Applications of GIS and Remote Sensing in Aquaculture

Over the past couple of decades, aquaculture has been the fastest growing food related industry in the world (FAO, 2011). This growth will most likely continue as the global population and demand for protein-rich seafood rises. However, in order to satiate this growing demand, we need to address one of the limiting factors to aquaculture growth -- space. In many areas, the culture of various species has become so concentrated that it has reached a certain social, and in some cases ecological carrying capacity in the area. This is especially the case in some parts of southeast Asia where high concentrations of farms are negatively impacting the surrounding environment. Simply adding more farms to an already overloaded ecological system is not a sustainable way to grow the industry. In order to ameliorate these issues, we need to identify and cultivate in areas that are not yet being used for aquaculture; this is where GIS and remote sensing come into play. These technologies have proven to be much more efficient means of identifying and quantifying site suitability than traditional methods of assay.

The primary role that GIS and remote sensing play in aquaculture is aiding in its expansion; their tools have become paramount in determining the suitability of a particular area for aquaculture. Without ease of access to certain “basic” data sources like NOAA navigational maps, and bathymetry depth contour maps, surveying for a potential site would be very time consuming and expensive, which would likely limit entry of smaller growers into the industry. However, smaller aquaculture operations are experiencing success due to their access to a plethora of data sources during the site selection process. Other data sources, like SSURGO, STATSGO, DEM, NLCD, Tiger Poly, DoD, and NHD -- to name a few -- have also been important for site selection of inshore, coastal and offshore aquaculture alike.

To further facilitate aquaculture expansion, previous research has created broader, large scale maps of areas with symbology depicting the suitability score of various areas for the culture of a specific species. These types of maps all incorporate a large number of criteria and data sources into the suitability analysis. The more non-redundant criteria included in the analysis, the more accurate the suitability score. These studies are often funded by public and private entities with an agenda to expand aquaculture in their region. For example, as a response to wild fishery pressure, Buitrago et al (2005) developed a suitability map for the culture of the mangrove oyster around Margarita Island, Venezuela. Their suitability map was a function of 20 different sets of mangrove oyster culture-specific criteria. All 20 criteria were weighted by 39 experts in the field, and incorporated into an overall suitability index for various coastal areas. This general procedure of assigning species specific criteria and weights to the analysis of site selection is typical and has been repeated in a number other similar studies (Nayak et al., 2014; Puniwai et al., 2014; Radiarta et al., 2008). Each criteria used is often represented as a individual layer in the end GIS output, with each layer having its own associated weight in regard to the final suitability score of that area. Most of these criteria are obtained through RS and GIS methods (i.e. Landsat imaging, SeaWiFS for chlorophyll-a concentrations, sonar for bathymetry, SoilWeb for subaqueous soils, NOAA navigational maps, e.t.c.) (Puniwai et al., 2014).

These suitability maps can be broadly applied to various stakeholders. Regulators may use them to delineate areas that are open or off-limits to aquaculture expansion. Industry officials can look at suitability maps as a preliminary measure, or way to narrow down potential sites for expansion. Also, depending on the criteria used, conservationists can site suitability maps as evidence for aquaculture having a positive or negative impact on an area’s ecosystem.

However, not all of the GIS and RS research in aquaculture is based around determining site suitability. Other studies have developed maps, which compare the economic utility of using specific
land units for the culture of one or another aquatic species (Salam et al., 2003). Heads up digitizing culture site delineations and tracking the flux of farm concentrations over a specific temporal range is also commonly done (Saxena et al., 2014). Moving forward, it is likely that we will see more studies trying to digitize and map the presence and growth of aquaculture, especially in areas like southeast Asia and China. Understanding total aquaculture coverage of a water body is essential in determining the relationship between the species cultured, and associated environmental impacts.

The future of the aquaculture industry certainly depends heavily on GIS and RS tools. Without these tools, the industry would have difficulty expanding in a fast enough manner to satiate the growing demand for its product. As coastal regions become excessively crowded with farms, we will need to be able to quickly identify and quantify potential areas for expansion -- this is where suitability maps may be especially useful. We are already seeing aquaculture reach social carrying capacity in the United States. For example, nearly all of the Rhode Island coastal lagoons have reached or are about to reach their 5% total aquaculture threshold (which is a function of social carrying capacity). To continue growing the industry, we will likely need to turn to offshore methods of aquaculture. Offshore aquaculture is especially dependent on these RS and GIS tools. The remote nature of offshore environments requires an equally remote form of site assay. Without RS, offshore aquaculture site selection would be overwhelming and impractical.
ANOTATED BIBLIOGRAPHY


In this study by Puniwai et al., the researchers discuss the limitations and benefits of GIS applications in aquaculture siting in Hawaii. In this context, GIS technology ultimately develops a site recommendation dependent on local marine spatial planning, biophysical properties, regulations, and social considerations. For these reasons, the researchers adeptly point out that the application of GIS in aquaculture siting can be used by various stakeholder groups. The GIS model was very thorough and incorporated over 80 layers, which ultimately produced delineations of suitable and off-limits areas for aquaculture. However, I would point out that the biological factors associated with site selection were not flushed out enough; bathymetry data was lacking and not enough factors were included to choose a suitable farming site. For this reason, the model may be less useful for growers.


Using RS and GIS technology, Nayak et al. identified and ranked various areas in the mid/high Himalayan region of Uttarakhand for their potential for aquaculture. Suitability scores (most suitable, moderately suitable, and not suitable) were computed as a function of soil quality, water quality, and existing infrastructure. The write up itself is a little disorganized and hard to follow as there are no headings. However, the substance of the exploration seems to be thorough; the researchers end product certainly has utility for aspiring aquaculturists in the region, as it incorporates a wide variety of relevant variables. They accurately point out that the development and use of suitability maps will be instrumental in increasing the likelihood of success for a potential aquaculture business.


This study by Saxena et al., used GIS and RS to map the change in land use between agriculture and aquaculture in the town of Chinna Cherukuru Village, India. The study used Indian RS satellite data and Cartosat data to survey the site over a temporal range of 18 years. Through the RS data, the researchers noticed a significant increase in land used for aquaculture, followed by a reduction and reversion to agricultural land towards the end of the time scale. They not only track the observed changes, but also tried to understand the underlying social, economic and logistical causes for the changes to adequately interpret the data.


Using Landsat TM data and data from various other sources, Salam et al attempted to identify and quantify the economic productivity of various brackish water regions in the southwestern region of Bangladesh. They were primarily interested in analyzing the utility of these areas for crab and shrimp
culture, but also included the opportunity costs associated with using the land for tilapia, rice, prawn and carp culture. In this way, their output seems to be applicable to many different stakeholders and especially useful in cost-benefit analysis. They eventually determined that shrimp culture was generally going to be a riskier endeavor, but possibly more profitable within this region.


In this study, Radiarta *et al.* identify suitable sites for scallop culture in Japanese waters. Most of the parameters weighed into the suitability of various sites were drawn from data obtained through MODIS (sea temperature), SeaWiFS (turbidity, chlorophyll-a) and ALOS (local infrastructure and logistical limitations). They modeled the viability of various sites for hanging scallop culture using a multiple criteria. Areas were ranked on a score from 1 (least suitable) to 8 (most suitable). The researchers also verified these scores through field analysis, which really sets it apart from other studies I have come across. Their results indicated that 56% and 32% of the total area of the bay was ranked with a suitability score of a 7 or 8, respectively. At the time of assay, existing scallop farms covered a total of 69% of the area scored 8 on the suitability index. The researchers state that the accuracy of the suitability scores could be improved with the addition of more criteria in the analysis. However, given the criteria that they did include, the suitability scores are likely to be of use to industry and regulatory officials.


In this study, Buitrago *et al.* determine the suitability of areas around Margarita Island, Venezuela for culture of the mangrove oyster, *Crassostrea rhizophorae*. This study uses similar techniques of ranking the suitability of areas via various environmental, social, and economic criteria. However, this study used a total of 20 different criteria, which is much more than previous studies. They also weighed the relative importance of these criteria through the input of 39 experts in the aquaculture field. In this way, the criteria used and their weighting seemed to be very well validated and thought out. The resulting map depicted suitable areas for raft culture over an approximately 4000 square mile area. The project was initially carried out in response to the overharvest of oysters in the region; regulators urged individuals to adopt raft culture of the oyster so they could grow their own and not negatively impact the wild stocks. In this way, this study is an example of how to expedite the expansion of aquaculture in a region that desperately needs it.

**OTHER REFERENCES**