Land: Water Surface Area Ratio for Aquaculture Ponds

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 3, 2014

Keywords: Land Use, Aquaculture Ponds,
Land: Water Ratio

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Abstract

Aquaculture farms use more land than the pond water surface area because of the necessity for embankments, canals, roads, storage areas, offices, parking lots, and staging areas. Aquaculture farms with different-sized ponds for culture of several species in 26 countries were evaluated using Google Earth Pro. The estimated water area was subtracted from the estimated total area used solely for aquaculture purposes. Ground-truthing on farms in Alabama revealed no difference in pond water surface area whether measured from the Google Earth Pro images or by hand-held GPS (Wild T1000 Theomat Electronic Total Station). The total area: water surface area was calculated and plotted versus average pond size for each farm. The average ratio for all ponds was 1.48. The ratio tended to decline to about 2.5 ha average pond size; it then stabilized at a ratio of about 1.25:1. The area of ponds worldwide has been estimated at 167,320 km^2. Thus, total aquaculture farm area might be around 247,634 km^2. Of course, additional land – about 0.21 ha/t of production for ponds that use feeds – is dedicated to the production of plant ingredients for aquaculture feeds.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Requirements for pond aquaculture include land for pond construction, soil with suitable properties for stable embankments, water availability, and an enabling socioeconomic environment (Giap et al. 2005). Aquaculture is conducted in water and it usually is considered to use an amount of land equal to the water surface area. However, additional land on farms is necessary to support the pond culture system, e.g., embankments, canals, roads, storage areas, offices, and parking lots. This land is needed for the farms to operate, but it is not included in production data that are based on water surface area.

In the 20th century, aquaculture experienced a sharp increase in demand for products, and farmers reacted by building more farms and by intensifying existing farms to meet this demand. This phenomenon is continuing in the 21st century. The demand for fisheries products is rising because of stagnation of capture fisheries production and the dramatic human population increase. Intensifying a system requires a higher stocking density, heavy use of feeds, antibiotics, pesticides and disinfectants, and a greater amount of aeration (Sapkota et al. 2008). At intensive farms, ponds tend to be smaller than at extensive and semi-intensive farms, but this means more roads and canals are placed on the farm.

It was estimated based on 2005 data that there were 110,830 km^2 water surface areas of ponds in the world including both fresh and saltwater areas (Verdegem and Bosma 2009). This number possibly has increased to around 167,320 km^2 based on 2011 production data from FAO – assuming no increase in production intensity during the intervening 6 years (Table 1). This area is, of course, an underestimate of the total amount of land dedicated to aquaculture use.

Geographic Information System, or GIS, and satellite imagery (a type of remote sensing) were developed for assessing conditions on the earth's surface; they are widely used in assessing land use and in land use planning. GIS may be used to assist in aquaculture planning; however, it is limited for evaluating three-dimension structures and dynamic boundaries of freshwater and marine habitats (Carette et al. 2008). GIS is an effective way to analyze direction, rate, and spatial pattern of land use change (Weng 2002). Satellite images ranges from being of poor resolution with cheap and easily available data to high resolution images that can be expensive. But, all systems can assess multiple sites around the world in systematic, rapid process (McLeod et al. 2002). GIS can be done on a computer or with a hand-held instrument.

Combined GIS and satellite imaging software such as Google Earth or Ocean could be used in advancing aquaculture in areas that are undeveloped and have little information on land use characteristics. The types of useful information that can be collected about aquaculture include selection of adequate sites, determination of area in production, other land uses, and land use updates. GIS also has been implemented for estimating carrying capacity for marine culture species (Saitoh et al. 2011).

The area determined by satellite imagery also can assist in the estimation of storm runoff from watersheds that enter ponds to determine water budgets of man-made impoundments and water bodies used for cage culture (Boyd and Shelton 1984). For more complex aquacultural uses, GIS data should be collected over time to minimize the effects of change in economic, demographic, and environmental factors (Tsai et al. 2006). The application of GIS to aquaculture has been reported by many authors (Arnold et al. 2000; Buitrago et al. 2005; Kapetsky and Aguilar-Manjarrez 2007; Longdill et al. 2008; Nath et al. 2000; Perez et al. 2005; Radiarta et al. 2008; Rajitha et al. 2007; Vincenzi et al. 2006). This study uses a combination of GIS and satellite imaging technology for analysis of farm and pond water surface areas.

At the moment, remote sensing and GIS are the only way to obtain a series of synoptic data for large geographic areas, e.g. globally, uniformly in space and time, and without the need for exhaustive field surveys (Green et al. 1996). This can predict impacts to the local environment of food production around the globe. Aquaculture competes for resources with aquatic ecosystems and human development, and should be evaluated for sustainable land management (Alonso-Perez et al. 2003). Aquaculture, unlike GIS, is unfortunately a series of time elapsing data. However, the satellite imaging approach requires up-to-date and accurate thematic information to make precise estimations, and data available to the public are a few years behind.

The purpose of this study was to compare the portion of water surface area in production ponds on the farm to the total land needed to support production in the production area. This information should be useful in assessing the total land use in aquaculture.

Table 1. Production by species in 2005 and 2011. Species that are cultivated mainly by pond aquaculture are listed with their production by year (FAO 2011).

Species Group		2005 (t)	2011 (t)
Carps, barbels, and other cyprinids		17,753,655	25,157,502
Tilapias and other cichlids		1,991,797	3,957,949
Miscellaneous freshwater fishes		3,927,566	6,483,984
River eels		217,185	255,284
Miscellaneous diadromous fishes		626,255	960,523
Freshwater crustaceans		913,638	1,674,309
Shrimps, prawns		2,667,929	3,930,059
	Total:	**28,098,025**	**42,419,610**

Materials and Methods

Google Earth Pro was obtained and used to determine areas of ponds and farms in selected areas around the world. The Google Earth Pro version was used because it offered a feature called the "polygon" tool which is not an option in the commonly used and free Google Earth software. A Google Earth Pro license must be purchased in order to use this package. This license lasts for one year and may be used on two computers (license may be renewed after the year comes to an end, if needed, with another payment). The software can be downloaded on to any computer for easy use. Google Earth and Google Earth Pro have the same average resolution of 15 m x 15 m. This means that the smallest area for each individual pixel is 15 m. The software uses Landsat imagery with a resolution of 30 m and pansharpens to obtain a higher resolution of 15 m. Some places have higher resolution, such as the United States, with a resolution of 1 m. The images were taken within the last 1 to 3 years, depending on altitude and location (Google 2014). The oldest date of images used in this study was 2012.

The polygon tool allows the user to click and drag the computer's cursor over the desired area and the tool outputs the perimeter and area of the polygon in units that are determined by the user (Figure 1). This tool also has options to set the outline color and the fill color of the polygon. Each polygon was outlined in a 1.0 width black line and filled with a light blue 10% opacity color for distinction. While drawing the polygon, the line is red. The polygon was completed in a clockwise motion so no lines from the tool interfered with the boundary of the desired area. The polygon needs to be completed in one, complete drag of the cursor. A new polygon was made if the cursor found its way off course from the desired area. A polygon was drawn for each individual pond and the entire farm area that appeared to have no use other than for aquaculture (Figure 2). Before drawing the cursor over the image, the tilt of the image was set so the camera looked directly down at the image. The zoomed distance to the ground was based on how big the ponds were: the smaller the ponds, the lower the elevation was for drawing the polygon. Each farm was named after the town it was located in or closest to and each pond was numbered individually. The amount of land at the farm that appeared dedicated solely to aquaculture was determined by taking the total farm area and subtracting it from the total area of all the ponds. Each farm was located in areas known by the investigator to be aquaculture areas and by scanning areas near easily accessible water.

Satellite imaging, however, had its complications: pictures could be blurry or unfocused (Figure 3), and taken at different dates. In coastal areas, aquaculture farms and salt farms appeared similar, and clouds and their shadows can cover the ponds and farm boundaries (Figure 4), too much reflection of the sunlight on the water surface blurred images, and in highly aquacultured areas, the farms are so close together that it is sometimes difficult to determine the boundaries between different farms (Figure 5). These complications created an issue when searching for farms but were overcome by expanding the search to areas that had little to no interferences.

The selection of aquaculture areas was assisted by the experience of my advisor who has traveled to aquaculture sites in many countries – including nearly all of these in this study. Once the areas in a country were located, farms on the imagery were assessed to find those that would be isolated with certainty from other farms and for which the supporting land area could be clearly distinguished from other nearby land.

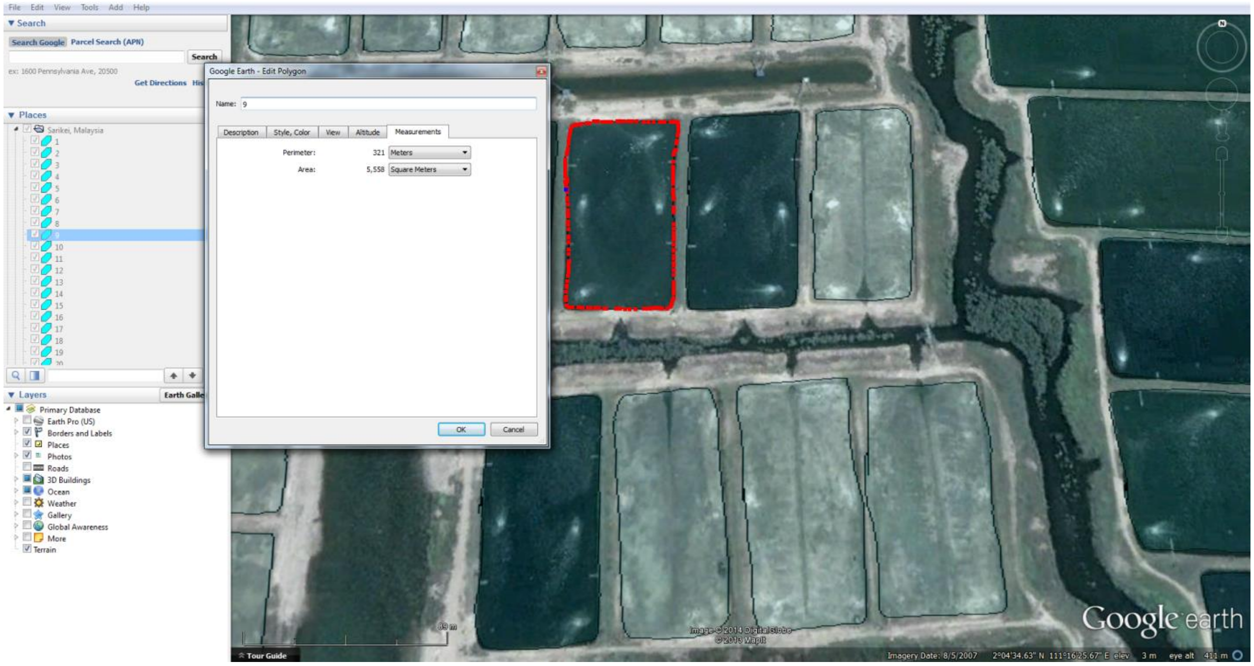

Figure 1. Polygon tool. The polygon tool was used to find the area of an individual farm and of each pond– highlighted in red – using Google Earth Pro. Farm located in Malaysia.

Figure 2. Farm and ponds. A typical farm that was used in this study. Farm located in Malaysia.

Figure 3. Satellite complications – unfocused. Satellite imaging can be blurry or unfocused making boundaries of pond and farms uncertain. Farm located in Malaysia.

Figure 4. Satellite complications – clouds. Satellite imaging does not remove clouds or their shadows which can make pond and farms boundaries uncertain. Farm located in Colombia.

Figure 5. Satellite complications – boundaries. Farms can be highly concentrated in an area causing difficulty in discerning boundaries between adjoining farms. Farms located in Malaysia.

Results and Discussion

The accuracy of aerial data obtained by GIS were ground-truthed using ponds in Alabama whose areas were determined from GPS coordinates measured with a hand-held GPS unit (Wild T1000 Theomat Electronic Total Station). The handheld units typically were driven around ponds with a four-wheeler which allowed a quick, but accurate estimate of area. Areas of ponds on 11 farms in west Alabama were used as reference data (Table 2). The information for the hand-held GPS unit was taken by the Alabama Fish Farming Center in Greenville, Alabama in 2004. New ponds developed since those dates were not used in this study.

The data provided by the GIS hand-held unit only included the individual pond areas and not the total farm area; thus, only the pond areas could be compared. A two sample t-test was attempted, but the data were not normal by distribution. The Mann-Whitney Rank Sum test was run with the null hypothesis that the GIS data area estimates were equal to the Google Earth Pro estimates of area. The hypothesis was accepted; there was no difference (P=0.694) in pond areas measured with the handheld unit and those obtained from Google Earth Pro. A study in 2007 discovered that using Landsat 5 TM satellite imagery provided a ground-truthing accuracy of 80% in identifying the number and area small impoundments in Lee County Alabama, or spatial data (Chaney et al. 2012). However, in that study, pond areas were estimated using a range finder – a technique not nearly as accurate as GPS coordinates.

Data were collected from 100 farms in 26 countries around the world (Table 3). They were divided into five categories - 20 farms in each - based on the average pond size on the farm: <0.5 ha, 0.5-1.0 ha, 1.0-5.0 ha, 5.0-10.0 ha, and >10.0 ha (the greatest being 25.89 ha in

Table 2. Ground-truthing. Comparison of pond area made with a hand-held GPS unit and Google Earth Pro for several farms in Alabama.

Farm	No. of ponds	Google Earth Pro (ha)	Hand-held GIS (ha)
Greene Prairie	20	26.72	26.45
Givhan	17	92.93	100.85
Bates	11	62.78	62.73
Clemmer	7	21.62	20.23
Diller	11	34.77	34.36
Bryant	82	390.29	382.63
Forkland	35	176.66	174.06
James	20	78.11	78.75
Smelley	13	45.79	45.49
Nichols	7	15.05	27.68
Wilson	36	64.18	61.19

Table 3. List of Countries. The collective data of the 26 countries that was used for the study for a total of 100 farms.

Country	No. Farms	No. Ponds	Total Land (ha)	Total Water (ha)	Avg Pond Size (ha)	Land:water
Australia	2	62	63.5	38.3	1.24	1.66
Belize	1	55	686.4	550.4	10.01	1.25
Brazil	10	171	177.0	138.4	7.84	1.3
China	4	101	12.1	7.9	0.28	1.51
Colombia	2	35	92.2	58.3	3.3	1.58
Costa Rica	2	69	244.5	181.4	4.89	1.35
Cuba	1	27	365.2	266.0	9.85	1.37
Ecuador	12	250	222.2	176.3	9.89	1.27
Egypt	16	587	24.8	15.8	0.52	1.72
El Salvador	1	12	49.4	40.5	3.37	1.22
Ghana	1	28	212.5	173.6	6.2	1.22
Guatemala	2	28	82.7	68.5	5.04	1.2
Honduras	3	79	442.1	371.0	13.97	1.24
India	2	47	18.4	14.2	0.59	1.3
Indonesia	7	96	191.5	166.3	12.58	1.17
Malaysia	3	81	36.8	17.3	0.61	2.07
Mexico	3	53	122.4	93.0	4.98	1.29
Nicaragua	2	24	150.3	115.9	9	1.36
Panama	2	74	173.9	126.1	4.18	1.75
Peru	1	18	173.6	137.6	7.64	1.26
Taiwan	1	17	74.7	53.2	3.1	1.4
Thailand	8	243	31.6	20.8	0.67	1.58
Ukraine	1	16	500.8	408.5	25.53	1.23
USA	4	202	88.3	64.8	3.2	1.79
Venezuela	2	137	438.4	296.3	4.28	1.53
Vietnam	7	271	124.0	96.8	2.12	1.64

Ecuador). These farms contained a sum of 2,783 individual ponds with a total water surface of 10,923 ha and 14,091 ha of land, or 1.48 ha of land for each hectare of water surface. This sample represents approximately 0.1% of the total water surface area of aquaculture ponds globally. The research can be thought of as a survey; only a small portion of the over-all, vast number of aquaculture farms, globally, were considered. This survey can be compared to telephone surveys for assessing public opinion on a particular issue. Only a few hundred residents will be called and complete the survey in a specific state, but millions of people may reside there. Given that this study was intended to obtain an approximate estimate of the land: water ratio, the sample used in this study was adequate to obtain that estimate for that purpose.

The data were analyzed based on the farm land: water ratios. Out of the 100 farms, farms with smaller pond size tended to have a greater average but more variable land: water ratio. The ratio exponentially decreased as the average pond size on the farms increased. Thus, the larger the pond the less land that is used per unit surface area of water. As the ponds become larger, the change in the ratio with respect to water surface area decreased and tended to stabilize at about 1.25 beyond a similar surface area of 3 ha (Figure 6).

The average ratio of all the farms was 1.48 with a range of 1.08-4.02. Jenks Optimization (Goodness of Variance Fit) classified the breaks in the data based on distribution (Figure 7). Jenks Optimization reduces the variance within groups while maximizing the variance between groups. The break points for these data were at 1.29, 1.49, 1.89, 2.65, and 4.02. Jenks Optimization determined that majority of the data had land: water ratios less than 1.89.

The farms were categorized by major climate zones according to the Koeppen's Climate Classification (Grieser et al. 2006). Some countries overlap into multiple zones, but the zones

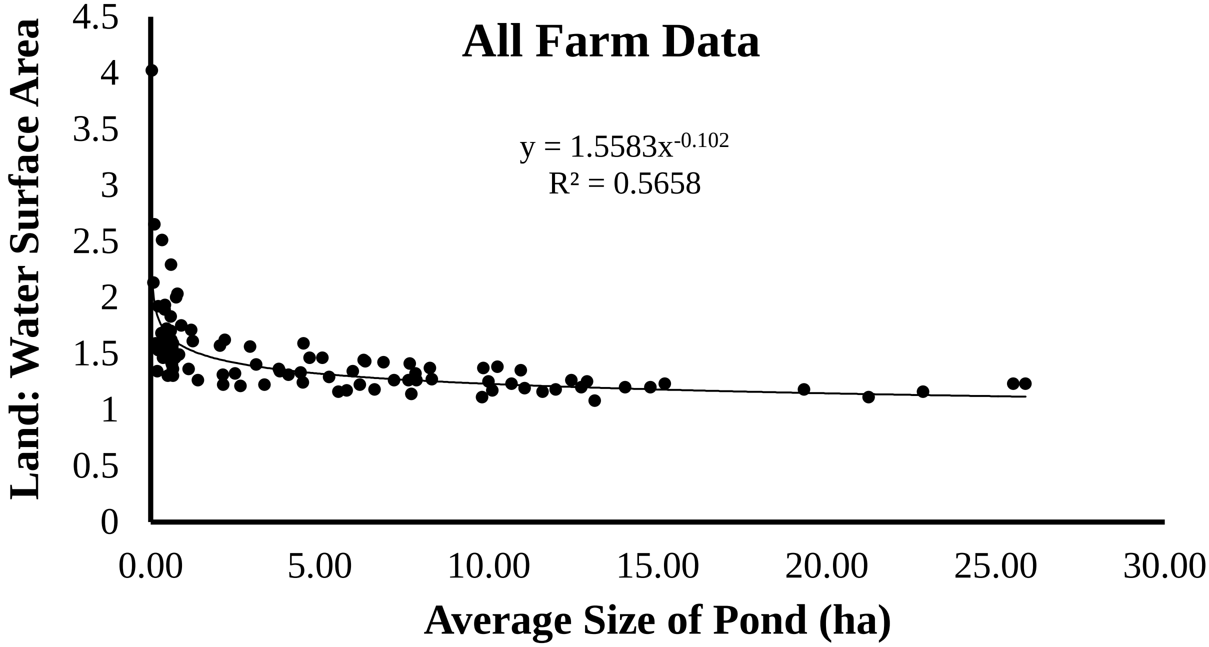

Figure 6. Average pond size vs. land: water surface area ratio. All 100 farms plotted by the average pond size of the farm by the land: water surface area ratio and the data treated by regression analysis.

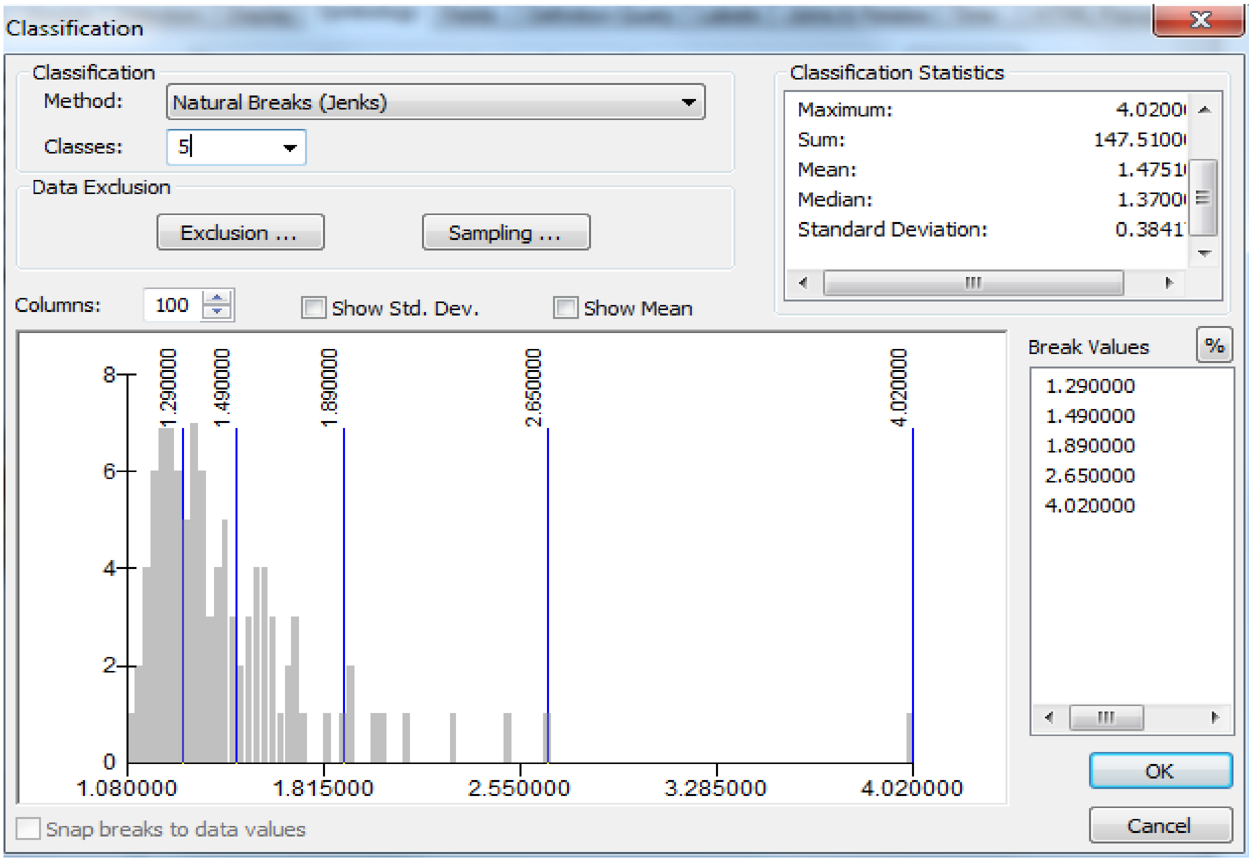

Figure 7. **Jenks optimization**. Natural breaks in the collective land: water ratios were determined of 100 farms.

chosen for those countries were based on the location of the majority of the farms in the country (Table 4). The largest proportions, or 68 of the farms including 1,715 ponds, were in tropical zones. In the tropics, average pond size were 6.63 ha; these ponds were significantly larger ($p<0.05$) than those in temperate and arid regions that had average areas of 4.38 ha and 1.17 ha, respectively. The relationship also tended to be the same for the land: water ratio; farms in the tropics had a lower ratio of 1.41, temperate farms had a ratio of 1.6, and farms in arid regions had a ratio of 1.62 (Table 5). There was a greater amount of variation in the temperate zone, but the arid and tropical regions had outliers of which temperate had none (Figure 8). The average pond sizes and the land: water surface area ratios were skewed, and an One Way ANOVA on Ranks was necessary. Dunn's method was used since it is the only valid method if treatment group sizes are unequal, which is true in this case, to find where the differences are among the means.

The ponds were distributed among continents as follows: North America, 623 ponds; South America, 611 ponds; Asia, 856 ponds; and Australia, Europe, and Africa, 693 ponds. Average pond size for North America and South America were 6.62 ha and 8.14 ha, respectfully. These ponds were significantly larger ($p<0.05$) than ponds in Asia and the other continents for which average pond sizes were 3.61 ha and 2.13 ha, respectfully. This same trend was observed with the land: water ratio in the Americas, where farms had greater pond sizes, but lower land: water surface ratios, than in Asia and the other continents that had smaller pond sizes, but larger land: water ratio (Table 6). All the continents had outliers in their data sets, but South America had a narrow range of ratios compared to the other continents (Figure 9). North America had the widest range and showed the highest correlation (R^2=0.7684, $p<0.05$) when the farms in North America were plotted by the average pond size against their land: water surface area ratios

(Figure 10).The average pond sizes and the land: water surface area ratios were statistically skewed so they were compared for statistical significance by running a One Way ANOVA on Ranks, as above. Dunn's Method was also used to determine where the differences lay.

Production may also have a role to play in the land: water ratio. The larger ponds in the Americas are stocked at a lower stocking density so they have more land per unit of production than in the eastern hemisphere where they have more intensive systems that would have considerably less land per unit of production.

Table 4. Countries divided by climate zones. Countries were divided into three major climate zones based on Koeppen's climate classification. If countries were divided into more than one zone, countries were placed where the majority of farms were located in a climate zone.

Tropical Zone	**Arid Zone**	**Temperate Zone**
Vietnam	Egypt	United States
Thailand	Mexico	China
Ecuador	India	Ukraine
Venezuela	Australia	
Colombia		
Taiwan		
Honduras		
El Salvador		
Guatemala		
Brazil		
Ghana		
Cuba		
Nicaragua		
Belize		
Malaysia		
Panama		
Costa Rica		
Indonesia		
Peru		

Table 5. Data distribution by major climatic zones. Farms were separated by major climates and are summarized by number of farms, ponds, water surface area, land area, average pond size, and land: water surface area ratios. Values with different letters were significantly different ($p<0.05$).

Climate	**No. Farms**	**No. Ponds**	**Total Land (ha)**	**Total Water (ha)**	**Avg Pond Size (ha)**	**Land:water**
Temperate	9	319	902.4	699.4	4.38a	1.6a
Arid	23	749	927.4	636.1	1.17a	1.62ab
Tropical	68	1715	12,260.5	9,586.9	6.63b	1.41ac

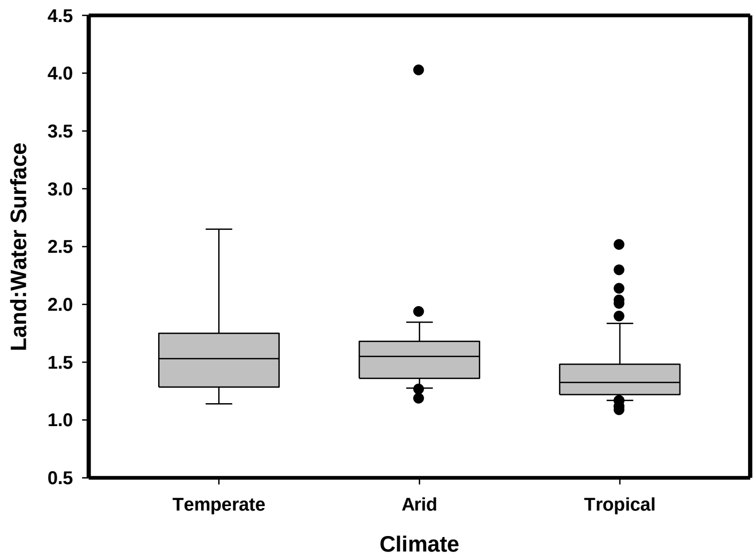

Figure 8. Box plot of the farms by major climates. Variance in land: water surface ratio by major climate region is illustrated by box plots. Black dots indicate out-liers.

Table 6. Data distributed by continents. Farms were separated by continents and are summarized by number of farms, ponds, water surface area, land area, average pond size, and land: water surface area ratios. Values with different letters were significantly different ($p<0.05$).

Continent	No. Farms	No. Ponds	Total Land (ha)	Total Water (ha)	Avg Pond Size (ha)	Land:water
North America	21	623	4,450.6	3,491.9	6.62a	1.42ac
South America	27	611	5,671.7	4,346.4	8.14a	1.32a
Asia	32	856	2,731.3	2,173.3	3.61b	1.52bc
Australia, Europe, and Africa	20	693	1,236.7	910.9	2.13b	1.67b

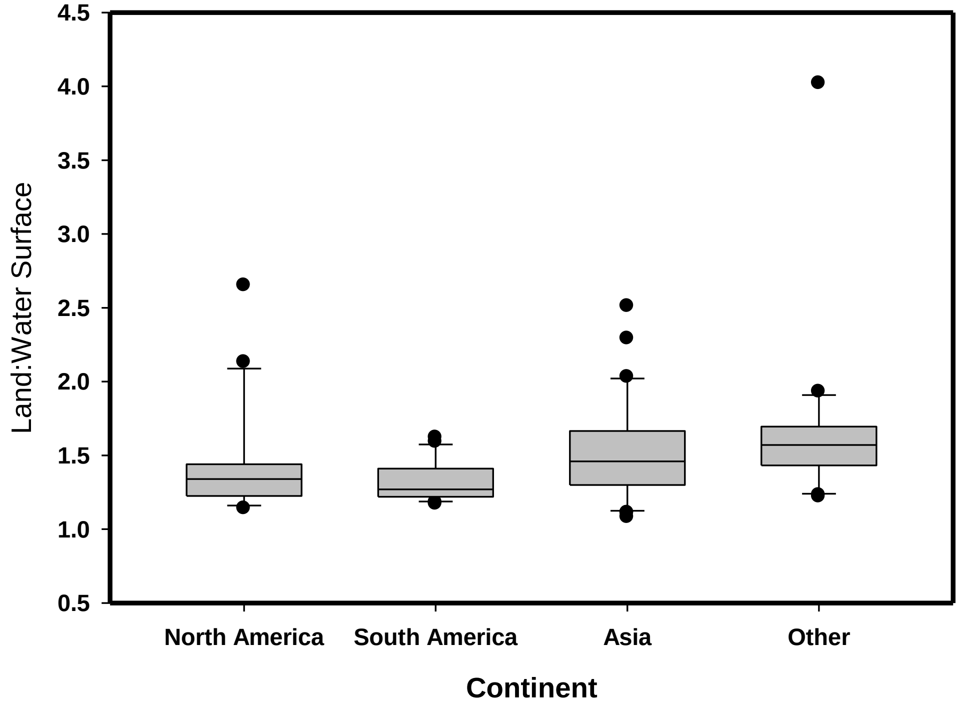

Figure 9. Box plot of the farms by continents. Land: water surface ratios' variance by continent is illustrated by box plots. Black dots indicate out-liers.

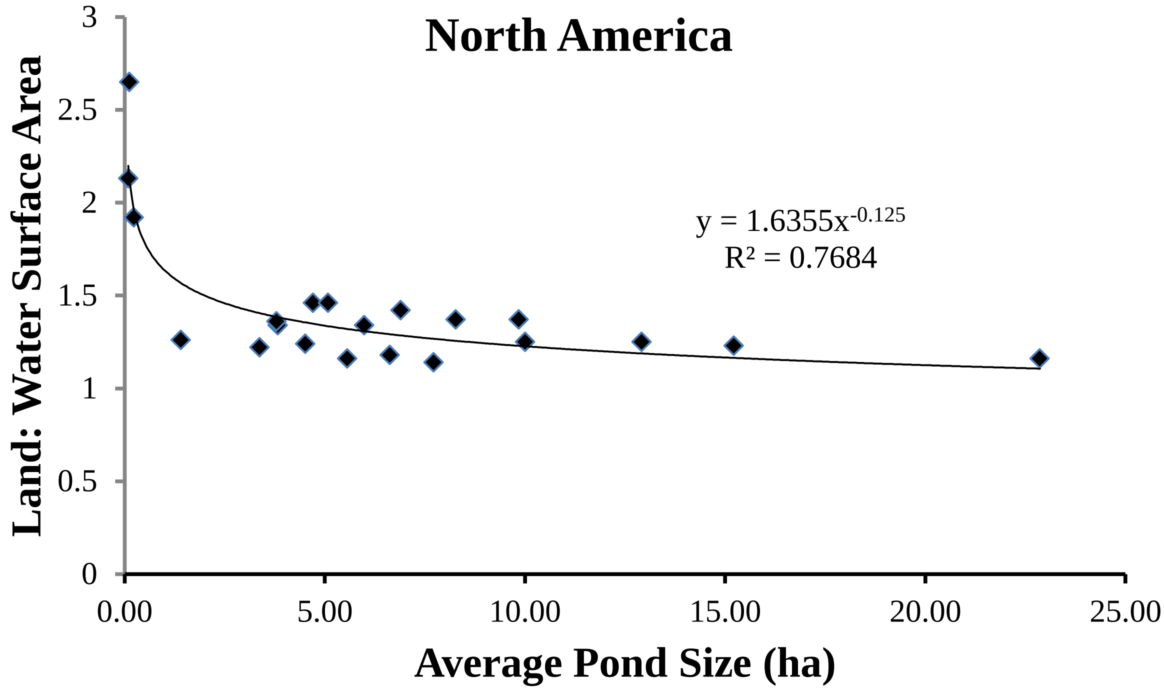

Figure 10. North American farms. The data gathered from North America were plotted by average pond size vs land: water surface area ratio.

Conclusions

The study could be continued to encompass a larger sample of farms and ponds with ground surveys to determine the species under culture, intensity of culture, whether or not feed was used, ground truthing in other regions, etc. However, such an effort would be considerably expensive because it would require travel, labor for ground truthing, language interpreters, etc. Different methods of determining area could also be examined, and the accuracy and expense of different methods compared. Satellite imaging creates a known error, most common involves spatial resolution, and some other method might be more accurate, or have a higher resolution. However, Google Earth Pro allows the user to find an area anywhere in the world from a satellite image on a computer screen.

The most accurate way of measuring the area of ponds and land areas is by conventional surveying and mapping techniques (Boyd and Shelton 1984). This technique requires surveying instruments and knowledge of their use. It also is time consuming and tedious. A much less accurate way of assessing areas is by counting someone's paces to measure distances or by using a range finder to estimate distance. Although cheaper, this method is also time consuming and can only be done by the same person who has to physically walk around the pond or farm. Considering the alternatives, the method of assessing areas from satellite imagery used in this study seemed appropriate for the objectives.

In agriculture, the production of crops is reported as the amount of a crop produced on a hectare of land planted with the crop. The cultivated area is equivalent to the water surface area upon which pond aquaculture production is reported. As in aquaculture, additional farm land is dedicated to the production of crops, because roads, lanes, drainage ditches, irrigation canals, barns, and other storage areas, etc. must be provided. Agricultural land use includes arable land, land under permanent crops, and land under permanent pastures. Arable land is defined as land under temporary crops, temporary meadows for mowing or for pasture, land under market in kitchen gardens, and land temporarily fallow (The World Bank 2014). At the farm level, the forest land is excluded, but the rest of the farm area is considered to be agricultural land in one of the above categories. The land devoted to supporting the production area is placed in the same categories. Data on the ratio total agricultural area: production area at the farm-level could not be found. Nevertheless, there are data on the total agricultural area in nearly all countries (The World Bank 2014), and total agricultural production can be related to total agricultural land. This possibly has not before existed for pond aquaculture production.

The intensity of aquaculture pond farms have been increasing the past few years as better management practices have being improved and implemented. For example, channel catfish production in the southern United States average less than 2,000 kg/ha in the late 1960s, but it is over 5,000 kg/ha today (Boyd et al. 2013).

Ecolabel certification that requires specific standards is becoming more popular among farmers as the demand for such products increases. These standards are intended to avoid negative environmental impacts, but they also are used to make the farm more efficient with resource uses such has feed, energy, and water use (Boyd and McNevin 2013). This could potentially lead to a standard requiring a specific land: water surface area ratio. The standards are determined based on being better than average use (<1.48). Using this study and Jenks Optimization, <1.29 heavily represents the data distribution, and this ratio might be the recommended ratio as a standard for improving land use efficiency.

Using the mean land: water surface ratio of 1.48, the total global area devoted to pond aquaculture farms might be around 247,634 km^2. This area is an underestimate of the land needed for aquaculture because land is needed to grow plants for plant meal included in aquaculture feed. The area for plant meal production is difficult to calculate because statistics for aquaculture feed use are not separated as to culture system in which they are used. In addition, not all species are grown only in ponds and not all ponds are supplied with feed. The total land area need for plant meals – soybean meal and corn meal - for shrimp, tilapia, and channel catfish were estimated to be 0.220 ha, 0.402 ha, and 0.388 ha, respectively (Boyd and Polioudakis 2006). Catfish and tilapia feeds, which are similar in ingredient composition, have an average requirement of 0.21 ha/t per crop for plant ingredients in feed (Boyd et al. 2007). Production, per unit area of water surface area is lessened in systems that are more intensive or in which there is more than one crop per year. This reasoning does not apply to land requirements for feed.

The amount of land for grain, however, can be estimated by aid of a few assumptions. According to Alltech's 2013 Global Feed Summary, 34.4 million (M) tonnes of aquaculture feed were produced globally in 2011. To get the total amount of feed produced for ponds, salmonides/ diadromous fish and cage culture feed production should be withdrawn. Assuming that the average feed conversion ratio (FCR) for salmonids and other diadromous fishes is 1.2 (Marine Harvest 2013) and that the production of these fish was 3.73 M tonnes (FAO 2011), 4.48 M tonnes of feed were consumed by these fish. Cage culture production was 3.4 M tonnes in 2005 (Tacon and Halwart 2007), but this production included salmonids and diadromous fish. Thus cage culture production of other species was 1.1 M tonnes. Using 1.1 M tonnes of fish production and a common FCR of 1.75 (Beveridge 1993), 1.92 M tonnes of feed were consumed by these fish. If the total feed used for salmonids/diadromous fishes and other cage culture (6.3

M tonnes) taken out of the total aquaculture feed production, the feed left amounts to 27.6 M tonnes that were used for pond aquaculture. If we take the land area required for plant meals needed in the feed for each tonne of shrimp, tilapia, and channel catfish of 0.220 ha, 0.402 ha, and 0.388 ha, respectively (Boyd et al. 2007), we get an average of 0.337 ha/t for grain in feed per tonne 27.6 M tonnes of feed used in ponds 9.23 M ha of land would be estimated. If added to the adjusted value of water surface area (16.7 M ha) and the land required for farms from this study (8.03 M ha), there are 33.96 M ha, or 339,600 km^2, dedicated to pond aquaculture.

It should be mentioned that the production of non-pond fish that was removed for calculation land use for grains to support pond aquaculture also required land for feed. This, even cage culture in natural lakes requires land to support it.

The estimates of pond water surface (Verdegem and Bosma 2009) and the land: water ratios and area needed for plant ingredients are subject to considerable error. However, even if they are 25 to 50% too low, aquaculture still uses a microscopic amount of land compared to world agriculture usage of 49,200,000 km^2 (Boyd and McNevin 2013). Although aquaculture is probably not a major land use in any country, it can bring significant changes to the landscape, redirect other land uses, and cause ecological distresses. Even if aquaculture production increases exponentially in the coming years, it will still be in small quantities compared to terrestrial animal agriculture – which will also increase in proportion with time. Despite having a small impact of total land use compared to agriculture, aquaculture remains to be of vital importance to the food security of many developing countries.

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