

GIS and Fish Population Dynamics

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The development and use of Geographical Information Systems in the marine environment lagged behind its use in terrestrial systems in the early stages of GIS, primarily due to the difficulty in obtaining spatially detailed data for the physical and biological parameters in aquatic systems. More recently, though, GIS is becoming an increasingly important tool in oceanographic research. In this paper I will focus on the current and potential uses of GIS in fisheries research, and look at how GIS can be used in investigating questions relating to fish population dynamics.

The increasing importance of GIS in the field was nicely illustrated by Fisher and Toepfer (1998) in their survey of the role of GIS in fisheries education and research in 24 U.S. universities. The responses to their questionnaire indicated that 96% of fisheries students at these universities were taking introductory and advanced GIS courses, and that 48% of students were taking courses in applying GIS to natural resource sciences.

The responses to the survey also indicated an expansion of the use of GIS into new areas in fisheries research. Traditional uses for GIS were mostly *descriptive*, such as mapping fish distributions and aquatic habitats. As larger amounts of suitable spatial data become available, *prescriptive* uses are becoming more common. Modeling of potential fish distributions, forecasting changes in habitat suitability, developing efficient sampling designs and integrating information for use as an aid to management are some of the new ways that GIS is being implemented in fisheries research (Fisher and Toepfer, 1998).

Amendments to the Magnuson-Stevens Fishery Conservation and Management Act in 1996 required that U.S. government fishery agencies protect and preserve "essential fish habitat". These habitats were defined as those areas necessary to fish for spawning, breeding or growth. It was implicitly assumed that there was a positive relationship between the quantity of fish habitat and fish abundance or productivity, following the principles of MacCall's basin model (MacCall, 1990). This amendment produced a large volume of work describing areas of essential habitat for various commercially important fish species, and many of these studies relied heavily on GIS applications to gather, analyze and present the data (Valavanis et al., 2004).

More recently, GIS analysis of fish habitat has become more sophisticated, often combining numerical or statistical models of fish abundance, growth and prey availability with the physical characteristics of the habitat in a GIS framework. These combined models can be used to produce predictions of fish abundance in space or time (Le Pape et al., 2003). Targeted sampling can then be used to test the robustness of the predictions. This approach was successfully used by Stoner et al. (2001) in analyzing estuarine habitat use of juvenile winter flounder, a commercially and recreationally important species.

The role of GIS in studies of fish population dynamics has been relatively minimal, but recently, some new lines of research have started to show the advantages of integrating GIS technologies into spatial dynamics of populations. Bioenergetics modeling attempts to relate prey size, prey density and water temperature to fish production and historically has been done for an entire area where a species is found (i.e. the growth rate for Atlantic menhaden in Chesapeake Bay). However, smaller scale variation in prey densities, physical factors and density-dependent processes such as predation can cause large changes in fish growth and production that would be missed by only using large-scale "average" values. By linking the bioenergetics models to a GIS

framework, however, rates of growth and production can be calculated for smaller areas and different times. Maps can be produced for an area such as Chesapeake Bay which indicate areas and depths most important for fish growth. If a series of maps are produced using data throughout a seasonal cycle, particular times of the year may become apparent as most important for the growth of that species (Brandt et al., 1992, Mason et al., 1995).

The development of these GIS-based analyses in marine environments has been slow compared to terrestrial environments because of the difficulty in obtaining spatial data on habitats or organisms in subsurface environments. Advances in wide-scale data collection will help greatly in advancing marine GIS. Acoustics is a developing technology that is one of the only (and best) ways of obtaining high resolution, spatially detailed data on fish or zooplankton distributions. Acoustic data measure volumes, and through data manipulation can be easily converted into 2- or 3-D GIS (Brandt et al., 1992). Other methods for obtaining spatial data in the marine environment include side-scan sonar for mapping benthic habitats (McRea et al., 1999), towed sensors such as video or optical plankton counters (Herman, 1992) and CTDs, and for small and/or shallow areas, orthophotographs and good old fashioned field work (Eklov, 1997).

A common theme that was apparent in a large percentage of the papers that I found regarding GIS in fisheries research was the use of GIS as a tool for fisheries management. GIS allows researchers to present data in an easily interpreted, user-friendly and web-accessible format which makes communication with coastal and fisheries managers much easier. GIS makes it easy to combine very different data types, such as socio-political boundaries, land use, habitat types, and fish distributions so that managers can more easily make educated and informed decisions (Stanbury and Starr, 1999). In one case that I found (Maury and Gascuel, 1999), a GIS-based simulator of a marine ecosystem complete with a "smart" fishing fleet was developed as an exploratory management tool to investigate the effects of marine reserves on fisheries and fish populations. Since management of fisheries resources will continue to be a "hot topic" far into the future, the use and importance of GIS in fish population dynamics will continue to grow.

Annotated Bibliography

Fisher, W. L. and C. S. Toepfer. 1998. Recent Trends in Geographic Information Systems Education and Fisheries Research Applications at U.S. Universities. *Fisheries* 23(5): 10-13.

This paper presents the results of a survey conducted by the authors on the use of GIS in fisheries education and research at U.S. universities and provides a nice overview of the status of GIS in the field (at least in 1998). The authors found that nearly all fisheries students (96%) are taking introductory and advanced GIS classes, and that 21-40% of fisheries students and researchers use GIS at least occasionally in their research. Traditionally, GIS in fisheries has primarily been used for descriptive uses such as mapping of fish distributions and habitats. However, GIS use is expanding into other uses such as modeling of potential fish distributions, habitat change forecasting, improving sampling schemes and integrating social and economic information.

Johannsson, O. E. 1995. Response of *Mysis relicta* Population Dynamics and Productivity to Spatial and Seasonal Gradients in Lake Ontario. Canadian Journal of Fisheries and Aquatic Science 52: 1509-1522.

This paper analyzed spatial and temporal patterns of several dynamic population parameters of a mysid shrimp (*Mysis relicta*) in relation to predation and physical conditions in Lake Ontario. Abundance data for mysids was first examined using a GIS, with each sampling station assigned to an area of the lake based on the nearest neighbor technique. While this would be a good way to examine patterns in abundance data, in this instance the distribution of mysids was not correlated geographically, but with depth. A more detailed sampling scheme within the depth range most frequented by mysids might allow for more investigation using GIS; for instance, if good bathymetric maps of the area were available, correlations between abundance and habitat structure could easily be made. In Lake Ontario the large size of the sampling area would probably make this not feasible.

Eklov, P. 1997. Effects of Habitat Complexity and Prey Abundance on the Spatial and Temporal Distributions of Perch (*Perca fluviatilis*) and Pike (*Esox lucius*). Canadian Journal of Fisheries and Aquatic Science 54: 1520-1531.

Temporal variation in the habitat distribution of two common freshwater fish species was examined in this paper. Although GIS was not used in this study, I think it is a good example of when using GIS might be helpful in determining these types of biological-physical interactions. In this case the physical structure of the lake's habitats was quantified using aerial photographs, and fish distributions were correlated to habitat structure to try and determine the effects of structure on fish behavior and foraging. Although the author did a very nice job of presenting the data, other correlations or interactions might have been picked up if the data had been presented spatially rather than numerically. Also, the GIS data might help in selecting better sampling sites for future studies.

Mason, D. M., A. P. Goyke and S.B. Brandt. 1995. A Spatially Explicit Bioenergetics Measure of Habitat Quality for Adult Salmonines: Comparison Between Lakes Michigan and Ontario. Canadian Journal of Fisheries and Aquatic Science 52: 1572-1583.

This is a very nice comparative study that uses a combination of acoustical measures of prey fish, physical measurements of temperature, and mechanistic foraging and bioenergetics models to determine the growth rate potential for two economically and environmentally important fish species in Lakes Michigan and Ontario. The outputs of this complex study are a series of maps that provide a visual representation of the "scope for growth" of the two fish species in time and space. This can be used as an indicator of habitat quality, changes in which can be simulated by varying model parameters. Again, GIS is not explicitly used here, although the maps are raster format representations of information in a spatial setting. This information presented in a user-friendly GIS format could be an excellent way to convey the results of this modeling effort to the public for use in management issues.

Maury, O. and D. Gascuel. 1999. SHADYS ('Simulateur Halietique de Dynamiques Spatiales'), a GIS Based Numerical Model of Fisheries. Example Application: the Study of a Marine Protected Area. Aquatic Living Resources 12(2): 77-88.

SHADYS is a virtual laboratory which couples three entities: the environment, fish populations and the fishing fleet. Numerical models representing these entities are interfaced with a GIS to aid in visualizing the results. In this example, a marine reserve was modeled and the effects of fishing outside the borders of the reserve were evaluated for different fish populations with varying levels of movement in and out of the reserve. The benefit of such a simulator is that it allows rapid assessment of various scenarios that would be impossible to test in the field. The simulator does not pretend to accurately represent reality, but is a useful way to test our knowledge of reality. The GIS component allows for a user-friendly graphical interface which, while not spatially referenced in this example, could be used in a real-world example.

Le Pape, O., F. Chauvet, S. Mahevas, P. Lazure, D. Guerault and Y. Desaunay. 2003. Quantitative Description of Habitat Suitability for the Juvenile Common Sole (*Solea solea*, L.) in the Bay of Biscay (France) and the Combination of Different Habitats to the Adult Population. *Journal of Sea Research* 50: 139-149.

One of the major uses for GIS in fish population dynamics is in the identification of habitats that are important spawning or nursery grounds for commercially or environmentally critical species. This paper combines a habitat suitability model for juvenile sole with physical environmental parameters in a GIS format to determine areas along the coast of the Bay of Biscay that are most important in supporting juvenile sole recruitment. The authors of this study were fortunate to have detailed maps of bathymetry and sediment structure, a detailed hydrodynamic model and a long time series of trawl data. Combining these data sources, they produced an estimate of the contribution of different habitats to total sole stock.

Stoner, A. W., J. P. Manderson, and J.P. Pessutti. 2001. Spatially Explicit Analysis of Estuarine Habitat for Juvenile Winter Flounder: Combining Generalized Additive Models and Geographic Information Systems. *Marine Ecology Progress Series* 213: 253-271.

This paper's goals were similar to those of the preceding paper (Le Pape et al. 2003). In this case the authors used trawl data for juvenile winter flounder and environmental data in a generalized additive model (GAM) whose output was combined with a GIS. They produced maps of the probability of catching fish of a certain size in a given area. This investigation identified two important areas for larval flounder settlement in the study area, and also showed that nursery locations shift dramatically as the juvenile fish grow. Independent test trawls after completion of the models showed that the combined GAM/GIS method had good predictive capability.

Luo, J., K. J. Hartman, S.B. Brandt, C.F. Cerco and T.H. Rippetoe. 2001. A Spatially-Explicit Approach for Estimating Carrying Capacity: An Application for the Atlantic Menhaden (*Brevoortia tyrannus*) in Chesapeake Bay. *Estuaries* 24(4): 545-556.

This paper also combines several models, in this case a three-dimensional water quality model, a foraging model and a bioenergetics model for Atlantic menhaden to provide a measure of spatially explicit carrying capacity. The analysis showed that environmental conditions caused two bottlenecks which could affect production of young menhaden, and potentially provides scientists and managers a way to estimate the effects of

changing water quality on fisheries. The principal use of GIS in this investigation was in the spatial analysis component, although the GIS output could be easily modified for use as a management or learning tool.

Hook, T. O., E. S. Rutherford, S.J. Brines, D.M. Mason, D.J. Schwab, M.J. McCormick, G.W. Fleischer, and T.J. DeSorcie. 2003. Spatially Explicit Measures of Production of Young Alewives in Lake Michigan: Linkage Between Essential Fish Habitat and Recruitment. *Estuaries* 26(1): 21-29.

This paper is similar to the preceding one (Luo et al., 2001) in that it uses a combination of modeling and GIS to identify critical habitat for juvenile fish but takes the concept one step further. Here, the authors distinguish between “high quality” habitat, which are areas defined by the modeling process as being highly suitable for juvenile fish growth, and “important” habitat, which are areas where the species density is high. These areas may or may not overlap if other factors not included in the determining models (such as predation, or if the area of “ideal” habitat is small) are involved. Temperature data for this study was obtained from AVHRR data, and the results of the modeling were presented graphically.

Additional References:

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Valavanis, V. D., S. Georgakarakos, A. Kapantagakis, A. Palialexis and I. Katara. 2004. A GIS Environmental Modelling Approach to Essential Fish Habitat Designation. *Ecological Modelling* 178: 417-427.