Aquaculture development potential in Arizona: A GIS-based approach

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Interest in aquaculture in the state of Arizona is on the rise. Currently, there are more than 30 licensed aquaculture operations in Arizona, including finfish producers, marine shrimp producers, research/educational facilities and distributors. Arizona aquaculture production in 2000 was 680 tons. Finfish including tilapia, bass, trout and catfish accounted for 590 tons, while other culture organisms, primarily marine shrimp, rounded out production (Toba and Chew 2001).

The Arizona aquaculture industry has weathered many startups and, sadly, almost as many failures. The lack of a strong industry and the high, new farm failure rate can be a deterrent to those farmers and investors interested in entering into new projects. Efforts must be made, therefore, to ensure that present and future aquaculture ventures will be successful.

Proper selection of species, location and culture practices can greatly improve the success rate of new aquaculture ventures. Unfortunately, owing to the small industry presence in the state and the long history of more traditional agriculture production, many extension personnel in Arizona are presently ill equipped to answer aquaculture related questions.

Kapetsky *et al*. (1990) demonstrated that a Geographical Information System (GIS) could be used to identify potential areas for aquaculture development on a statewide scale. Using their work as a model, and considering the rising interest in aquaculture in Arizona, we believe that a GIS based model of aquaculture development potential for the state would be a valuable planning tool. The primary objective of this project, therefore, was to develop a GIS based model capable of predicting areas in Arizona that would be suitable for aquaculture development
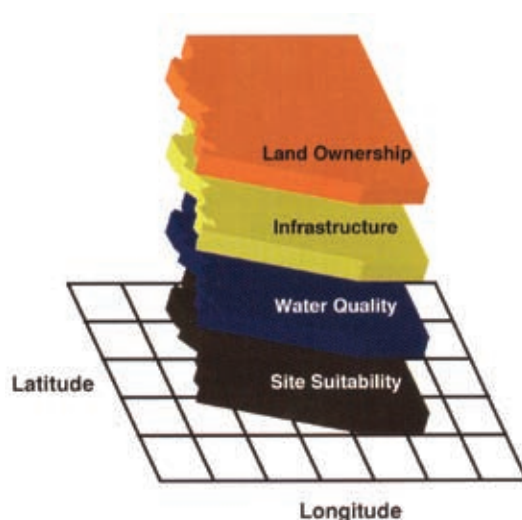

Fig. 1. Illustration showing how GIS assimilates various data 'layers' into a single model that can highlight otherwise hidden relationships important for potential aquaculture development in Arizona.

and expansion, in hopes of reducing the likelihood of a new venture failing as a result of improper site selection.

GIS - What and Why?

Geographical Information Systems or GIS have been described as "an integrated assembly of computer hardware, software, geographic data and personnel designed to efficiently acquire, retrieve, analyze, display and report all forms of geographically referenced information geared towards a particular set of purposes" (Nath *et al*. 2000). Another way of thinking about this, if you are unfamiliar with GIS, is to think of a series of transparencies, stacked on top of each other (Figure 1). Each transparent layer contains specific information that, while important, does not necessarily give the viewer the whole picture. It is not until you are able to evaluate the whole stack that relationships and patterns emerge.

One is reminded of the book of the human body that you may have checked out of the library as a child. Each transparent page contained one of the body's systems; skeletal, circulatory, respiratory, muscular, nervous and skin. If all you could see was one page at a time, you got great detail about that system, but no indication of how that system works in relation to the rest of the body systems. The complex nature of the human body as an organism was lost until you had all of the pages stacked together and suddenly you realized that each detailed, complex system is a part of one, living thing. GIS acts in much the same way, allowing the end-user to see relationships that might otherwise be lost. Our model was designed to enable extension personnel, land-use managers, farmers and other interested persons who may be unfamiliar with the specific requirements of aquaculture to evaluate potential farm sites in Arizona for aquaculture development and expansion.

Model Development

Existing data sets were collected from a variety of independent sources and synthesized to meet the needs of this project. Seven individual models were produced, one corresponding to each of the five most common aquaculture species in Arizona: bass, catfish, marine shrimp, tilapia and trout and two general models, designed to offer more flexibility in site selection (Figure 2). These non-species specific models allow the database to be queried by user defined limits placed on the various parameters of the model and/or location, coordinates or city name. All data contained in the model were manipulated using ArcView GIS 3.2[4].

Table 1.	Data categories included in the development of the GIS model and the specific data sets comprising each category.

Data Category	Data Used
Site Suitability	Land slope
	Soil clay content
Water Quality	Temperature
	Alkalinity
	pH
	Total dissolved solids
Infrastructure	Interstates
	Roads
	Towns with population
	Power lines
	Railroads
Land Ownership	Private
	Government
	Reservation
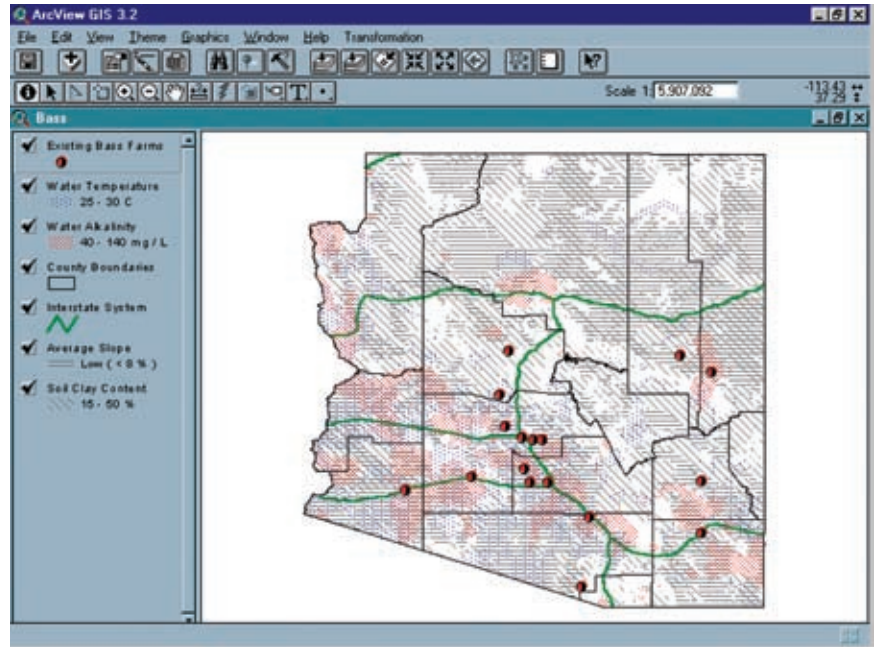
Fig. 2. GIS model of existing bass farms and the areas that are suitable for further bass farm development.

Data incorporated into the model were chosen to address some specific concerns facing a new aquaculture venture. Because of the complex construction needs of recirculating and raceway aquaculture facilities, model parameters were selected for inclusion based on the construction of an outdoor, pond-based production system. Therefore, altering these hypothetical design parameters could significantly influence the applicability of the data contained in this model. Data sets selected were grouped into four major areas — site suitability, water quality, infrastructure and land ownership (Table 1).

Site Suitability

The primary data sets describing site suitability were the slope of the land and the soil properties. These are important when considering the feasibility of constructing an outdoor pond system. Average slopes were calculated and used in the site evaluation. An average slope of less than eight percent was considered suitable. Similarly, soil clay contents between 15 and 50 percent were chosen as suitable for pond construction. Slope data and soil property data were obtained from the State Soil Geographic (STATSGO) database, maintained by the U. S. Department of Agriculture, Soil Conservation Service.

Water Quality

Surface water sources are often not available in the arid southwest. Therefore, in Ari-
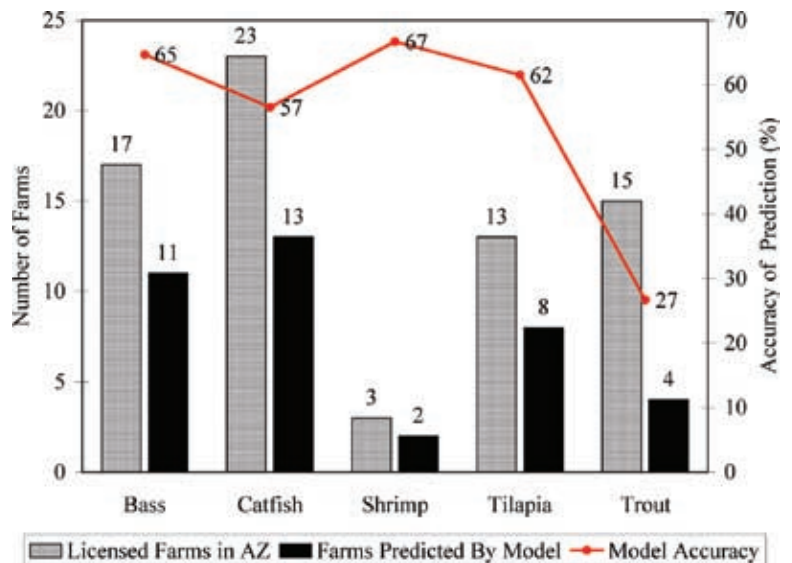

Fig. 3. Graph depicting the accuracy of the five, species specific GIS models developed, showing the number of extant aquaculture facilities, the number of farms that fall in the 'predicted' area and the accuracy of each model.

zona aquaculture operations commonly require the use of groundwater. The water quality database used was the Groundwater Site Inventory (GWSI) database, published by the Arizona Department of Water Resources. Specifically, water temperature, pH, alkalinity and total dissolved solids data were used, inasmuch as each commonly cultured species has specific water quality needs (Table 2). Water quality requirements are species specific, so were modeled accordingly. Total dissolved solids affect primarily the culture of marine shrimp farms and were not included in the other species' maps. With the exception of a few locations in the state, water pH was adequate for aquaculture, so only pH extremes are indicated in the models.

Infrastructure

Infrastructure data are important to the assessment of potential aquaculture sites because they address the operational viability of a new farm. It is certainly beneficial to have easy access to an adequate labor pool, local markets and power delivery systems, but the obstacle that their absence presents can be overcome in many ways. Locations of roads and interstate highways, power transmission lines, railroads and towns with their respective populations are presented in this GIS model, primarily for reference (Table 1). Infrastructure data were obtained from the Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database and the Arizona Land Resource Information System (ALRIS) database.

Individuals using this model will likely have their own ideas as to what infrastructure is or is not necessary. Unfortunately,

there is no easy formula that can predict the success of a new aquaculture venture based on the existing infrastructure to help make siting decisions. Therefore, specific infrastructure limitations that could exclude otherwise suitable areas for aquaculture development were not built into the model, as in the case of the water quality, slope and soil clay content data. We want to present this information so that decision makers will be better informed.

Land ownership

Land ownership data were also obtained from the ALRIS database. Three categories of ownership have been identified: private, government or reservation. Government owned land comprises both state and federal holdings, including parks, monuments and military bases. With few exceptions, this land is closed to development. There are instances where federal lands have been leased for private use, namely cattle ranching, however, we are not currently aware of any private aquaculture or other confined animal feeding operations being built and/or operated on leased federal lands.

Private land is considered any land owned by individuals or corporations and, as such, is seen as a possible location for aquaculture development. Reservation land is owned by one of the many Native American tribes in Arizona. While this land is not available for sale, there are at least two established fish farms that have been built on land leased from one of the tribes. Additionally, a few of the tribes have expressed an interest in developing aquaculture projects of their own.

Model Testing

Species-specific models were tested against the extant aquaculture facilities

in the state. Maps corresponding to each of Arizona's five commonly cultured species were generated with the currently licensed farms plotted on each. Of the five models tested, marine shrimp farms were most likely to occur in areas predicted accurately 67 percent of the time as suitable by the model. Bass, catfish and tilapia farm locations were predicted accurately 65 percent, 57 percent and 62 percent of the time, respectively. Trout farms were least likely to have their sites predicted as suitable by the model, with only 27 percent accuracy. Figure 3 summarizes this information.

Given the low degree of accuracy obtained from the trout model, a closer look at the GIS model seems natural. When you keep in mind, however, that one major assumption we made in building the model was that parameters included were chosen specifically for the construction of a hypothetical, pond based culture system, this lower level of accuracy for trout is understandable. Two factors were quickly singled out. First, trout are much more likely to be raised in raceways than in a pond-based system and, secondly, trout are commonly cultured in areas that have more hilly terrain. These two factors alone, soil clay content and slope, would cause many real world trout farm sights to be overlooked by our GIS model.

Conclusions

Overall, the GIS based model was 56 percent accurate in its ability to predict the locations of licensed farms. We believe that this is largely because the farms were plotted based on the city in which they are licensed, not the actual farm locations, latitude and longitude. We think that the accuracy of the model would be greater had farms been plotted by their

actual locations. Latitude and longitude data are not currently available for all of the licensed farms in Arizona, so it was decided that plotting farm locations should done using one consistent method. Future refinement of the model will include a more accurate 'test' of the models.

To offer one example, a farm with which we have a strong collaborative relationship is known to be approximately 16 km north of the location where our model has 'plotted' the location. This particular farm falls just to the south of the predicted area on the map generated by the GIS model. Had this farm been plotted by its coordinates rather than its mailing address, it would fall directly in the area predicted by the model.

Regardless, the results do suggest that this model has sufficient predictive power to help extension personnel, land-use managers, farmers and other interested persons who may be unfamiliar with the specific requirements of aquaculture to evaluate potential farm sites in Arizona for aquaculture development and expansion. It is important to keep in mind that the goal of this model is not to eliminate the need to make a site visit prior to the initiation of an aquaculture project, but rather to help refine the search area by eliminating those areas that are grossly inadequate. Arming interested individuals with this tool could reduce the failure rate of new aquaculture ventures by improving site selec-tion and, thereby, improve the success of the aquaculture industry in Arizona.

Notes

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Acknowledgments

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