your classroom or teacher preparation:
-

5. Comments? Changes?
-

6. Web Pages— Examine the web page **Teacherlinks.html** found in the teacher folder. Read the **Teacher Section** as well as the **Student Section** (The student section contains the same information as what is contained in studentlinks.html).

1. Rate the **Web pages** section in terms of organization.

Not Well Organized

Very Well Organized

1

2

3

4

5

Type your answer here:

2. Rate the **Web pages** section in terms of usefulness.

Not useful

Very useful

1

2

3

4

5

Type your answer here:

3. Describe how you would use the web pages in your classroom:

Use the web pages to answer the following questions:

4. How would you define/describe El Niño?

5. What are phytoplankton and why are they so important?

6. What is remote sensing?

7. What is the basic principle behind the remote sensing of ocean color from space?

8. How difficult was it to find answers to questions 6-9 using the web pages?

Very Difficult

Very Easy

1

2

3

4

5

Type your answer here:

Type any written comments here:

9. Comments? Changes?

7. GIS Projects– Follow the Student Instructions in Student.doc to perform the described GIS lesson using the data for the month of January 1998.

1. Rate the **GIS Projects** in terms of organization.

Not Well Organized

Very Well Organized

1

2

3

4

5

Type your answer here:

2. Rate the **GIS Projects** in terms of usefulness.

Not useful

Very useful

1

2

3

4

5

Type your answer here:

3. Describe how you would use these projects in your classroom:
-

4. What patterns do you see in the distribution of the nutrients?
-

5. Describe any individual nutrient patterns that you see:
-

6. How might this affect the living things found in the ocean?
-

7. How difficult was it to use **only** this project to answer questions 4-6?

Very Difficult

Very Easy

1

2

3

4

5

Type your answer here:

Type any written comments here:

-
8. List three hypotheses that you could investigate using this project:
- 1.
 - 2.
 - 3.

-
9. How difficult was it to use this project **and** the web pages to create hypotheses in question 8?

Very Difficult

Very Easy

1

2 3 4

5

Type your answer here:

Type any written comments here:

-
10. Comments? Changes?
-

8. Overall

1. Rate the GIS Oceanography CD in terms of organization.

Not Well Organized

Very Well Organized

1

2

3

4

5

Type your answer here:

2. The organization of the CD made the resource easy to use.

Strongly Disagree

Disagree

Neutral

Agree

Strongly Agree

1

2

3

4

5

Type your answer here:

3. Rate the resource in terms of usefulness.

Not useful

Very useful

1

2

3

4

5

Type your answer here:

4. The materials and activities are written at a level appropriate for a middle and high school audience.

Strongly Disagree

Disagree

Neutral

Agree

Strongly Agree

1

2

3

4

5

Type your answer here:

5. These materials address my needs to teach to the local, state, and national standards in **Science**.

Strongly Disagree

Disagree

Neutral

Agree

Strongly Agree

1

2

3

4

5

Type your answer here:

6. These materials address my needs to teach to the local, state, and national standards in **Geography**.

Strongly Disagree

Disagree

Neutral

Agree

Strongly Agree

1

2

3

4

5

Type your answer here:

7. What do you think your students would gain by using these materials? Please explain conclusions.

8. Are there any activities, background information, or resources for teachers and students that you recommend adding to these materials? Please include references for your suggestions.

9. Technology limitations aside, how would you use this resource in your classroom? Type your answer here:

10. What part of the resource was most useful and why? Type your answer here:

11. What part of the resource was least useful and why? Type your answer here:

12. What difficulties do you anticipate in the use of this resource CD in your teaching? Type your answer here:

13. How do you think this resource will help you develop activities for your own classroom?

-
14. The GIS Oceanography CD communicated the relationship between the physical and the biological components of the ocean.

Strongly Disagree Disagree Neutral Agree Strongly Agree
1 2 3 4 5

Type your answer here:

-
15. List 3 principles that you learned about the relationship between the physical and the biological components of the ocean using the GIS Oceanography CD:

- 1.
- 2.
- 3.

-
16. I gained a better understanding of the relationship between the physical and the biological components of the ocean.

Strongly Disagree Disagree Neutral Agree Strongly Agree
1 2 3 4 5

Type your answer here:

-
17. I believe that students can use the GIS Oceanography CD to gain a better understanding of the relationship between the physical and the biological components of the ocean.

Strongly Disagree Disagree Neutral Agree Strongly Agree
1 2 3 4 5

Type your answer here:

-
18. Suggestions for improvement:
-

Appendix N: MULTIMEDIA TOOL EVALUATION RESULTS

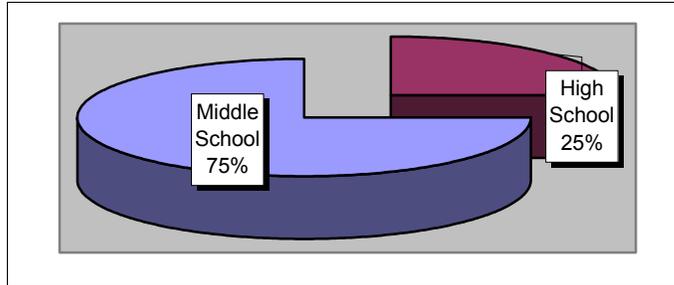


Figure N-1: Grade Level Taught by Evaluator Percent Composition

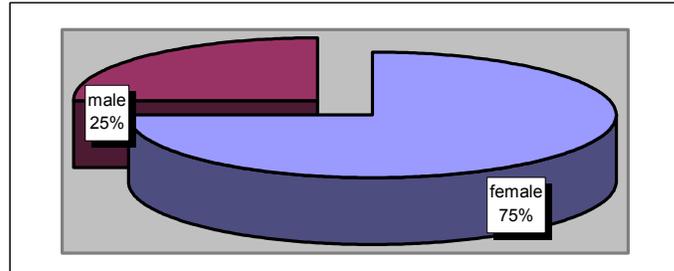


Figure N-2: Evaluator Gender Percent Composition

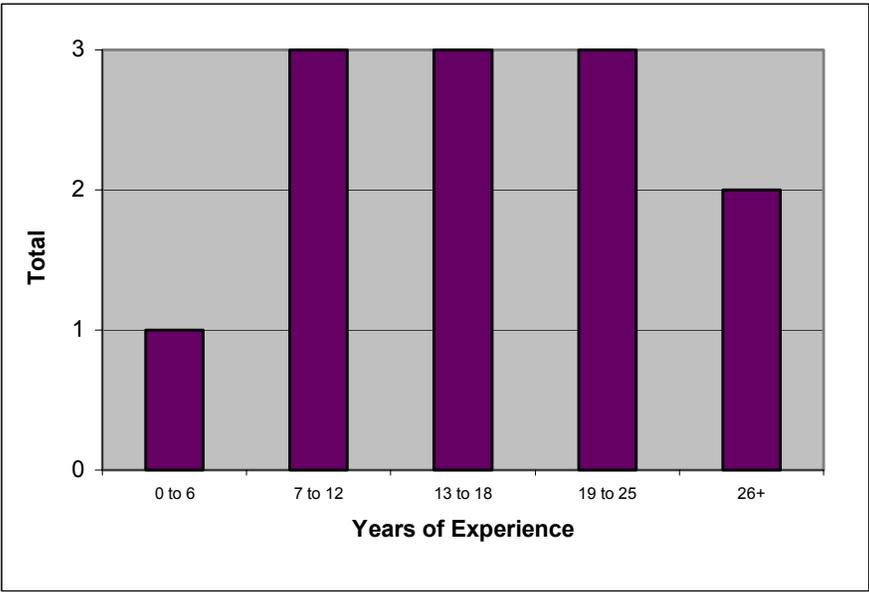


Figure N-3: Amount of Teaching Experience in terms of Years Teaching

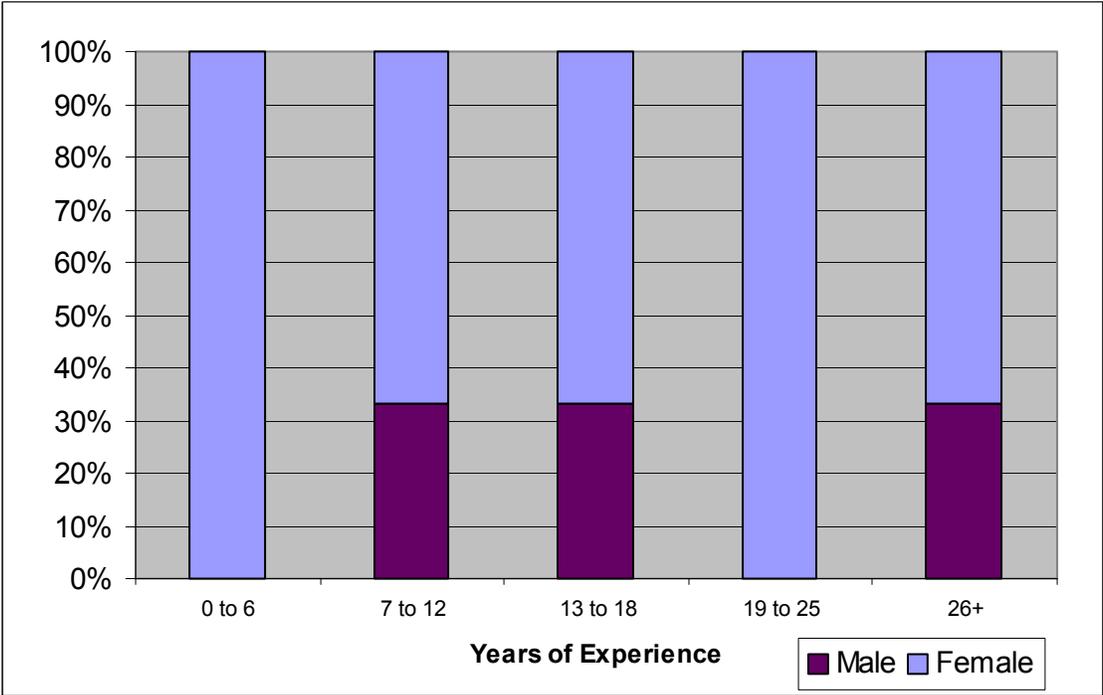


Figure N-4: Amount of Teaching Experience in terms of Years Teaching by Gender

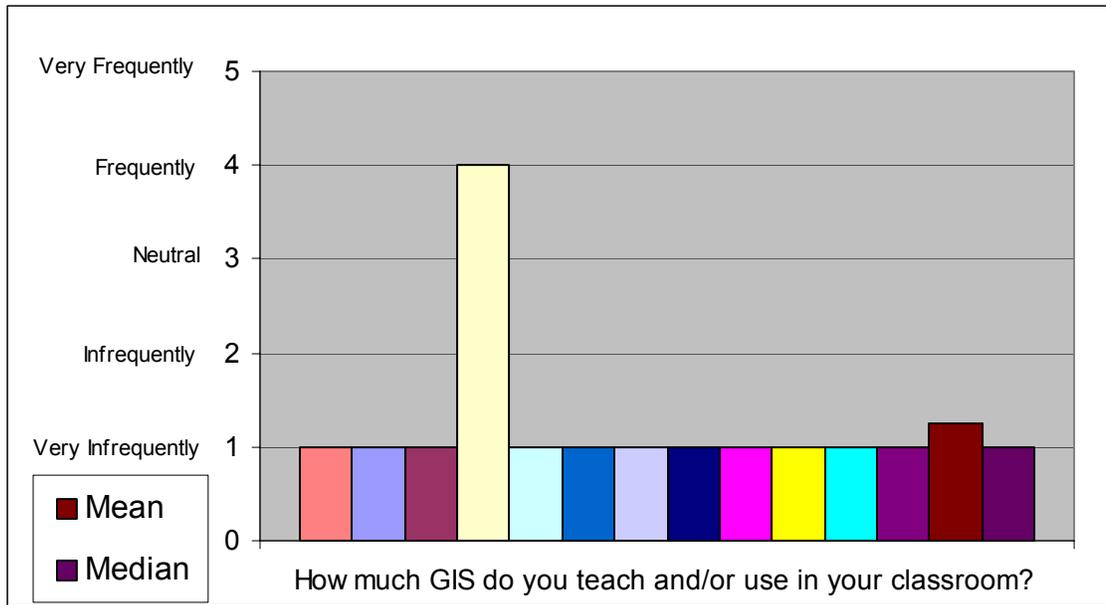


Figure N-5: Amount of GIS classroom use per teacher and by average

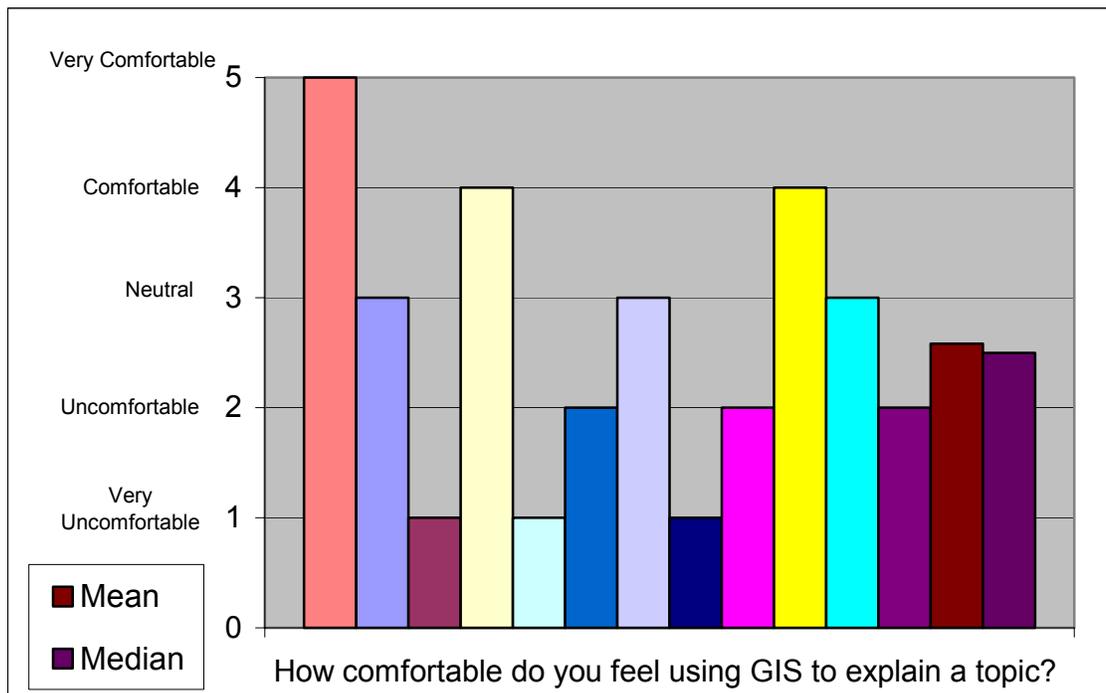


Figure N-6: Level of Comfort using GIS to explain a topic per teacher and by average

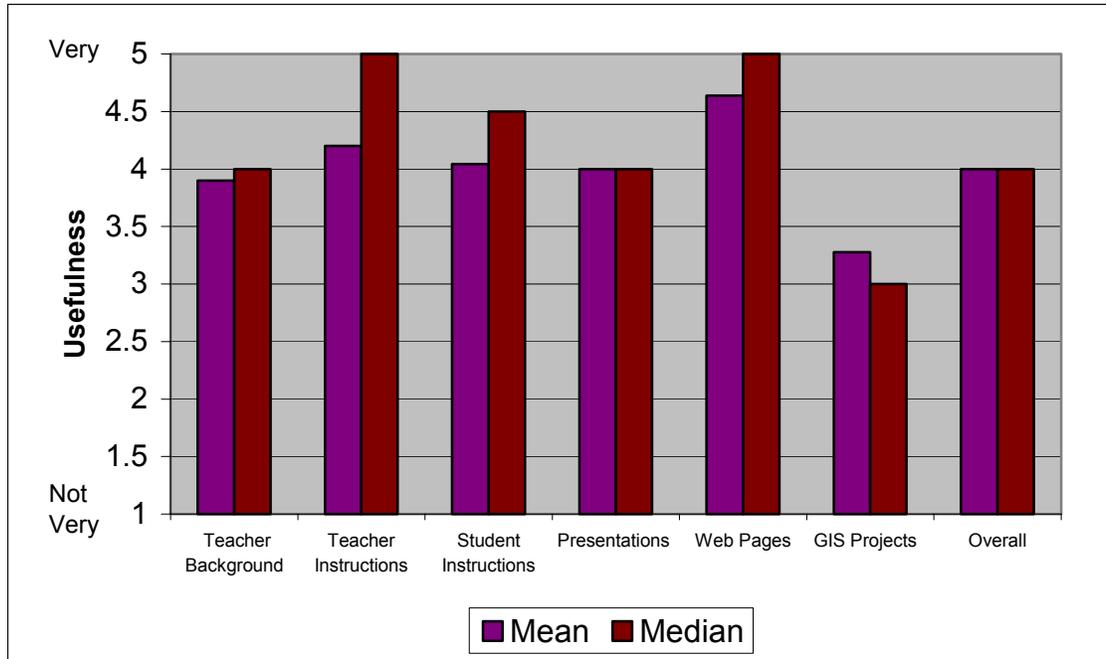


Figure N-7: Average Level of Usefulness of each component of the Educational CD-ROM multimedia tool

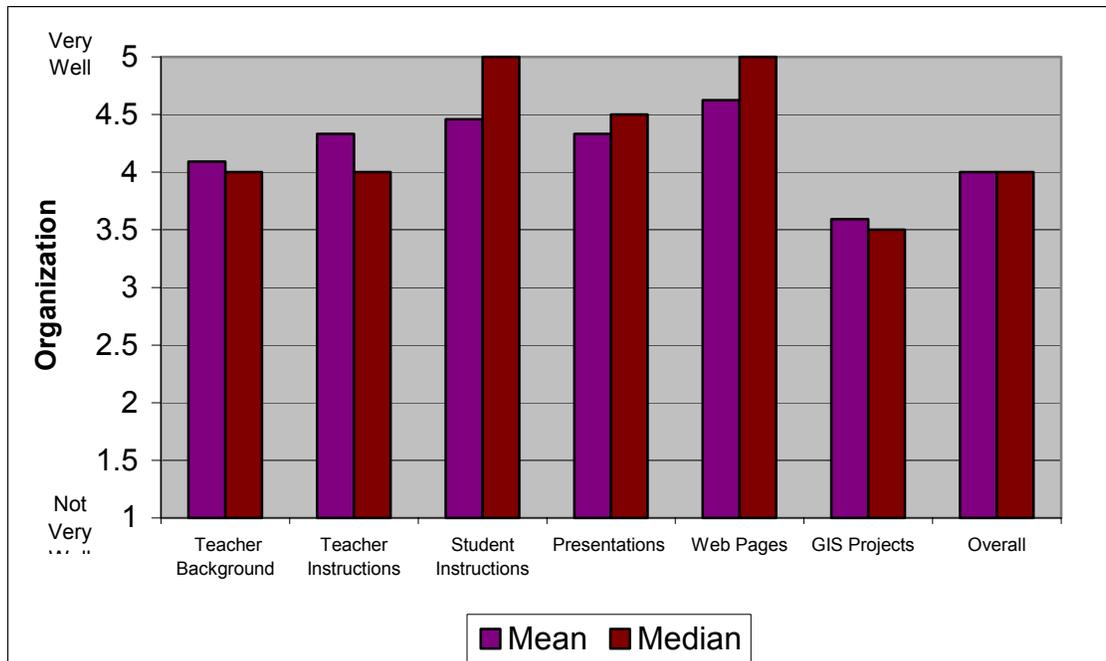


Figure N-8: Average Quality of Organization of each component of the Educational CD-ROM multimedia tool

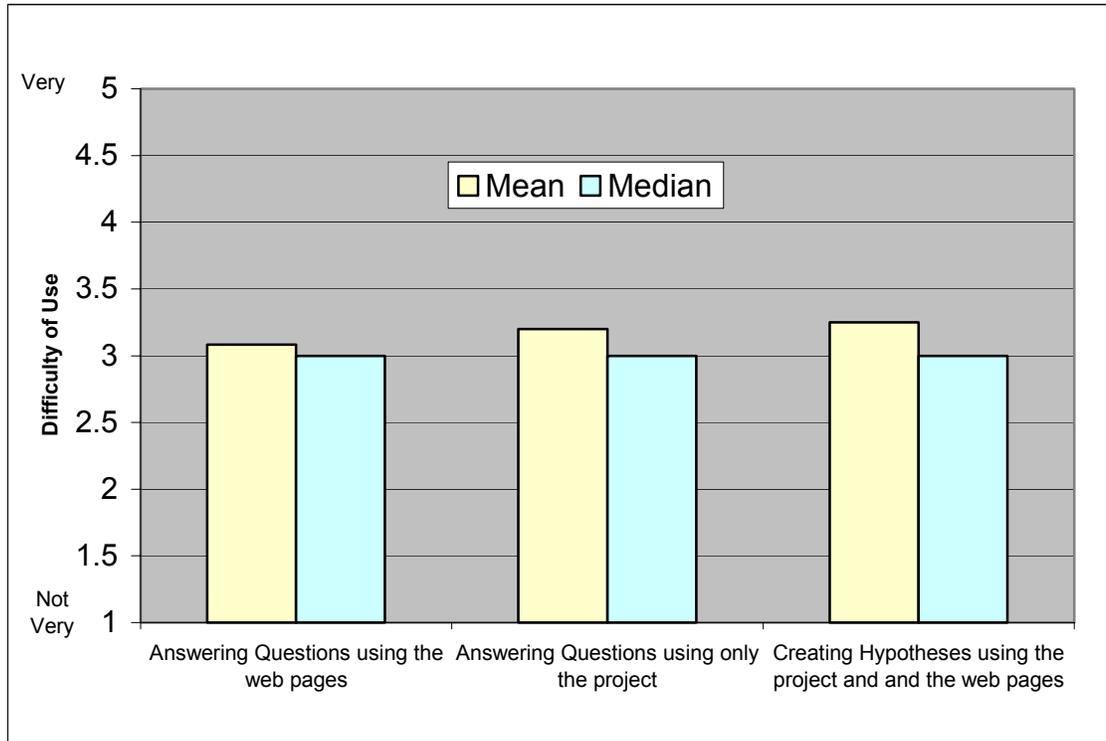


Figure N-9: Average difficulty answering questions utilizing different components of the Educational CD-ROM multimedia tool

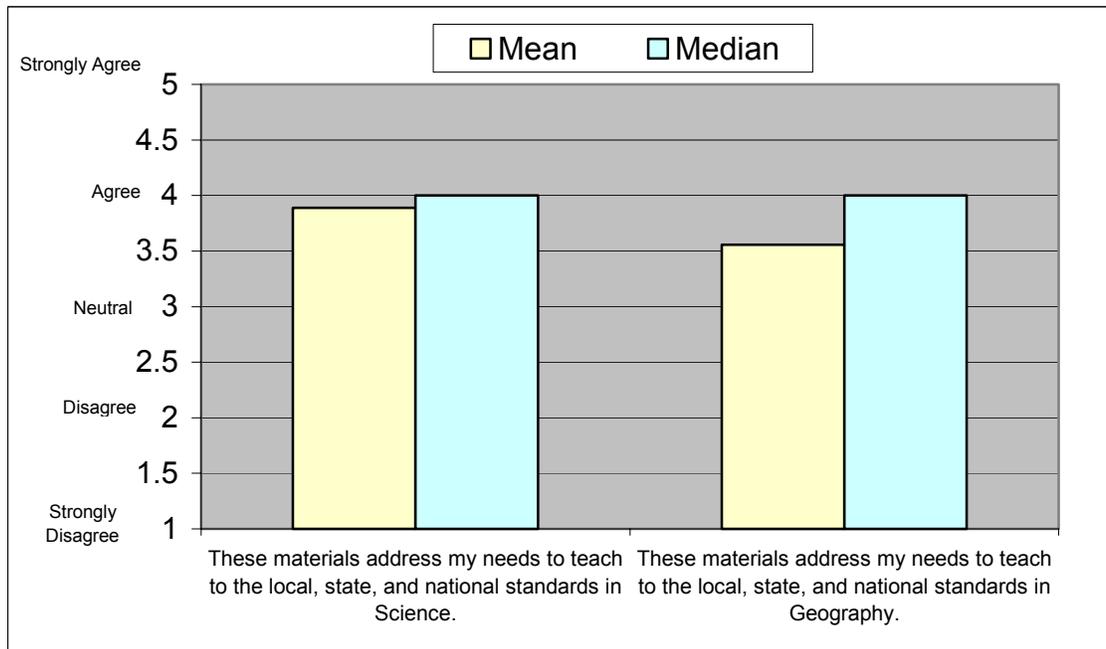


Figure N-10: Average quality level of the Educational CD-ROM multimedia tool to address the needs of the classroom

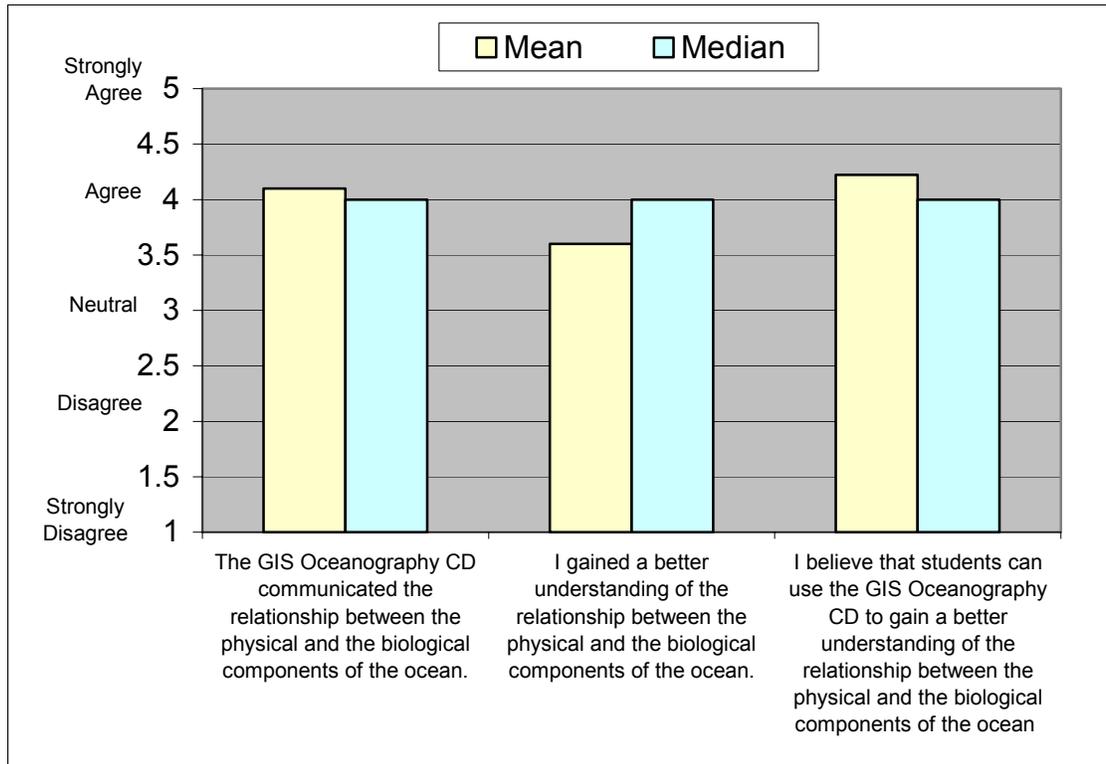


Figure N-11: Average quality level of the communication of content of the Educational CD-ROM multimedia tool