Advances in Spatial Analyses, Remote Sensing and Virtual Technologies to Enhance Aquaculture Management

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Attention is presently turning to the processes, methods, and tools that allow the principles of the ecosystem approach to aquaculture (EAA) (Soto, Aguilar-Manjarrez, and Hishamunda (2008) to be translated into practical implementation.

According to a recent review by Ferreira *et al.* (in preparation), virtual technology is a way by which conceptual models can be made more formal and tested against reality. It involves the collection of data, the integration of these data within a system (information system), the formalization of the system and the action on the system (simulation) with a given purpose. Virtual technologies have an important role to play, be it through the use of (i) geographic information systems (GIS), remote sensing and ecosystem-scale models to determine suitability and carrying capacity; (ii) farm-scale tools to support licensing, environmental impact assessment, and optimisation of production; or (iii) sensors for data acquisition for monitoring and modelling.

The present article includes a few extracts from the above review on "Progressing aquaculture through virtual technology and decision-making tools for novel management". However, in this article, emphasis is placed on the use of spatial planning tools including GIS, and remote sensing for data management, analysis, modelling and decision-making to illustrate the work being carried out by the Aquaculture Service (FIRA) of the FAO Fisheries and Aquaculture Department.

Natural resource managers, aquaculturists, and other stakeholders, pose questions on water quality diagnosis, growth and system carrying capacity and environmental effects, local-scale interactions, prediction of harmful algal blooms, disease control systems, environmental product certification, socio-economic optimization, spatial definition of natural and human components of ecosystems and of competing, conflicting and complementary uses of land and water. A good many of these can be addressed, at least in part, by means of virtual technologies and decision-support tools. Different stakeholders are seeking answers to these questions at differing time and space scales. For instance, an environmental manager for an estuary or coastal bay might be interested in system-scale carrying capacity, both in terms of production and environmental impact, while at the level of Integrated Coastal Zone Management (ICZM) the role of bottom-up (e.g. nutrient-related) effects and top-down (e.g. shellfish grazing) control might be an important consideration. Farmers will also be concerned with optimizing production and profit, disease control, and market acceptance. While, farmers and managers in the west may be more focused on open coastal systems, in Asia, Central and South America, or in Africa, their emphasis may be more on inland or fringing systems such as shrimp and/or fish pond culture.

The data that are needed for management and decision-making are similar across most aquaculture operations. However, since space and time resolution of the datasets are dependent on the scale of the aquaculture operation, data acquisition approaches and needs also expand accordingly.

FAO-FIRA's Global Gateway to GIS, remote sensing and mapping for fisheries and aquaculture (www.fao.org/fishery/gisfish) is a rich resource of information on publications and case studies demonstrating the benefits of these tools to resolve issues in fisheries and aquaculture. Aguilar-Manjarrez, Kapetsky and Soto (2010) provide a description of selected case studies illustrating a range of such virtual tools; previous issues of the FAO Aquaculture Newsletter [e.g. FAN 35 (pp. 13–19), FAN 37 (p.33), FAN 38 (pp. 32–33), FAN 41 (p. 11) and FAN 42 (pp. 24–25; pp. 36-39)] describe activities on GIS, remote sensing and mapping at FIRA.

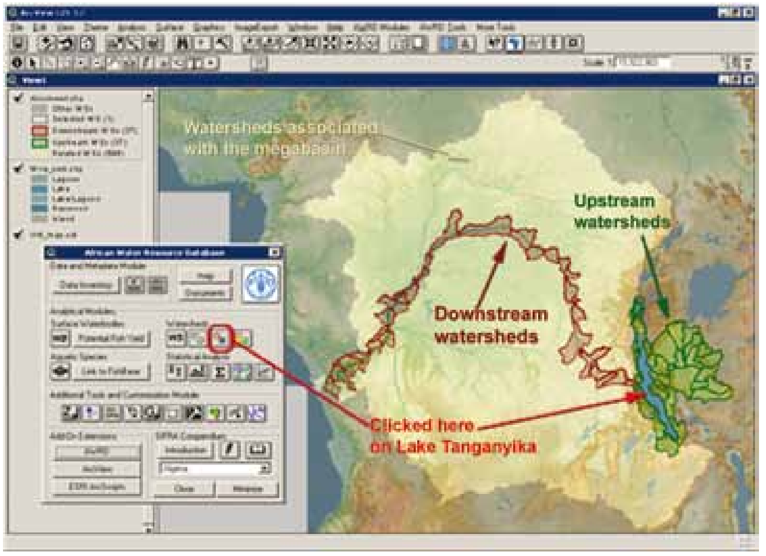
Examples of current applications on virtual technologies at FIRA are illustrated below addressing a range of culture types, environments and cultivated species.

EXAMPLE APPLICATIONS

Example No. 1: African Water Resources Database (Jenness *et al.*, 2007a;b)

The African Water Resource Database (AWRD) contains an assortment of custom-designed applications and GIS-based tools to display and analyze spatial data. AWRD tools can assist in a wide variety of issues such as: improving the reporting on status and trends in inland fisheries and aquaculture; co-management of shared inland fisheries resources; transboundary movements of aquatic species; and increased participation of stakeholders in the decision-making process about watershed area uses. The Watersheds Module and related analytical tools represent perhaps the most comprehensive and intensive programming effort undertaken within the AWRD interface. This module is specifically designed to analyse and visualize watersheds which can be of great value for assessing pollution from runoff of "upstream" watersheds into aquaculture ponds or residuals from aquaculture ponds into "downstream" watersheds. Analysis of invasive and introduced aquatic species is another area where this tool has great value because such introductions can have impacts both upstream and downstream within a hydrological system. Figure 1 shows upstream and downstream watersheds for Lake Tanganyika. At present, two FAO Technical Cooperation projects in Cameroon and Mauritania have made use of the AWRD to support the development of master plans for the development of aquaculture in Cameroon, and aquaculture and inland fisheries in Mauritania. The AWRD also serves as an excellent tool for GIS training.

Figure 1
Visualization of the flow regime associated with lake Tanganyika



Source: Jenness *et al.* (2007a;b)

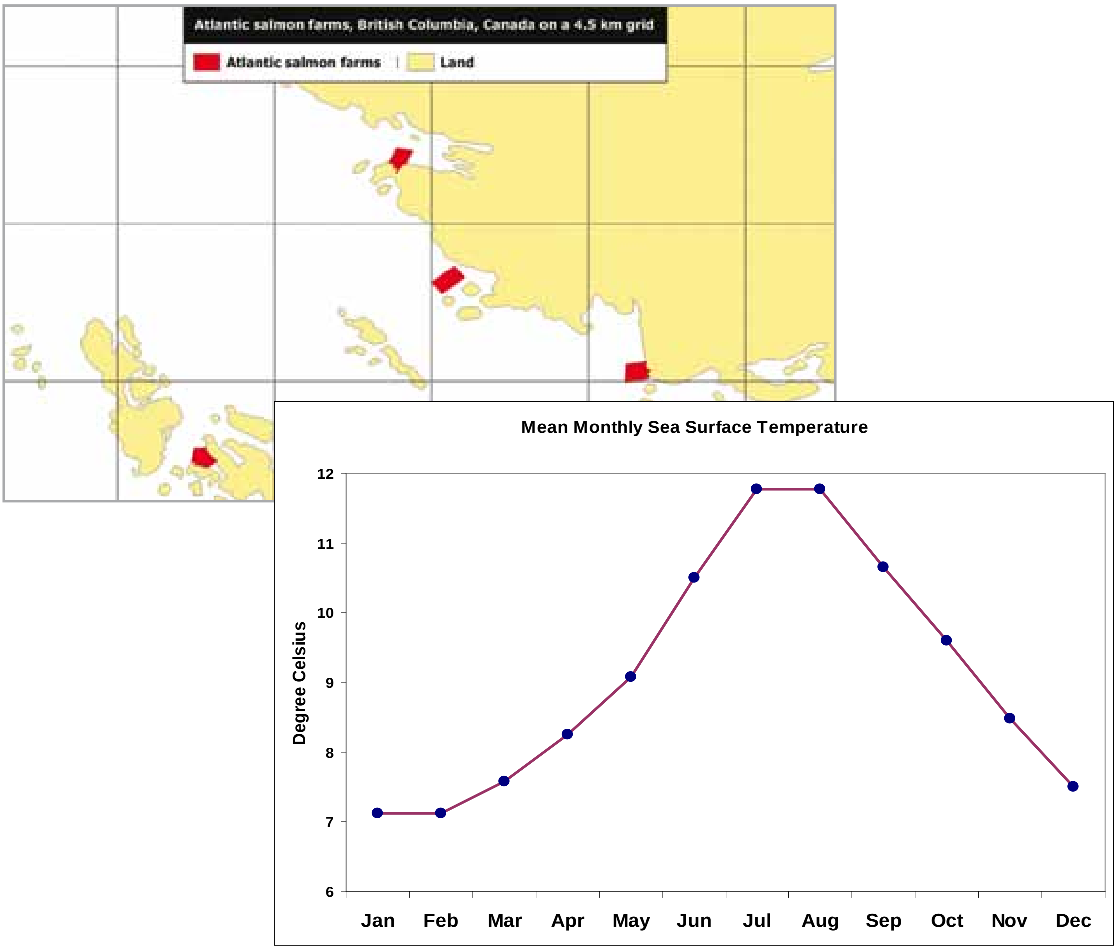
Example No. 2: GIS and remote sensing for the development and management of offshore aquaculture (Kapetsky *et al.*, in preparation; Dean and Salim, in preparation)

The issues associated with the expansion of mariculture to offshore areas can be categorized as technical, environmental, social, economic and legal. Environmental issues relate both to suitability of mariculture operations and more broadly to mariculture as a user of ecosystem services. Many of these main issues have components that can be addressed separately or together using spatial analyses, particularly the technical, environmental and jurisdictional problems. Among the criteria that have to be satisfied for offshore mariculture are appropriate locations for good growth and high survival rates of cultured species. In line with this criteria, FIRA is currently exploring the use of fish growth models as one of the means to estimate aquaculture potential for offshore aquaculture. Our vision is for a model that could be run for all geographic areas of interest to identify locations with growth advantages for any species. Because of the ready availability of a growth model and because of the relatively easy access to farm locations and temperature data through remote sensing climatologies, the Atlantic salmon model is being used to test the concept. Locations of Atlantic salmon farms in four countries, Canada (British Columbia – see Figure 2), Chile (limited area), Ireland and Norway, were selected to span the broadest range of latitudes available. Also, as our focus is on offshore mariculture, farms with the most exposure to the open sea were selected in Norway and Ireland. At these selected farm locations, mean monthly temperatures were obtained from remote sensing climatologies and used as input to the growth model. The output was the number of days required to reach a harvestable size at each farm location. The preliminary results showed a near five-month difference between Chile and Norway for the time required to reach a harvestable size. The results suggest that real differences between growth potentials among locations can be detected through remote sensing. The next step is to validate the results with actual growth data from the farm locations and eventually to model growth for species relevant to mariculture in developing countries.

Example No. 3: National Aquaculture Sectors Overview (NASO) map collection (in preparation)[1]

FIRA is in the process of mapping aquaculture sites (see Figure 3 as an example) as part of the National Aquaculture Sectors Overviews (www.fao.org/fishery/naso/search/en). The NASO map collection is to be released via the world wide web in June 2010. The collection consists of Google maps showing the location of aquaculture sites and their characteristics at an administrative level (state, province, district, etc) and in some cases even at an individual farm level depending on the degree of aquaculture development,

Figure 2
Estimating potential growth: acquiring data from Atlantic salmon farm locations in Canada



the resources available to complete the data collection, and the level of clearance provided by country experts (Figure 3). Data collection is of fundamental importance to the implementation of the Ecosystem Approach to Aquaculture, the improvement of aquaculture statistics and the dissemination of information. The work is still in its early stage but holds potential use in a number of ways such as the development of an aquaculture investment and management tool currently under construction (N. Hishamunda, and D. Valderrama, FAO-FIRA, pers. comm.., 2010; see also page 23, this issue); monitoring status and trends of aquaculture development and addressing site selection issues.

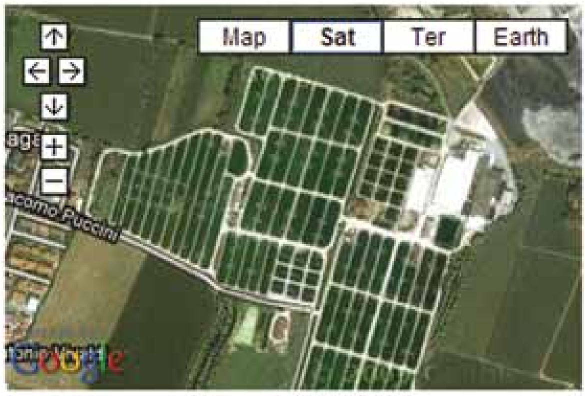
CONCLUSIONS

The aquaculture industry is going to be affected by many different issues and trends over the coming years, often operating concurrently, sometimes in unexpected ways, and producing changes in the industry that may be very rapid indeed. Without a doubt, virtual technology and decision-support tools will play important roles in addressing many of these, and will therefore underpin many elements of the Bangkok Declaration and Strategy. Some of the directions and challenges are: innovations that will drive virtual technology; information exchange and networking; links between industry and research centres; collaboration between developed and developing countries; strategic alliances in developing countries; making virtual technology tools more production- and management-oriented. Even if attractive and promising, these tools will have to be adapted to local realities and conditions to really become useful (and used) in the future. These require a compromise with respect to ease of use, data requirements, and scientific complexity.

In the future, virtual technologies will play an increasingly important role in the prediction of potential aquaculture siting and production, environmental impacts, and sustainability. The next decade will bring about major breakthroughs in key areas such as disease-related modelling, and witness a much broader use of virtual technology for improving and promoting sustainable aquaculture in many parts of the world.

More specific to GIS, there are many benefits that GIS can bring to aquaculture management processes, from simple mapping to sophisticated modelling. Aguilar-Manjarrez, Kapetsky and Soto (2010) demonstrated that GIS has the potential to support EAA, therefore,

Figure 3
NASO map collection for Italy



Freshwater farm, sturgeons and stripped bass, North Italy

the principal task is to determine best ways to utilise these spatial tools for implementing EAA. An enabling environment is crucial and it is essential to match potential requirements and current capacities (human resources, infrastructure, finances) at national and/or regional level so that capacity building activities can be initiated.

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