Monitoring Individual Growth of Tilapia (*Oreochromis niloticus* and *Tilapia zillii*) in An Artificially Heated River

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**Abstract:** Individual growth of wild tilapia (mixed population of Nile tilapia *Oreochromis niloticus* and redbelly tilapia *Tilapia zillii*) was investigated using a release-and-recapture approach in a thermally enriched small river during the period from April to December, 2007. Both total length and body weight increased as water temperature increased. When water temperature decreased, the body weight of large fish above 400 g decreased, whereas that of small fish under 400 g showed no change or slight increase. This seasonal growth performance of large fish was also confirmed by the change in the length-weight relationship. A short-term cold shock in early November due to factory shutdown exerted severe adverse effects on the tilapia population, including death; however, the shutdown had no effect on individual growth of survived fish. This study indicated that fish growth was dependent on fish size and season. Additionally, the length-weight relationship was useful when measuring approximate seasonal growth performance of fish despite the small sample size.

**Key words:** Tilapia; Individual growth; Length-weight relationship; Seasonal variation

Elucidating the growth performance of certain fish populations is especially important to fisheries and ecophysiological research. Existing growth monitoring methods can be divided largely into two groups. One determines fish growth relative to changes in mean values of certain parameters (e.g. length, weight) using a large number of specimens collected regularly. This method facilitates an investigation of how fish growth and physiological status, such as water and lipid contents, are related (Booth and Keast 1986; Griffiths and Kirkwood 1995; El-Sayed et al. 1996). However, whether the data acquired by this approach is applicable to growth patterns of individual fish remains uncertain. To evaluate individual fish growth, the growth of identical fish must be measured. To achieve this goal, one must mark or tag captured fish, and the fish must be released in the same body of water. Fish growth can be assessed directly by comparing particular parameters when the fish are released and recaptured (Tranquilli and Childers 1982; Galloway and Kilambi 1988; Morita and Morita 2002). Hence, this approach is convenient for identifying actual growth as long as the fish physiology is unaffected by the presence of a mark and tag. However, evaluating the effects of environmental factors on fish growth processes is difficult when tagged fish are recaptured after several seasons as fish growth is generally seasonally dependent (Booth and Keast 1986; Griffiths and Kirkwood 1995; El-Sayed et al. 1996). Overall, the merits of one method correspond to the shortcomings of the other method. Thus, by combining the results of seasonal variation of mean fish growth and fragmentary data on the change in body size of individual fish, one can evaluate growth response of individual fish to their external environment.

This study describes seasonal changes in tilapia growth (Nile tilapia *Oreochromis niloticus* and redbelly tilapia *Tilapia zillii*) in a small...
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A municipal river where a high recapture rate of tagged fish was likely for the relatively low population density of target fish within a restricted area of the river. The group of tilapia is thermophilic and originally native to Africa and the Middle East; however, several species are now regarded as cosmopolitan and commonly farmed (especially Nile tilapia) in Africa, Southeast and East Asia (Gupta and Acosta 2004; De Silva et al. 2006; El-Sayed 2006). Furthermore, some studies note the effective ability of Nile tilapia to digest bloom-forming cyanobacteria, such as *Microcystis*, making an attempt to control cyanobacterial blooms by feeding tilapia and have achieved encouraging results (Datta(Saha) and Jana 1998; Turker et al. 2003; Lu et al. 2006). The feeding habits of Nile tilapia are size-dependent and change from omnivorous to roughly phytoplanktivorous as tilapia grow (Yada 1982a, b). Information for tilapia growth based on size and season will prove exceptionally useful to aquaculture and future utilisations of tilapia.

### Materials and Methods

This study was performed at an upstream section of the Minami River, Moriyama, Shiga, central Japan (Fig. 1). Both sides of the entire river are covered with concrete, and the bottom consists of sand gravel. The total length of the study section was ca. 560 m, and river width was 1.2 – 2.5 m. The majority of the study section was less than 30 cm deep, except for the southwest short length (ca. 10 m), which had a maximum depth of ca. 70 cm. No dike existed in the study section. Thus, fish were able to move freely. Water temperature was high throughout the year due to continuous discharge of heated groundwater from a chemical factory located on the uppermost stream of the river. This high temperature has allowed tropical tilapia to reproduce for more than 30 years (Personal communication). The tilapia population consisted of Nile tilapia and redbelly tilapia; the former is the predominant species. The fish fauna in the Minami River, except for the existence of tilapia, was comparable to those in the middle or lower reaches of many rivers in Japan. The overwhelmingly dominant species was pale chub *Zacco platypus*, followed by dark chub *Zacco temminckii*. The numbers of both Nile tilapia and redbelly tilapia to the fish fauna were clearly higher than those of other species, such as crucian carp *Carassius gibelio langsdorfi*, far eastern catfish *Silurus asotus*, gudgeon *Pseudogobio esocinus* and largemouth bass *Micropterus salmoides*; at least one specimen of these species were observed or captured during the study period. Only a few large colored carp *Cyprinus carpio* existed in the southwest part of the study section that was very deep.

Physico-chemical factors were measured at a fixed station (N35°04´42.8˝, E135°59´90.8˝), typically at around 10:00 am once or twice per month during the period from April to December, 2007. Water temperature and concentration of dissolved oxygen (DO) in the river were measured concurrently with a Handy DO meter TOX-90.

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![Fig. 1. Location of the sampling area in the Minami River (denoted by a closed circle in the left figure). Sampling was carried out within the section surrounded by dotted lines in the figure on the right side.](image-url)
Growth Monitoring of Individual Tilapia

(Toko Inc., Tokyo, Japan). Flow velocity at 5 cm above the riverbed was measured with the Yokogawa CR-7 (Yokogawa Electric Cooperation, Tokyo, Japan). The electrical conductivity (EC) and pH at the surface were measured by the ECTestr10 Low+ (Eutech Instruments Pte Ltd, Ayer Rajah, Singapore) and the pH/NO3/Eh meter PRN-41 (Fujiwara Scientific Company Co., Ltd., Tokyo, Japan), respectively.

All fish were captured using a hook and line in April; however, two net types were used after May. A green agricultural net (5 × 2 m, 1 cm mesh size) was submerged at a specific location in the river, and was fixed with stones such that it was not swept away. One of the authors drove fish into the net using a dip net starting several tens of meters upstream. The other author waited near the net, and withdrew that net immediately when at least one target fish reached the net. This method was used to catch tilapia selectively as small fish passed through the large mesh in the net. Additionally, fish were caught with a dip net throughout the study period. Captured fish were collected in a 35-l container containing river water treated with a water conditioner, Catch-And-Release (Professional Sporting Goods, Texas, USA). A portable aerator (air supply rate at 7.3 ml/s) and the oxygen spray O2W (Ohara Co., LTD., Osaka, Japan) were used to oxygenate the container water.

Total body length and weight were measured to the nearest 1 mm and 1 g, respectively, and fish were tagged (except for June, July and December) beside the river. Each fish was placed in a transparent plastic bag. Body weight was determined by subtracting the wet bag weight from gross weight. After recording body measurements, a handmade plastic anchor tag (25 mm length, 34 – 44 mg weight, Fig. 2) with a unique serial number was inserted between the posterior end of the dorsal fin and caudal fin. The tagged fish was promptly released back to the river. The anchor end of the tag and needle in the tagging gun were sterilized with 80% ethanol each time just prior to tag insertion. Captured fish were not tagged in June, July and December.

**Results**

Water temperature increased continuously from April to September, and decreased from
October (Fig. 3A). Flow velocity started increasing in April and a maximum of 0.44 m/s was measured in October (Fig. 3B). A factory shutdown in early November led to significant decreases in water temperature to 16.5°C and flow velocity to 0.11 m/s on November 9, and returned to the previous temperature and velocity on November 21. The EC gradually decreased from April and reached 21.7 mS/m in August, and then increased until October (Fig. 3C). A rapid increase in EC was observed on November 21 following a minimum of 21.2 mS/m on November 9. The pH fluctuated at 6.89–7.70 (Fig. 3D). The minimum concentration of DO (6.51 mg/l) was observed on October 9, followed by a rapid increase in November (Fig. 3E).

The number of captured fish in a day was 5–21 and the number and percentage of recaptured fish was 0–7 and 0–53.8%, respectively (Table 1). The efficiency of fish collection decreased during midsummer (July and August). Ultimately, 72 of 89 captured fish were tagged and 20 were recaptured (27.8% recaptured rate) (Table 2).

Table 1. Total number of captured fish and number and percentage of recaptured fish

<table>
<thead>
<tr>
<th>Date</th>
<th>Captured fish</th>
<th>Recaptured fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr. 12</td>
<td>20</td>
<td>3 (23.1)</td>
</tr>
<tr>
<td>May 10</td>
<td>13</td>
<td>3 (33.3)</td>
</tr>
<tr>
<td>Jun. 7</td>
<td>9</td>
<td>2 (28.6)</td>
</tr>
<tr>
<td>Jul. 19</td>
<td>5</td>
<td>2 (11.1)</td>
</tr>
<tr>
<td>Aug. 9</td>
<td>7</td>
<td>4 (33.3)</td>
</tr>
<tr>
<td>Sep. 7</td>
<td>9</td>
<td>6 (53.8)</td>
</tr>
<tr>
<td>Oct. 9</td>
<td>12</td>
<td>6 (33.3)</td>
</tr>
<tr>
<td>Nov. 9</td>
<td>21</td>
<td>5 (25.8)</td>
</tr>
<tr>
<td>Nov. 21</td>
<td>13</td>
<td>5 (25.8)</td>
</tr>
<tr>
<td>Dec. 13</td>
<td>11</td>
<td>5 (25.8)</td>
</tr>
<tr>
<td>Total</td>
<td>120 (89*)</td>
<td>31 (25.8)</td>
</tr>
</tbody>
</table>

* Duplications of individuals were eliminated.

Table 2. Number and percent of tagged fish and recaptured times

<table>
<thead>
<tr>
<th>Recaptured times</th>
<th>Tagged fish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
</tr>
<tr>
<td>0</td>
<td>52</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>72</td>
</tr>
</tbody>
</table>

Recaptured fish were divided into two groups based on body weight, i.e., a small group under 400 g of body weight (12 fish, mixture of Nile tilapia and redbelly tilapia) and large group above 400 g of body weight (8 fish, all fish were Nile tilapia). Fig. 4 shows changes in total body length and weight. The first small fish No. 30 (Nile tilapia) was recaptured on August 9, 91 days after its release on May 10. Total body length and weight of this fish increased from 16.0 to 23.2 cm and from 82 to 250 g, respectively. Both total body length and weight of fish No. 4 (redbelly tilapia) on April 12 (16.5 cm, 82 g) were almost same as those of fish No. 30 on May 10. Total body length and weight of fish No. 4 were 20.7 cm and 150 g, respectively, when recaptured after 180 days. The growth rate of fish No. 4 was lower than that of fish No. 30. Many recaptures of fish released after September 7 were made until December 13; however, none exhibited notable growth during 12–75 days. The smallest fish No. 44 with 11.6 cm total body length and 28 g body weight on September 7 grew to 13.3 cm and 47 g, respectively, after 75 days.

Body weights of fish Nos. 9 and 16 increased 49 and 38 g, respectively, over 28 days from
April 12 to May 10; however, that of fish No. 15 decreased 41 g during the same period, though its total length increased from 34.4 cm to 35.0 cm (Fig. 5). Total body length and weight of fish No. 2 increased from 25.7 to 33.2 cm and from 401 to 796 g, respectively, during the period from April 12 to November 9 (211 days). Total body length of fish No. 26 was at 32.3 – 33.0 cm from May 10 to December 13 and its body weight remained roughly the same for 152 days from May 10 (614 g) to October 9 (617 g), but decreased in November. The largest fish No. 47 was captured first on September 7, when total body length and weight were 37.0 cm and 1018 g, respectively. Its body weight gradually decreased to 935 g on December 13.

Fig. 6 shows the length-weight relationship of captured tilapia derived by \( M = aL^b \), where \( M \) and \( L \) are body weight and total body length, respectively, and \( a \) and \( b \) are constants. The

![Fig. 5. Changes in total body length (A) and weight (B) of large fish. Numbers next to the symbols show tag numbers of recaptured fish.](image)

![Fig. 6. Length-weight relationships of tilapia. Closed circles and open circles indicate non-tagged and tagged fish, respectively.](image)
body weight of all fish captured, including those recaptured, were curvilinearly related to total body length, and all correlation coefficients of regression lines were significant at $p = 0.001$. Fig. 7 shows the seasonal changes in the body weight of tilapia calculated by allometric equations. The estimated body weights were only for fish with total lengths of $23 \sim 32$ cm, which fall within the range of fish for all study months. The body weights of fish of all sizes were high during summer months and decreased in autumn.

**Discussion**

Both pH and dissolved oxygen concentration in the Minami River are in the range suitable for tilapia growth (Popma and Masser 1999). Redbelly tilapia has a high salinity tolerance (Stickney 1986; Gupta and Acosta 2004), whereas high salinity has a detrimental effect on the growth of Nile tilapia (Likongwe et al. 1996). The values of EC, which can be used as an index of salinity to some extent, remained in the level frequently measured in the lower reaches of general rivers. Rather than these factors, one should focus on the influence of water temperature on various tilapia behaviors as they are generally very tolerant to poor water quality. Temperature is extremely important in regulating fish growth and physiology, and generally each species adapts to a certain temperature range. In fact, the principal environmental factor that has enabled tropical- and subtropical-adapted tilapia to exist in the Minami River is definitely the high water temperature throughout the year. The heated effluent from the chemical factory maintains the water temperature above 20.4°C (Nakai and Yamamoto, unpublished data), which is slightly low for optimum reproduction, but is considered sufficiently high to maintain appetite (Popma and Masser 1999). High water temperatures in June – October ($25.9^\circ \sim 29.1^\circ$) were within the range of optimum temperature for tilapia growth (Popma and Masser 1999; El-Sayed 2006). Azaza et al. (2008) showed that the growth of juvenile Nile tilapia is enhanced with temperature within the range of $22 \sim 30^\circ$.

The data for the small group of fish captured in April or May show that total lengths and body weights increased when fish were recaptured after several months. Clearly, the growth of Nile tilapia Nos. 29 and 30 surpassed that of redbelly tilapia No. 4. Increases in total body length and weight were also observed in some recaptured fish belonging to the large group.

The pattern in body size change differed between the two groups after September when water temperature declined. The small fish exhibited slight or no growth from September to December, except for the temporal decrease in the body size of fish No. 49, whereas 2 of 3 large fish exhibited a clear reduction in body weight during the same period. The estimated
changes in the body weight of fish with fixed total lengths indicated that the body weights of all size fish were lower between September and December than those between June and August. However, body weight fluctuated markedly in November. Long-term exposure to low-temperature water is detrimental to tilapia; however, responses of tilapia to water temperature vary among species and strains. Generally, feeding activity of tilapia is restricted at temperatures <20°C and they stop feeding at approximately 16°C (Popma and Masser 1999; El-Sayed 2006). Additionally, small fish are typically more susceptible to low temperatures than large fish, especially those at the juvenile stage (Dan and Little 2000; Atwood et al. 2003; Charo-Karisa et al. 2005). That fish growth during the warm season is associated with increases in body lipid and protein contents is well documented (Booth and Keast 1986; Griffiths and Kirkwood 1995; El-Sayed et al. 1996). In this case, the motion of small fish may have been restricted in response to the decrease in water temperature even though they still maintained an appetite. The energy intake from digested food was roughly the same or slightly higher than the energy expended for physiological demands, and resulted in maintenance or slight growth. Conversely, large fish may not be as affected by a reduction in water temperature, and therefore maintained motile activity at a relatively high level. The energy required to maintain high voluntary and physiological activity exceeded the energy intake from digested food. Additionally, the growth difference of small fish may be due to species specificity. Because redbelly tilapia is more tolerant to low water temperatures than Nile tilapia (El-Sayed 2006), some small fish Nos. 44 and 52 that grew slightly may have been redbelly tilapia.

In 2007, the factory shutdown ran during November 6–9, which reduced the water temperature remarkably. Although the cold shock lasted only a few days, it restricted active movement of many tilapia, and some Nile tilapia died. Two dead fish and one live fish floating upside down were observed on November 9. The water temperature of 16.5°C on November 9 was far higher than the lower lethal temperature of most tilapia species reported by El-Sayed (2006); however, the drastic degradation of the aquatic environment may have particular adverse effects on fish physiology. Wu et al. (1998) reported an abrupt death of Mozambique tilapia (O. mossambicus) when the fish were transferred from 26°C to under 14°C. The sudden decrease in water temperature and subsequent rapid temperature increase may stress the fish. Thus, this study made a second sampling on November 21 to assess the effects of severe environmental change on tilapia growth. No effect was observed on growth performance of individual fish between November and December; however, large fluctuations existed in body weight estimated using allometric equations. The form of allometric equation is regulated principally by the size distribution and sample numbers. In this study, the sample number in a day was 5–21, which is not sufficiently high and the equation can be changed by adding even one datum. The gap between real and estimated growth suggests a risk of misinterpretation of fish growth based on allometric equations, especially when dealing with a small sample.

In conclusion, the growth performance of tilapia is depended upon season and fish size. Notable growth occurred from spring to summer regardless of initial fish size. After water temperature peaked and then decreased, the growth of small fish was stopped or restricted. Conversely, large fish decreased in body weight. Similar seasonal variation in the body weight of large fish was also confirmed by changes in length-weight relationship. Tilapia are commonly adapted to high water temperature, whereas low-temperature tolerance is species specific. In this study, the tilapia population was comprised of Nile tilapia and redbelly tilapia; the latter is known to have better low-temperature tolerance. Although it remains unknown, this physiological difference may cause species-specific growth responses to decreasing water temperature during September – December. Therefore, in the future research, one should target a single species to obtain reliable information on fish growth.
Acknowledgments

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References


温排水流入河川におけるティラピアの個体成長

山本芳正・中井大介

2007年4月から12月にかけて，温排水流入河川に生息するティラピア（ナイルティラピア Oreochromis niloticus とジルティラピア Tilapia zillii）の野生個体の成長を標識再捕法によって調べた．全長および体重は水温の上昇に伴い増加したが，低下すると大型個体（体重＞400 g）の体重は減少したが，小型個体（体重＜400 g）では変化しないかわずかに上昇した．大型個体の全長・体重間の関係式に季節変化が確認された．11月上旬の一時的な工場の操業停止で温排水の流入が停止した際は，ティラピアの個体群に死ねなどの悪影響がもたらされたが，生存個体の成長に目立った影響はなかった．本研究からティラピアの成長は魚体サイズと季節（水温）に支配されることが示唆された．また，全長・体重の関係式は大まかなティラピアの季節変化を知る上で有用であることが示唆された．