Techniques to Assess Fish Productivity in Aquaculture Farms and Small Fisheries: An Overview of Algebraic Methods

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Abstract: The main goal of aquaculture and small fisheries is the bioaccumulation of chemical elements in edible tissue. Fish, shellfish, decapods and/or algae are commonly cultivated organisms in marine and freshwater aquaculture systems. Total biomass is the best indicator of production system performance. However, due to the high variation of technologies and methods used in aquaculture, special techniques are required to make thorough studies. The present study is a summary of algebraic fish biometric techniques to assess fish biomass production. Numerical computations were carried out for didactical purposes.

Key words: Fish growth, relative density, metabolic growth rate, von Bertalanffy’s growth function

INTRODUCTION

Fisheries and aquaculture both involve the production of high quality fish protein (Obaroh and Achiornye-Nzeh, 2011; Bozoglu et al., 2006; Huda et al., 2002). Fisheries are based on the extraction of living resources in water bodies (Bostock et al., 2010; Akca et al., 2006). Aquaculture is the farming of aquatic plants and animals (Iwama, 1991). Both disciplines provide most of the world’s aquatic edible resources (Food and Agriculture Organization of the United Nations (FAO, 2010).

Aquaculture productivity is commonly measure as total biomass. However, in many cases additional parameters are required to make thorough studies (Alagaraja, 1991). Simple algebraic models can be used to make important decisions in farm (Rooman and Jamili, 2011). These methods are relative easy to carry out and their implementation requires basic mathematical background. In scientific research they can be used to compare similar experimental procedures (Alatorre-Jacome et al., 2011).

In the case of fisheries, direct and indirect methods to assess productivity have been extensively developed (Cochrane, 2002; Sparre and Venema, 1998; Pauly, 1983). But as for inland, small-scale aquaculture systems, the application of large and complex fisheries analysis could be far to be done.

The purpose of the present study was to propose a synthetic methodology in order to assess small-scale fish productivity. Formulae for collective and individual fish growth determination are presented. A case study in aquaculture is analyzed for collective growth performance indexes. A small-fisheries study case is analyzed to explain the procedure for individual fish growth determination.

MATERIALS AND METHODS

Data measurement: For the following parameters, there were required four types of response variables: Fish total length (mm), fish wet weight (g), time (days) and number of fish measured. The correct techniques for accurate measures can be found in the literature (Sparre and Venema, 1998; Brander, 1975). For explicative purposes, examples on calculations were analyzed on results.

Total biomass production: According to Ricker (1971) biomass is the amount of substance in a population expressed in material units, such as living or wet weight, dry weight, ash-free weight, nitrogen contents, etc. It is also termed as standing crop.

For the total biomass wet weight (W) we use:

\[ W_t = \sum_{i=1}^{n} W_i \]  

(1)

where, \( W_i \) is the weight of the \( i \)th fish in the system.

Because the aquacultural systems are very heterogeneous about its size and capacity, is useful apply
the term relative density (prer) per volumetric unit (kg m\(^{-3}\)) to compare among them:

\[
\text{prer}(t) = \frac{W_t}{V}
\]  

(2)

where, \(W_t\) is the total biomass on the system and \(V\) is its volume. In extensive systems it often used the area instead volume.

Akinwole and Faturoti (2007) use the next equations as useful indicators for the system productivity. The Total Weight Gain (TWG) function indicated the gain of biomass in a given time:

\[
\text{TWG (g)} = M_f - M_i
\]  

(3)

where, \(M_f\) is the final mass of the fish and \(M_i\) is the initial mass.

The Average Daily Growth Rate (ADGR) indicate the average weight gained each day:

\[
\text{ADGR (g day}^{-1}\text{)} = \frac{\text{TWG}}{D}
\]  

(4)

where, \(\text{TWG}\) is the total weight gain (from Eq. 3) and \(D\) are the culture day (Shnel et al., 2002).

According to Ebwala and Omoregie (2009), the Specific Growth Rate (SGR) is:

\[
\text{SGR (kg g}^{-1}\text{ day}^{-1}\text{)} = \frac{100 \times (\ln M_f - \ln M_i)}{D}
\]  

(5)

where, \(M_f\) is the final weight of the fish, \(M_i\) is the initial mass of the fish, \(\ln\) is the natural logarithm and \(D\) are the culture.

Metabolic Growth Rate (MGR) and the Feed Conversion Efficiency (FCE) can be computed with the methodology exposed on the work of Frei and Becker (2005):

\[
\text{MGR} = \left(\frac{(M_f - M_i)/((M_f + M_i/2000))^{0.3}}{D\text{ (kg kg}^{-1}\text{ day}^{-1})}\right)
\]  

(6)

where, \(M_f\) is the final mass of the fish, \(M_i\) is the initial mass of the fish and \(D\) are the interval time (in days). For FCE:

\[
\text{FCE} = \frac{F}{(M_f - M_i)}
\]  

(7)

where, \(M_f\) is the final mass of the fish, \(M_i\) is the initial mass of the fish and \(F\) is the dry weight of the feed.

**Individual fish growth:** In hatchery or nursery system is also important the length of the fish. Both variables (weight and length) are related by the next equation (Sparre and Venema, 1998):

\[
W_i = a \times L_i^b
\]  

(8)

where, \(W_i\) is the weight for the \(i\)th fish, \(L_i\) is the total length of the fish and the letters \(a\) and \(b\) are the growth parameters obtained by linearization.

In many cases is useful to predict the increment of the length and weight of the fish in a given time. It can be achieve using potential growth model. A very popular model among fish researchers is the von Bertalanffy's growth function:

\[
L_t = L_m (1 - \exp^{(-kt)})
\]  

(9)

where, \(L_t\) is the total length of the fish on time \(t\), \(L_m\) is the maximum total length at infinite time, \(k\) is the growth constant, \(t_0\) is the initial time to growth and \(t\) is time. In the case of weight, the equation is the following:

\[
W_t = W_i (1 - \exp^{(-kt)})
\]  

(10)

where, \(W_t\) is the total weight of the fish on time \(t\), \(W_i\) is the maximum total weight at infinite time, \(k\) is the growth constant, \(t_0\) is the initial time to growth and \(t\) is time (Pauly, 1983).

**RESULTS AND DISCUSSION**

**Total biomass production:** Soto-Zarazua et al. (2010) cultivated 1,200 tilapia fingerlings on circular tanks with a capacity of 20 m\(^3\). The average initial weight was 20 g and after 180 days the weight of all the fishes was measured. Applying the formula 1, the total biomass production on one tank was 580.33 kg. For relative biomass production (Eq. 2):

\[
\text{Pr el} = \frac{W_t}{V} = \frac{580.33\text{ kg}}{20\text{ m}^3} = 29.016\text{ kg m}^{-1}
\]  

(11)

The initial total weight gain assumed 1,200 fish and 20 g per fish was 24 kg. For Eq. 3:

\[
\text{TWG} = M_f - M_i = 580.33\text{ kg} - 24\text{ kg} = 556.33\text{ kg}
\]  

(12)

And the average daily growth rate per tank, according to Eq. 4:
The Specific Growth Rate (SGR) was:

\[
\text{SGR} = \frac{100 \times \frac{M_f - M_i}{M_i}}{180} = 100 \times \frac{(580.33 - 24) (24 kg)}{180} = 1.77
\]

(14)

Metabolic Growth Rate (MGR) and the feed conversion efficiency (FCE) can be computed with the methodology exposed in the work of Frei and Becker (2005):

\[
\text{MGR} = \frac{(580.33 \text{ kg} - 24 \text{ kg})}{180} \times \frac{(580.33 \text{ kg} + 24 \text{ kg})}{2000} = 1.173 \text{ kg kg}^{-1} \text{ day}^{-1}
\]

(15)

In addition, there was reported 940.13 kg of feed consumed during the experiment, so the feed conversion efficiency was:

\[
\text{FCE} = \frac{940.13 \text{ kg}}{580.33 \text{ kg} - 24 \text{ kg}} = 1.6899
\]

(16)

**Individual fish growth:** In 2006, Alatorere-Jacome measured the following data for length and weight on *M. salmoides* located in a small lake in center México (Table 1).

<table>
<thead>
<tr>
<th>No.</th>
<th>Length (mm)</th>
<th>Weight (g)</th>
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<th>Length (mm)</th>
<th>Weight (g)</th>
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<td>83</td>
<td>34</td>
<td>189</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 1: Length and weight measured on largemouth bass (*M. salmoides*) on Camecuaro Lake, 2006

In fitting the data for an exponential model (\( r^2 = 0.97 \)) the specific length-weight relation was:

\[
W_i = 1.08 \times 10^{-5} L_i^{1.15}
\]

(17)

To obtain the parameter for Von Bertalanffy equation, \( K \) and \( L_\infty \), there are several methods. In this case we used the following. In literature, the propose value \( L_\infty = 358.4 \). With the data of age and length (Table 2), in a third column there was calculated:

\[
y = -[\ln (1-L_i/L_\infty)] 1.08 \times 10^{-5} L_i^{1.15}
\]

(18)

Plotting the values of the first and third columns, there was obtained by linear regression (\( R^2 = 0.9971 \)) the parameters \( a = 0.33 \), which is the value \( x \) at \( y = 0 \) and \( b = 0.3255 \), the slope of the line. The value \( K = b \) and \( T \), was:

\[
t_i = a = -0.515
\]

(19)

And the Von Bertalanffy’s weight equation for this population is:

\[
L_i = 358.4 (1- \exp^{0.3255x+0.315})
\]

(20)

In ADGR, the index can be used to make more accurate feed management schedules. A variation can be made with the data, dividing ADGR by number of fishes. Then the average day growth rate per fish can be obtained. In this case, 2.57 g day\(^{-1}\) fish\(^{-1}\) is reported. Rezg et al. (2002) reported ADGR from 1.87 g day\(^{-1}\) fish\(^{-1}\) in *O. aureus* after 35 days of culture. This value is lower than the observed on Soto-Zarazua et al. (2010) but the main difference is that Rezg cultured fingerlings, who have a different metabolism than adults. In other hand, Liti et al. (2005) reported ADGR from 0.06 to 1.5 g day g day\(^{-1}\) fish\(^{-1}\) found on tilapia fed on two formulated diets with locally available feed in Kenya.

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Table 2: Linearization of time (age) and length values to parameter determination on von Bertalanffy’s equation

<table>
<thead>
<tr>
<th>L_i</th>
<th>(4\ln(1-L_i/L_\infty))</th>
<th>4L_i</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>174.3</td>
<td>0.666170593</td>
</tr>
<tr>
<td>2</td>
<td>221.4</td>
<td>0.961687553</td>
</tr>
<tr>
<td>3</td>
<td>262.4</td>
<td>1.317530499</td>
</tr>
</tbody>
</table>
```

Calculating the fish weight at \( L_\infty = 652.07 \), so the Von Bertalanffy’s weight equation is:

\[
W_i = 652.07 (1- \exp^{0.3255x+0.315})
\]

(21)

**DISCUSSION**

There are many different values for productivity index on literature, which explained the global performance for one system. In this case, the value of 29 kg m\(^{-3}\) is obtained Timmons et al. (2002) recommended less than 40 kg m\(^{-3}\) for systems with blowers. However, Rakocy et al. (2006) reported densities of 60 kg m\(^{-3}\) for aquaponic systems. In extensive systems, Sarkar et al. (2005) reported lower values (479 kg ha\(^{-1}\) even with strains of genetically improved farm tilapia. The principal causes of productivity are due to managing practices, temperature (Ghosh et al., 2008; Sarkar et al., 2007) and water quality factors in culture water (Hossain et al., 2007).

In ADGR, the index can be used to make more accurate feed management schedules. A variation can be made with the data, dividing ADGR by number of fishes. Then the average day growth rate per fish can be obtained. In this case, 2.57 g day\(^{-1}\) fish\(^{-1}\) is reported. Rezg et al. (2002) reported ADGR from 1.87 g day\(^{-1}\) fish\(^{-1}\) in *O. aureus* after 35 days of culture. This value is lower than the observed on Soto-Zarazua et al. (2010) but the main difference is that Rezg cultured fingerlings, who have a different metabolism than adults. In other hand, Liti et al. (2005) reported ADGR from 0.06 to 1.5 g day g day\(^{-1}\) fish\(^{-1}\) found on tilapia fed on two formulated diets with locally available feed in Kenya.
From SGR, Akinwole and Fatuori reported SGR from 2.656 to 2.86 measured on C. gariepinus cultivated in recirculating aquaculture system. Velazquez and Martinez (2005) reported 0.97 and 0.86 for C. auratus. Hlophé et al. (2011) reported SGR values lower than 1.7 in T. rendalli fed with kikuyu grass.

On the other hand, Cho and Bureau (2001) suggested the elimination of the parameter due to the non-realistic approaching of its calculation. In MGR, the index is used in nutritional studies. Richter et al. (2002) reported several index (From 1.76 to 5.04 g kg\(^{-1}\) day\(^{-1}\)) in order to assess a more convenient maintenance diet formulations in red tilapia. At last, the feed conversion efficiency of 0.59 means that almost 60% of the mass provided for the tilapia was assimilated as tissue. This is very convenient, due the requirements of the fish to its energy for respiration and the balance of non-assimilated food.

In the example presented for individual fish weight, it can be observed that in Eq. 16 the parameter b\(^{3.05}\). When the parameter b = 3, the growth is called isometric and if b<3 is called allometric negative and if b>3 is allometric positive (Pauly, 1983). So we can see that the fish measured have a good increment of weight. For the equations of von Bertalanffy’s equations, the parameter k is very important, because is the growth constant and is species specific (Lv and Pitchford, 2007). For this case, in the study of Guzman-Arroyo made 35 years earlier in the same place, the value was k = 0.56, so we can assume that the conditions were more favorable to a faster growth for M. salmoides.

CONCLUSION

Selected fish biometric indexes were presented in this work. The use of the parameters mentioned can bring more information for the intrinsic factors in the fish culture that influenced growth. They also allow the comparison between different populations in space and time. This paper can be used as a quick guide to measure fish productivity in small systems. The following parameters can be used by scientist or producers to compare different systems each other.

ACKNOWLEDGMENT

The Fondo de Investigación de la Facultad de Ingeniería (FIFI, 2011) of Queretaro State University sponsored this work, the financial support is greatly appreciated.

REFERENCES


