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Analytical Approaches for Addressing The Variation in Back-Calculated Age-Length Relationships for Fish

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Abstrak: Menganggar pertalian di antara umur dan panjang ikan merupakan suatu aspek rutin dalam banyak kajian perikanan dan ianya telah dipermudahkan dengan penggunaan program komputer komersil. Program-program ini boleh mengelirukan memandangkan suatu keputusan boleh dihasilkan tanpa mengambil kira kualiti dan jumlah data, dan juga terdapat sedikit kebimbangan mengenai pertalian umur dan panjang ikan yang dikira secara kebelakang (*back calculated*) yang sensitif kepada saiz dan komposisi sampel. Kami telah menyelidik isu ini dengan membandingkan anggaran purata umur dan kadar tumbesaran ikan *channel catfish Ictalurus punctalus* liar (N=788) yang telah dikira secara kebelakang. Sampel tersebut telah diambil daripada beberapa subset dalam satu sampel yang besar yang telah diambil pada tahun 2001 dan 2002 dari 9 sungai di Mississippi, United States. Anggaran kadar tumbesaran adalah berbeza daripada kadar tumbesaran purata untuk sampel keseluruhan. Kadar tumbesaran adalah sama bagi subset-subset rawak daripada jumlah sampel keseluruhan (20%–100% dalam peningkatan 10%) tetapi berbeza bagi sub-sampel 10%. Kedua-dua panjang ikan mengikut umur dan kadar tumbesaran daripada komponen sampel 2001 dan 2002 adalah berbeza. Semua keputusan adalah signifikan pada $P < 0.05$.

Kata kunci: Ikan, Umur dan Tumbesaran, Variasi Panjang pada Umur

Abstract: Estimating an age-length relationship is a routine aspect of many fisheries studies and is simplified by the use of commercially available computer programs. These computer programs may be misleading since a result can be produced irrespective of the quality or the extent of the data, and there is some concern that back-calculated age-length relationships are sensitive to the sample size and composition. We investigated this issue by comparing estimates of mean back-calculated lengths at age and growth rates derived from subsets of a large sample of wild channel catfish *Ictalurus punctatus* (N=788) collected in 2001 and 2002 from 9 rivers in Mississippi, United States. Estimates of growth rate varied among subsets consisting of individual year class (2–6) of channel catfish separated from the overall sample. For nine subsets, comprising randomly-selected and increasing proportions of the overall sample (20%–100% at 10% increments of the overall sample), growth was similar. However, growth differed for a subset representing a random 10% of the overall sample. Lengths at age and growth rates derived from each of the 2001 and 2002 components of the sample both differed. All results were significant at $P < 0.05$.

Keywords: Fish, Age and Growth, Variation of Length at Age

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INTRODUCTION

Estimating an age-length relationship and producing a growth curve are routine aspects of many fisheries studies. Commercially available fisheries science computer programs make this estimation a deceivingly easy procedure, since a result may be produced irrespective of the quality or extent of the data. Authoritative statements based on such results are frequently made about population descriptors, including growth rate.

Despite this confidence, there is concern (Carlander 1981) that back-calculated age-length relationships are sensitive to sample size and composition, and some care is required if an estimate of growth rate is to be valid. We investigated this issue by back-calculating mean lengths at age and developing age-length regressions for subsets of a large sample of wild channel catfish *I. punctatus* (N=788). We compared the back-calculated length at age estimates and the regression slopes to assess the influence of sample composition on growth rate.

We selected the channel catfish for our study because of its natural history and because the river fisheries that exploit it (e.g., small scale artisanal and subsistence fisheries) closely parallel those of the riverine catfish *Pangasius* spp. found in lowland river ecosystems throughout Southeast Asia. Additionally, we focused on rivers in the extreme southern United States for this study because the long growing season in this region (including extended long, hot summers) provides seasonal environmental conditions that are similar to those found in tropical regions. Although environmental conditions may influence growth and annulus formation differently in the two groups of catfishes, the approaches outlined in this study transcend regional specificity.

MATERIALS AND METHODS

Samples were taken from wild channel catfish populations in 9 rivers in Mississippi (U.S.A) during 2001 and 2002 using passive gears (trotlines, hoopnets and slat traps/ baskets) and electrofishing. These nine rivers (Fig. 1) represented all physiographic regions in Mississippi. All of the collected fish were individually tagged; each fish's system of origin, capture date and total length (in mm) was recorded. All captured fish were subsequently transferred to the fisheries laboratory at Mississippi State University for processing.

The pectoral spines were removed from each fish for an age and growth determination (Turner 1980). Cross-sections of approximately 0.8 mm thick were cut from each spine and mounted on a microscope slide; later, annuli were counted at a magnification of 40X. The distances from the central focus of each spine section to the respective annuli were measured for the back-calculation of age (Carlander 1981).

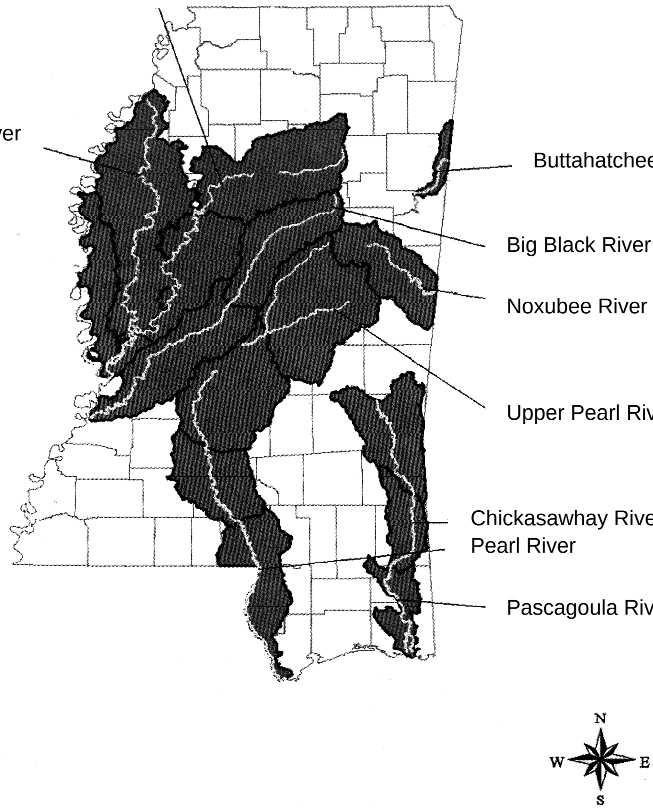

Figure 1: The locations of the nine rivers in Mississippi, United States where the channel catfish were collected for age and growth analyses.

The length at age (at the time of annulus formation) for each fish was back-calculated using both the untransformed and the log-transformed age and length data. The resulting length estimates and intercepts were then compared to the observed lengths at age for channel catfish of each year class represented in the sample. The most 'realistic' back-calculated estimates of length were produced using the untransformed age and length data without manipulating the intercept. Utilising a 'direct proportion' in the back-calculation avoids the problems associated with the use of an inappropriate intercept (Schramm *et al*. 2000, 1992).

In order to find the most appropriate model, a simple linear relationship defined as Length = $a + b$ Age (Ashley *et al*. 1981) and both Von Bertalanffy and Gompertz growth curves (Quinn & Deriso 1999) were fitted to the mean back-calculated lengths at age derived from the whole sample. Growth in channel catfish progresses at a relatively uniform rate for a longer period of time than is characteristic of most freshwater fishes (Appleget & Smith 1951) and the straight line provided a correspondingly good fit to the data ($R^2 > 0.99$). Although the residuals of the Gompertz curve were marginally smaller than for the linear model, this curve better described the decline in growth rate observed in the oldest year class of channel catfish. As a result, it was decided to use a straight line to model growth in all designated subsets of the total sample. The slope of this relationship (*b*) represents an estimate of growth rate throughout the life history of a fish. Analysis of this slope allows for a more direct comparison of growth rates from different samples than the slope of the Gompertz curve, which only represents the decelerating stage of growth.

Mean lengths at age were back-calculated, and corresponding age-length regressions produced were based on fish from each of:

-nine rivers from which the total sample was accumulated
-individual year class represented in the total sample (ages 1–7 years)
-random subsets of the total sample (10%–100% of the sample at 10% increments)
-two sampling years (2001 and 2002).

Mean back-calculated lengths at age and age-length regressions then were compared among each of rivers, year class and percentage sub-samples; and between each of the two sampling years. We tested for significant differences in slope (i.e., growth rate) among regressions by investigating departure from parallel. Parallel lines have similar slopes although they may differ in magnitude. This was achieved by incorporating a dummy variable or ‘interaction term’ into the age-length model. For instance, when testing for differences among rivers we used the model

$$\text{Length} = a + {}_{b}\,\text{Age} + {}_{b2}\,\text{River} + {}_{b3}\,\text{Age} * \text{River}$$

where Age * River is the interaction. A significant regression coefficient (slope) for the interaction implies a significant difference in the slopes of the two lines (i.e., significantly different estimates of growth rate).

RESULTS

There were 788 channel catfish collected for this study, composed of fish from year classes 1–7. Fish from all year classes were used in age-length regressions although <30 individuals of each of ages 1 and 7 were taken (Table 1), and these data points may be deemed less robust.

All the linear models of the mean back-calculated lengths against ages provided a good fit to the data ($R^2 > 0.97$). While the regression slopes (*b*) did not differ among rivers (i.e., growth rate was similar), the mean back-calculated lengths at age differed between some rivers ($P < 0.05$). Since growth rate did not differ among rivers, we combined these samples into one homogenous dataset.

We found a significant variation in the slopes of the age-length regressions in the channel catfish in the year classes 2–7 ($P < 0.05$). The slopes became progressively less for the fish in the year classes 3–6 (Fig. 2). The age-length regressions based on year classes 6 and 7 had the same slope (b=65.2), which was similar to that derived from the overall sample (b=65.1) (Table 1).

Table 1: Mean back-calculated lengths at age were estimated from random components of a large sample of channel catfish that were collected from 9 Mississippi floodplain rivers during 2001 and 2002. These estimates were based on data from seven different year classes and include data from both the combined samples and the annual samples (2001 and 2002). The slopes (*b*) were calculated from a linear regression of mean back-calculated lengths (cm) against age (y).

N	26	55	127	254	196	101	29	788	543	245
Year class	1	2	3	4	5	6	7	Total	2001	2002
Age	Mean back-calculated length at age for channel catfish (cm)									
1	60	68	63	68	63	62	66	64	63	68
2		147	140	133	122	117	123	127	126	130
3			224	211	192	174	184	202	199	208
4				302	269	242	252	278	273	290
5					353	313	320	337	330	355
6						387	389	388	375	413
7							452	453	417	501
Slope (*b*)		79	80.5	78	72.7	65.2	65.2	65.1	60.4	71.9

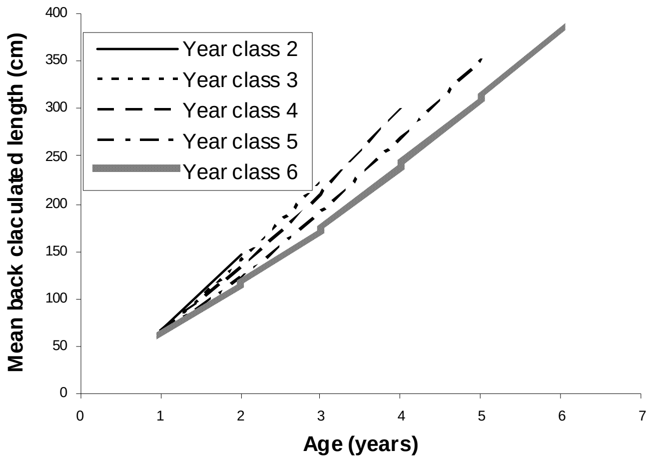

Figure 2: The plots of mean back-calculated length against age for channel catfish from the Mississippi floodplain rivers. Age was back-calculated from the five individual year classes (year classes 2–6) of fish that were a subset of a mixed overall sample (N=788). The slopes (*b*) of the regressions represent the estimates of growth rate and were significantly different among year classes ($P < 0.05$).

The slopes of the age-length regressions based on the random percentage subsamples were similar; that is, the slopes were parallel for 20%–100% of the samples. The slope of the 10% sample differed from the rest ($P < 0.05$). The estimates of the mean back-calculated length at age were similar among subsamples, and these estimates became more consistent as the sample size increased (Table 2).

Table 2: The mean back-calculated lengths at age were estimated from random subsamples of a large sample of channel catfish that were collected from 9 Mississippi floodplain rivers during 2001 and 2002. These subsamples were calculated in 10% increments and included 10%–100% of the total sample. The slopes (*b*) were calculated from a linear regression of mean back-calculated lengths (cm) against age (y).

N	77	156	234	325	394	473	552	631	710	788
% of sample	10	20	30	40	50	60	70	80	90	100
Age	Mean back-calculated length at age for channel catfish (cm)									
1	62	63	64	65	64	64	64	64	64	64
2	124	127	128	129	127	126	126	127	127	127
3	203	205	205	205	202	201	202	202	202	202
4	278	283	282	280	277	278	278	279	278	277
5	338	342	337	339	337	336	338	339	337	337
6	385	391	390	393	392	389	389	389	388	388
7	488	488	460	467	458	454	451	453	450	453
Slope (*b*)	69.1	69.3	65.9	66.7	66.0	65.4	65.1	65.3	64.8	65.1

The mean back-calculated lengths at age differed between the samples from 2001 (N=543) and 2002 (N=244) (paired t-test, $P < 0.05$). The age-length regressions based on the 2001 and 2002 samples had significantly different slopes ($P < 0.05$) (Fig. 3).

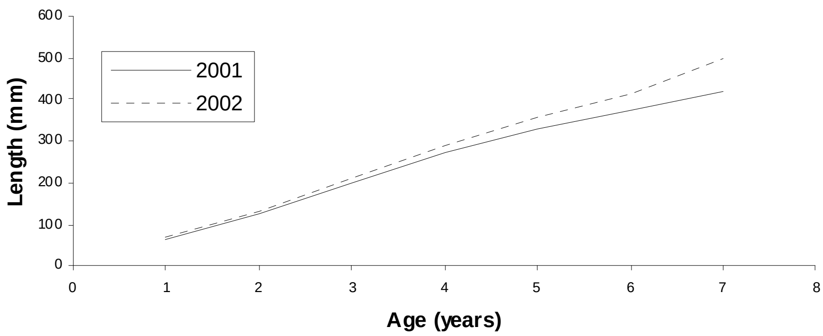

Figure 3: The plots of mean back-calculated length against age for channel catfish that were sampled from 9 Mississippi floodplain rivers in 2001 (N=543) and 2002 (N=245). Age was back-calculated from fish collected during the two sampling years. The slopes (*b*) of the regressions represent the growth rate estimates and were significantly different between years ($P < 0.05$).

DISCUSSION

Although growth rate of channel catfish (the slope of the age-length regression) was similar among rivers in Mississippi, size at age differed significantly among rivers. This has been related to variation in the floodplain river system and watershed characteristics (Shephard & Jackson 2006) and is beyond the scope of this paper. Of direct relevance is similarity in growth rates that allowed data from all rivers to be combined, creating a large data set for further analysis.

It is possible that channel catfish that may have escaped from regional fish farms could have been included in samples for two of the rivers in our study (Yalobusha and Sunflower rivers in the "Delta" region of western Mississippi). However, their influence in the results of this study is considered minor (if at all) because previous and ongoing studies indicate that stocked channel catfish in Mississippi's rivers are quickly assimilated into and/or are overwhelmed numerically by the dynamics of the resident channel catfish stock (Cloutman 1997; Alford *et al.* 2008) and interrelationships of the stock with the riverine environment (Jackson 2004).

There was significant variation in the slopes of age-length regressions based on channel catfish of each of year classes 2–7 within the overall sample, and slopes became progressively lesser as fish of year classes 3–6 were used.

This is likely to be an illustration of the Lee effect, a problem associated with back-calculating length at age for fish from exploited populations. Fishing typically selects for faster growing individuals as these are recruited to the exploitable population first. This means that fish surviving to year classes are often slower growing individuals. Back-calculating length at age from these fish can lead to values that reflect the slower growing component of the population, and correspondingly underestimate true mean length at age. This phenomenon implies that the structure of a sample in terms of number and proportions of year classes represented could seriously bias estimates of growth rate based on mean back-calculated length at age.

Slopes for regressions based on each of year classes 6 and 7 and on the whole sample were similar. This is likely because regression points for fish in the oldest year classes have more influence or 'leverage' on the line and may be predominately responsible for shaping regressions in which these data are incorporated. Linear regression is much more robust to changes in the magnitude of data points in the middle of the distribution.

A large sample, containing all year classes up to the oldest individual in roughly equal proportions should avoid this problem and also mitigate against the Lee effect. If only a very small number of fish from the oldest year classes are present in the sample, it may be valuable to test for disproportionate influence on the age-length regression.

Considering sample size, it is reassuring to see that the slopes of age-length regressions based on 20%–100% subsets of the overall sample were similar. This means that an estimate of growth rate is likely to be valid for a relatively small sample if it contains an appropriate distribution of year classes. Increasing consistency among estimates of length at age as sample size increased is to be expected as the data become more robust to addition and to extreme values.

Differences in both mean back-calculated lengths at age and growth rate were observed between the 2001 and 2002 samples. These samples were collected in the same rivers but likely had a different year class composition. This effect may have been accentuated in the 2002 sample, which was smaller and correspondingly vulnerable to unbalanced year class representation.

The effect of different environmental regime (e.g., rainfall) on growth may also have influenced the growth increment between sample years and reasserts that growth rate in a population is not a static value but shifts in relation to both intrinsic and extrinsic factors. Differences between years highlight the susceptibility of growth rate estimation to sample variability and the influence of individual year classes.

CONCLUSION

Using wild channel catfish, we investigated of the influence of sample size and composition on estimates of mean back-calculated length at age and growth rate, observed the Lee effect, and highlighted the significance of this phenomenon. We concluded that the influence on the age-length regression of length data for fish in the oldest age observed should be tested. Sample size may influence estimates of mean back-calculated length at age but a smaller sample can provide a valid estimate of growth rate as long as all year classes are represented in proportion. Sample composition, a function of variables such as fish catchability and sample date can also influence estimates.

REFERENCES

Alford J B, Jackson D C, O'Keefe D M and Barabe R M. (2008). Recovery of river fisheries following Hurricane Katrina. Federal Aid to Sport Fish Restoration Project F-140-R. *Freshwater Fisheries Report Number 254.* Mississippi: Mississippi Department of Wildlife, Fisheries and Parks, 89.

Appleget J and Smith L L Jr. (1951). The determination of age and rate of growth from vertebrae of the channel catfish, *Ictalurus lacustris punctatus*. *Transactions of the American Fisheries Society* 80: 119–139.

Ashley K W, Garling D L Jr. and Ney J J. (1981). Use of the age-length relationship as a marker for differentiating geographical stocks of adult channel catfish. *North American Journal of Fisheries Management* 1: 77–79.

Carlander K D. (1981). Caution on the use of the regression method of back-calculating lengths from scale measurements. *Fisheries* 6(1): 2–4.

Cloutman D G. (1997). *Biological and socio-economic assessment of stocking channel catfish in the Yalobusha River, Mississippi.* PhD diss., Mississippi State University.

Jackson D C. (2004). Natural history and fisheries. In C S Tucker and J A Hargreaves, (eds.). *Biology and culture of channel catfish. Developments in Aquaculture and Fisheries Science 34.* New York: Elsevier Publishers, 15–35.

Quinn T J and Deriso R B. (1999). *Quantitative fish dynamics.* USA: Oxford University Press, 542 pp.

Schramm H L, Malvestuto S P and Hubert W A. (1992). Evaluation of procedures for back-calculation of lengths of largemouth bass aged by otoliths. *North American Journal of Fisheries Management* 12(3): 604–608.

Schramm H L, Eggleton M A and Mayo R M. (2000). Habitat conservation and creation: Invoking the flood pulse concept to enhance fisheries in the lower Mississippi River. *Polskie Archiwum Hydrobiologii* 47(1): 45–62.

Shephard S and Jackson D C. (2006). Difference in channel catfish growth among Mississippi stream basins. *Transactions of the American Fisheries Society* 135: 1224–1229.

Turner P R. (1980). Procedures for age determination and growth rate calculations of flathead catfish. *Proceedings of the Annual Conference of Southeastern Association of Fisheries and Wildlife Agencies* 34: 253–262.