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WEIGHT GROWTH OF ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS*, L. 1758) AS A RESULT OF A 6-7 MONTHS FATTENING PROCESS IN THE CENTRAL MEDITERRANEAN

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SUMMARY

The study calculates the fork-length to round weight (L-W) relationship and condition index (K) of fattened bluefin tuna for 6-7 months in a tuna farm in western Greece and compares these morphometric parameters with those of wild bluefin tuna using the set of measurements obtained in the context of the EU-funded research projects REPRO-DOTT & SELF-DOTT. The L-W relationship and K values found were very different to those of the wild bluefin suggesting a minimum weight gain of 27.2-32.6% and 33.8-37.8% for size classes 205-245cm and 255-295cm during the fattening period through improvement of condition and fat content of the fish. The results are consistent with similar studies conducted by other authors in the past, however the actual weight gain rates in farming conditions may be bigger because the above method does not take into account the length increase of the fish during the fattening period and additional weight gain resulting from structural growth.

RÉSUMÉ

L'étude calcule la relation entre la longueur à la fourche et le poids vif (L-W) et l'indice de condition (K) du thon rouge engraissé pendant 6-7 mois dans un établissement d'engraissement de Grèce occidentale et compare ces paramètres morphométriques avec ceux du thon rouge en liberté en utilisant l'ensemble de mesures obtenues dans le cadre des projets de recherche financés par l'Union européenne REPRO-DOTT & SELF-DOTT. La relation L-W et les valeurs de K étaient très différentes de celles du thon rouge en liberté, ce qui suggère un gain de poids minimal de 27,2-32,6 % et de 33,8-37,8 % pour les classes de taille 205-245 cm et 255-295 cm pendant la période d'engraissement au moyen de l'amélioration de la condition et de la teneur en matière grasse des poissons. Les résultats sont conformes aux études semblables réalisées par d'autres auteurs dans le passé, toutefois, les taux de gain de poids réel dans des conditions d'engraissement pourraient être supérieurs, car la méthode mentionnée ne tient pas compte de l'augmentation de la longueur des poissons pendant la période d'engraissement ni du gain de poids supplémentaire résultant de la croissance structurelle.

RESUMEN

El estudio calcula la relación entre longitud a la horquilla y peso vivo (L-W) y el índice de condición (K) del atún rojo engordado durante 6-7 meses en una instalación de engorde en Grecia occidental y compara estos parámetros morfométricos con los del atún rojo salvaje utilizando el conjunto de mediciones obtenidas en el contexto de los proyectos de investigación financiados por la Unión Europea, REPRO-DOTT & SELF-DOTT. La relación L-W y los valores de K descubiertos eran muy diferentes a los del atún rojo salvaje, lo que sugiere una ganancia de peso mínima del 27,2-32,6% y del 33,8-37,8% para las clases de talla de 205-245 cm y 255-295 cm durante el periodo de engorde mediante la mejora de la condición y el contenido de grasa de los peces. Los resultados son coherentes con estudios similares llevados a cabo por otros autores en el pasado, sin embargo, las tasas de ganancia de peso reales en condiciones de engorde podrían ser mayores ya que el método mencionado no tienen en cuenta

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el incremento de longitud de los peces durante el periodo de engorde y la ganancia de peso adicional resultante del crecimiento estructural.

KEYWORDS

Bluefin tuna, Thunnus thynnus, length-weight relationship, condition index, fattening, farming

1. Introduction

Atlantic bluefin tuna is a highly migratory tuna species, with a wide distribution in the Atlantic Ocean and the Mediterranean Sea, which is most sought after by commercial fisheries because of the top price it achieves in the sashimi market (raw fish). The International Commission for the Conservation of Atlantic Tunas (ICCAT) regulates this fishery and recognizes two stocks separated by the 45°W meridian, the West and the East Atlantic stock (ICCAT, 2008a), primarily based on the premise of their principal zones of spawning occurring respectively in the Gulf of Mexico (in April-May) and the Mediterranean Sea (May-June in the eastern and June-July in the central and western Mediterranean) (Rooker *et al.* 2007).

As derives from ICCAT's catch report tables (ICCAT, 2008a), seining, hook long-lines, bait boats, and tuna traps are in turn the main fishing gears in use to catch the East Atlantic stock, the large majority of reported catches taken in the Mediterranean and by purse seining (a gear that accounts for around 60% of the total reported bluefin tuna catches in recent years). The purse seining of bluefin tuna in the Mediterranean developed rapidly in the 1960s and 1970s (Mather *et al.* 1995); Purse seine catches, used to be sold mainly for canning (Majkovski, 2007), were traditionally marketed poorly. It is known in the industry that this was because such catches were made up mainly by "spent" adult fish with very low muscle fat content (caught during or just after their spawning season) and to a smaller extent by very small immature fish both of which categories did not qualify for the lucrative sashimi market.

The development of the tuna farming/ranching techniques after 1996, allowed these fish to be kept alive, and be fed/fattened until their size and flesh quality can qualify for the sashimi market. The harvesting of such fattened fish in inshore controlled conditions and the employment of the deep freezing technology (at -60^{o}C) permit the sale of close to 100% of the farmed output in the sashimi market. The added value to the particular finite fisheries resource created by this process (through improved final product grade and increase of the weight output of the catch) enabled tuna farming to evolve into an important "capture-based" aquaculture industry in the past decade in the Mediterranean and the purse seine fishers to obtain a higher price for their product (double or triple of that obtained before).

As derived from industry sources (Tzoumas, 2006 & 2009), the global annual farmed bluefin tuna production after reaching a peak in 2006 at around 43,000 tons it has dropped to around 35,000 tons thereafter limited by quota restrictions/cuts in S. Australia (where production reached a plateau at around 9,000 tons) and in the Mediterranean where production dropped to levels below 20,000 tons and is continuing to decline). The only part of the sector still growing (assisted by the lack of quota/minimum size restrictions) is the Pacific northern bluefin tuna production (Japan and Mexico) that has approached the 10,000 tons mark in annual production.

Within the context of ICCAT's management and conservation measures resolved in recent years regarding the eastern Atlantic bluefin tuna stock, Iccat Recommendation 06-07 introduced several management measures pertaining to the tuna farming sector, and mandated its Standing Committee on Research and Statistics (SCRS) to study and identify the growth rates and weight gains during the fattening/caging periods. The ICCAT's Contracting Parties have been requested by SCRS (ICCAT, 2008b) to assist in this effort while they have also been mandated by ICCAT (ICCAT, 2009) to submit in 2009 management plans regarding tuna farming capacity issues.

The present study is a contribution to the efforts of concerned parties to identify such growth rates and weight gains. The study calculates the fork-length to weight (L-W) relationship and condition index (K) of fattened bluefin tuna from measurements taken over the 4-year period 2006-2009 in a farm in western Greece in the context of the mandatory harvesting sampling program of the farm, and compares it to that of wild bluefin tuna using the set of measurements obtained in the context of the EU funded research projects REPRO-DOTT & SELF-DOTT.

2. Materials and methods

2.1 Fattened tuna

A total number of 2661 fattened bluefin tuna were sampled over the 4-year period 2006-2009, at the tuna farm of Bluefin Tuna Hellas S.A., which is located at the Echinades Islands, western Greece. All the tuna were obtained in the months of May and June of years 2005-2008 from purse seine fleets operating at the Central Mediterranean fishing grounds between Malta and Libya and towed to the farm located around 500 miles NE from the above fishing grounds in the Ionian Sea. The fish sampled had been fattened for 6-7 months, i.e. from their arrival to the farm, in late June to beginning of August, and until harvesting, which took place in the period late December of the year of catch to mid February of the following year. The sampling was carried out by farm staff, on board the processing vessel immediately after slaughter, in the context of the mandatory national tuna sampling program of Greece under the supervision of the national observers assigned by the relevant authorities (the program requires the measurement of length and weight of a minimum 10% of the harvested fish for every cage). The measurements of such sampling program are reported annually to the relevant Greek authorities that subsequently communicate them to the EU and the EU to ICCAT.

Fork length (FL), as a straight line measured with a 3-m slide gauge to the nearest centimeter and round weight (RW) after bleeding, measured with a digital balance to the nearest kilogram, were recorded.

2.2 Wild tuna

The set of data obtained during the EU funded research project REPRO-DOTT & SELF-DOTT were used. From this set of data we utilized the length-weight data for the wild fish sampled in the months of May and June in the period 1998-2008 (419 fish), captured by commercial vessels which made use of long-line or purse seines in different locations of the central Mediterranean and Levantine Seas as well as tuna traps. During these samplings the fork length (FL) and round body weight (RW) had been measured to the nearest cm and 100 g, respectively.

2.3 Farming conditions

The farm is located at a distance of around 4 miles off the coast, and uses 50m diameter HDPE cages with nets 20m deep at the side and ~29m deep at the bottom which are moored at a depth of 45-65m.

From the annual environmental impact reports of the farm, submitted to the supervising Fisheries Department of the Prefecture of Kefallonia, the following data derive:

The water temperature ranges at 14.7-27.4^{o}C, 14.2-26.4^{o}C and 14.1-25.9^{o}C at depths of 2m, 10m and 25m respectively (lowest in February and highest in August). There is a good water circulation at the farm, with mainly wind generated currents ranging between 0.2 to 2.5 knots. Oxygen saturation ranges between 97 and 101% and salinity between 39 and 42 ppt. Inorganic salt concentrations in the water at the farm, TKN and TOC are monitored regularly and range at normal levels, the same as the microbiological load. The chlorophyll-a measurements at the farm indicate an oligotrophic character of the waters (data provided by Fisheries Department of Kefallonia Prefecture).

The stocking densities practiced at the farm range at around 1.2-2.5 at the beginning of the farming period to 2.5-4.0 kg/m^3 at the end.

Food consists of defrosted small pelagic fish mainly of Atlantic origin; Depending on availability and price, a combination of mainly 3 species is fed: herring (*Clupea harengus*), sardine (*Sardina pilchardus*) and mackerel (*Scomber japonicus*). The food is distributed twice a day (in the morning and early afternoon), 6 days a week, by means of small feeding cages floating at central position in the farming cages. Feeding rates are estimated to start at around 5-8% of bodyweight of farmed fish/day, in the beginning, and drop to 2-3%, in the end of the fattening season.

For slaughtering, bluefin tuna are enclosed in lots of up to around 50 tons by means of a harvesting net and then small lots of 3-5 tons at a time are herded in a small culling compartment of the harvesting net and killed by divers using the "power-head" method, for fish >100-120kg, while smaller fish are killed with asphyxiation.

The fish are then transferred on to a work-boat where they are immediately bled and their spinal cord destroyed, then placed in tanks containing ice-slurry and transferred to the processing vessel where they are sampled before processing.

2.4 Statistical analysis

The Fulton's Condition factor (K) was calculated according to the following equation (Froese, 2006): $K = 10^5 \times W / FL^3$ where W is the round weight in kg of the fish and FL the fork length in cm.

The Length to Weight (L-W) relationship for wild and fattened bluefin tuna samples was estimated using the following equation:

$W = aFL^b$, where W is the round weight in kg of the fish, *a* and *b* are the parameters determined by the method of least squares in the logarithmic form of the above equation and FL the fork length in cm. To examine possible significant differences of the L-W relationships between wild and fattened samples, analysis of covariance (ANCOVA; P=0.05) was used (Zar, 1999).

To express the round weight difference in percentage form, between fattened and wild bluefin tuna of the same given FL class, the following formula was used:

$IW(FL)\% = 100 \times \left(1 - a_1 a_2^{-1} FL^{b_1 - b_2}\right)$ where *IW(FL)* is the "weight difference index" for a given FL class, a_1, b_1, a_2 and b_2 are the parameters of the L-W relationship of wild (subscript=1) and fattened (subscript=2) sample, respectively. If *IW(FL)%*>0, then the weight (for fish of the same FL) is greater in fattened than in wild fish, while if *IW(FL)*<0 then the weight (for fish of the same FL) is greater in wild than in fattened fish.

In order to compare different L-W relationships and display the weight difference in percentage form, between fattened and wild bluefin tuna over a range of FL classes, the following formula was employed:

$$Wdf\% = 100 \times \frac{\sum_{i=1}^{20} p_i a_1 FL_i^{\,b_1} - \sum_{i=1}^{20} p_i a_k FL_i^{\,b_k}}{\sum_{i=1}^{20} p_i a_1 FL_i^{\,b_1}},$$

Where: Wdf% is the "percent weight difference" between the set of data of fattened tuna of the present study on one hand and several other wild and fattened tuna sets of data on the other (comparison is made with the wild bluefin set of data of the present study, as well as wild and fattened bluefin tuna sets of data deriving from L-W relationships published earlier by other authors); i is the i^{th} class size of fork length distribution, p_i is the numerical percentage of specimens in the i class, FL_i is the fork length at i^{th} class, a_1, b_1 are the L-W relationship parameters of the fattened fish set of data of the present study and a_k, b_k are the L-W relationship parameters of the compared sets of wild or fattened bluefin tuna data. Twenty length classes from 105 to 295 cm FL were used as the basis of comparison. As a baseline length distribution, the mean length distribution of the fattened bluefin tuna set of data of the present study was used.

To identify statistical differences between the wild and fattened bluefin tuna examined in the present study, the Student t-test was used regarding FL data and the Mann-Whitney test regarding RW and K data (Zar, 1999).

3. Results

The fattened bluefin examined, sampled over the 4-year study period, ranged from 100cm to 299cm in FL, while the wild tuna of the REPRO-DOTT & SELF-DOTT data set caught in the months of May and June ranged from 60cm to 294cm. The form of length distributions of both the fattened and wild bluefin tuna were found to be bimodal. The first peak occurs at 140cm and the second at 240cm for the fattened fish and at 130cm and 230cm respectively for the wild **(Figure 1)**.

The descriptive statistics for the fattened and wild tuna sets of data examined are given in **Table 1**, including numbers of fish sampled, as well as: ranges, means and standard deviation of FL, RW and calculated K values.

As it is seen in **Table 1**, the condition index (K) was significantly higher in fattened than wild bluefin tuna, with mean values of 2.17 compared to 1.74 respectively. The ranging of K values for fattened and wild fish and the difference between them is presented graphically in **Figure 2** in the form of Box-Whisker plots.

The highest values of K were observed in larger fattened bluefin, while in wild bluefin tuna the smallest specimens showed the highest K values. The K of fattened fish showed a positive and significant correlation with the FL (K=1.78+0.0019FL; R^2=0.18; $p<0.05$), while the wild displayed a negative and significant correlation with the FL (K=2.168-0.0027FL; R^2=0.20; $p<0.05$).

The L-W relationship equations were for the fattened fish: $W = 0.83 \times 10^{-5} FL^{3.182}$ (R^2=0.974, n=2661), whereas for the wild: $W = 5.94 \times 10^{-5} FL^{2.752}$ (R^2=0.968, n=419) **(Figure 3)**. The high values of R^2 (>0.968) showed the high adaptation of these equations to the raw data. The L-W relationship was found to be significantly different between wild and fattened bluefin tuna (ANCOVA; P<0.05).

As calculated with the use of the IW(FL)% index **(Figure 4)**, the weight of fattened fish was found to be bigger than that of the wild at fork lengths bigger than 98cm, with the weight difference increasing proportionately with the increase in fish length. The weight difference of the fattened over the wild fish was calculated to range from 0.6kg for the FL class of 105cm to 226.6kg for the FL class of 295cm, or from 3% to 37.8% respectively. More specifically at FLs from 105cm to 295cm, the weight difference of the fattened over the wild fish ranged as follows:

At FLs 105-145cm: 0.6-9.7kg or 3-15.6%;
At FLs 155-195cm: 13.9-41.2kg or 17.9-25.7%;
At FLs 205-245cm: 51.3-108.3kg or 27.2-32.6 %;
At FLs 255-295cm: 108.3-226.6 kg or 33.8-37.8 %.

The IW(FL)% index for fattened over wild fish was found to range at negative values at fork lengths below 98cm, however the absolute weight differences per individual were lower than 1kg, which is very close to the sampling accuracy limits, and therefore cannot be evaluated.

The fattened fish L-W equation was compared with that of the wild fish, using the Wdf% index at fork lengths from 105 to 295cm and found to be bigger by 29.4%. The L-W equation of the fattened fish was compared similarly with the L-W equations reported by several other authors for large wild bluefin tuna of the eastern stock caught and sampled on/around the same fishing season: El-Kebir et al (2002), Hattour (2003), El Tawil *et al.* (2004), Aguado-Giménez and García-García (2005), as well as with L-W equations of fattened fish reported earlier by Aguado-Giménez and García-García (2005) and Dos Santos *et al.* (2004). All these equations (and their statistical parameters) are presented in Table 2. The results of these comparisons, given graphically in **Figure 5**, revealed:

a) A rather constant difference of the fattened fish of the present study over all sets of wild fish data compared, with Wdf% indexes ranging at 25-31%.
b) A superior weight of the fattened fish of the present study (6-7 months fattening) over the fattened fish examined by Aguado-Giménez and García-García (2005) (5 months fattening) as well as by Dos Santos *et al.* (2004) with Wdf% indexes of 8.2% and 28.2%, respectively.

4. Discussion

The ability of juvenile northern bluefin as well as southern bluefin tuna to withstand and survive barb-less hook capturing and live handling has permitted the estimation of the growth/fattening rates under farming conditions for these categories of farmed tuna with accuracy, via weight/length sampling of live fish at the beginning of the farming period and weight/length measurement of the same fish that survived the live sampling handling at the end of the farming period: Tičina *et al* (2007) showed that juvenile bluefin tuna stocked at an average weight of 6.4 kg are able to increase their initial biomass by more than 340% within 511 days of farming. Katavic et al (2003) had showed earlier that juvenile bluefin stocked at an average weight of 12 kg are able to increase their weight by 375% in 540 days of farming to an average weight of 45kg. It has been proven in fact, that juvenile northern bluefin tuna would gain weight twice as fast in farming conditions as compared to the wild. Southern bluefin tuna during 6-8 months of farming/fattening register growth rates ranging from 50-70% to 100% (CCSBT, 2007). In both these categories of farmed tuna the commercial value of individual fish is not very big due to the small size and inferior value compared to adult northern bluefin, and a certain mortality caused by such sampling procedures can be afforded.

On the contrary the challenges that live handling of large bluefin tuna presents have not permitted to date the estimation of growth/fattening rates of large bluefin tuna with similar accurate methods. These challenges are described in the final study of REPRO-DOTT (2006): the specific physical characteristics and behaviour of BFT, its large body size, fast and continuous swimming, high sensitivity to catch and transport operations that usually cause physical damage such as skin lesions or abrasions of fish and mortality, as well as the high commercial value of the fish.

Only recently a large scale experimental trial was conducted in a Maltese tuna farm (February to June 2009), promoted by the Federation of Maltese Aquaculture Producers in collaboration with University of Malta, involving the harvesting/sampling in the beginning and the end of a statistically acceptable number of fish from a given uniform farmed population of large bluefin. The trial registered, in 4 months of farming, weight and length increases from 60.9 to 87.4 kg (43.5% increase) and from 142 to 158 cm (11.2% increase) respectively (Deguara, personal communication).

Until such time as the above experiment or other similar ones undertaken produce more data, one method available to scientists and regulators to help them assess the weight gain achieved during farming/fattening of large bluefin is by comparing L-W data of fattened fish to similar sets of data of wild fish. A comprehensive such study for large bluefin was undertaken first by Aguado-Giménez and García-García in Spain (2005). This is also the subject of the present study.

In such comparisons, and due to the seasonal variability in condition of Atlantic bluefin tuna populations occurring in the wild, one needs to be careful to use sets of data of wild fish caught/sampled during the same season the fish destined for fattening are caught, i.e. during the months of May and June (in past years before the shortening of the fishing season, July was also a fishing month for purse seiners in the Baleares region). Extensive seasonal changes in the length-weight relationship of large Atlantic bluefin tuna have been found by many investigators working in different areas which collectively represent a considerable part of the coastal habitat of the species (Mather *et al.* 1995). Such variations are linked with the reproductive/migratory phase of the fish: just before and during breeding, bluefin tuna feed very little, while after spawning they disperse in smaller schools and feed actively (Cort and Liorzou, 1991), recovering rapidly in terms of fat content and condition. Authors referenced by Mather *et al.* (1995) observed that mature Atlantic bluefin fish lose about 14.73% of their weight between the pre- and post-spawning state, but they can increase rapidly their weight in the months after spawning i.e. from August to November at rates that can reach up to 7.5-10% per month. This is why bluefin tuna in the wild are leaner during late spring and summer months ("spent" status) and peak in condition during late autumn to winter. This pattern can be seen very clearly if one takes into consideration and plots together the L-W data equations available in ICCAT's Manual (ICCAT 1990) for wild bluefin tuna of the western Atlantic stock for which detailed data are available covering 7 different time periods in a year with a full year span: Dec-Mar, Apr-May, Jun, Jul, Aug, Sep, Oct-Nov (equations deriving from the work of Parrack and Phares 1979, cited in ICCAT's Manual, and from samplings of 7090 fish in total).

Unfortunately, with regard to Mediterranean eastern Atlantic bluefin tuna, there is only one L-W equation provided in the same above manual (deriving from unpublished work of Arena P. as cited in it), the details of the samplings, this is based upon, are not known (season, number and size range of fish sampled); Therefore it would be unsafe to try and draw conclusions using this equation.

Nevertheless, the appropriateness of the set of wild bluefin tuna data used in the present study to depict the condition of the wild fish, which are caught during the late spring to summer season for fattening purpose,s was demonstrated through the L-W equation comparisons **(Figure 5)** that showed its consistency with the L-W equations reported by several other authors for large wild bluefin tuna of the eastern stock caught and sampled on/around the same fishing season.

The L-W equation of the fattened bluefin tuna of the present study on the other hand was found to be consistent with that of the fattened fish set of data examined by Aguado-Giménez and García-García (2005) although our fish attained a bigger size overall, probably because of the longer period of fattening (6-7 months as opposed to 5 months). This weight difference however remains relatively constant as displayed by the values of IW/(FL)% index between the two sets of fattened fish that range from 8.38% (FL class of 105cm) to 7.98% (FL class of 295cm). The weight difference between fattened and wild bluefin tuna in both studies increases with a similar pattern in both studies, i.e. with increasing length of fish, although in the case of Aguado-Giménez and García-García (2005) the IW/(FL)% attains positive values at FLs >135cm as opposed to >98cm in our study. The consistency in the findings of these two studies is further confirmed if one considers the results pertaining to the condition index (K): in both studies, the K values range at significantly higher levels in large fattened bluefin than in wild bluefin of the same length, with mean K values ranging close (at around 1.7 for wild and at around 2 or more for fattened fish).

If we take into consideration the high K values of fattened fish in both these studies as well as the higher than 3 values of the parameter b in their respective L-W equations, we will tend to attribute the difference in weight of fattened over wild large bluefin tuna to their meat lipid content build-up during the fattening process. According to Froese (2006), if b is >3, then large specimens of fish have increased in height or width more than in length, either as the result of a notable ontogenetic change in body shape with size, which is rare, or because most large specimens in the sample were thicker than small specimens, which is more common. In *Dicentrarchus labrax* the above parameter b has been found to increase proportionately with the total lipid content of the fish (Dendrinos and Thorpe 1985).

Aguado-Giménez and García-García (2005), citing earlier work, report that the fattening process causes an increase in the meat lipid content in fattened tuna of up to 1% per week, reaching a maximum of 20% meat lipid content in larger bluefin tuna. Orban *et al* (2006) report that large bluefin tuna fattened for 5-6 months show an important increase of muscle fat from as low as 5% to as high as 30% at the start and end of the fattening period respectively. This pattern is consistent with the differences noted in the condition index of fattened compared to wild bluefin tuna and in the mode in which K values increase the longer the fattening period.

From proximate analyses of muscle tissue of large tuna at the end of the fattening period (included in the reporting of the aforementioned Greek farm to its supervising Fisheries Department of the Prefecture of Kefallonia) it is derived that muscle fat content in tuna fattened for 6-7 months can range from 18 to 43% depending on the part of the loin cut of the fish examined; The lower fat content values were found in the muscle adjacent to the spine and the end tail part, while the higher from the belly-loin part closer to the head.

As Catarci (2005) reports, the market value of sashimi cuts depends on their fat content: the higher the fat content, the lighter the colour and the more valued the sashimi will be; The best sashimi comes from “toro”, the underbelly part of the lower loin cut of the tuna which has the highest fat content that lends a characteristic marble texture to the meat and a special delicate flavour. Ikeda (2003) reports that the fattening process in cultured tuna, compared to the wild fish, largely increases the toro meat yield.

In clear distinction with the fattened fish sets of data of the present study and that of Aguado-Giménez and García-García (2005), the L-W equation of the fattened fish set of data examined by Dos Santos *et al.* (2004) is rather consistent with the wild fish sets of data and parameters and lags in weight by 28.2% (Wdf% value) compared to the present study’s set of fattened fish data, suggesting that fattening of only 2 months is not sufficient to improve the condition of the fish to a level that these could be differentiated from when they were wild caught.

5. Conclusions

The difference in the L-W relationship between fattened and wild large bluefin tuna found in the present as well as in other similar studies before can give a fairly good estimate of the minimum weight gain obtained during the fattening period through improvement of condition and fat content of the fish, which reaches bigger values the bigger the size of the fish, with possible weight gains of up to 37.8% for the FL class of 295cm.

The longer the fattening period the bigger the weight gain at least for fattening periods of up to 6-7 months studied by the present and earlier similar studies.

However, the weight gain estimated with this method is most probably an underestimation of the total weight gain obtained in actual tuna farming conditions, because the method does not take into account the weight gain from the relative length growth of fattened fish, which is more prominent in juvenile and small adult bluefin tuna. The growth curves for adult wild Atlantic bluefin tuna available in the literature (Santamaria *et al*, 2009; Restrepo *et al* 2007; REPRO-DOTT 2006) show that FL can increase by a rate in the range of 15% to 3% per year in fish of 4 to 15 years of age respectively, the growth rate reducing with age.

Moreover, the preliminary results (Deguara, personal communication), mentioned above suggest that are that the length of fish in cultured conditions can grow faster than in the wild and have a big impact on the overall weight gain of bluefin tuna, combining with the effect of the increase in fat content and condition to produce weight gains of >40% in small adult bluefin tuna fattened for only 4 months.

All the above need to be taken into consideration by regulators when estimating the weight gains that can be achieved in bluefin tuna under farming conditions, especially since the bluefin tuna market situation in the recent couple of years, as well as the bluefin tuna quota cuts regarding the eastern stock, are causing drastic changes in the farming strategy and practices of the Mediterranean tuna farms. Indeed, the increased supply in recent years of small and medium size farmed bluefin tuna from the Japanese, Mexican and Australian farming sectors (fish exclusively <100kg in round weight) has caused a big decline in final market prices in particular for such sizes of tuna; This lead the Mediterranean farmers to selectively harvest only the big in size fish after the traditional 5-7 month fattening period and to carry-over the <100kg fish to the next year for further farming for periods of 1.5-2.5 years and sell their fish at a larger size. Industry reports indicate that growth achieved through such extended farming of these sizes of fish can result in doubling or tripling their weight depending on fish size and duration of farming. The farmers are finding this practice more profitable not only because of the increased weight gain but also because of the fish climbing price categories as they are sold bigger (one can obtain a price/kg increase of more than 30% going from the 60-120kg to the 120kg+ round weight category).

Moreover, progressively, several farmers have already started and more are considering carrying-over even large adult bluefin tuna for extended farming in order to improve the weight gain and restore the economies of scale in their operations that have suffered recently with the reduced quotas and subsequent reduced seed availability, and also in order to support year-round fresh sales of tuna (that recently give better returns that frozen sales) to Japan and to the growing sashimi markets of Europe and N. America.

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Table 1. Summary statistics of fork length (FL), round weight (RW) and condition index (K) of fattened and wild bluefin tuna (n is number of individuals, SD is the standard deviation, P is the probability of equal mean values of each variable between wild and fattened bluefin tuna).

Variable		*n*	*range*	*Mean*	*SD*	*P*
FL	Wild	416	60-294	125.2	44.63	<0.05[1]
	Fattened	2661	100-299	196.1	42.5	
RW	Wild	416	3.7-380	72.36	60.9	<0.05[2]
	Fattened	2661	25-624	194.2	121.1	
K	Wild	416	1.06-2.63	1.74	0.25	<0.05[2]
	Fattened	2661	1.38-3.09	2.17	0.27	

[1] Student t-test.
[2] Mann-Whitney test.

Table 2. Parameters of L-W equations of wild and fattened bluefin tuna caught and fattened in central and western Mediterranean.

	Authors	*range FL*	*n*	*a(x10^{-5})*	*b*	*R^2*	
Wild (May-June)	El-Kebir *et al.* 2002	112-285	90	6.00	2.761	0.89	
	Hattour, 2003	118-277	171	2.00	2.964	0.96	
	El-Tawil *et al.* 2004	100-315	790	4.00	2.821	0.90	
	Aguado-Giménez and García-García, 2005	130-215	336	7.26	2.721	0.96	
	present study	60-294	416	5.94	2.752	0.97	
Wild (Apr-May)	Dos Santos *et al.* 2004	175-280	22	0.781	3.138	0.91	
Wild (Jul-Sep)	Dos Santos *et al.* 2004	113-257	53	3.86	2.814	0.98	
							Fattening period (in months)
Fattened	Aguado-Giménez and García-García, 2005	124-282	204	0.74	3.186	0.97	5
	Dos Santos *et al.*, 2004	99-296	68	4.33	2.814	0.94	2-4
	present study	100-299	2661	0.83	3.182	0.97	6-7

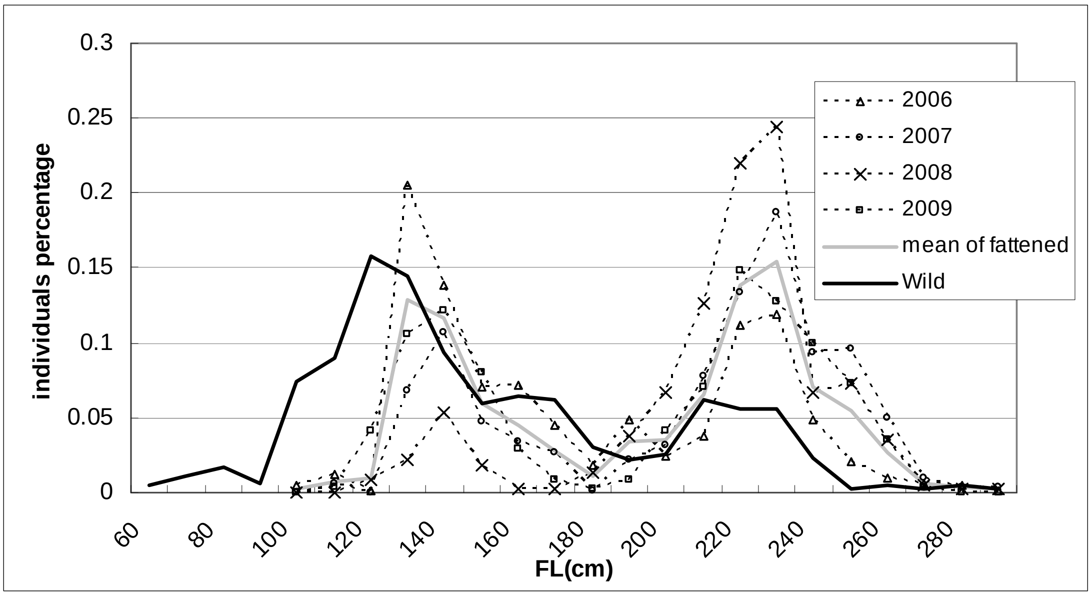

Figure 1. Fork length distribution of wild and fattened bluefin tuna examined in the present study.

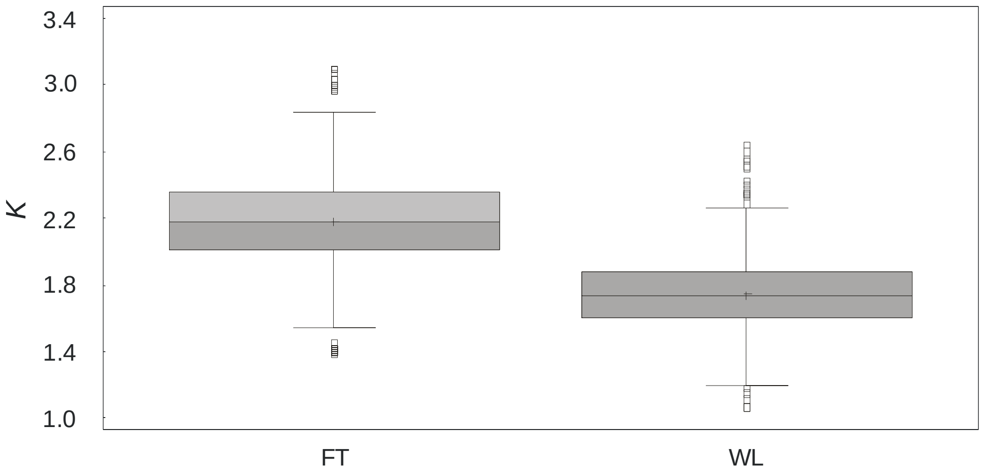

Figure 2. Box-Whisker plot of condition index (K) values of wild (WL) and fattened (FT) bluefin tuna examined in the present study.

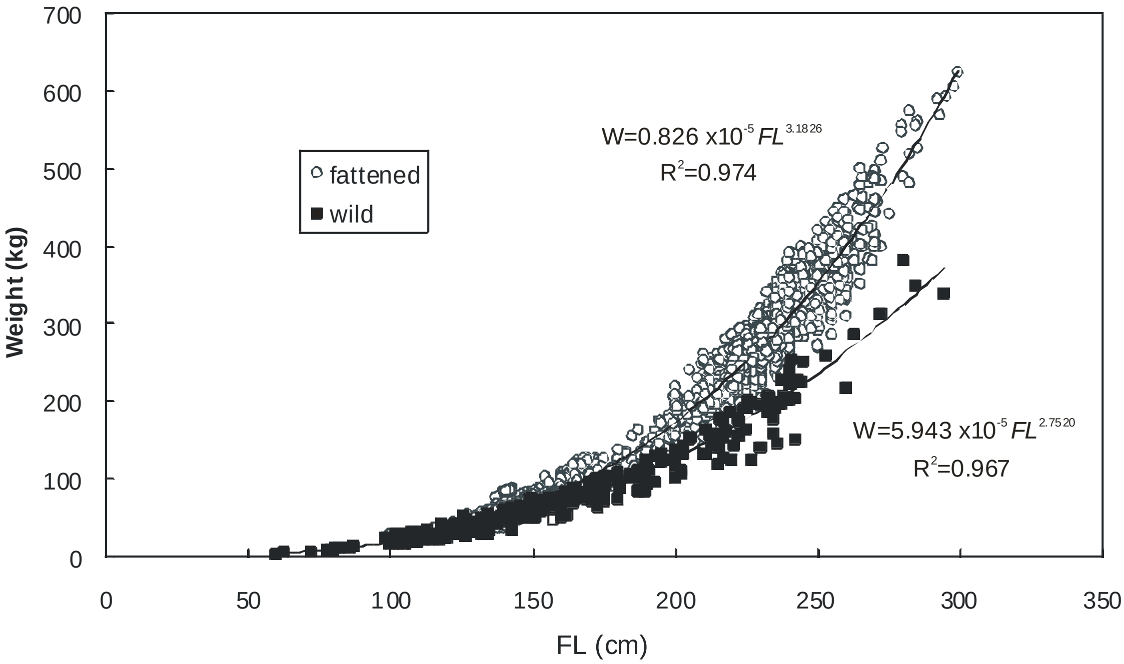

Figure 3. Length-Weight relationships and equations of wild and fattened bluefin tuna examined in the present study.

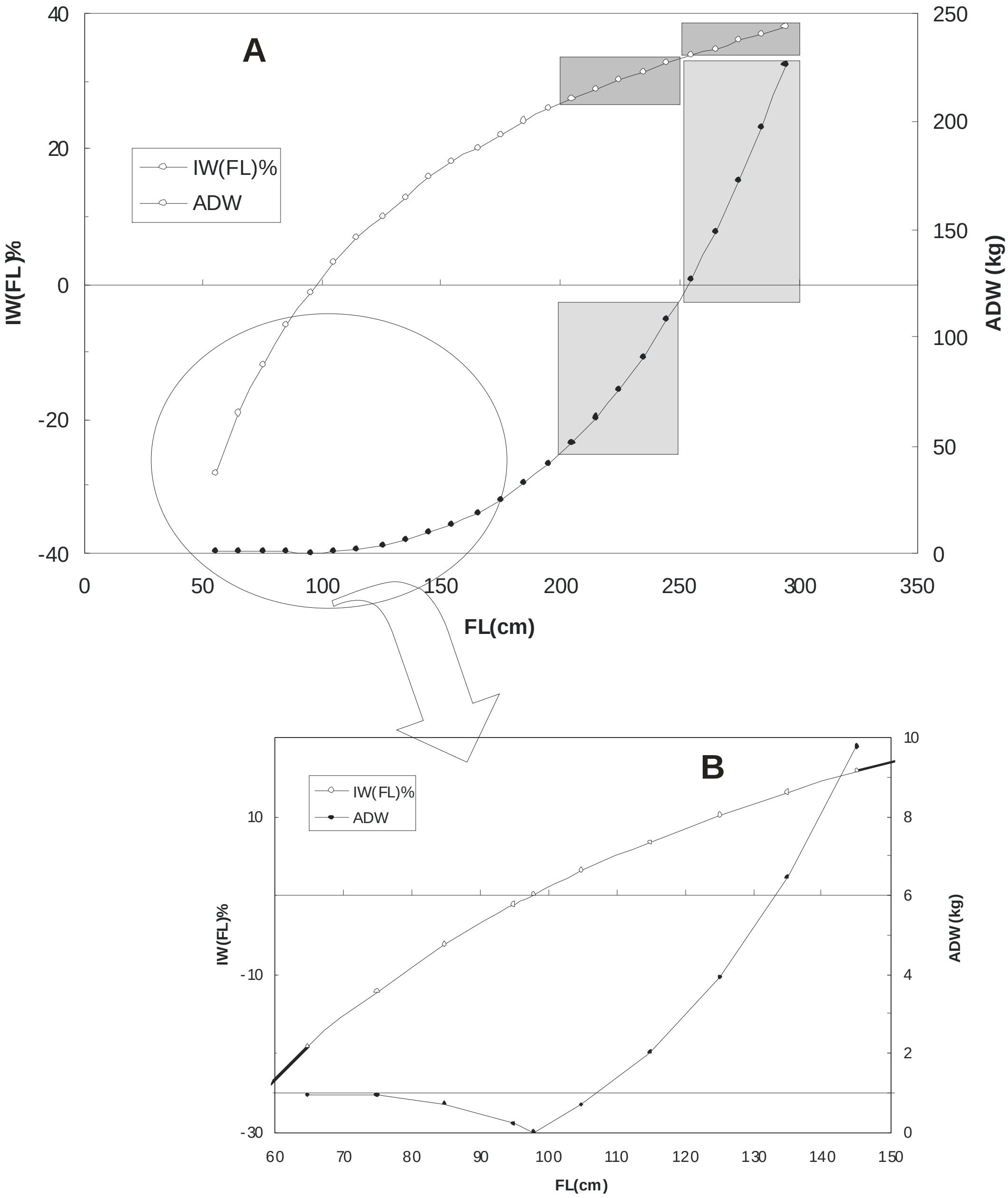

Figure 4. Percentage and absolute weight difference between fattened and wild bluefin tuna for fork length classes between 55 and 295cm (in 10cm increments) examined in the present study (Graph A). IW(FL)% is the "weight difference index" and AWD the absolute weight difference in kg. Graph B presents a detail of Graph A for small FL classes up to 145cm; the dark regions mark the FL classes 205-245cm and 255-295cm.

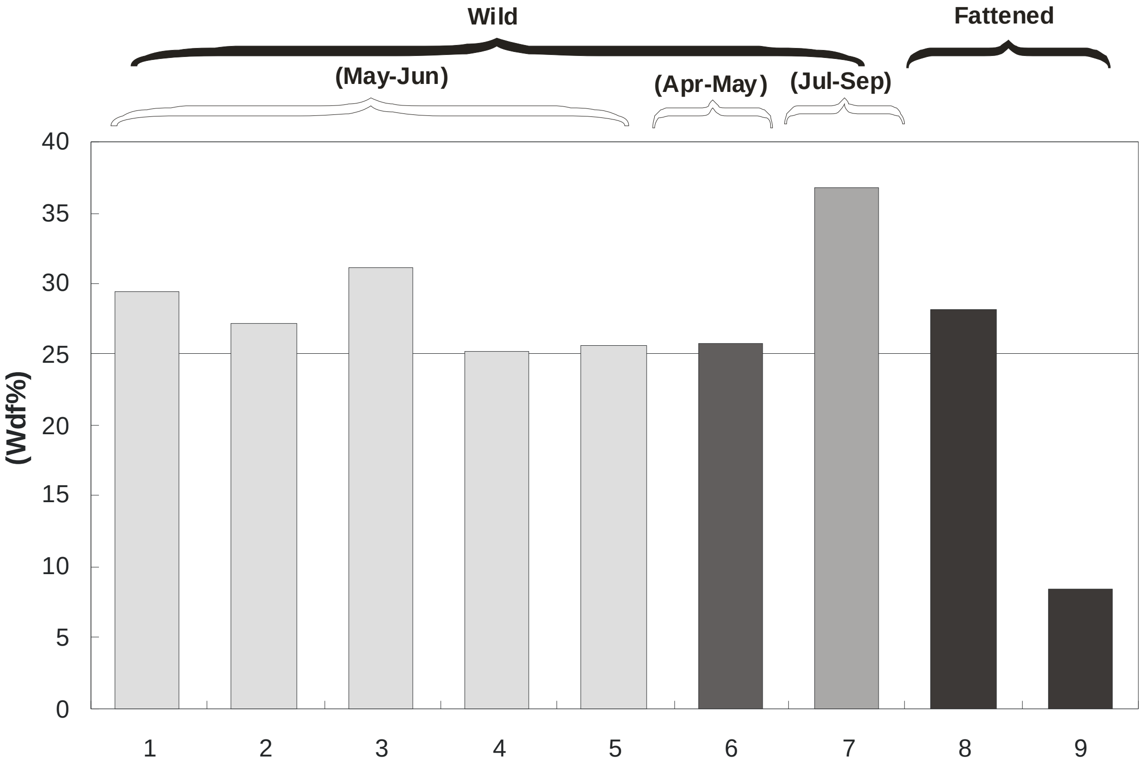

Figure 5. Percentage weight difference (Wdf%) of the fattened bluefin tuna set of data examined in the present study on one hand, and to several other wild and fattened bluefin tuna sets of data on the other: wild fish examined in the present study (column 1); wild fish from Aguado-Giménez and García-García, 2005 (column 2), El-Tawil *et al.* 2004 (column 3), El-Kebir *et al.* 2002 (column 4), Hattour, 2003 (column 5), Dos Santos *et al.* 2004 (columns 6 and 7); and fattened fish from Dos Santos et al., 2004 (column 8) and Aguado-Giménez and García-García, 2005 (column 9).