***Fish ponds for culture of Nile tilapia, African catfish and African bonytongue, Cameroon***

*There is considerable potential to expand inland aquaculture in Africa to improve food security. To aid aquaculture planning and management, GIS modelling techniques can be used to identify and map specific sites for fish ponds, and GIS tools can assist in allocating further land and water space for sustainable aquaculture expansion.*

*Courtesy of José Aguilar-Manjarrez*

# 8. Current issues, status and applications of GIS to aquaculture

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While it is important to explain the purposes of GIS technology, it is also essential that the reader gains a true impression of the realistic capabilities of the technology. This knowledge is best achieved through examples. This chapter provides GIS-based case studies of aquaculture, whereas Chapters 9 and 10 discuss GIS applications to inland fisheries and marine fisheries and also include case studies. The case studies presented in these three chapters have been selected from a number of different sources. They not only illustrate the technical capacity of GIS applications in aquaculture, inland fisheries and marine fisheries, but they also address issues that are of global to local importance and that span environmental, social and economic considerations. The case studies are as varied as possible, and include a variety of GIS-based techniques and differing degrees of complexity. Each study is structured to show various facets of the project, such as the publication date and title, number of staff or researchers, duration of the study, and who the study was aimed at. Before the case studies are introduced, an attempt is made to clarify the main issues that the use of GIS is attempting to resolve within aquaculture, inland or marine fisheries, and an indication is given on the geographical distribution of GIS usage in these sectors. The rest of this chapter is concerned specifically with aquaculture case studies.

Aquaculture is an extremely broad activity in terms of species cultured, environments utilized, geographical distribution, techniques used and the socio-economic milieu in which it takes place. It is also an activity that is practised at varying production and economic scales, i.e. varying from one of many activities on one small farm to a single activity pursued by a multinational corporation. Output from aquaculture can be for direct human consumption, or used as an input to bolster natural fisheries through restocking. Given the huge diversity in aquaculture, it is not surprising that the pursuit of the activity will have strong spatial implications in terms of a range of social, economic and environment considerations. And the implications are two-way in the sense that aquaculture may impact the environment (including social and economic) in which it operates, but this environment can greatly impact the success of the activity. This two-way breadth of spatial implications means that GIS-based analyses are particularly suited to support problem-solving and decision-making in aquaculture.

Turning to the range of issues that aquaculture has recently sought to address, an analysis was made of FAO's GISFish global gateway to GIS, remote sensing and mapping for fisheries and aquaculture (www.fao.org/fishery/gisfish), both to identify the main issues, as well as the sub-issues (which are discussed in the technical paper), and to quantify them (as of April 2012). Although the classification is complicated because many issues may not conform to single (or simple) boundaries, it was found that the 391 relevant studies from the GISFish database (for the period 1985–2012) could be best classified under the following issues:

- **Development of aquaculture (209 records).** As noted here, more than half of all issues being addressed by GIS fall into this classification. These issues mainly relate to the use of GIS for working out the site suitability for aquaculture at the local level, but also for widespread strategic planning of where aquaculture might best be integrated into the development of regional or national plans. It is also important to investigate the likely impacts of aquaculture at any scale and to identify sources of potential external problems to successful aquaculture in any location(s). A number of examples covering the development of aquaculture are discussed.
- **Aquaculture practice and management (124 records).** This is also an important area of concern for aquaculture. Here, the main sub-issues are the inventory and monitoring of aquaculture and the environment, and the environmental impacts of aquaculture, e.g. mainly in terms of carrying capacity and zoning. This is done because there is a strong potential either for aquaculture to have some impact on other primary activities or the reverse situation in which resource-use activities may have an impact on aquaculture success. The availability of high-definition remotely sensed imagery provides an important and relatively inexpensive data source for this issue, and FAO has developed the National Aquaculture Sector Overview (NASO) map collection, which is a selection of Google-based maps (at varying scales) for a range of countries showing aquaculture inventories (mainly by administrative units) and their characteristics (www.fao.org/fishery/naso-maps/naso-home/en). The technical paper discusses the NASO map collection in some detail, and also describes various examples showing why environmental impacts of aquaculture are a many-faceted spatial issue. It also considers why Web-based aquaculture information systems will be increasingly important to the future success of aquaculture.
- **Training and the promotion of GIS (32 records).** This issue is concerned with education about both the usefulness of GIS-based analyses and the training possibilities that are available for learning the principles of GIS. It is therefore addressed to senior management or decision-makers who might have to decide on implementing systems such as GIS and to technical staff who need to know exactly how best to parameterize the system. FAO plays a key role worldwide in the promotion of GIS within the sectors for which it is responsible. However, promotion per se is more regularly conducted by the main software houses and by the organizers of exhibitions, conferences and symposia. Training materials specifically for aquaculture GIS are mentioned in Chapter 4.

- **Multisectoral development and management that includes aquaculture (26 records).** The main issue addressed here is the role of GIS in establishing aquaculture in the context of competing, conflicting and complementary uses of land and water space. The fact that only 7 percent of GIS-based work has addressed this issue indicates that planners and developers may not have taken aquaculture into much account in the overall context of development. The technical paper provides an example of how this issue could be positively addressed within both the emerging contexts of an ecosystem approach to aquaculture or fisheries or as part of a study addressing marine spatial planning.

Two other indicators concerning the recent or current status of GIS work are then reviewed:

(i) An analysis of FAO's Aquatic Sciences and Fisheries Abstracts (ASFA) database of published aquaculture studies to show where GIS work is being undertaken gives not only the basic facts of the spatial distribution of such work, but it also shows the prevailing level of interest or experience in such GIS applications, and this fact itself might be useful with respect to deploying resources for training or technical assistance. Information on the worldwide distribution of GIS applications to aquaculture is presented in both mapping and tabular formats. It is of interest to note that publications come from about 25 percent of all countries, yet about 80 percent of countries report some aquaculture production, i.e. less than one in three countries practicing aquaculture publish reports on their use of GIS. North America, especially the United States of America, dominates GIS-based publications, though many South and East Asian countries are now making advances in their use of GIS.

(ii) The technical paper also highlights some of the main institutions worldwide where aquaculture-related GIS research and projects are pursued. Ten institutions are specifically identified for their contributions to GIS work, with about half of them being located in developing countries.

Attention now turns to the four case studies dedicated to aquaculture. The first case study, entitled "Sustainable options for people, catchment and aquatic resources" (also known as the SPEAR project), was a large-scale, three-year study (2004–07) involving 35 experts from different countries, with the project being based in the People's Republic of China (Ferreira *et al.*, 2008). This study is considered "sophisticated" with respect to its GIS mapping and analyses, though as such it gives a good indication of the high-level potential for GIS work and is an excellent example of a holistic assessment of aquaculture. SPEAR's objective was to develop and test an integrated framework for management of the coastal zone, using two test cases where communities depend primarily upon marine resources, of which a large component is the farming of finfish, shellfish and seaweeds. Full details of the research are available at www.biaoqiang.org. In summary, GIS was used in this project for:

- **Decision support** – in the form of mapping all the key components within the two test-case areas.

- **Modelling** – GIS formed the platform on which a number of models (e.g. catchment, hydrodynamic, ecosystems, aquatic resources) could be parameterized, calibrated and integrated in order to develop a robust ecosystem modelling framework where GIS and remote sensing play an integral part.
- **Visualization** – allowing researchers and stakeholders to best conceptualize all relevant inputs and results.

The SPEAR project represents an example showing how GIS aids the integration of spatial data across different scientific disciplines; it is novel because it combined models running at widely different time and space scales for different ecosystem components; and socio-economic viewpoints could also be incorporated. The technical paper describes how the SPEAR work is now being extended into other spheres of marine shellfish aquaculture.

The second case study, entitled "AkvaVis decision support system", is again a large-scale and quite sophisticated project, which is still ongoing and based in the Kingdom of Norway (Ervik *et al.*, 2008). It employs about eight aquaculture specialists assisted by three GIS technology experts, and their main aims are to inventory and monitor marine aquaculture and its environment, examine the environmental impacts of aquaculture, and develop a Web-based aquaculture information system. Aquaculture is a major economic activity in the Norwegian fjords, and farming is dominated by the production of Atlantic salmon for local and world markets, though diversification into other marine species is being pursued. As with aquaculture elsewhere, increases in production cause problems, not only with potential disease and water quality issues, but also with competition for access to marine space. To help resolve environmental and space conflicts, AkvaVis is being developed as a Web-based interactive site selection, coastal zone area planning, carrying capacity, management and monitoring, and decision support system. The Web site is widely accessible and dynamic, in the sense that it is adaptable to new knowledge and new regulatory frameworks and that it can address the demands from the industry, plus public and private stakeholders. It can further be integrated to other activities as part of marine spatial planning. AkvaVis operates in three modules, two of which are relevant to GIS:

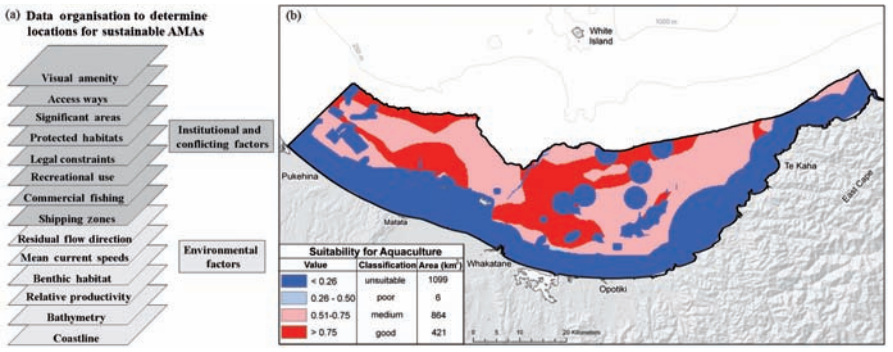
- A *management module* that compiles information needed to optimize aquaculture management, and this includes adopted area management plans and other geographic information of relevance regarding the conflicting use of the coastal area, and information on mandatory environmental monitoring and environmental quality standards.
- A *siting module* that identifies and evaluates the suitability of areas for specified aquaculture activities and provides simulations of their carrying capacities.

The siting module is discussed in detail in the technical paper because of its sophisticated capabilities. Thus, through Web-based interaction with maps of any desired area, potential fish culturists can see the consequences of their desire to locate a new production unit at any specified point. This requires sophisticated and widespread information on existing conditions for all Norwegian marine areas

in terms of water depth, quality, hydrodynamics, existing farm locations, benthic fauna, sewage outfalls, and the ability for the GIS to function as a modelling platform that assesses the combined influence of all these marine variables at any location. Location implications can be perceived as both the effect of a new farm on its surroundings and the effect of the prevailing environmental conditions on the proposed new farm. This modelling potential is demonstrated at www.akvavis.no. The interactive capability of AkvaVis allows the users to immediately see the consequences of their choices. AkvaVis combines a broad-scale approach by covering Norway's coastal aquaculture and by including all the main fish and shellfish species under culture. Moreover, it is holistic in EAA social terms by being designed for transparency, public participation and outside scrutiny. The case study usefully concludes with some of the main challenges facing the adoption of such a complex decision-support system.

The third case study is concerned with assessing an offshore open coast area in the Bay of Plenty, New Zealand, as to its suitability for shellfish farming (Longdill, Healy and Black, 2008). The study implemented a framework to collect and analyse a large number of data sets relating to the environmental effects of bivalve culture, competing uses of the marine environment, as well as the productive capacity for aquaculture. To achieve this framework, a network of factors that aid the development of a sustainable and viable aquaculture industry was identified and examined. The study gives details on all the data required, how they were collected and assembled, and how they were standardized and subsequently utilized, including the various models used in order to obtain specified results. The resulting outputs initially provide an indication of the relative suitability of the benthic habitats to assimilate the inputs from suspended bivalve aquaculture for a 2 390 km$^2$ area of the continental shelf, plus an indication of the suitability in the same area for suspended offshore bivalve aquaculture (Figure 8). More sophisticated temporal modelling was applied to show the relationship between the spatial suitability for bivalve aquaculture and various physical processes (tides, winds, etc.) and the 3D natural chlorophyll-*a* concentrations, i.e. as a measure of natural food availability at different times. From these observations, it was possible to model the influence of siting bivalve production facilities at any preferred location within the bay on the depletion rates of naturally available foods. The results of this exercise provide a measure of the ecological impact of shellfish farming in the Bay of Plenty, though there will always have to be discussions on what acceptable rates and scales of nutrient and plankton change might be. The authors further indicate how their study might be refined, though they note that there will always remain factors causing some limitations to this type of GIS analysis, i.e. such as the favouring of pre-existing aquaculture uses, the unaccounted potential for future change in these uses, the legal setting, or the use of different culture methods. These factors could substantially alter the outcome. Despite these limitations, the use of an ecological model to simulate potential farms and the corresponding GIS analysis represents a valuable and exciting future direction for the use of GIS and aquaculture.

FIGURE 8
**Data layers and organizational structure (a) used to determine locations for sustainable aquaculture management areas (AMAs) and (b) output suitability index classes for suspended offshore bivalve aquaculture within the Bay of Plenty, New Zealand**




*Source*: Longdill, Healy and Black (2008).

The final case study looks at the potential and financial viability of fish farming in the Republic of Ghana, West Africa (Asmah, 2008). This is a fairly basic study carried out by a PhD-level student using precollected data. With the country currently experiencing a 40 percent shortfall in fish needs, it is increasingly important to try to supplement capture fisheries output with production from aquaculture. A key issue in aquaculture development is that of defining its potential location and scale, and thus the objective of this study was to use GIS to assess the potential for small-scale and commercial freshwater aquaculture development in the Republic of Ghana, with a particular focus on tilapia. Secondary data covering the whole country was collected on some 20 variables that were positively required for aquaculture success, plus data on a number of factors that might constrain aquaculture, e.g. the existence of forest or game reserves. Raster-based maps were produced for all variables, with each map being classified according to mapped areas that were considered as being "Very Suitable", "Suitable", "Fairly Suitable", and "Unsuitable". Each mapped variable was also given a weighting (from zero to one) depending on its relative importance to aquaculture, and different weightings were given with respect to how important the variable was to either small-scale or to commercial fish culturing. The weighted maps were then integrated (including the constraint maps) to produce final maps showing the suitability of all areas for either type of culturing. All tabular, numerical and mapping results are shown in the case study. The models that were used to produce the final maps could be verified by visually comparing their results with the real distribution of fish farms in the country, and it is shown that the results were very encouraging. The authors were finally able to calculate the rate at which fish farming would need to expand in order to catch up with national fish consumption requirements.

While further data refinement and model adjustments could be achieved, the outcome is nevertheless a powerful illustration of the integrative use of GIS systems and their ability to work with and model from widely disparate data sets. The study is based on a relatively simple model structure and, consequently, can be easily replicated for other countries (assuming that the data are available), e.g. to support the preparation of national aquaculture strategies and national development plans.