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USE OF FULTON'S CONDITION FACTOR TO FILTER OUT OUTLIERS FROM ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS* L.) LENGTH-WEIGHT RELATIONSHIPS

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SUMMARY

*Length-weight (L-W) relationships are important parameters in Atlantic bluefin tuna (*Thunnus thynnus *L) (ABFT) stock assessments. Some datasets used to determine L-W relationships contain outliers which may significantly affect the accuracy of these L-W relationship and other parameters utilised during stock assessments. A method is proposed to filter out these outliers and provide more meaningful L-W relationships. This method is based on the application of the Tukey's Outlier method on the Fulton's Condition Factor (K) data derived from available fork length (FL) and round weight (RWT) data. In this paper Tukey's Outlier method was applied to K data derived from the FLs and RWTs of eight Atlantic bluefin tuna datasets from both wild and farmed Atlantic bluefin tuna. Lower and upper filtering limits were used to filter out outlying FL and RWT data points in the original datasets to determine new L-W relationships. It was shown that applying Tukey's Outlier filtering procedure significantly improved the coefficient of determination (R^2) in these datasets in which R^2 was initially low, demonstrating that applying Tukey's Outlier method to K can provide more accurate L-W relationships for Atlantic bluefin tuna.*

RÉSUMÉ

*Les relations longueur-poids (L-W) constituent des paramètres importants dans les évaluations des stocks de thon rouge de l'Atlantique (*Thunnus thynnus L*). Certains jeux de données utilisés pour déterminer les relations L-W contiennent des éléments atypiques susceptibles d'altérer considérablement la précision de ces relations L-W ainsi que d'autres paramètres utilisés pendant les évaluations des stocks. Il est proposé une méthode visant à éliminer par filtrage ces éléments atypiques et fournir des relations L-W plus significatives. Cette méthode repose sur l'application de la méthode des données atypiques de Tukey sur les données du Facteur de condition (K) de Fulton obtenues des données disponibles de longueur à la fourche (FL) et de poids vif (RWT). Dans ce document, la méthode des données atypiques de Tukey a été appliquée aux données de K à partir des FL et RWT de huit jeux de données sur du thon rouge de l'Atlantique à l'état sauvage et d'élevage. Des limites de filtrage supérieures et inférieures ont été utilisées pour éliminer les points de données atypiques FL et RWT dans les jeux de données originaux afin de déterminer de nouvelles relations L-W. On a démontré que l'application de la procédure de filtrage des données atypiques de Tukey améliorait considérablement le coefficient de détermination (R2) dans les jeux de données où R2 était initialement faible, ce qui montre que l'application de la méthode des données atypiques de Tukey à K peut donner lieu à des relations L-W plus exactes pour le thon rouge de l'Atlantique.*

RESUMEN

*Las relaciones talla-peso (L-W) son parámetros importantes en la evaluación de stock del atún rojo del Atlántico, (*Thunnus thynnus, *L) (ABFT). Algunos conjuntos de datos utilizados para definir las relaciones talla-peso contienen datos atípicos que podrían afectar en gran medida a la precisión de estas relaciones y a otros parámetros utilizados durante las evaluaciones de stock. Se propone un método para filtrar estos datos atípicos y facilitar relaciones L-W significativas. Este método se basa en la aplicación del método de valores atípicos de Tukey a los datos de Factor de Condición de Fulton (K) derivados de los datos disponibles de longitud a la horquilla (FL) y peso en vivo (RWT) En este documento se aplica el método de valores*

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atípicos de Tukey a los datos de K obtenidos de la FL y el RWT de ocho conjuntos de datos de atún rojo del Atlántico, tanto para el atún rojo del Atlántico capturado en estado silvestre como para el atún rojo procedente de actividades de cría. Los límites de filtrado superiores e inferiores se utilizaron para filtrar los puntos de datos de FL y RWT subyacentes en los conjuntos de datos originales para determinar las nuevas relaciones L-W. Se demostró que la aplicación del procedimiento de filtrado de valores atípicos de Tukey mejoraba significativamente el coeficiente de determinación (R2) en estos conjuntos de datos en los que R2 era inicialmente bajo, demostrando que la aplicación del método de valores atípicos de Tukey a K puede proporcionar relaciones L-W más precisas para el atún rojo del Atlántico.

KEYWORDS

Outliers, Fulton's Condition Factor, Atlantic bluefin tuna,
Thunnus thynnus, length-weight relationships

1. Introduction

A tremendous amount of Atlantic bluefin tuna (ABFT) biometric data is available to the SCRS for use in stock assessments. Such data is available from the fishery itself and, more recently, also from fattening/farming activities. One important set of data is that related to Fork Length – Round Weight (L-W) data for the purpose of determining the L-W relationships for use in stock assessments.

A closer analysis of some of the data available shows up data points which appear to clearly be outliers and, unless removed, may in fact skew the determination of the L-W relationship. Such data may also have implications on other biological parameters utilised in stock assessments. It is therefore essential to be able to ensure that all points utilised in the analysis are valid and are true representations of the fish sampled and not an error of measurement or recording.

An approach is being put forward as a means of filtering this data to remove these outliers, thereby providing a more useful and realistic dataset. The method also provides an indication of the quality of the dataset.

The method is based on the use of the Fulton's Condition Factor K (Ricker, 1975), which is calculated as:

$$K = 10^5 * RWT/FL^3$$

where RWT = Round Weight in kg and FL = Fork Length in cm.

K is generally used as an indicator of the nutritional status of the fish (and is also used as such in the aquaculture industry). In the case of ABFT, L-W relationships (and therefore K) have been shown to vary at different times of the year (Parrack and Phares, 1979), particularly in relation to spawning activity (for e.g. dos Santos *et al*., 2004, Deguara et al., 2012) and following fattening in tuna pens (for e.g. Aguado-Gimenez & Garcia-Garcia, 2005; Deguara et al., 2010, 2012; Tzoumas et al.; 2010, Galaz, 2012).

As K is a biological parameter, it is expected that there are biological limits to the values of K which can occur in nature. These limits would be determined by biological constraints related to the implication of the nutritional status of the fish. Below a certain value of K fish would have died of starvation and cannot function physiologically. On the other hand, going beyond an upper value of K for a particular species would be anatomically impossible.

The filtering method applied is the Tukey's Outlier method (Tukey, 1977; Hoaglin et al., 1983). This method allows the generation of an interval based on a criterion for outlier determination and any observations which then fall beyond the interval determined were considered as outliers. This method is very useful because it makes no distributional assumptions nor does it depend on values, such as the mean or standard deviation, which are sensitive to extreme data. The method is quite effective, especially when analysing large continuous datasets that are not highly skewed, and, furthermore, is resistant to extreme values because it is based on such robust measures as the first and third quartiles and the interquartile range. The filtering limits are calculated as:

Filtering Lower Limit = Lower Quartile – (1.5 x Interquartile Range), and
Filtering Upper Limit = Upper Quartile + (1.5 x Interquartile Range).

2. Materials and Methods

Eight ABFT datasets were used for the purpose of carrying out the analysis for the determination of outliers using K. The eight datasets included datasets from ABFT capture fisheries (various gears) from both the West and East ABFT stocks and from farmed fish harvested in the Mediterranean.

For the analysis carried out, only data points which provided both FL and RWT were used. Any conversions from the raw data were carried out prior to the analysis as required by converting FL from curved fork length using a factor of 0.955 (Parrack, Brunenmeister & Nichols, 1979) and RWT from gilled and gutted weight using a factor of 1.13 (Anonymous).

Before application of the Tukey's Outlier method, K was calculated for all the data points in each of the datasets. Tukey's Outlier method was then applied to the K data in each of the datasets.

Levene's Test for the equality of variances was used within the eight datasets, following which the Kruskal-Wallis test to determine if there were significant differences between medians.

The filtering lower and upper limits were determined for each of the eight datasets. These lower and upper limits were then used to remove the K outliers and thereby to remove the corresponding L and W data points from the original datasets. New plots of the filtered L and W datasets were then executed to determine the new L-W relationship.

3. Results

Table 1 presents the summary of the statistics for K of the unfiltered datasets. The minimum and maximum values of K in the raw datasets varied considerably between datasets, the lowest being 0.00 (Dataset 2) and the highest 2,504 (Dataset 3). Median values varied from 1.64 (Dataset 3) to 2.12 (Dataset 7). % coefficients of variation also varied considerably, from the smallest value of 8.94 (Dataset 4) to as high as 1,464 (Dataset 7). These variations are demonstrated in the box-and-whisker plots shown in **Figure 1** and **Figure 2** which is the same plot showing only values of K from 0 to 15.

The lower and upper quartile values varied between datasets as did the interquartile range. The largest interquartile range was found in Dataset 1 having a range of 0.52 whilst Dataset 6 had the lowest interquartile range at 0.27. Lower quartile values varied from 1.47 (Dataset 3) to 1.99 (Dataset 7); there was less variation in the upper quartile ranges, between 1.94 (Dataset 3) and 2.27 (Dataset 7).

Figure 3 shows the L-W relationships for Datasets 1-8 in the unfiltered form with the equation describing these relationship being:

$$RWT = aFL^b$$, where a is the intercept and b is the slope.

The results of the constants a and b for each of the L-W relationships for each of Datasets 1 to 8 are summarised in **Table 2**, along with the coefficient of determination (R^2). The L-W relationships shown in **Figure 1** demonstrate the variability in the quality of the data in terms of distribution of data points in the respective graphs, with a wide dispersion apparent in most of the datasets shown; this is reflected in most cases in the coefficients of determination (R^2) shown in **Table 2**, with the lowest coefficients being obtained with Datasets 1, 3 and 5 (0.56, 0.58 and 0.77 respectively). The best coefficient was found with Dataset 4 (0.99) followed by Dataset 8 (0.97).

Levene's test on the unfiltered datasets gave a P value of < 0.05. The Kruskal-Wallis test also gave a P value of < 0.05 indicating that the medians were statistically different.

The results of applying the Tukey's method for determination of outliers and the filtering limits on each of the datasets are presented in **Table 3**. Filtering limits varied between 0.73 in Dataset 1 to 2.81 also in Dataset 1 to give the biggest range of 2.08. The lowest filtering range was found in Dataset 4 where the filtering limits were 1.40 and 2.44, giving a range of only 1.04.

The effect of applying the determined filtering limits on the summary statistics of each dataset are presented in **Table 4** and **Figure 4.** Application of the filtering limits greatly reduced the variability in the data points in Datasets 1, 2, 3, 6 and 7. This resulted in a reduction of the coefficients of variations in these datasets as well as in the skewness and kurtosis values for the resulting distributions.

Figure 5 shows the new L-W graphs for each of the datasets using the filtering limits determined in **Table 3** rounded to the nearest first decimal point. **Table 5** summarises the new values of a, b and R^2 for each of the datasets after application of the filtering limits determined in **Table 3**. The results of the filtering reduced the variability in the data points in the L-W graphs most clearly for Datasets 1, 2, 3, 6 and 7, and this is reflected in the improved R^2 values (except that of Dataset 4), most clearly for Datasets 1, 3 and 7.

4. Discussion

Stock assessments are dependent on the data available for the analysis. A very large amount of data is available for the ABFT and is utilised in the determination of the status of the stock. It is important that the quality of the data used in these assessments be of the best quality possible.

Outliers are a recognised problem within statistics and it is acknowledged that errors can occur during the actual measurement of the particular parameter itself, such as when measuring FL, and also during data entry into the actual dataset. Some data points are often quite clearly mistakes. However, most are less easily justified on this basis and require some other justification for their removal.

This paper presents a method of determining outliers of data points utilised in the determination of L-W relationships, i.e. based on the measurement of FL and RWT. An intrinsic relationship of these two parameters is the Fulton's Condition Factor and is generally accepted as being an indication of the nutritional status of a fish. This implies that there are upper and lower limits to K determined by the physiology and anatomy of the fish being analysed.

This feature formed one of the basic components in the energy allocation model for ABFT proposed by Chapman et al. (2011) in which minimum and maximum values of K were set. In the model, minimum and maximum values for K were set (for wild fish) at 1.4 and 2.1 respectively as based on analysis of K by (Golet and Lutcavage, unpublished data cited by Chapman *et al*., 2011). Similar approaches, using minimum and maximum Ks have been used in other species (e.g. cod, Jorgensen and Fiksen, 2006).

It is well known that any fish species will undergo changes in condition as a result of food deprivation and spawning activity and is reflected in the L-W relationships of the fish at different times of the year. This has been documented for wild ABFT (e.g. Parrack and Phares, 1979; dos Santos *et al*., 2004; Deguara *et al*., 2012). It has also been demonstrated that farming activities can significantly influence the L-W relationship and thereby K (e.g. Ticina et al., 2007; Tzoumas et al., 2010, Galaz, 2012).

Various values of K have been given for ABFT in the literature. After analysing numerous data from various geographical areas and from various fishing gears caught during a period of 12 years, Alot et al. (2011) found an average K of approximately 1.88 ($\pm$ 0.17). Rodriguez-Roda (1964) reported values of K in the traps of the Straits of Gibraltar which ranged between 1.6 (after spawning) to 2.0 (before spawning). Percin and Akyol (2009) reported K values of average 1.56 ($\pm$ 0.12) and 1.69 ($\pm$ 0.06) for male and female ABFT respectively caught by purse seiner from late winter to early summer in the Levantine Sea. The average K of purse seine caught ABFT in the Adriatic was found to be 1.95 ($\pm$ 0.14) (Ticina *et al*., 2007), increasing to 2.33 ($\pm$ 0.22) after a period of farming. Aguado-Gimenez and Garcia-Garcia (2005) reported that the majority of ABFT caught by purse seiner in July in the Balearics ranged between 1.4 and 1.8 whilst after fattening, the majority of harvested fish had Ks ranging between 1.8 and 2.2. Tzoumas *et al.* (2010) determined an average K of 1.74 ($\pm$ 0.25) for ABFT caught by various gears in different locations in the Mediterranean during May and June. The same authors found an average K of 2.17 ($\pm$ 0.27) in fattened fish. Galaz (2012) found that ABFT caught by purse seine from the West and Central Mediterranean showed a K of 1.81 ($\pm$ 0.18) in July, rising to a K of 2.12 ($\pm$ 0.21) after 7 months of fattening.

The procedure presented in this work clearly demonstrates the benefit of applying the Tukey's method to filter out outliers within a dataset. This was most apparent in Datasets 1, 2, 3, 6 and 7 with significant improvements in R^2 being recorded in Datasets 1, 2, 3 and 7. Any effects on the filtering of Datasets 4, 5 and 8 were negligible as would be expected from looking at the original L-W relationships and summary statistics of these datasets.

Notwithstanding the improvement in R^2 seen in Datasets 1 and 3, the improvement did not result in sufficiently high R^2 values (whilst all the other datasets ended up after application of the filtering procedure with R^2 values above 0.95). These relatively low values of R^2 seen in the filtered Datasets 1 and 3 are also apparent from the filtered L-W graphs of Datasets 1 and 3 (**Figure 5** (1) and (3). At the same time, the lower filtering value determined for Datasets 1 and 3 (0.73 and 0.77) were lower than the K values that are considered appropriate for ABFT as indicated in the paragraph above). These results for Datasets 1 and 3 indicate that the original data of these two datasets may need to be revisited in more detail.

Running the filtering procedure on all the data points available in the datasets analysed here together, but excluding data points from Datasets 1 and 3, gives upper and lower filtering limits of 1.47 and 2.63 (lower and upper quartiles of 1.90 and 2.19 respectively). This upper and lower K values lie within the ranges of K indicated in the literature for ABFT.

The Tukey's method can be applied to K data to improve the L-W relationships obtained from datasets where outliers may be present. It provides a means of improving the coefficient of determination of these datasets giving greater confidence in the resulting relationships and information they provide to stock assessments and parameters used in stock assessments.

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Table 1. Summary of statistics for Condition Factor (K) of unfiltered Datasets 1 to 4.

Statistic	**Dataset 1**	**Dataset 2**	**Dataset 3**	**Dataset 4**
Count	9,910	4,315	2,901	344
Average	1.85	2.41	1.76	1.93
Median	1.75	1.87	1.64	1.96
Standard deviation	0.59	27.91	0.53	0.17
Coefficient of variation (%)	31.92	1,151.31	30.29	8.94
Minimum	0.27	0.00	0.27	1.57
Maximum	8.35	1,830.63	9.44	2.39
Range	8.08	1,830.63	9.17	0.82
Lower quartile	1.51	1.72	1.47	1.79
Upper quartile	2.03	2.04	1.94	2.05
Interquartile range	0.52	0.32	0.47	0.26
Skewness	3.58	65.22	4.25	-0.10
Kurtosis	21.02	4273.15	32.98	-0.53

Table 1 continued. Summary of statistics for Condition Factor (K) of unfiltered Datasets 5 to 8.

Statistic	**Dataset 5**	**Dataset 6**	**Dataset 7**	**Dataset 8**
Count	583	24,414	4,042	12,645
Average	2.13	2.05	5.48	2.07
Median	2.10	2.04	2.12	2.06
Standard deviation	0.25	0.30	80.28	0.22
Coefficient of variation (%)	11.52	14.56	1,463.82	10.85
Minimum	1.33	0.33	0.10	1.07
Maximum	2.99	14.73	2,504.28	3.12
Range	1.66	14.40	2,504.18	2.05
Lower quartile	1.96	1.91	1.99	1.91
Upper quartile	2.26	2.18	2.27	2.22
Interquartile range	0.30	0.27	0.28	0.31
Skewness	0.56	12.62	25.61	0.04
Kurtosis	0.59	387.31	671.34	0.34

Table 2. Summary of constants a and b and coefficient of determination (R^2) for the unfiltered Datasets 1 to 8.

Dataset	**a**	**B**	$\mathbf{R^2}$
1	2.0740×10^{-3}	2.1416	0.5645
2	8.1092×10^{-5}	2.7175	0.8900
3	1.6516×10^{-3}	2.1705	0.5768
4	5.3335×10^{-5}	2.7782	0.9928
5	1.6845×10^{-4}	2.6034	0.9502
6	1.6757×10^{-5}	3.0376	0.9569
7	3.4802×10^{-4}	2.4599	0.7655
8	9.1359×10^{-6}	3.1530	0.9734

Table 3. Results of the application of the Tukey's method for the determination of lower and upper filtering limits on the Datasets 1 to 8.

Dataset	Lower quartile	Upper quartile	Interquartile range	Filtering lower limit	Filtering upper limit
1	1.51	2.03	0.52	0.73	2.81
2	1.72	2.04	0.32	1.24	2.52
3	1.47	1.94	0.47	0.77	2.65
4	1.79	2.05	0.26	1.40	2.44
5	1.96	2.26	0.30	1.51	2.71
6	1.91	2.18	0.27	1.51	2.59
7	1.99	2.27	0.28	1.57	2.69
8	1.91	2.22	0.31	1.45	2.69

Table 4. Summary Statistics for Condition Factor (K) of filtered Datasets 1 to 4 as per the lower and upper filtering limits calculated as per **Table 3** rounded to the nearest first decimal point.

Statistic	Dataset 1	Dataset 2	Dataset 3	Dataset 4
Upper and lower filtering limits	0.7-2.8	1.2-2.5	0.77-2.65	1.40-2.44
Count	9,460	4,115	2,797	344
Average	1.76	1.87	1.69	1.93
Median	1.73	1.86	1.62	1.96
Standard deviation	0.33	0.23	0.30	0.17
Coefficient of variation (%)	18.94	12.14	17.75	8.67
Minimum	0.70	1.20	0.85	1.57
Maximum	2.80	2.50	2.65	2.39
Range	2.10	1.30	1.80	0.82
Lower quartile	1.50	1.71	1.46	1.79
Upper quartile	1.99	2.01	1.91	2.05
Interquartile range	0.49	0.30	0.45	0.26
Skewness	0.48	0.123	0.563	-0.10
Kurtosis	-0.11	-0.07	-0.238	-0.53

Table 4 (continued). Summary Statistics for Condition Factor (K) of filtered Datasets 5 to 8 as per the lower and upper filtering limits calculated as per **Table 3** rounded to the nearest first decimal point.

Statistic	Dataset 5	Dataset 6	Dataset 7	Dataset 8
Upper and lower filtering limits	1.51-2.71	1.5-2.6	1.6-2.7	1.45-2.69
Count	573	24,051	3,764	12,563
Average	2.12	2.04	2.12	2.07
Median	2.09	2.04	2.12	2.06
Standard deviation	0.23	0.19	0.20	0.22
Coefficient of variation (%)	10.85	9.44	9.62	10.63
Minimum	1.55	1.50	1.60	1.45
Maximum	2.71	2.60	2.70	2.69
Range	1.16	1.10	1.10	1.24
Lower quartile	1.96	1.91	2.00	1.92
Upper quartile	2.25	2.18	2.25	2.21
Interquartile range	0.29	0.27	0.25	0.29
Skewness	0.42	0.05	0.06	-0.04
Kurtosis	-0.14	-0.22	0.09	-0.24

Table 5. Summary of constants a and b and coefficient of determination (R^2) for the filtered Datasets 1 to 8 using the upper and lower filtering limits determined by Tukey's method as indicated in **Table 3**.

Dataset	**a**	**B**	**R^2**
1	5.7909×10^{-5}	2.7826	0.6998
2	2.3408×10^{-5}	2.9551	0.9759
3	9.8551×10^{-5}	2.6780	0.7229
4	5.3335×10^{-5}	2.7782	0.9928
5	1.5530×10^{-4}	2.6186	0.9577
6	1.3974×10^{-5}	3.0723	0.9726
7	2.0386×10^{-5}	3.0069	0.9820
8	9.1863×10^{-6}	3.1520	0.9751

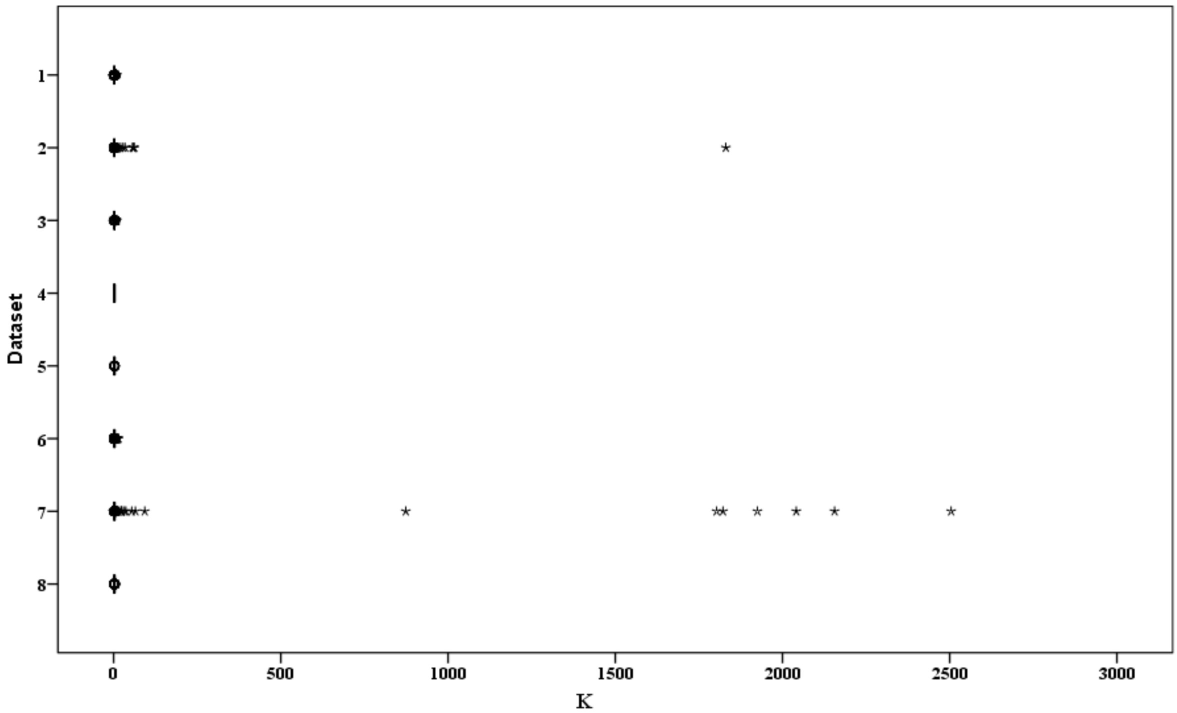

Figure 1. Box-and-Whisker plot of unfiltered Datasets 1 to 8 for the distribution of K showing full range of K values.

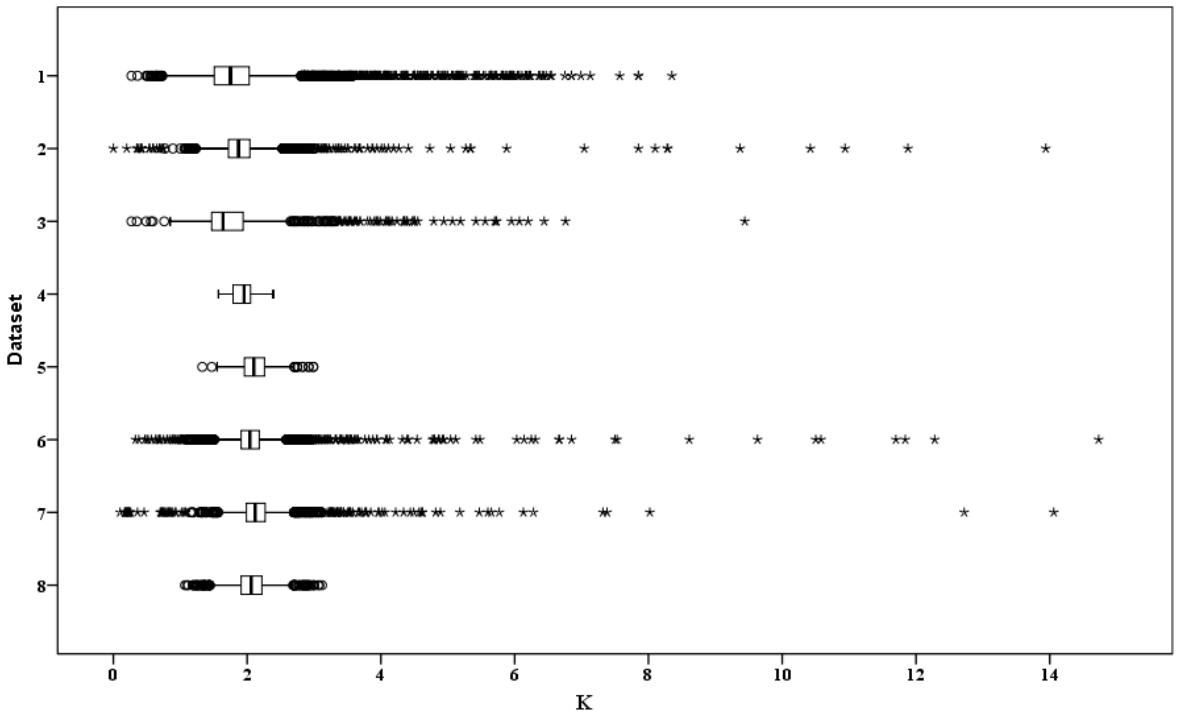

Figure 2. Box-and-Whisker plot of unfiltered Datasets 1 to 8 for the distribution of K showing lower only the ranges of K values from 0 to 15.

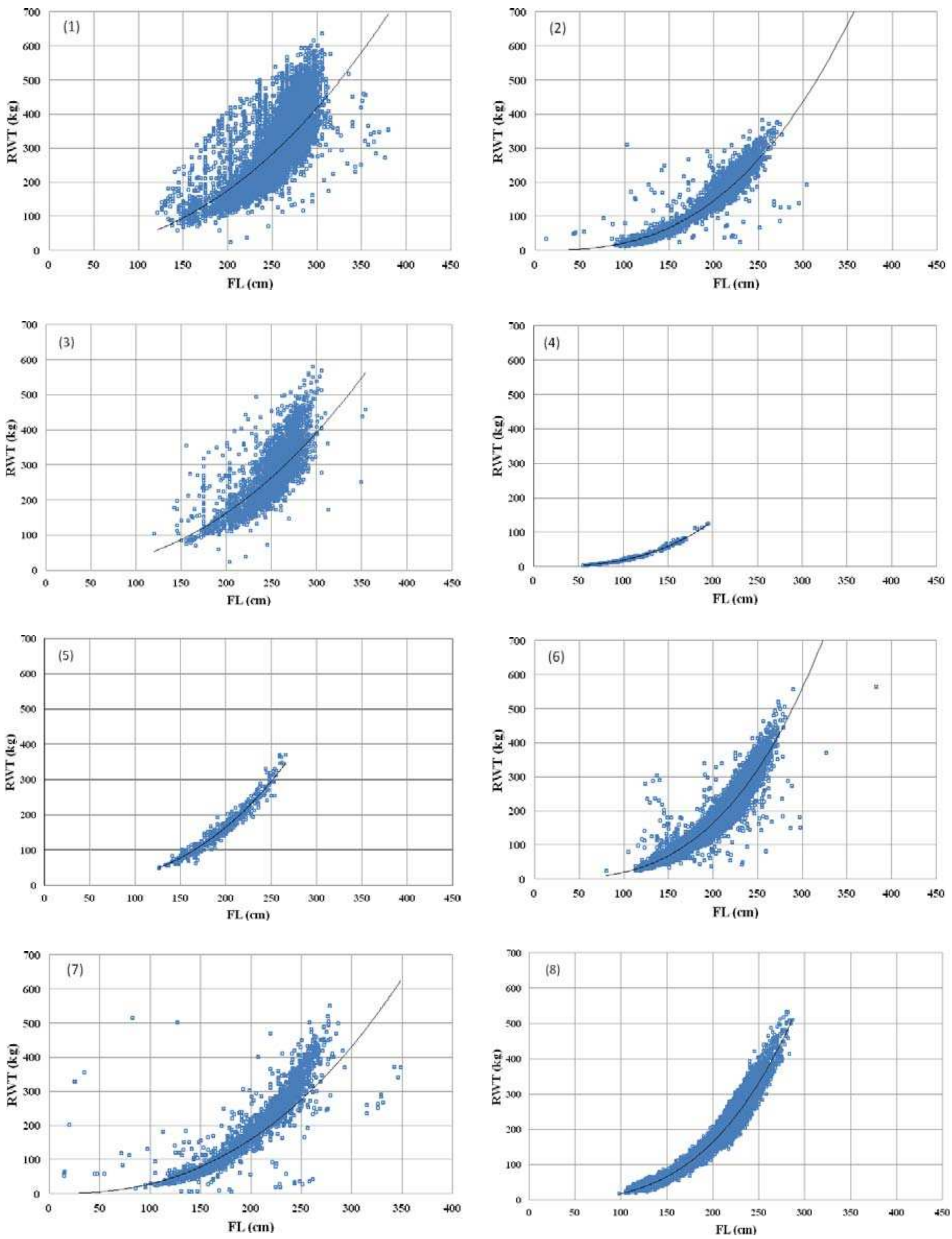

Figure 3. Length-Weight relationships of unfiltered Datasets 1 to 8 as indicated in brackets in each of the graphs (FL = Fork Length, RWT = Round Weight).

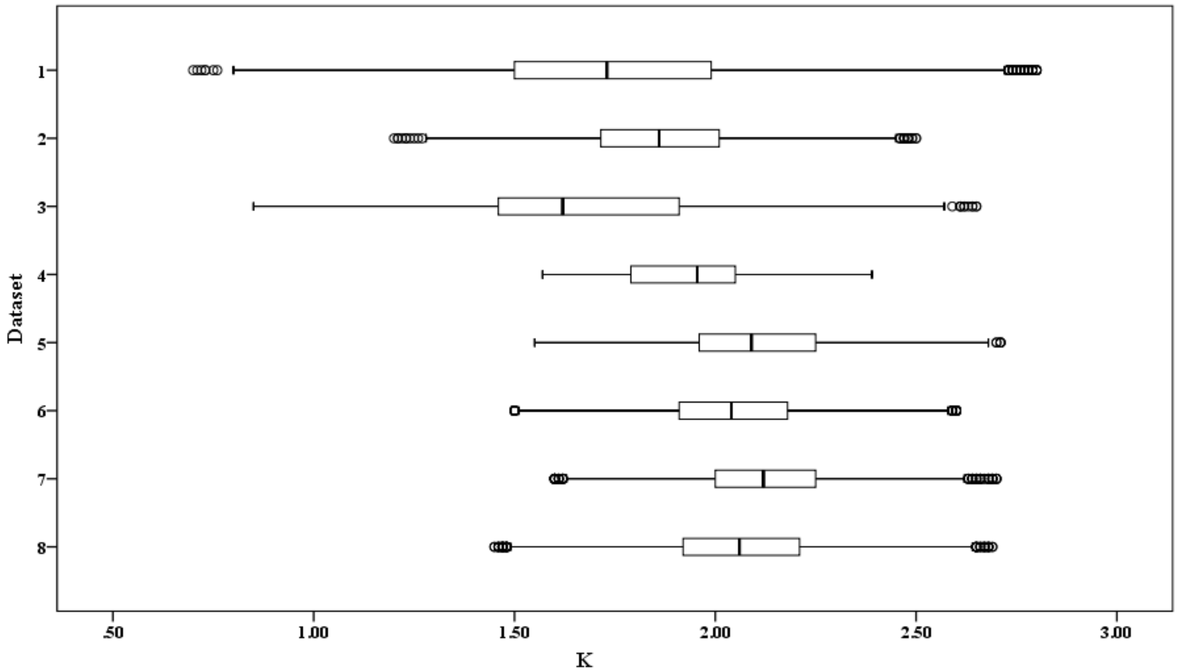

Figure 4. Box-and-Whisker plot of filtered Datasets 1 to 8 for the distribution of K showing full range of K values.

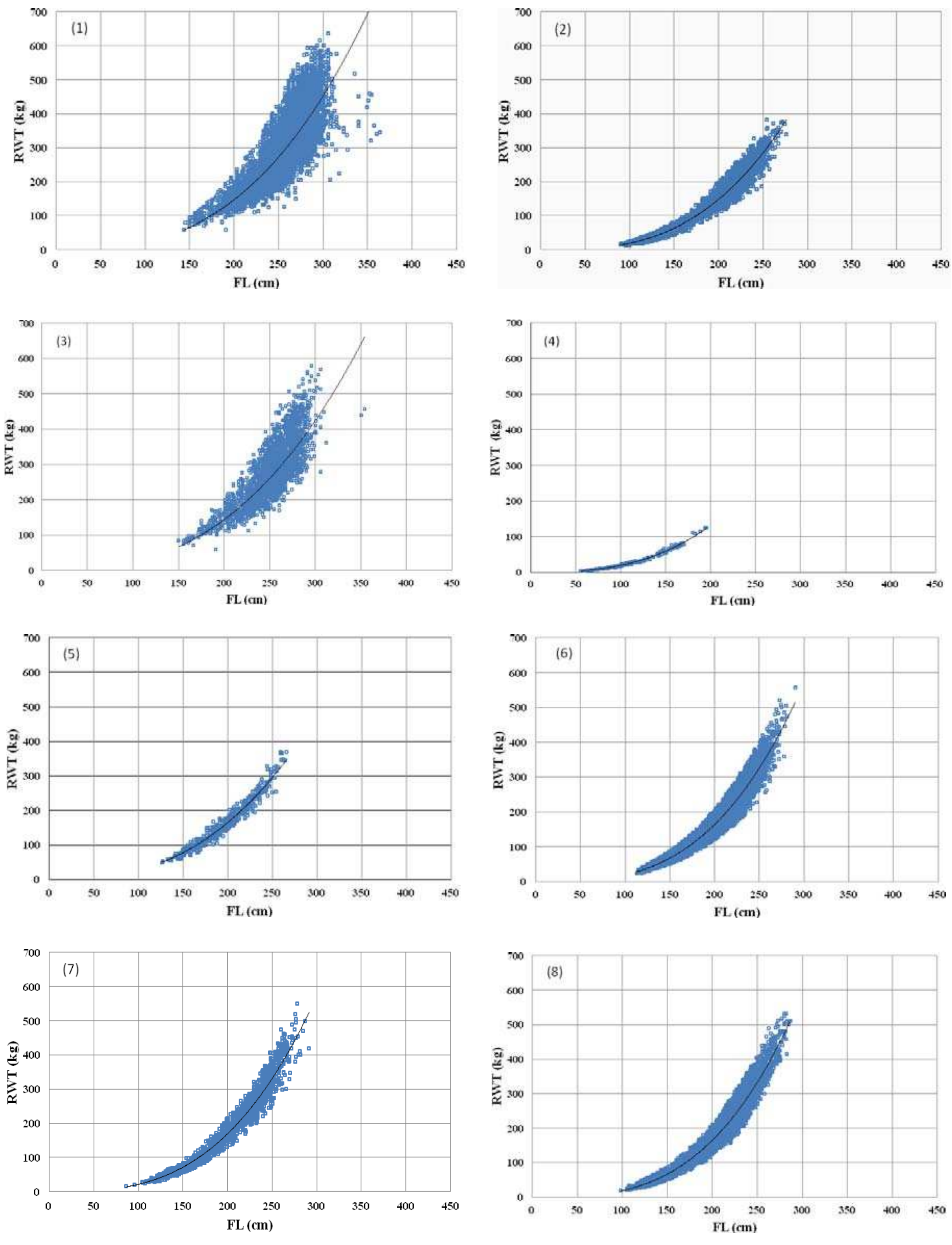

Figure 5. Length-Weight relationships of filtered Datasets 1 to 8 as indicated in brackets in each of the graphs (FL = Fork Length, RWT = Round Weight) using the upper and lower filtering limits determined by Tukey's method as indicated in **Table 3**.