The Contribution of Geospatial Technology to Elasmobranch Management

Sharks and rays have been steadily fished in the United States for decades (Kohler et al. 1998). The most highly sought species are the blacktip shark and the sandbar shark, but fisheries for other species (e.g., batoid rays) are expanding (Cartamil 2003, Grace and Henwood 1997). Successful stock assessment and management requires highly-supported estimates of life history parameters such as fecundity, recruitment, growth, and mortality. However, without an understanding of spatial dynamics (e.g., range, migration, fine-scale movement, habitat partitioning, and segregation), management efforts would be incomplete. Over the past two decades, geospatial technology has risen to the challenge of informing management about these complex spatial dynamics.

GIS technology has predominantly been used to map the distribution of sharks and rays. To that end, vector-based models are most often used (Kohler et al. 1998). However, the literature has seen an evolution of data presentation, from simple point representations of catch sites to point representations of Catch-Per-Unit-Effort (CPUE) to interpolated raster maps of CPUE to raster maps of density and model variance. Kriging has been an important procedure for generating these raster maps, although Theissen polygons have also been used (Machado et al. 2004). In addition to simply mapping distribution, some papers investigate movement on small and large scales (Kohler et al. 1998, Cartamil et al. 2003). Recently, authors have used GIS to investigated sex-specific, age-specific, and species-specific habitat partitioning of elasmobranchs (Abella and Serena 2005, Pikitch et al. 2005, Martin et al. 2010). The following paragraphs serve as a brief introduction to major changes in this field over the last two decades.

The earliest way that geospatial technology informed elasmobranch management was through the use of spatial distribution maps. The seminal work of elasmobranch spatial distribution is Kohler et al. (1998). The GIS program MapInfo was used to create simple plots of tag and recapture locations. Relatively little quantitative data was derived from these maps, but these vector-based visualizations represented a crucial first step in informing fisheries
management. Kohler et al. (1998) can be considered the “go-to” work on shark distribution maps; numerous papers and stock assessment reports have cited it. Nevertheless, generating point maps of catch events is only one of thousands of possible applications of geospatial technology.

The next step in evolution of this field is combining spatially-based catch data with other datasets. Pikitch et al. (2005) layered CPUE data (a proxy for abundance) with habitat data. With the help of ArcMap 9.0, the authors were able to find evidence for age-specific and species-specific habitat partitioning. Younger individuals tend to occupy lagoons, while older individuals tend to occupy offshore reefs. The implication for elasmobranch management is that conserving diverse habitats should become a high priority.

Vector based models of abundance have several strengths, but management would benefit even more from a continuous raster surface of abundance. Abella and Serena (2005) were the first authors to plot CPUE as a continuous surface for elasmobranchs. The elegance of this type of data presentation leaped forward with Martin et al. (2010), who interpolated spatial distribution maps of elasmobranchs in the English Channel. The authors created presence probability maps for species with low sample size, and density maps for those with a larger sample size. Because the authors interpolated through kriging method, a variance (error) surface was also provided. The authors modeled the data separately for males and females, finding positive evidence for sexual segregation in the small-spotted catshark. The extensive information is an impressive accomplishment for geospatial technology.

Geographic Information Systems have had the largest impact on elasmobranch management, but remote sensing has also been used for this purpose. Acoustic Telemetry is the most popular form of remote sensing in the study of elasmobranchs. This technology allows scientists to track the fine-scale movements of fish that are unobservable without this technology. The diel movements of benthic batoids were virtually unknown before Cartamil et al. (2003) investigated them. Acoustic telemetry also has been used to map movements of blacktip sharks within Terra Ceia Bay, Fl (Heupel et al. 2003, Heupel 2007). It is likely that this approach toward fine-scale spatial monitoring will expand in the near future.
While much of the literature focuses on the elasmobranchs themselves, Machado et al. (2004) uses GIS to analyze optimal fishing practices. This paper was focused on maximizing yield of kitefin sharks in the Azores. They used RDMS and thematic layering in MapInfo to optimize fishing strategies. Bathymetry was interpolated into a raster surface with Inverse‐Distance Weighting. Raster math was used to create a “friction” surface to model factors such as bathymetry, land, catch, and other factors. The friction surface was used to generate a raster surface that models cost of movement between pixels. This cost surface was then used to calculate an optimal fishing path that maximizes yield relative to the factors considered. The same technology that optimizes travel routes in motor vehicles is used to optimize fishing.

Data for these papers has come from a great variety of sources, including fisheries‐independent scientific surveys, commercial harvest reports, and even private landings. Most of the data comes from highly‐controlled, fisheries‐independent experiments and surveys (Cartamil et al. 2003, Pikitch et al. 2005, Abella and Serena 2005, Martin et al. 2010, Wiley and Simpfendorfer 2007). Some papers used commercial fisheries catch data (Machado et al. 2004, Abella and Serena 2005). One study was supplemented by opportunistic surveys of fish markets (Pikitch et al. 2005). Perhaps the most unique data source is the Cooperative Shark Tagging Program used by Kohler et al. (1998). This program relies on volunteer data submission from recreational and commercial fishermen around the world. As a result, this database represents one of the largest tag‐recapture databases for sharks in the world (Wood et al. 2007). In a world of open‐source mapping and crowd‐sourcing, it is possible that programs like the CSTP are the way of the future.

The future of geospatial technology in elasmobranch management is bright. The recent use of acoustic telemetry opens the door for extensive fine‐scale mapping of diel movement patterns. In addition, I expect to see many more papers that create continuous raster maps of fish density. Martin et al. (2010) were able to successfully extend this concept to demonstrate evidence for sexual segregation. This approach should be applied to as many stocks as possible, data permitting. The next step is creating models that explicitly consider environmental variables such as substrate, temperature, and salinity. These models could be critical in predicting changes to distribution caused by climate change.
Knowing the location, movements, and spatial abundance patterns of a stock is critical to successful management. Through a quick survey of the use of geospatial technology, we find that each advance in technology permits multiple advances in applied research. It is truly exciting to imagine how GIS and remote sensing will be used in this field in five, ten, and twenty years in the future.

References


Abella and Serena analyzed catch per unit effort data for elasmobranch species in the Mediterranean Sea. They compared abundance patterns from two sources of data: commercial landings and scientific research trawls. The spatial distribution was analyzed with the Mapper of Landed Fish Data (MLFD) application in ArcView GIS. The researchers focused their efforts on four species (two rays and two sharks), and showed that the species seemed to partition geographic space. Furthermore, the researchers were able to combine outside knowledge of spatial distribution of potential prey species (i.e., hake) in order to explain distribution of two species, *S. canicula* and *R. clavata*. This paper is a very informative exploration of two sources of abundance data, and it included several useful key pieces of information for management (e.g., temporal trends in abundance and length-frequency distribution). However, I believe that the authors could have spent more time analyzing and explaining the spatial trends using geospatial analysis. It might be possible to use some geostatistics to determine if the suggested space partitioning is statistically significant.


Dasyatid rays are becoming popular fisheries resources, especially in developing countries. However, their fine-scale movement patterns and habitat utilization are relatively unstudied. Cartamil et al. used acoustic telemetry to track the movements of Hawaiian stingrays in Kaneohe Bay, Hawaii. They followed tagged rays using a directional hydrophone and recorded the location with a handheld GPS every 15 minutes. This allowed the researchers to effectively plot vector data that had never been seen before for benthic batoids. They utilized the Animal Movement Analyst Extension in ArcView GIS to analyze their data, overlaying and merging spatial use polygons. As a result, the authors could create intuitive and clear maps that complemented the complex mathematical spatial analysis only possible with GIS. The authors found that the rays traveled faster and covered a larger area by night, that there is little evidence of fidelity to daytime locations, and that tides did not seem to affect
movement patterns. These excellent findings provided useful information to inform stock assessment.


Fortunati et al. describe a GIS tool that can be used by a broader scope of fisheries scientists that are not experts in geospatial technology. The Trawl Survey Data Viewer (TSDV) is an extension of ArcView GIS that is specifically designed to create distribution maps based on trawl data. This program can visualize data from multiple species, graphically displaying data based on sex, size, age, abundance, and other attributes. The program uses a UTM reference system, and it can handle geographic (SHP) and tabular (DBF) inputs. The combination of multiple types of data allows for spatial analysis that would otherwise be impossible. I believe that one of the program’s greatest strengths is also its greatest weakness. The authors detail how TSDV can be used to quickly and easily make a large variety of maps without knowledge of GIS technology and interpolation techniques. I would argue that the dangers of a map-making “black-box” could outweigh the benefits if the analyst is unfamiliar with the basics of GIS.


In this paper, Kohler et al. analyze a multi-decadal database from the National Marine Fisheries Service (NMFS) Cooperative Shark Tagging Program (CSTP). Recreational and commercial fishermen catch these sharks and record pertinent information, resulting in an extensive database of 33 species. The tags and recaptures were plotted as points and lines, respectively, with the GIS MapInfo, providing a first glimpse of species-specific and sex-specific spatial distribution and movement patterns. One of the drawbacks to the CSTP, as admitted by Kohler et al., is that the large spatial and temporal scale prevents quantitative estimates of shark density. In addition, the number of sharks tagged per year cannot be used as a proxy for abundance, because the number of sharks tagged is highly vulnerable to fishing effort and other variables. Nevertheless, this paper has been critical to elasmobranch management; it is often cited in stock-reports and other papers. One of the most useful results of this paper is the direct evidence of shark movement across political boundaries that define stocks for management. Twenty species moved across the U.S. Exclusive Economic Zone, and the blue shark even moved across the equator! This foundational paper is unique in its notoriety and its emphasis on the need for international management.

The kitefin shark is sought by small fishing vessels in the Azores for both its meat and squalene oil. Machado et al. use a vector-based GIS to evaluate changes in the number of kitefin sharks caught over space and time. Machado et al. used relational database management, data aggregation, and thematic layering to create a vector model in MapInfo Version 5.5. They also created a raster surface with IDRISI 3.2, creating a friction surface based on the number of fish caught in an area, bathymetry, and land. Machado et al. then created a cost-distance surface based on friction and the distance between points. They present an optimal fishing pathway to increase yield, but fail to specify how this pathway would assist the sustainable management of this species (which is already near its maximum sustainable yield). Bathymetry data from the General Bathymetric Charts of the Oceans Digital Atlas was interpolated using IDW for the vector-based model and Theissen polygons for the raster model. One minor drawback of this paper is the prevalence of typos and small mistakes associated with English translation. Nevertheless, the innovative use of available catch and bathymetry data through Geospatial technology is inspiring. As the authors wrote, “The evaluation of fisheries condition should… [be] preceded by a comprehensive analysis of different types of information related to the exploitation of this fishery resource.”


In this paper, Martin et al. analyze time series fisheries-independent trawl data in the English Channel with ESRI ArcMap 9.2 and Genstat software. The authors create point maps for species found at fewer than 10 stations, continuous presence probability maps for those found at 10 to 50 stations, and continuous density maps for those found at 50 or more stations. The authors utilized kriging to interpolate these maps and determine variance associated with each pixel. One of the greatest strengths of this paper is the excellent explanation of background material, including the process of kriging and the variance coefficients C and C0. Martin et al. were able to interpolate the relative proportions of each sex, creating a density map that displays possible sexual segregation. As a result, they were able to demonstrate a convincing trend in sexual segregation in *Scyliorhinus canicula*, such that females tend to be found more so in shallow coastal areas. All of these results were based on bottom trawl data, so certain faster-swimming species could not be analyzed. However, the elegant species-specific and species-combined
spatial distribution maps will likely inspire many future papers to use similar methods in other contexts. Martin et al. suggest that management policies should incorporate this research in order to limit exploitation in particularly dense areas of elasmobranchs or areas associated with critical life-history stages. Future work in this area should involve modeling with specific environmental variables, in order to determine which factors (e.g., substrate, temperature, depth, salinity, etc...) are most important in determining species-specific distributions.


Glover’s Reef, Belize has been the subject of local elasmobranch fisheries, but little scientific information was known about its elasmobranch population prior to this paper. Specifically, the age-specific habitat partitioning of various species in this area was completely unknown. The researchers were able to complete an extensive spatial analysis, layering CPUE data onto a map of habitat classification using ArcMap 9.0 from ESRI. The researchers found evidence of age- and species-specific habitat partitioning in the Caribbean, and that lagoon environments were more often utilized than reef habitats. This type of research illuminates the need to conserve a variety of habitat types in order to manage all the fauna present. Pikitch et al. write that “reserves should be designed to include diverse habitats in order to adequately conserve shark assemblages.” Even though data collection was done in situ through longline fishing, geospatial analysis was critical to the strength of the author’s conclusions.


The Florida Everglades National Park was established with the goal of conserving species diversity, but for many years, the status of elasmobranchs in the marine and estuarine waters of the park was unknown. Wiley and Simpfendorfer collected information on 12 elasmobranch species, including size, sex, and ambient temperature, salinity, and depth. Geospatial technology was critical for this paper’s analysis. The researchers plotted tag and recapture locations with ArcView 3.3, and described the species’ preference ranges in salinity, temperature, and depth. The vector-based GIS work allowed for intuitive visualization of the park boundaries, as well as sampling locations. Even though this paper focused on GIS, remote sensing was mentioned in the discussion section. The authors referenced a previous paper that used acoustic telemetry to map the fine-scale movements of newborn sharks in Gulf of Mexico nursery. Wiley and Simpfendorfer conclude that the bays and estuaries of the Everglades
National Park may be critical nursery habitat for several elasmobranch species, and that management of commercial fisheries should include protection of these sensitive areas.