Geographical Information Systems (GIS) and Remote Sensing use with Global Aquaculture Development

Gabriel Betty

Department of Fisheries, Animals and Veterinary Sciences

University of Rhode Island

As fisheries stocks continue to decline from excessive fishing in the world’s oceans coinciding with an increase in seafood based products for a human population growing every year, places a burgeoning burden onto global aquaculture production systems to satisfy a daunting seafood demand. The United Nations Food and Agriculture Organization (FAO), which monitors the state of world fisheries, has estimated that since 1990, approximately one-quarter of fish stocks have been overexploited, depleted, or are recovering from depletion (17%, 7%, and 1%, respectively) (Beddington et al 2007). Aquaculture, probably the fastest growing food-producing sector, now accounts for nearly 50 percent of the world's food fish (FAO 2014). These aquatic products (mainly fish, aquatic mollusks, and crustaceans) have a critical role in the food system, providing nearly 3 billion people with at least 15% of their animal protein intake (Evans 2009, Smith et al 2010). Since there is only a certain amount of seafood that can be harvest from the world oceans on a yearly basis, roughly 80 million metric tons a year (FAOSTAT 2013) makes aquaculture the only means of fulfillment. However, the rapid growth of aquaculture worldwide has stimulated considerable interest among international technical assistance organizations and national-level governmental agencies in countries where fish culture is still in its infancy, and has resulted in increased concerns about its sustainability in countries where the industry is well established (Nath et al 2000).

Like any food production system, any inputs that are placed into a system will accordingly create outputs. Though the obvious outputs from aquaculture are food products, there are others which negatively impact the water column and the natural environment around that system. Aquaculture may cause harm to the environment because of its direct release into water bodies of organic effluents or disease treatment chemicals, indirectly through its dependence on industrial fisheries to supply feeds and by acting as a source of diseases or genetic contamination for wild species (Evans 2009), making the needs for reliable information on all related subjects a key issue for its responsible management (FAO 2014). This is one of the great questions that that the human race faces in the 21st century, how to build/develop future aquaculture sites for a growing world, without jeopardizing the overall sustainability/overall quality of the environment around it? One means of addressing this question is by applying both Geographical Information Systems (GIS) and Remote Sensing (RS) technologies onto this global industry. The goal is no longer simply to maximize productivity, but to optimize across a far more complex landscape of production, environmental, and social justice outcomes (Evans 2009).

The use of GIS/RS allows the people within the industry to define what the sustainable practices are for aquaculture; however defining its specifics is often a subject of some debate between countries and governments (Boyd and Schmittou 1999, Longdill et al 2008). To reflect desire and also maintain sustainability of both environmental concerns and the economic
operation of the industry, Boyd and Schmittou (1999) is often the best adopted where sustainable
aquaculture is defined ‘where ecologic and economic viability persist indefinitely’. In other
words the question of (1) feeding people and (2) sustainability must be in-sync with both the
ecological and economics of the aquaculture system; additionally in order to define that a system
is truly ‘sustainable aquaculture,’ they must be in-sync with all the social communities around
them and the only means of determining this is with GIS/RS.

GIS is as a collection of computer hardware & software tools used to enter, edit, store,
manipulate, and display spatial (geographically referenced) data (Hunter, 2012). RS is the art,
science and technology of obtaining reliable information about physical objects and the
environment, through the process of recording, measuring and interpreting imagery and digital
representations of energy patterns derived from non from non-contact sensor systems (Colwell
1997). What GIS and RS does together, is that it takes data (facts without any meaning) and
turns it into information (knowledge derived from data). It takes collected data from sensor
systems (satellites, planes) and manipulates that data from people using various hardware and
software technologies; the data does not become information though until it is applied to specific
procedures. The eventual goal of using GIS/RS is to create information for specific problems in
the aquaculture industry and to develop them into sustainable systems. The use of GIS has
become of increased significance for environmental planning and assessment mainly because of
the need to compare a great number of spatially related data, and because it can be used to couple
these spatial data with their attributes and overlay them (Perez et al. 2003). The use of RS
demonstrates that with the appropriate satellite record, in situ measurements and field
observations, is a promising technology that can help monitor compliance treaties, international
trade in endangered species, substances that deplete the ozone layer, biological diversity,
framework on climate change and others (Seto, and Fragkias 2007).

Specifically the use of GIS/RS in global aquaculture development is that it can physically
take collected data from sensors of specific/potential sites and turn them into layers of
information. As an example, mangrove forests are coastal ecosystems that are dramatically
impacted from aquaculture development. These forest contribute significantly to the well-being
of coastal communities through a wide array of services, fishery and forestry products, however
they are often viewed as wastelands to be developed (Primavera 2007). Since shrimp culture is
so popular, most farmers will cut down these forests on land usually not owned by anyone and
excavate for farming. Typically these are intensive systems where large amount of shrimp are
grown within constrained areas and systems are pushed to their limits. After the harvest, these
systems are often disregarded and the farmer moves to another site. It’s estimated that there is a
yearly loss of 2.1% of existing area, and an average loss of 35% since the 1980s, with half of
such loss due to shrimp and fish culture (Primavera 2007, Valiela et al. 2001).

In order to rectify this dilemma, GIS/RS can collect data on mangroves (location,
existing/deforested, rare species presence, amount of aquaculture etc.) over a large timespan and
create detailed imagery that can be manipulated again and again until it address all the issues.
This imagery could show when and where mangroves have been impacted and could show areas
that need the most effort in restoring/protection. Additionally, this imagery could be used by
country government bodies to create regulations in controlling future aquaculture development
by defining which areas would be best for sustainable aquaculture development. In order to
ensure that the information is accurately being applied to the development of the imagery, a
Multi-Criteria Evaluation (MCE) is often applied. A MCE is a means of evaluating the suitability or constraints of the information layers being projected onto the imagery, a way of double checking the accuracy. Seto and Fragkias (2007) compared two wetland reserves in Vietnam where one was located within a Ramsar Convention on Wetlands (wetlands under international conservation) and one that was not. They took Landsat imagery that spanned over 25 years in order to evaluate mangroves abundance and aquaculture development. Though the results showed that both wetland had similar impacts (more aquaculture, mangroves relatively constant), it also shows that the use of GIS/RS has tremendous applications on the past, future and present. Appropriate satellite record, in situ measurements and field observations, these are a promising technologies that can help monitor compliance with international environmental agreements (Seto, and Fragkias 2007).

**Future Applications of GIS/RS in Global Aquaculture Development:**

Despite the large variety of GIS/RS articles on global aquaculture development, there were several instances where the articles began repeating similar ideas/concepts for improvements in future applications. These ideas/concepts were not primarily focused on the improvement of GIS/RS technology or the advancement of aquaculturing techniques, though these were commented time and again. The bigger, more defining criticism was questioning how to get both GIS/RS technologies to more people within the aquaculture field. This question though rephrased per paper, typically revolved around these four points: (1) a lack of appreciation of the benefits of such systems on the part of key decision-makers; (2) limited understanding about GIS principles and associated methodology; (3) inadequate administrative support to ensure GIS continuity among organizations; and (4) poor levels of interaction among GIS analysts, subject matter specialists and end users of the technology (Nath et al 2000). Additionally, with more than 36 million people employed directly through fishing and aquaculture (Pauly and Froese 2012) makes this an even more challenging problem.

Overall these are the critical issues getting people together to (1) define the issues and (2) resolve them; within the aquaculture community it would be defining aquaculture impacts and resolve them with sustainable aquaculture practices. Suitable environments are develop a suite of tools designed for environmental management of aquaculture sites, including carrying capacity prediction, land–water interactions and multi-site effects (Corner et al 2006). Resolving these issues is not just a problem for people in the aquaculture communities, it’s a problem for everyone and the people within the GIS/RS community are already doing a great job. “Give a man a fish and he will eat for a day, teach him to use GIS and he will develop informed, sustainable practices in aquaculture and fisheries management (Esri, 2008).”
References


Annotated Bibliography


This paper was focused on validating the particulate fish waste dispersion modeling by integrating GIS software with the specific programed modules. The integrating of the software is important because is guarantees that (1) there will not be any data loss from the several data sources used and (2) the modeling itself can be identified again later as a layer within an integrated Coastal Zone Management (ICZM) plan. ICZM itself is a global coastline management process that uses geographical data in site management for sustainable practices. So they used dispersion IDRISI32 model created by Clark Labs (Massachusetts, USA) to model the mass balance, carbon accumulation, waste settling velocity, cages sizing and cage movement from water movement, to then develop raster maps of the water dispersion. They used data from a dispersion model originally located off the coast of Scotland from 12-off 70-m circumference (~22 m diameter) circular cages in a 2×6 arrangement. They created three models over a two year (18–24 month) timeframe from the Scotland site. It was concluded by Corner et al. that there was only a ±58.1% average predictive accuracy of understanding for the waste distribution from the cages. Because there is still limits with GIS technology in following exactly where all waste will travel to (irregular water movement, mortalities, etc.) you cannot get 100% accurate data.


This paper describes the process of transferring mangrove oyster *Crassostrea rhizophorae* raft culture technology to selected coastal communities in Margarita Island, Venezuela. The reasoning for the transfer is in order to reduce the pressure on natural overexploited mangrove oyster populations and reduce the destruction on the mangroves themselves. This was done by creating a bibliographic database that had 20 variables (temperature, waste, salinity, human impacts etc.) that were based off of intrinsic environmental, environmental extrinsic, logistic, and socioeconomic criteria. The GIS image used a base map that was compiled from 1:25,000 scale maps that were off the islands coastline. A Multi-Criteria Evaluation (MCE) was used to combine the variables and to generate a final output. MCE is an important because it’s an evaluation on the data and is used to gain reliable information on the strengths, weaknesses and overall utility of each variable. The results indicated by Buitrago et al. was that 137 sites (about 37.5 km2) were ranked in having 75%-70% acceptance by the MCE as being a acceptable place to move the mangrove oysters to the new coastal location.


In this paper, Longdill et al. discuss the several data collection programs used to find Aquaculture Management Areas (AMAs) for *Perna canaliculus* mussels within the Bay of Plenty, New Zealand. An AMA is a planned future aquaculture sites, that is designed to
maximize the development of environmentally sound and economically sustainable farms off of a country's coastline. They found these AMA's with GIS based models and using Multi-Criteria Evaluation (MCE) technique to evaluate each variable within the data in order to find their strengths and weaknesses. The push for developing was paper was due to the increased demand for *Perna canaliculus* mussels, an industry that has doubled during one decade (1995–2005) to reach 100,000 tonnes/yr. It was found that the AMA’s areas, where maximum sustainability may be achieved overall made up 18% (or 421 km2) of the total bay area, with conflicting uses and other constraints accounting for 46% of the total bay area. Some of the issues found were mainly in the lack of GIS technology being able to imply 100% estimates of carrying capacity (either physical, production, ecological, or social) within the bay. It was also discussed that there needs to be a push in the technology if it is expected to give a 100% guarantee that a future farm to meet AMA’s standards.


Nath et al. describe how the deployment for spatial decision support is rather slow in the aquaculture community. This is an older paper (2000), it does acknowledge that there is a lack of understanding within the aquaculture community of GIS technology, a recurring theme with several GIS/Aquaculture articles. In order to resolve this problem Nath et al. reviewed of basic GIS terminology, methodology, case studies in aquaculture and describe where the future trends are going. Overall, Nath et al. is an easy to read article/step by step guide for those within the aquaculture community who lack GIS understanding. The article begins with simple GIS terminology (raster, vector), the methodologies (identifying project requirements, analytical framework, etc.), case studies that have been done using GIS within the aquaculture industry and where the future trends are heading with the technology and where the aquaculture industry is heading. The Nath et al. is a great article to people read if they want to begin using GIS technology on the aquaculture industry.


This paper looks assess the aquaculture development potential for watershed ponds in Thai Nguyen, Vietnam. The data collected was during a two year period where Giap et al. integrated the socioeconomic and environmental data into GIS database. The socioeconomic data can be generalized as how aquaculture and the Thai Nguyen community interact (money, population growth, aquaculture growth, etc.) and the environmental data is how the watershed ponds are impacted by aquaculture and the Thai Nguyen community (algal blooms, habitat loss, etc.). After they collected this data, they located (1) the land use changes and (2) identified potential areas for aquaculture development. The socioeconomic and environmental data were collected using pre-test questionnaires and field measurements and the land suitability evaluation was based off the suitability ratings established to FAO classification. They used three SPOT (Satellite Pour l’Observation de la Terre) multi-spectral band satellite images to detect land use change and future sites. Giap et al. conclude that about 4.7% (2,725 ha) of the total land area of the total 57,618 ha Thai Nguyen water bodies were suitable sites for watershed pond construction.

Hossain et al. identified the suitable sites for carp farming development in Urban Water Bodies (UWBs) of Chittagong, Bangladesh by using GIS based technology and Multi Criteria Evaluation (MCE). They focused on the water, soil and infrastructure data to design the GIS images and to evaluate the data. They also used ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imagery and 14 thematic layers to develop a series of GIS models to identify appropriate UWBs for farming. In general this was an easy read where the recurring theme with GIS/Aquaculture articles, they use GIS technology to design the maps, use data on the site and then evaluate the accuracy of the data with the MCE. It was found that there are 487 UWBs occupying 362 ha in Bangladesh and 280 ha (77%) are the most suitable to place carp farms, 36 ha (10%) is moderately suitable and 46 ha (13%) is not suitable for farming at all. Another interesting aspect about the article is that Hossain et al. placed an chart into the conclusion that list Urban Aquaculture’s strength and weaknesses and compared them to its opportunities and treats.


Seto and Fragkias, used satellite imagery to monitor aquaculture farm development in Vietnam. They did this by using the satellite imagery to assess the impact of the Ramsar Convention on wetlands within the area. The Ramsar Convention is an international treaty for the conservation and sustainable utilization of wetlands. They assess land cover conditions before and after the designation of Ramsar status in two case studies where they evaluated the success by using four metrics: (1) total mangrove extent; (2) mangrove fragmentation; (3) mangrove density; and (4) aquaculture extent. This is a great article that looks at aquaculture impacts onto local ecosystems, a growing concern especially since global mangroves themselves are under treat from many human impacts. It was found that the Ramsar Convention (1) did not slow the development of aquaculture in the region and that (2) total mangrove extent has remained relatively constant, only due to replanting programs in the region.


This paper by Saitoh et al. looked at the benefits of using Satellite Remote-Sensing (SRS) in two case studies, one focused on fisheries and the other aquaculture. This article is great by taking two similar industries and looking at their impacts onto the envioment and how (or if) they will be impacted from climate change. The second case study focused on determining the impact of climate change on site suitability for scallop Mizuhopecten yessoensis aquaculture. Based on the Intergovernmental Panel on Climate Change scenarios there will likely be impacts onto the scallop aquaculture industry in Japan. This is a growing concern for the Japanese themselves because scallop aquaculture is the most successful marine shellfish farming in the country.

Pérez et al. used GIS and Remote Sensing technology in order to build a spatial database that analyzes water quality data around marine European Seabream, *Sparus aurata* and European Seabass, *Dicentrarchus labrax* cages along the Canary Islands. Pérez et al. first begin the paper by discussing how site selection is the key factor in any aquaculture operation and how it affects both the success of the farm and sustainability of the ecosystem due to farm impacts. For water quality they observed the changes in temperature, turbidity and potential disease stressors, including predator impacts over a four year timespan (1997-2000). They used AVHRR (Advanced Very High Resolution Radiometer) sensor measurements on board NOAA-14 satellite to take images every month, 4 per month, with minimum cloud cover. It was concluded that there are 4 water quality variables greatly influencing cage culture; these included temperature, turbidity (runoff and sewage), risk of diseases (sewage) and waste feedback from the cages (bathymetry). This is a great article that shows a lot of the images to look at water quality and the authors did a good job at explaining every step of the process.