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Growth indices of small northern bluefin tuna (*Thunnus thynnus*, L.) in growth-out rearing cages

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Abstract

The principal objective of the paper is to describe the growth pattern of small northern bluefin tuna (*Thunnus thynnus*) in floating cages in the Adriatic Sea. For this purpose, several sampling and tagging experiments on live small tunas (mean weight: 10.47±5.817 kg) in various growth-out floating cages were carried out during different rearing periods. Length and weight data of live fish were analyzed at sampling and tagging time, and recapture data eventually at harvesting time. Based on the obtained data condition parameters (*K*), specific growth rates (SGR) and relative growth rates (RGR) and thermal growth coefficient (TGC) were calculated. Additionally, weight–frequency distributions at sampling and harvesting time are compared.

It was observed that biomass of tagged fish, as a consequence of post-tagging related stress, decrease due to starvation (SGR<0), although fish were able to recover to initial biomass (SGR=0) within 2–3 months. Significant differences in *K* between wild tuna (1.95±0.136) and farmed tuna (2.33±0.216) were noticed. Also, no significant increase of *K*-value between tagged tunas (2.12±0.246) and recaptured tunas (2.21±0.231) in the rearing cages was noticed.

However, after rearing for extended periods (>1 year), one-year old tuna considerably increased their biomass ($RGR_{\%}$= 342.79). Such a production of tuna biomass using capture-based aquaculture, may satisfy increasing market demands without additional impact on fish mortality.
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1. Introduction

Northern bluefin tuna (BFT) aquaculture has developed very quickly in the Mediterranean area, particularly in the 90's. Initially, large lean fish captured in the trap were used for fattening, but later use of fish caught by purse-seines has been most common (Miyake et al., 2003).

Since 1996 BFT rearing in the floating cages has been practiced in the eastern part of the Adriatic Sea. Recently, almost all BFT catches from the eastern Adriatic and considerable amounts of Mediterranean purse-seine BFT catches have been transferred into floating cages for rearing purposes. The concept of BFT aquaculture is based on capture of "wild" fish, which are then transferred into floating cages and reared in different periods of time depending on initial size of the

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fish and market demands. Large fish are used for fattening up to 1 year as to meet specific requirements of sashimi market, while small specimens are transferred into cages for real farming that is regularly above 1 year. Such farming concept is directed towards better use of resources through increasing biomass of caged tunas, and also to improve the value of the fish and consequently obtaining better market price (Katavić et al., 2003a).

This practice does, however, cause difficulties in terms of the catch statistics and concurrence of catch data with trade data. Tuna aquaculture has been recognised as a very important issue, thus it is necessary to improve BFT tuna statistics. This improvement should be based on some specific knowledge about growth patterns of tunas in the captivity, related to commercial aquaculture activities. So far, data on growth rates of captive tunas reported by Farwell (2001) include larval culture and rearing of juvenile or young of the year Pacific bluefin tunas (*Thunnus orientalis*) carried out at Kinky University, and reports from the Japan Sea-Farming Association about captive adult yellow fin tuna (*Thunnus albacares*). Ikeda (2003) provided some information on BFT growth under farming conditions in Japan, while Carter et al. (1998) and Glencross et al. (2002) reported growth changes in juvenile southern bluefin tuna (*Thunnus maccoyii*) farmed in Australia. Farwell (2001) gives growth rates in length of bluefin and yellowfin tuna kept at the Tuna Research and Conservation Centre (Monterey, California) for public aquarium purposes. Norita (2003) also reported growth estimates of BFT under farming conditions in Japan and under fattening conditions in Spain. The most recent information on BFT growth changes in captivity, based on underwater length measurements converted in weights, under fattening conditions in Spain, are reported by Aguado-Gimenez and Garcia-Garcia (2005).

Given the fact that the northern BFT (*Thunnus thynnus*) farming practice is a relatively new activity in the aquaculture, there is a very few information on growth performances of this species under farming conditions in the Mediterranean Sea (Katavić et al., 2003b). The aim of this paper is to describe the growth pattern of northern bluefin tuna in captivity under the standard farming procedures.

2. Materials and methods

All BFT used in these experiments were caught by commercial purse-seine fishing vessels in the Adriatic Sea. Captured fish were transferred to five different growth-out circular floating cages (50 m in diameter with net suspended to 20–25 m in depth) at three different farming sites for further commercial farming purposes. In all cages, initial rearing densities were approximately 2–3 kg/m^3. After a few weeks of acclimatisation, tuna were fed with raw, defrosted and/or fresh small pelagic fish such as sardines, herring, small mackerels and sprats. The tuna in the growth-out floating cage were fed to satiation, six days per week, following practices are described by Katavić et al. (2003b).

2.1. Data collection

Tagging of tuna in the rearing cages was done for different rearing periods. Tunas were hooked with barbless hook (Owner Gorilla, size 4), measured using the "cradle" device, tagged with "spaghetti" tags, weighted with a hanging scale (Kern HTS) and released back into cage, as described by Tičina et al. (2003, 2004). The majority of recapture information was collected at harvesting time, while tag-recapture information related to fish mortality were collected and submitted by tuna farmers.

In caging experiment, about 25 tons of small BFT specimens (mean weight: 6.4 kg) were placed in an experimental cage, with no additional fish stocked, and reared according to the usual commercial BFT farming practices. Random sampling and weighting of 100 live fish from this cage has been done at the beginning of the rearing period, and their weights have been eventually compared with weight frequencies of all fish harvested from the cage, after a 511-day rearing period.

In all cases, the fork lengths (FL) were measured (Miyake, 1990) with an accuracy of ± 1.0 cm. A quick weight check of the fish round weight (RWT), with accuracies of ± 0.1 and ± 0.5 kg, were obtained by means of hanging scales. Weight loss of approximately 1%, due to fish bleeding before weighting, has been taken into consideration (Tičina et al., 2005).

Tuna's length (FL) ranged from 53 to 113 cm for live fish and from 59 to 152 cm for dead fish. Historical data on wild tuna (Tičina, 1994) of similar sizes (FL = 50–127 cm) has been used for comparison. Estimated ages of fish stocked, based on age-length keys (Rey and Cort, 1984; Tičina and Kačić, 1998) were from 1 up to 3 years.

Mean values of sea temperature (°C) were taken from nearby meteorological station Punta Jurana in front of the Institute of Oceanography and Fisheries — Split.

2.2. Data analyses

Kolmogorov–Smirnov test was applied to check data for normality, and Bartlett's test for homogeneity of variances. Eventually, significance of differences among condition factors of different groups of tunas has been tested using the Games–Howell method (Sokal and Rohlf, 1997). All figures reported are mean ± standard deviation (±sd), unless otherwise stated.

Condition factors (K) were estimated using Eq.(1):

$$K = 100 \times W/L^3 \quad (1)$$

where W is the RWT in grams, and L is the fork length (FL) in cm (Ricker 1979).

Data on individual tag-recapture information and mean fish weights from experimental cage at the beginning and at the end of rearing period were used to estimate specific growth rates (SGR) for different rearing periods. SGR in % body weight/day has been calculated from the Eq. (2):

$$\mathrm{SGR} = 100 \times (\log_e W_f - \log_e W_i)/(t_f - t_i) \quad (2)$$

where W and t are body weights and times (in days) respectively, at the initial (i) and final (f) experimental times (Ricker 1979, Moyle and Cech 1996). Furthermore, according to Copeland et al. (2002) relative growth rate in % ($\mathrm{RGR}_{\%}$) has been estimated using Eq. (3):

$$\mathrm{RGR}_{\%} = 100 \times (\text{wet final weight} - \text{wet initial weight})/(\text{wet initial weight}). \quad (3)$$

Differences between two groups were tested with an appropriate t-test (Sokal and Rohlf, 1997). Level of significance in all cases was set at $P \le 0.05$.

Coefficients of variations (CV) have been used to describe temperature variations (Sokal and Rohlf, 1997) during different rearing periods. Fish growth in relation to temperature is estimated based on thermal-unit growth coefficients (TGC) calculated according to Cho and Bureau (1998) using Eq. (4):

$$\mathrm{TGC} = \left(W_f^{1/3} - W_i^{1/3}\right)/\sum(T \times (t_f - t_i)) \times 100 \quad (4)$$

where W_f and W_i are final and initial body weights in kg, respectively.

3. Results

3.1. Growth rates

3.1.1. Tagging experiments

Based on tag-recapture data, SGR, RGR and TGC have been analysed for different groups of tunas, in relation to different rearing periods in the cages (Table 1). The 1st group is related to fish mortality caused by tagging, while all other groups refer to fish harvested after different post-tagging periods. All fish that died up to 10 days after tagging had negative growth rates.

In the group of tagged BFT that were harvested 44–53 days after tagging, the negative SGR and TGC were observed in 19 out of 20 fish. The highest mean SGR (>0.3% per day) was observed for 1-year and 2-year old tuna farmed for periods up to 1 year, while the highest mean TGC (>1.0) was observed in the group harvested after 572–597 days farming period (Table 1). For the two groups of fish farmed more than 500 days under the similar temperature conditions ($p = 0.7347$), highly significant difference in SGR between 1-year and 2-year old fish was observed ($p < 0.001$). For the fish with positive growth rate, reared under the variable temperature conditions ranging from 10°–25 °C, an overall mean TGC value was 0.85 ± 0.259.

The highest RGR values were obtained for one-year old fish farmed over 17–18 months. These values were also significantly higher than RGR values obtained in

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Table 1
Specific growth rate (SGR), relative growth rates ($\mathrm{RGR}_{\%}$), and thermal-unit growth coefficient (TGC) values (mean ± sd) of small bluefin tuna after different post-tagging rearing periods, based on tag-recapture data

Estimated age of fish stocked	Fish number	Rearing period			SGR (%/day)	RGR (%)	TGC
		Days	$T_{(sea)}$°C				
			Mean	CV%			
1 & 2	28	1–10 [a]	–	–	−0.91 ± 0.753	−3.48 ± 2.558	–
2 & 3	20	44–53	16.4	9.87	−0.15 ± 0.101	−7.55 ± 4.509	−0.76 ± 0.461
2 & 3	13	144–152	20.4	17.18	0.26 ± 0.120	48.41 ± 25.992	0.65 ± 0.331
2	4	171–190	19.1	26.26	0.31 ± 0.087	75.81 ± 34.172	0.94 ± 0.095
1 & 2	7	223–224	17.8	32.21	0.38 ± 0.090	134.53 ± 43.952	0.70 ± 0.178
1	22	507–526	18.6	22.08	0.28 ± 0.021	322.55 ± 48.653	0.75 ± 0.142
2	35	572–597	18.1	25.91	0.20 ± 0.021	218.86 ± 39.866	1.02 ± 0.211

[a] Mortality caused by sampling and tagging procedures.

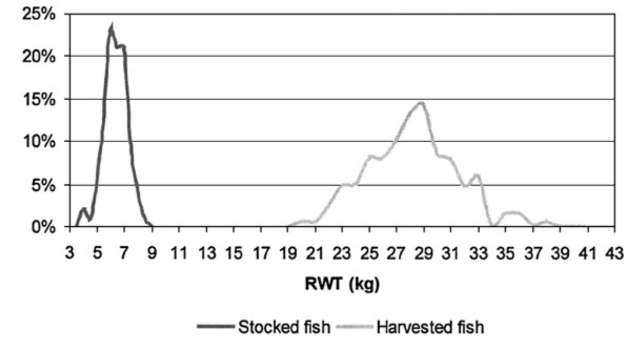

Fig. 1. Size frequency distributions of randomly sampled stocked fish (N=100) and fish harvested (N=3934) from the experimental cage after a 511-day farming period.

the two-year old fish farmed over 19 months time period ($p<0.05$). However, large differences in RGR mainly related to duration of farming period, initial size of fish stocked and sea temperatures were observed (Table 1).

3.1.2. Cage experiment

In the cage experiment, approximately 25 MT of one-year old tuna (6.4 kg in average weight) has been stocked into growth-out floating cage for farming purposes. Mean monthly sea temperatures during this experiment ranged from 11.8 to 24.8 °C with an average value of 18.3 °C (CV=22.79%). After a 511-day farming period, large difference in size distribution between stocked and harvested fish was noted (Fig. 1). RWT of tuna harvested from the cage ranged from 20 kg up to 43 kg, with bulk of fish being between 21 and 34 kg and average weight of 28.3 kg. The calculated TGC at the given conditions was 0.78. Total biomass of farmed BFT harvested was slightly more than 111 MT compared to 25 MT of fish stocked. Consequently, the mean SGR and RGR in this case were 0.291 and 342.79%, respectively. These values correspond to the production of 86 MT of "new" BFT biomass. Average daily gained weight was 6.8 g/kg of 1-year old BFT.

3.2. Condition factors (K)

Condition factors of wild BFT caught in Adriatic Sea estimated from length and weight data given by Tičina (1994), show that average K-value of small wild BFT is <2, while K-values of farmed BFT are generally >2 (Table 2). As it was expected, mean K-value of BFT tagged at the beginning of the farming period was lower than the mean K-value of these fish when recaptured, and also lower than the mean K-value of harvested non-tagged BFT at the end of farming period. The mean K-value of harvested non-tagged BFT was significantly higher than mean K-values of other groups tested (Table 3). K-values of tagged and recaptured BFT were significantly higher compared to K-value of wild BFT. No significant increment in K-value of the tagged BFT was noticed compared to the recaptured fish at the end of farming period.

Table 2
Condition factors (means±sd) for different group of BFT

	N	K	Range	$CI_{95\%}$
Wild BFT	150	1.95±0.136	1.66–2.25	1.93–1.97
Tagged BFT	213	2.12±0.246	1.42–2.83	2.08–2.15
Recaptured BFT	132	2.21±0.231	1.65–2.86	2.17–2.25
Harvested BFT	2488	2.33±0.216	1.29–3.31	2.32–2.34

Table 3
Comparisons of differences between mean condition factors of different groups of BFT

	K-wild	K-tagging	K-recapture	K-harvest
K-wild	–	0.074	0.084	0.044
K-tagging	0.17 [a]	–	0.095	0.063
K-recapture	0.26 [a]	0.09	–	0.075
K-harvest	0.38 [a]	0.21 [a]	0.12 [a]	–

Differences are given below the diagonal, and corresponding minimum significant difference values (Games–Howell method) are given above the diagonal.
[a] Significant difference.

4. Discussion

Negative values of the SGR for the fish that died due to post-tagging stress and/or injuries can be clearly explained by fish starvation. However, the negative SGR values for the fish that were reared 44–53 days after tagging were surprising. Underwater observations confirmed that tagged fish for certain post-tagging period did not take the feed on the surface as other fish did, probably because of previous «bad experience» (i.e. they were hooked, pulled out of water and tagged). Such behaviour reflected in their weight loss and condition index decrease. Given the fact that all other tagged fish reared for more than 4-month time period demonstrated positive SGR, it seems that tagged tunas are able to compensate weight loss (SGR ≥ 0) within a 2 to 3 months.

Our findings on growth rates are in line with information reported by Katavić et al. (2003b). These authors have found out that small BFT averaging 12 kg reached RWT of approx. 45 kg after a 540-day farming period, indicating approximate SGR and RGR values of 0.245 and 275%, respectively. During the same period, tunas with initial average RWT of 5 kg increased their weight up to 25–30 kg (SGR approx. 0.298–0.332; RGR approx. 400–500%), that is in accordance with our

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finding about differences in growth rates related to initial size of fish stocked.

Carter et al. (1998), while experimenting with SBT (initial weight 25.62±6.38 kg) in Australia, being fed on pilchard for 133 days, have reported SGR=0.210±0.082, that seems slightly lower than our findings for farmed BFT. Concerning BFT growth in the Mediterranean Sea, Norita (2003) reported that after 8 months fattening period, "smaller" BFT showed a weight increase of 40–50%.

Furthermore, Aguado-Gimenez and Garcia-Garcia (2005), based on indirect initial weight determination of the fish, calculated SGR values of 0.29 and 0.06 related to small BFT (mean weight: 32 kg) and large BFT (mean weight: 219 kg) respectively, obtained during fattening practices from February to October in Murcia region, Spain. Their results obtained for small fish are similar to our results, where the mean SGR and RGR obtained in our cage experiment were higher than SGR and RGR values obtained using tag-recapture data.

We have noticed that in our case tunas reared from 4 to 8 months had higher SGR values than tunas reared for approximately 17 to 20 months. In the first case, SGR values are related mostly to summer growth, while in the other case SGR values are related to combined summer and winter growth. It is in accordance with findings that the summer growth of small BFT (age: 1–3 years) in the wild is on the average five to six times more intensive than their winter growth (Cort, 2003). Ikeda (2003) reported large differences in growth performance of bluefin tuna at different farming locations. He noticed that in the case of Kinki University research station (Wakayama) small bluefin tuna (150–500 g) after 3-year farming period reached a maximum weight of 50 kg, while the same size BFT farmed at the JASFA research station (Okinawa) reached 100 kg within 4 years. Those differences were addressed to the environmental factors such as temperature, stocking density and sea currents, which might influence growth performance of small BFT during farming activities. The growth rates of fish are highly variable, because they greatly depend on a variety of interacting environmental factors such as water temperature, levels of dissolved oxygen and ammonia, salinity, photoperiod, the amount and quality of food ingested, and the age of the fish (Moyle and Cech, 1996). Since TGC values are relevant for a given aquaculturing conditions, specific environmental factors (i.e. nutrition, husbandry, biophysical descriptors, etc.) are likely to explain our findings of slight differences between TGC values for BFT reared at different farming sites.

Condition factor (K) is vitally important in BFT aquaculture production, because it is the basis by which farmed BFT are graded, and eventually BFT with higher K obtain higher prices at sashimi market. Significant increase in K-values of BFT harvested after the certain farming period, as compared to K-values of wild BFT of similar size, was noticed. Our results are in accordance with similar changes observed in farmed juveniles of southern bluefin tuna (SBT) where an increase in K, from 1.94 to 2.38 after a 133-day rearing period, was recorded when feed on pilchard (Carter et al. 1998). Glencross et al. (2002) observed an increase of K from 19 kg/m^3 (stocked wild fish) to 22 kg/m^3 (harvested fish) for SBT farmed over a 19-week period. All these changes suggest that biomass is gained more by fish fattening than by length increment. Surprisingly, no significant increment in K-values of tagged BFT during the farming period was noticed. This fact together with differences in SRG and RGR between tagged and non-tagged fish, suggests that tagging related stress may have significantly adverse effect on BFT condition and growth performances.

5. Conclusions

During farming procedures small BFT (non disturbed by tagging) demonstrated relatively high growth rates ($SGR_{\%}$=0.298–0.332) and significant increase of their initial biomass ($RGR_{\%}$=342.79), followed by an increase of their condition index ($K_{increase}$>0.2). Changes of conditions suggest that the growth of the farmed BFT on a biomass basis was greater relative to changes in fish length.

It seems that post-tagging related stress had a negative influence on overall growth performance of BFT. Negative SGR values for tagged fish (within two months post-tagging period) have been noticed. Also, the mean K-value of non-tagged tunas was 0.12 higher than mean K-value of tagged specimens. Consequently, growth rates calculated on the basis of tag-recapture data probably underestimate overall growth performance of small BFT farmed in given conditions.

Growth rates and TGC obtained in this study probably are not representative for the entire BFT farming industry in the neither Mediterranean nor Adriatic Sea, but they provide important indications on the growth performances of the small BFT under given rearing conditions. Since the rearing conditions are not fully controlled but depend on environmental changes, these indications should not be used for back-calculations to determine the initial quantity of fish stocked into cages.

In general, this study demonstrated the economic benefits in terms of biomass increase achieved by the farming of small BFT in growth-out floating cages for

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extended periods (> 1 year). For an industry that is based on a quota-restricted BFT fishery, this represents a significant biomass production as well as value adding opportunity. Significant production of the new BFT biomass, using limited amount of 1-year old fish ($RGR_{\%}$> 300), may help to satisfy increasing market demands without additional increase in fishing mortality.

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