

Lake Dal, rich in submerged aquatic plants, is threatened by pollution, Kashmir, India

Lakes, reservoirs, rivers and streams are important habitats for inland fisheries, but they are threatened by human activities that pollute these environments. Using GIS, research teams and managers are developing survey designs to allocate resources efficiently for inland fisheries surveys. Within lake and river catchments, GIS modelling of habitat suitability provides estimates of areas that are preferred by fish, which can be used to manage and restore inland fisheries habitats.

Courtesy of Tomi Petr

9. Current issues, status and applications of GIS to inland fisheries

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This chapter is concerned with GIS applications made to inland fisheries. These include fisheries in freshwater rivers, lakes and reservoirs. Although these GIS applications have increased rapidly since the late 1980s, this area of fish production receives less attention than either aquaculture or marine fisheries. This is probably because inland fisheries are often practised in remote areas, at a semi-subsistence level, or are recreational in many developed countries, and data on most aspects of the fisheries are scattered, fragmented and frequently unsuited for use as inputs to GIS. The GIS-based inland fisheries work has concentrated on mapping the distribution and abundance of fish species and mapping and modelling habitats in rivers, reservoirs and lakes, and relating the two. Much of the material included in the chapter on inland fisheries comes from either Fisher and Rahel (2004) or from the series of symposium proceedings published by the Fishery-Aquatic GIS Research Group (Nishida and Caton, 2010).

With respect to the main issues affecting inland fisheries that are currently being addressed by GIS, five main thematic areas of study are identified. They are:

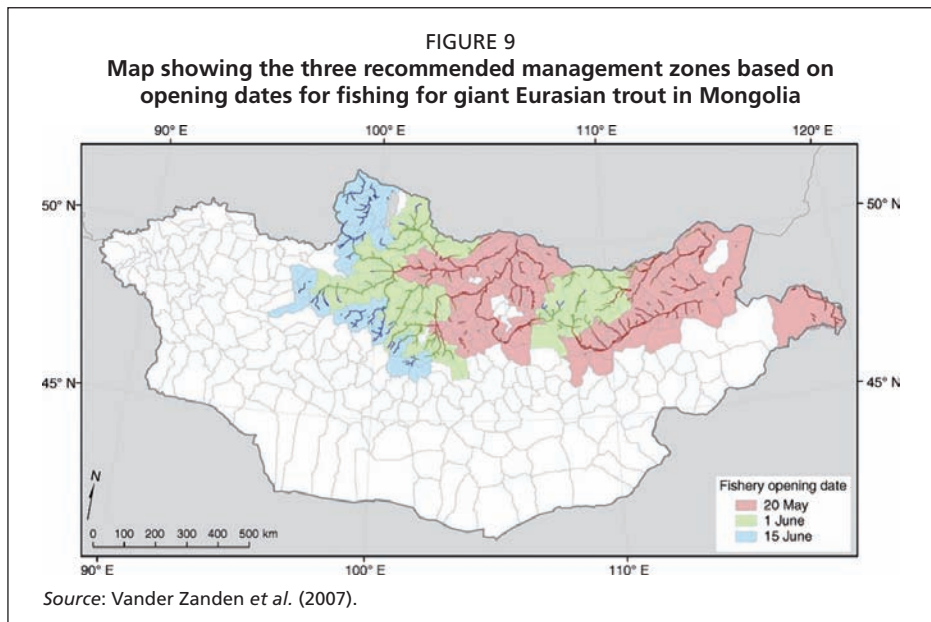
- **Visualization and species distribution modelling.** Mapping and visualizing fish distribution and their abundance and aquatic habitats remains the most common use of GIS in inland fisheries. This visualization is accomplished by simply using GIS as a mapping tool that offers significant versatility in scale, presentation, classification, categorization, etc., and examples are given to demonstrate this versatility. Species distribution modelling evolves from the relationship between species distributions and their habitats, and is a valuable tool for managing and conserving inland fishery resources.
- **Fish movements.** Mapping fish locations and measuring rates of fish movement provides information for managing populations and their habitats. Movement measurement can be achieved through tagging and then catching tagged fish, or through various radio or ultrasonic telemetry devices, with both methods providing important georeferenced fish locations for the mapping of selected species.
- **Habitat modelling.** GIS is widely used as a platform to model fish habitat in inland rivers and lakes, particularly to assess habitat suitability in relation to physical (e.g. flow, depth, substrate) and chemical (e.g. temperature, dissolved oxygen) conditions. Models can be constructed from independent data or from data collected in the field. These data are incorporated into mathematical models that combine the habitat factors and in some cases

weight them according to their importance based on statistical analyses or expert opinion.

- **Watershed management.** Streams and lakes drain watersheds where land-use activities, topography, local geology, soil types, hydrology and many other factors can affect the runoff of sediment and nutrients into streams or lakes, thereby affecting water quality plus fish populations and communities. Understanding the relationship between these watershed factors and fish population and communities enables resource managers to prioritize areas for restoration and protection.
- **Spatial design and conservation planning.** Developing designs for survey site selection in streams, rivers, reservoirs and lakes enables researchers and managers to efficiently allocate resources for fisheries surveys. Also, at a larger scale, habitat suitability classes can be assigned to varying stretches of river within large catchment areas so as to provide estimations of class areas and then probable species abundances within the catchment according to species habitat class preferences. For example, Figure 9 shows a map of recommended fishery management zones developed by Vander Zanden *et al.* (2007) for the giant Eurasian trout (*Hucho taimen*) in Mongolia based on spawning dates and potential habitat.

Four other factors concerning the recent and/or current status of GIS work in the area of inland fisheries are briefly examined:

- (i) A break-down of the number of records appearing, under various thematic headings, in FAOs GISFish database between 1985 to about 2009 showed that most of the 224 records were for GIS applied to assess habitat quality/quantity linked to plant and animal abundance and distribution – 67 records; followed by classification and inventory of habitats – 29 records.



- (ii) An analysis of FAO's ASFA database showing where studies on inland fisheries using GIS were carried out between 1996 and 2010 showed a dominance by North America, with some 56 studies being carried out there. However, recent evidence shows that this dominance is declining, with inland fisheries GIS work now being pursued in 32 countries, many of which are in the developing world.
- (iii) A second analysis of the main institutions where GIS work on inland fisheries was being pursued between 1996 and 2010 found that nearly all the main institutions were located in developed countries, and that there were relatively few institutions pursuing this type of applied work. This is unsurprising given the highly technical nature of the work and the fact that most inland fisheries are not commercial and are thus not valued so highly.
- (iv) The chapter also describes in some detail the types of spatial tools (e.g. GIS, remote sensing, spatial models) and analyses that are possible for both the larger bodies of standing freshwater (lakes and reservoirs) and the linear networks that comprise rivers and streams. In the case of the former, many terrestrial, aerial (spatial) GIS methods can be deployed, and in the latter case most GIS functions within the so-called network analysis may be applicable (see Chapter 7).

The first of three case studies, exemplifying typical work undertaken by projects linking inland fisheries to GIS, is entitled "A spatially explicit resource-based approach for managing stream fishes in riverscapes" (Le Pichon *et al.*, 2006), a sophisticated study carried out by six research scientists and managers based at two institutions in the French Republic. The study aims to provide a riverscape approach in combination with spatial analysis methods to assess multiscale relationships between patterns of fish habitat and fish movements. Riverscape is defined as the "mosaic of heterogeneous and dynamic habitats which to most observers is often hidden beneath the opaque layer of water", and it is the underwater, riverine equivalent of the terrestrial landscape. GIS can be a valuable tool to assess the degree of relationship existing between a fish species and any identified component of the riverscape, e.g. shallow areas with riffles, deep pools in the river and areas with dense riverside vegetation. This relationship may vary according to species, age of fish, time of day, season, fish activity, state of the water, etc. However, rather than following the more commonly used habitat classification approach, here the authors classified habitat by defining the resource-based (i.e. spawning, feeding and resting) habitat patches preferred by individual fish species. An understanding of the spatial and temporal dynamics of fish and their movements has a major influence on fisheries management and on habitat conservation and restoration.

Fieldwork was carried out in the upper Seine River, in the French Republic, and the species studied was Barbel (*Barbus barbus*). The authors describe in some detail the study area, the methods for establishing habitats, the scales and resolution that they worked to (spatial precision), the data themes used, the parameters measured, the map layers produced, some additional freeware GIS that was integrated with ArcInfo GIS, and the modelling used. Most of the

modelling aimed to assess the likelihood of the fish species occupying certain habitat patches, the degree of connectivity between patches, and the likelihood of fish actually reaching their feeding, resting or spawning areas (their different habitat patches). The study concluded with a discussion showing the value of this work in terms of realistically assessing the different habitats utilized for the whole life cycle of a species and the effects that this could have on predicting any prioritization of stream restoration and species management, i.e. based on the spatial proximity of habitats and different spatial scales. Although there would be many challenges to replicating this project, it offers a glimpse of the work that is possible through the use of GIS, though the authors also point out the difficulties of working in aquatic environments that experience continual spatial and temporal change.

The second case study, conducted by three researchers and two government agency fisheries managers during the 1997 to 2002 period, looked at predicting fish yields in reservoirs located in the Democratic Socialist Republic of Sri Lanka (Amarasinghe, De Silva and Nissanka, 2004). In this country, there are numerous reservoirs whose primary purposes are to provide irrigation water for agriculture and to act as a location for the island's artisanal inland fisheries, where species consist mostly of exotic cichlids, Mozambique tilapia (*Oreochromis mossambicus*) and Nile tilapia (*Oreochromis niloticus*). Most reservoirs have received little fisheries management attention, and thus little was known about actual or potential fish yields. In this study, the authors used GIS to quantify land use in nine reservoir catchments, and they related the fish yield to land-use patterns, selected limnological characteristics (conductivity, chlorophyll-*a*) and reservoir morphometry (area and capacity). The statistical methods used showed highly significant relationships between fish yield and forest cover, shrubland, and ratios of these (reservoir area and capacity) and the morphoedaphic index. The authors further suggested that, with the aid of GIS-derived information, they could provide an accurate yield assessment for reservoir fisheries. The study methods involved the use of ArcInfo GIS and, for the reservoirs studied, data were obtained to allow for the production of all relevant map layers, including 16 land-use types covering the reservoir catchments, morphological data relating to the lakes, and a variety of water-quality parameters. These data allowed the morphoedaphic index to be calculated for each reservoir. Fish catch data for the reservoirs were established for the 1997–99 period, and these data were expressed as fisheries yield (kg/ha/yr) and fishing intensity (boat days/ha/yr). Based on the above data, regression models were developed and principal component analyses were performed. The results of these GIS-based studies showed that land cover type, particularly forest cover and to a lesser extent shrubland cover, was strongly linked to reservoir morphometry and directly related to fish yield in the reservoirs. Thus, land cover influences nutrient supply, which can result in increased production from the aquatic ecosystem. In order to optimize future fish yields, reservoir management needs to pay greater attention to catchment land cover types.

The final case study on applications of GIS to inland fisheries looks at the conservation of freshwater biodiversity throughout the state of Missouri in the United States of America (Sowa *et al.*, 2007). This was a long duration study (1997–2006) by four university-based research scientists whose aims were to develop a practical strategy to halt the decline of long-term species noted in many North American river systems. A special need was to identify gaps in existing efforts to conserve freshwater biodiversity and to prioritize efforts to fill these gaps. The study was part of a larger study to identify areas of high species richness and endemism that may be filled by establishing new management or protected areas or by implementing changes in land management practices. Four primary GIS data sets were used in this study: (i) river ecosystem classification; (ii) modelled species distributions; (iii) public land ownership/stewardship; and (iv) human threats. The technical paper gives details on how each of these data set areas were compiled and mapped. Mapping of riverine ecosystems was carried out at a hierarchy of scales in order to identify, classify and map distinct ecological units and habitats of all rivers in the state of Missouri. Predicted distributions of 315 aquatic species were made from nearly 6 000 collection records using a suite of seven environmental predictor variables relating to stream size, stream gradient, stream temperature and stream flow. GIS was used to map the modelled distributions. An assessment was made of where all gaps in aquatic species distributions occurred in areas classified as “public land” – because conservation measures could only be made obligatory in streams or rivers located on these lands. The final set of maps showed human threats, and these areas were interpreted in terms of a measurement of the degree of human disturbance (related to 11 types of possible disturbance) that could be affecting freshwater ecosystems.

After all the relevant data were assembled and mapped, a variety of analyses were pursued that together indicated which parts of Missouri’s river networks would be most suited for the aquatic conservation of specific species. For instance, stream stretches (reaches) of varying lengths that were located in areas considered to have “reasonably secure conservation plans and management actions that would benefit biodiversity conservation” were identified, and only these reaches were considered as being suitable for conservation purposes. The number of species presently occupying reaches of specific quality or stream length was also calculated, as was the length and location of suitable streams (for conservation) within each major river catchment. Based on all the GIS output, a team of aquatic resource professionals identified and mapped a set of aquatic conservation opportunity areas (COAs) that represented the breadth of distinct riverine ecosystems and habitats in Missouri. The 158 selected COAs contained 6.3 percent of the total stream length in the state, but they could provide suitable protection and habitat for 296 identified native aquatic species. Although the total amount of data and the range of analyses used were considerable, it was suggested that this effort was well worthwhile in terms of it being an essential task in helping to ensure the future for most species, i.e. species that often live in degraded aquatic environments situated on private lands where conservation may be impossible.



Shrimp trawl fisheries

Marine fish stocks are under increasing threat from a range of spatially based problems that might be natural or involve socio-economic factors. To best manage spatial problems, systems such as GIS and remote sensing are now being extensively deployed. For these systems to be effective, it is important that spatially based catch and fishing effort data can be recorded from electronic fisheries logbooks or via vessel monitoring systems. In many parts of the world, vessels such as this one are actively acquiring appropriate data.

Courtesy of John Mitchell