Does global warming affect morphology of birds?

Abdullah Al-Hayali

Bachelor's thesis, 15 hp
Biologi och Geovetenskap, inriktning biologi, 180 hp
Supervisor: Keith Larson
Vt 2020

Abstract

Bergmann's and Allen's rule suggest that for the same species individuals found further north, tend to have larger body sizes and smaller appendages compared to individuals further south, respectively, due to constraints for thermal regulation. This has shown especially true for birds and mammals. In this paper, I test to see if global warming has led to a change in morphology for birds, i.e. body weight and wing size. We use year as a proxy for temperature as global warming has on average lead to an increase in the earth's surface temperature over the last century with most of the change occurring since the 1980's. To test the hypothesis, I gathered data of male, young of the year birds during autumn migration for a select number of species with different wintering strategies, i.e. resident to long-distance migration. This data came from two Swedish bird observatories where standardized wing and weight measurements have been collected since 1986, coincident with the observed climate warming. The results of this study show that during this period, changes in body mass and wing length did not support the hypothesis that global warming has had a broad impact on the morphology of birds. Given that these results contradict that of other studies, analysis from species across a much wider latitudinal breadth of Europe, including, additional species and different age and sex classes should be investigated.

Table of Contents

Acknowledgments

I would like to express my appreciation and gratitude to my supervisor, Dr. Keith Larson for all the help and constructive suggestions he has provided throughout the development of this research work. His professional guidance has been invaluable for the completion of this research.

A special thanks to the staff at the bird observatories in Falsterbo and Ottenby for providing all the data for this research, especially given the current global circumstances.

I would also like to thank my dear friend Jesper Hassellöv for providing me with the map from figure 3 under such a short period of time.

Finally, I wish to thank mother for all the support and encouragement she has provided throughout my study.

1. Introduction

1.1 Background

Birds and mammals in higher latitudes have shown that they tend to have bigger body size and shorter appendages i.e. tarsus, wing length and bill size, when compared to same species in lower latitudes. This has been explained by Bergmann and Allen's rules, respectively (Meiri, 2003) as a mechanism for thermal regulation, with animals at more northerly climes requiring adaptations for conserving body heat, i.e. shorter appendages, and larger body mass. Given the fact that climate has changed in predictable cycles over the last 2.5 million years of the Quaternary, it is likely that species have had to adapt by changing their morphology as the climate warms and then cools again. For example, the woodrat (*Neotoma Cinerea),* has shown a decrease in body size during periods of climatic warming (Smith, et al. 1995). The red-billed gull (*Larus novaehollandiae scopulinus),* have also shown similar changes in body size which supports Bergmann's rule (Teplitsky, et al. 2008). While the grey-bellied flowerpiercer (*Diglossa carbonaria)*, has been shown to have a correlation between body size and climate, where individuals found in warmer parts of their range exhibited smaller body sizes compared to those in colder parts (Graves, 1991).

Humans have been warming the climate since the beginning of the industrial revolution and most pronounced the 1980's (Houghton, 2009; IPCC, 2013) through the burning of fossil fuels that release heat trapping greenhouse gases.

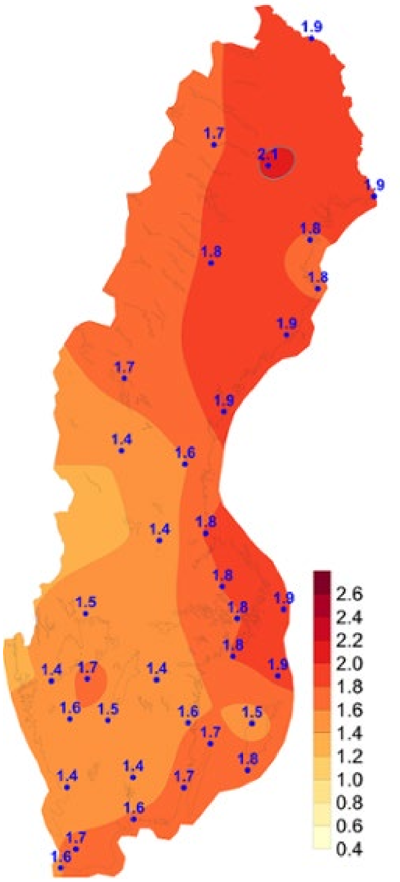

Figure 1: Figure from SMHI showing the change in temperature from the periods 1860-1900 and 1991-2019 where the northern parts of Sweden are showing the largest changes in temperature (SMHI, 2020).

With climate warming we should expect that animals, for example birds, should adapt by changing their body and appendage size to compensate for the warmer conditions (Weeks, et al. 2020). Alternatively, species could track their climate niche to higher latitudes and altitudes (Tingley, 2009). A recent study using museum specimens, shows that birds in North America have shown a decrease in body weight and an increase in wing length over the past four decades (Weeks, et al. 2020). Prior studies with British passerine birds show a decrease in weight and increase in wing length, supporting Bergmann and Allen's rules (Yom-Tov, 2006). The same changes for body weight are found in Israeli passerines (Yom-Tov, 2001). Migration could be a factor for an increase in wing length as species that contain both migratory and resident populations have greater wing length in the migratory populations (Mayr, 1942). However, migration patterns might change as a response to climate change, for example, *Turdus merula* populations in the Netherlands since the 1950's have decreased in the proportion that undertake migration due an increase in availability of food because of climate change (Vliet, et al. 2008). This change in wintering strategy could offset the need to change morphologically for thermoregulation.

At high latitudes, including Scandinavia, global warming has been influencing the temperatures more rapidly than those in temperate regions due to the reduction of albedo and influence of warm ocean currents at these latitudes (IPCC 2013). This has led to a phenomenon called "accelerated warming" or "Arctic amplification" (Sollid, et.

Al. 2007). In comparison, the global temperature change has been increasing with an estimate of 0.2°C per decade since the 1980's (Hansen, et al. 2006), whilst in Sweden the mean winter temperature has increased by 2°C in the period 1991-2000 when compared to the period 1961-1990 (Räisänen, et al. 2003). Swedish Meteorological and Hydrological Institute (SMHI, 2020) has recently reported the change in temperature when the two periods 1860-1900 and 1991-2019 are compared on based data from 35 weather stations spread out in Sweden (Figure 1). Their conclusion was that the minimum change was around 1.4°C, the national average was 1.7°C. They compared these changes to the global average of 0.8°C (SMHI, 2020). Further, they have also shown that temperature change varies across the four seasons (Figure 2) with winter and autumn showing the largest changes compared to summer and spring (SMHI, 2020).

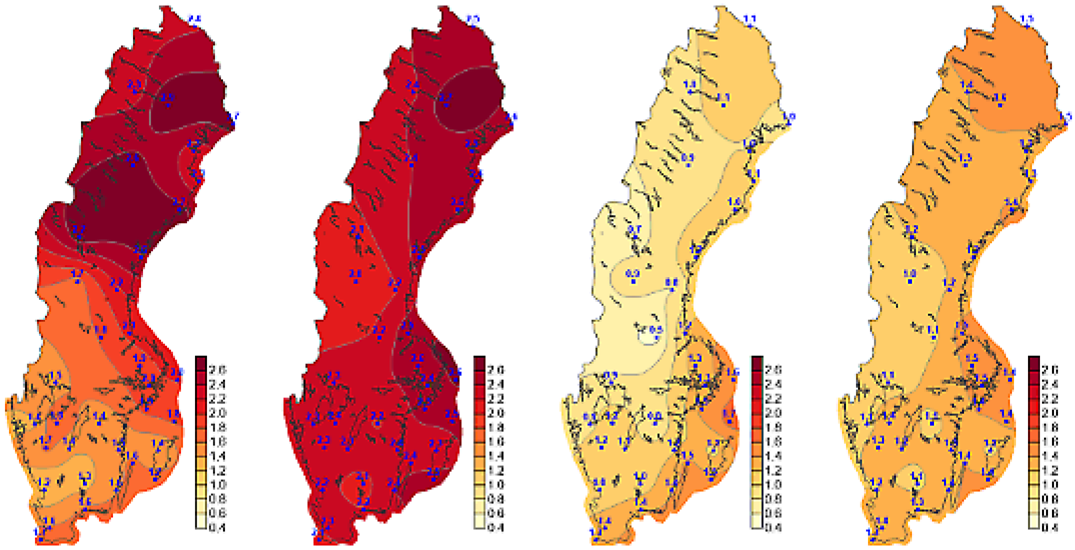

Figure 2: The change of temperature in Sweden across the four seasons when comparing the periods 1860-1900 and 1991-2019. Left to right: winter, autumn, summer, and spring (SMHI, 2020).

Given the observed climate warming, I ask the following question: Has global warming had an influence on bird's body size and appendage length? To answer this question, two mechanisms will be used as an explanation for the possible change in relation to a bird's ability to thermoregulate in a changing climate. The first mechanism is Bergmann's rule and the second is Allen's rule. Bergmann's rule explains that animals living in colder climates generally have larger body sizes or are "bulkier" compared to same species living in warmer climates, this is to better preserve heat in cold climates (Bergmann, 1847). Allen's rule explains that for same species individuals in colder climates would have shorter appendages than those in warmer climates to reduce heat loss (Allen, 1877).

The validity of these two mechanisms is often questioned, for example, Geist (1987) states that Bergmann's rule cannot be used as an explanation for body size to preserve heat since that means that the body size should be increasing in size from south to north with higher rates than we have in reality. Yet, Meiri and Dayan (2003) found that "Over 72% of birds and 65% of the mammal species follow Bergmann's rule" and that Bergmann's rule is generally valid for both taxonomic groups. Similar arguments have been made for Allen's rule. A study of the common frog (*Rana rana*) concluded Allen's rule cannot solely explain the variance in appendage length, but the results were consistent with Allen's rule under some environmental conditions (Alho, et al. 2010).

Wing length is an important factor in bird migration as longer wings increase performance (Mayr, 1942, Hamilton, 1961 & Alerstam, 2011). This should be reflected in long-term migrating birds having a stronger effect of increase in wing length than resident and short-term migrating species. Thus we might expect that resident and short-distance migrants should increase wing length less than long-distance migrants as a response to warming. However, longer wings would increase the surface area of the bird which would allow more heat to escape (Allen, 1977). This could be challenging for long-distant migrants that breed at high latitudes and winter in low latitudes, e.g., the pied flycatcher (*Ficedula hypolueca*). Passerines migrate at night to better thermoregulate during these extended periods of heat generating activity (Alerstam, 2009). Andean passerine birds, for example, show that there is a correlation between body mass and latitude, where the body mass increases at higher latitude (Blackburn, 2001). It is also shown that resident birds tend to have larger body masses when compared to migrant birds (Greendwood, 1997).

1.2 Aim and hypothesis

The aim of this study was to investigate whether global warming has influenced bird's morphology in line with predictions from Allen's and Bergmann's rules.

To explore this question, time is used as a proxy for temperature and we gathered data on wing length and weight from bird observatories for a variety of species covering the full range of wintering strategies, from resident to long-distance migrants.

Hypothesis (H_0): Global warming has had no significant effect on the bird's morphology.

Prediction: Global warming and bird morphology (wing length and weight) are not linked, and thus the change of climate has no significant effect on the bird's morphology.

Alternative hypothesis (H_1): Global warming has resulted in a change in body size (Bergman's rule) and wing length (Allen's rule) for birds.

Prediction 1a: Migrating and resident birds will have reduced their body size in accordance to Bergmann's rule and furthermore, resident birds should experience a higher rate of weight loss compared to migrating birds due to the greatest warming taking place at high latitude countries such as Sweden where they spend the winter.

Prediction 1b: Migrating and resident birds should have an increase in wing length following Allen's rule and migrating birds should be experiencing these increases in wing length at higher rates than resident birds. This should be the most pronounced in long-distance migrants relative to medium and short distance migrants.

2. Method

2.1 Sampling

Falsterbo (55.38°N, 12.82°E) and Ottenby (56.20°N, 16.40°E) bird observatories are large observatories both located in the south of Sweden. All data used was provided by these two observatories, this would allow us to obtain reasonable sample sizes for the several species. They have provided us with data of ringed birds since 1986-2019, both stations established standardized measurements and protocols in 1986 hence why data is restricted to that period. All included datasets are of male birds with age marking "1" which translates to young of the year birds.

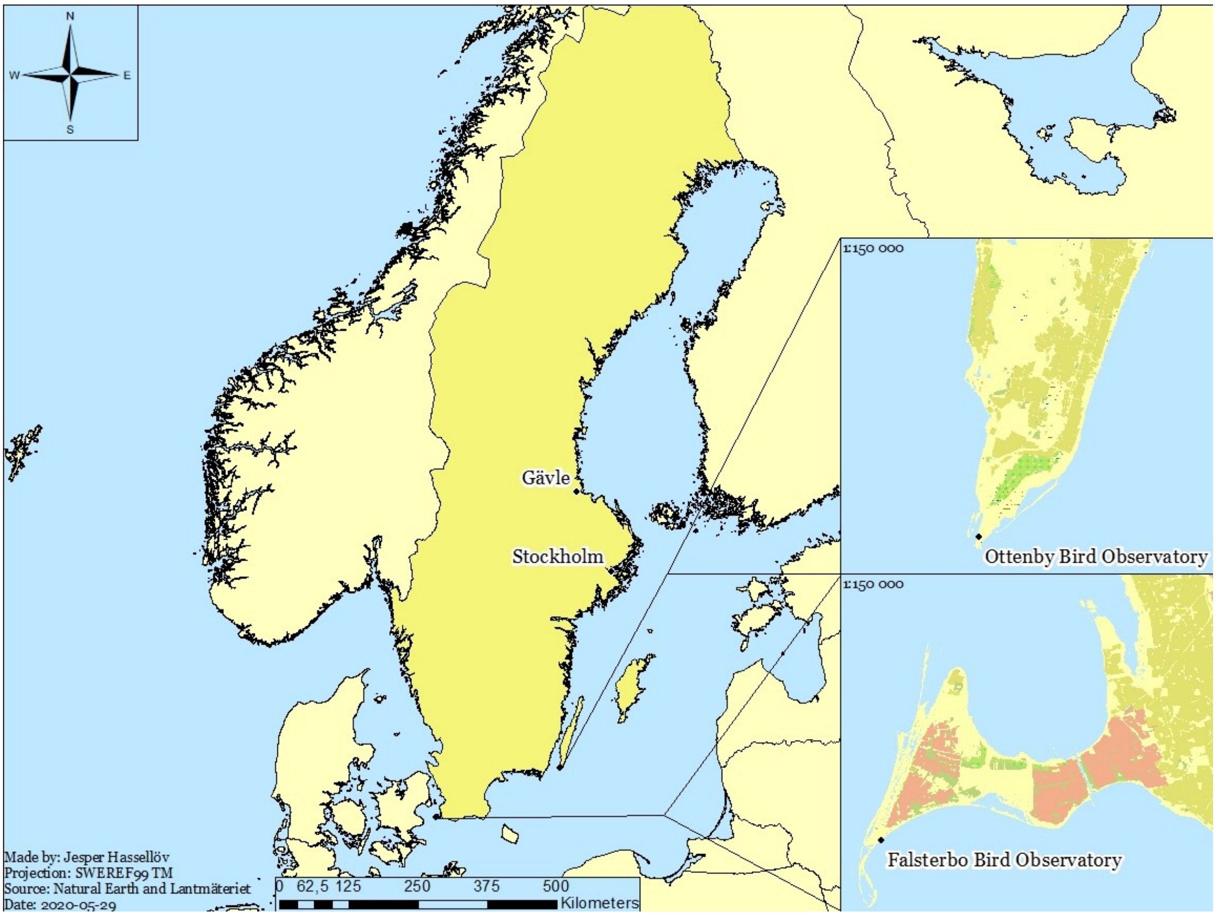

Figure 3: Location of Falsterbo and Ottenby bird observatories. Coordinates to Falsterbo: 55.38°N, 12.82°E. Coordinates to Ottenby: 56.20°N, 16.40°E. Both coordinates are in WGS84 and are extracted from Google Earth.

With the information available in *Fåglarna I Sverige* (Ottosson, et al. 2012) and with consultation with the Swedish Ringing Centre and both ringing stations, the species were selected based upon three criteria, 1) species had to be reliably aged (young of the year) and sexed (male), 2) adequate sample sizes over the period of 1986-2019, and 3) a diversity of species that would cover all wintering strategies (i.e. residency to long-distance migration). Table 1 presents the chosen species as well as their migration patterns and distance of migration, this is important as migration could affect the change in wing length and weight for birds. Migration status and distance of migration was established in accordance to Svensson et al. (2009). I choose only young of the year birds as they represent by far the largest portion of individuals captured during autumn migration. I selected only males to minimize the confounding effect of sexual dimorphism in the analysis. Appendix A shows how many birds were ringed for each species at station over the entire examined period.

Table 1: Data of species examined, their migration status and distance of migration. Migration distances can be defined as: short distance to central Europe, medium to southern Europe and long distance to Africa and Asia (Svensson et al. 2009).

Species/Migration status	Migration status	Distance of migration
Tardus merula	Partial migrant	Medium
Sylvia atricapilla	Migrant	Long
Cyanistes caeruleus	Partial migrant	Short
Fringilla montifringilla	Migrant	Short-medium
Fringilla coelebs	Partial migrant	Short-medium
Regulus regulus	Partial migrant	Short-medium
Parus major	Resident	
Ficedula hypoleuca	Migrant	Long
Phoenicurus phoenicurus	Migrant	Long
Spinus spinus	Partial migrant	Short-medium

2.2 Analysis

All data received was in Microsoft Excel (2004) but all analysis was made on R (2013). Appendix A shows the samples sizes for each species and station combination. Boxplots are presented in Appendix B to present the weight and wing length data over the sample period (1986 to 2019).

A generalize linear model (GLM henceforth) was used to conduct the regression analysis. A GLM is appropriate for this time-series analysis because we are not sampling the same individuals from year to year, but rather populations. The model residuals were plotted to inspect for extreme outliers, and they were removed if they were outside 1.5*IQR (Interquartile range is the middle 50%, being the difference between the upper quartile Q3, and the lower quartile Q1) as any number greater than this is a suspected outlier (Rousseeuw, 2011). These outliers were assumed to be either data entry or measurement errors that occurred while ringing the birds. The Levene test was used to for homogeneity of variances and the Shapiro-Wilks text for normality to ensure linear model assumptions are not violated.

F-statistics from the individual GLM's were compared to the critical values for the one-tailed *F* distribution in Zar (1999, Appendix B, Table B.4) for significance.

The GLM results are with plots of the regression line with confidence intervals in Appendix C. All results were plotted using ggplot2 (Wikham, 2016).

The significance threshold was set to $\alpha = 0.05$ for all statistical analysis.

3. Results

Does global warming effect bird morphology?

Weight. Results from the regression analysis for weight as a response variable and year as an explanatory variable shows that only seven of fifteen species tested had a significant *p-values* and crossed the critical threshold of significance for the *F distribution* of 3.84 (Table 2). For example, the resident *Parus major,* captured at Falsterbo ($F_{1,\ 1812} = 66.02$, $p < 0.001$, $R^2 < 0.04$) showed a significant variation in weight. The long-distance migrant, *F. hypoleuca*, at both Falsterbo ($F_{1,\ 1102} = 6.52$, $p = 0.01$, $R^2 < 0.01$) and Ottenby ($F_{1,\ 641} = 8.82$, $p < 0.01$, $R^2 = 0.01$) also showed significant variation in weight. However, the extremely low R^2 value for all species shows that year explains only an insignificant part of the variation in weight with the possible exception of *P. major*.

Table 2: Results from regression analysis for weight (response variable) and year (explanatory variable) for all species examined at both Falsterbo and Ottenby bird observatories between 1986 and 2019 (Fig. 3).

Species/Statistical results	*N*	*F*	*DF*	*p*	R^2
Turdus merula Falsterbo	495	.09	493	.766	< .01
Turdus merula Ottenby	1069	.23	1067	.631	< .01
Sylvia atricapilla Falsterbo	1622	.12	1620	.725	< .01
Sylvia atricapilla Ottenby	743	.53	741	.465	< .01
Cyanistes caeruleus Falsterbo	5721	31.97	5719	< .001	< .01
Fringilla montifringilla Falsterbo	353	1.62	351	.204	< .01
Fringilla coelebs Falsterbo	947	.08	945	.772	< .01
Fringilla coelebs Ottenby	826	15.49	824	< .001	< .01
Regulus regulus Falsterbo	9772	35.79	9770	< .001	< .01
Parus major Falsterbo	1814	66.02	1812	< .001	.04
Ficedula hypoleuca Falsterbo	1104	6.56	1102	.011	< .01
Ficedula hypoleuca Ottenby	643	8.82	641	.003	.01
Phoenicurus phoenicurus Falsterbo	1834	.82	1832	.364	< .01
Phoenicurus phoenicurus Ottenby	1680	3.53	1678	.060	< .01
Spinus spinus Falsterbo	3230	8.43	3228	.004	< .01

Wing length. The results from the regression analysis for wing length as a response variable and year as the explanatory variable show that only three species, *Sylvia atricapilla* at Falsterbo ($F_{1,\ 1620} = 5.22$, $p = 0.02$, $R^2 < 0.01$), *F. hypolueca* at Ottenby ($F_{1,\ 641} = 9.77$, $p < 0.01$, $R^2 = 0.02$), and *Spinus spinus* at Falsterbo ($F_{1,\ 3228} = 12.87$, $p < 0.001$, $R^2 < 0.01$) showed significant *p-values* and crossed the threshold for the critical value for the *F-statistic* (Table 3). However, the extremely low R^2 value for all species shows that year explains only an insignificant part of the variation in wing length.

Table 3: Results from regression analysis for wing length (response variable) and year (explanatory variable) for all species examined at both Falsterbo and Ottenby bird observatories between 1986 and 2019 (Fig. 3).

Species/Statistical results	***N***	***F***	***DF***	***p***	***R^2***
Turdus merula Falsterbo	495	.19	493	.663	< .01
Turdus merula Ottenby	1069	.12	1067	.635	< .01
Sylvia atricapilla Falsterbo	1622	5.22	1620	.023	< .01
Sylvia atricapilla Ottenby	743	3.31	741	.069	< .01
Cyanistes caeruleus Falsterbo	5721	1.25	5719	.263	< .01
Fringilla montifringilla Falsterbo	353	.25	351	.617	< .01
Fringilla coelebs Falsterbo	826	.82	945	.366	< .01
Fringilla coelebs Ottenby	947	.26	824	.610	< .01
Regulus regulus Falsterbo	9772	.38	9770	.538	< .01
Parus major Falsterbo	1814	.55	1812	.460	< .01
Ficedula hypoleuca Falsterbo	1104	1.12	1102	.291	< .01
Ficedula hypoleuca Ottenby	643	9.77	641	.002	.02
Phoenicurus phoenicurus Falsterbo	1834	2.31	1832	.127	< .01
Phoenicurus phoenicurus Ottenby	1680	1.45	1678	.223	< .01
Spinus spinus Falsterbo	3230	12.87	3228	< .001	< .01

4. Discussion and conclusion

Global warming has had its most pronounced effects in high latitudes in countries like Sweden. For many species, the ability to thermoregulate creates a constraint on their fitness. Based on Allen's and Bergman's rules, it is predicted that animals at high latitudes should have shorter appendages and higher body mass than the same species at a lower latitude. I tested whether the observed warming was effecting these two aspects of a birds morphology in Sweden. I choose a diversity of species ranging from residents to long-distant migrants where the constraints of thermoregulation should be different. Further, I chose species where wing length and body mass are assessed on a regular basis since 1986 at ringing stations coincide with the period of most significant warming (Houghton, 2009; IPCC, 2013).

Results from analysis showed that global warming did not explain the variation observed in body mass, thus accepting the rejecting my hypothesis (H_1) for all species (Table 3). However, there were a handful of species that showed minor significance in both wing and weight that might yield suggesting that further analysis maybe warranted. Additional metrics collected during bird ringing operations may improve this analysis, for example, factors such as the time-of -day, day-of-year they were ringed and fat score, were not considered in the analysis. These factors could help to improve interpretation of the variation in body mass over time. For example, birds ringed late during the day generally have higher body mass then those first thing in the morning after they arrive from a night of migration. Further, those ringed close to when they are about to start their migration might have a lower body mass then those at stop-over locations where birds intentionally engage in hyperphagia during migration. Despite the inability to support our hypothesis, Weeks et al. (2020) has shown that winter increasing winter temperature lead to an increase in body size. This has been explained by the need to preserve heat as larger body sizes preserve heat better than smaller body sizes (Bergmann, 1847).

Wing length results showed that no species showed any change attributable to global warming. Based on my prediction, we were expecting that there would be a trend of increasing wing length over time, where the greatest changes would be shown in long-distance migrants. This was based on the optimal migration theory where it is predicted that long-distance migrants should have the longest wings and changes in selection pressure such as climate should have a greater effect on these birds versus the resident and partial migrants (Alerstam 2011).

An aspect that could potentially improve these analysis would be using direct measurements of annual and seasonal temperatures rather than using the proxy year. Note however, that all individuals captured during migration likely come from a very large catchment area of Scandinavia making use of direct temperature observations a challenge.

A change in migratory behaviour of populations might also explain why no change in morphology has been found. Bird populations might track their wintering climate niche and forgoing migration (Vliet, et al. 2008), eliminating the need for a change in morphology.

Other measurements to consider including in the future would be bill size and tarsus length, as other studies have found that both bill and tarsus size change as a reaction to climate warming (Weeks, et al. 2020, Ryeland, et al. 2017, Greenberg, et al., 2012). Birds might experience a change in morphology through bill size and tarsus length rather than wing length and an overall change in body mass. However, this data is rarely collected at bird ringing stations, thus making it very unlikely to get large sample sizes.

In conclusion, despite evidence presented in other studies, I found no significant trends in wing or weight changes over time in line with the predictions from Allen's and Bergman's rules given the observed warming climate. However, additional analytical methods and a more expansive dataset both in terms the number of species, age and sex classes, and a latitudinal breadth of the sample locations across Europe could reveal patterns not observed in the species selected for the two sites in Sweden. For example, there are numerous bird observatories across the breadth of Europe and Israel with millions of observations taken over many decades that might improve the ability to detect trends in bird body size in relation to the rapidly warming climate.

5. Sources

Alerstam, T. 2011. Optimal bird migration revisited. *J Ornithol* 152, 5–23. DOI: 10.1007/s10336-011-0694-1

Alho, J. S. Herczeg, G. Laigen, A. T. Räsänen, K. Laurila, A. & Merilä, J. 2010. Allen's rule revisited: quantitative genetics of extremity length in the common frog along a latitudinal gradient. *Journal of Evolutionary Biology*. 24(1): 59-70 DOI: 10.1111/j.1420-9101.2010.02141.x

Alerstam T. 2009. Flight by night or day? Optimal daily timing of bird migration. *Journal of theoretical biology*, *258*(4), 530–536. DOI: 10.1016/j.jtbi.2009.01.020

Allen, J. A. 1877. The influence of physical conditions in the genesis of species. *Radical review* 1, 180-140.

Bergmann, C. (1847). Uber die verhaltnisse der warmeokonomie der thiere zu ihrer grosse. *Gottinger Stud.*, 1, 595–708.

Blackburn, T., & Ruggiero, A. (2001). Latitude, Elevation and Body Mass Variation in Andean Passerine Birds. *Global Ecology and Biogeography, 10*(3), 245-259. Retrieved June 17, 2020, from www.jstor.org/stable/2665349

Geist, Velerius. 1987. Bergmann's rule is invalid *Canadian Journal of Zoology*. 65(4):1035-1038. DOI: 10.1139/z87-164

Graves, G. 1991. Bergmann's rule near the equator: latitudinal clines in body size of an Andean passerine bird. *Proceedings of the National Academy of Sciences*. 88 (6) 2322-2325 DOI: 10.1073/pnas.88.6.2322

Greenberg, R., Cadena, V., Danner, R.M. & Tattersall, G. 2012, Heat Loss May Explain Bill Size Differences between Birds Occupying Different Habitats. *PLoS One,* vol. 7, no. 7.

Greenwood J. J. D., Gregory, R. D., Stephen, H., Morris P. A. & Yalden D. W. 1997. Relations between abundance, body size and species number in British birds and mammals. *Phil. Trans. R. Soc. Lond.* B351265–278. DOI: 10.1098/rstb.1996.0023

Hamilton, T. (1961). The Adaptive Significances of Intraspecific Trends of Variation in Wing Length and Body Size Among Bird Species. *Evolution, 15*(2), 180-195. doi:10.2307/2406079

Houghton, J. 2009. *Global warming the complete briefing*. 4. Edition. Cambridge University press.

Hansen, J. Sato, M. Ruedy, R. Lo, K. Lea, D & Medina-Elizade, M. 2006. Global temperature change. *Proceedings of the National Academy of Sciences*. 103(39) 14288-14293. DOI: 10.1073/pnas.0606291103

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Mayr, E. 1942. Systematics and the origin of species. *Columbia Univ. Press, New York*.

Meiri, S. & Dayan, T. 2003. On the validity of Bergmann's rule. *Journal of Biogeography*. 30(3) 331-351 DOI: 10.1046/j.1365-2699.2003.00837.x

Ottosson, U. Ottball, R. Elmberg, J. Green, M. Gustafsson, R. Haas, F. Holmqvist, N. Lindström, Å. Nilsson, L. Svensson, M. Svensson, S. & Tjernberg, M. 2012. *Fåglarna i Sverige – antal of förekomst*. SOF, Halmstad.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Rousseeuw, P. & Hubert, M. 2011. Robust statistics for outlier detection. *WIREs Data Mining Knowledge Discovery*. 1:73-79. DOI: 10.1002/widm.2

Ryeland, J. Weston, M.A. & Symonds, M.R. 2017. Bill size mediates behavioural thermoregulation in birds. *Functional Ecology*. 31: 885-893. doi:10.1111/1365-2435.12814

Räisänen, J. & Alexandersson, H. 2003. A probabilistic view on recent and near future climate change in Sweden. *Tellus A: Dynamic Meteorology and Oceanography*. 55:2(113-125) DOI: 10.3402/tellusa.v55i2.12089

SMHI. 2020. *Starkast uppvärmning i norra och östra Sverige*. https://www.smhi.se/nyhetsarkiv/starkast-uppvarmning-i-norra-och-ostra-sverige-1.159340 (Accessed 2020-06-28)

Sollid, J. Holmlund, P. & Harris, C. 2007. Recent warming of mountain permafrost in Svalbard and Scandinavia. *Journal Of geophysical Research: Earth Surface*. 112(F2) DOI: 10.1029/2006JF000522

Smith, F. Betancourt, J. & Brown, J. 1995. Evolution of Body Size in the Woodrat over the past 25,000 Years of Climate Change. *Science*. 270(5244) 2012-2014 DOI: 10.1126/science.270.5244.2012

Stresemann, E. 1941. Bemerkungen iiber Zonotricha capensis. *Ornith. Monatsber*. 49: 60-61

Svensson, L. Mullarney, & Zetterström, Dan. 2009. *Fågelguiden – Europas och Medelhavsområdets fåglar i fält*. 2. Edition. Bonnier fakta.

Teplitsky, C. Mills, J. Alho, J. Yattall, J. and Merilä, J. 2008. Bergmann's rule and climate change revisited: Disentangling environmental and genetic responses in a wild bird population. *Proceedings of the National Academy of Sciences*. 105(36) 13492-13496 DOI: 10.1073/pnas.0800999105

Tingley, M. Monahan, W. Beissinger, S. & Mortiz, C. 2009. Birds track their Grinnellian niche through a century of climate change. *Proceedings of the National Academy of Sciences*. 106 (2) 19637-19643 DOI: 10.1073/pnas.0901562106

Vliet, J.V. Musters, C.J.M. & Keurs, W.J.T. 2008. Changes in migration behaviour of Blackbirds *Turdus merula* from the Netherlands. *Bird study*. 56: 276-281. DOI: 10.1080/00063650902792148

Weeks, B. Willard, D. Zimova, M. Ellis, A. Witynski, M. Hennen, M. & Winger, M. 2020. Shared morphological consequences of global warming in North American migratory birds. *Ecology letters*. 23: 316-325 DOI: 10.1111/ele.13434

Wickham H (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Yom-Tov, Y. (2001). Global warming and body mass decline in Israeli passerine birds. Proc. R. Soc. B Biol. Sci., 268, 947–952.

Yom-Tov, Y. Yom-Tov, S. Wright, J. J. R. Thorne, C. and Du Feu, R. (2006), Recent changes in body weight and wing length among some British passerine birds. *Oikos*, 112: 91-101. DOI: 10.1111/j.0030-1299.2006.14183.x

Zar, J.H. 1999. Biostatistical Analysis. *Prentice Hall, Upper Saddle River*. 4th ed.

6. Appendix A

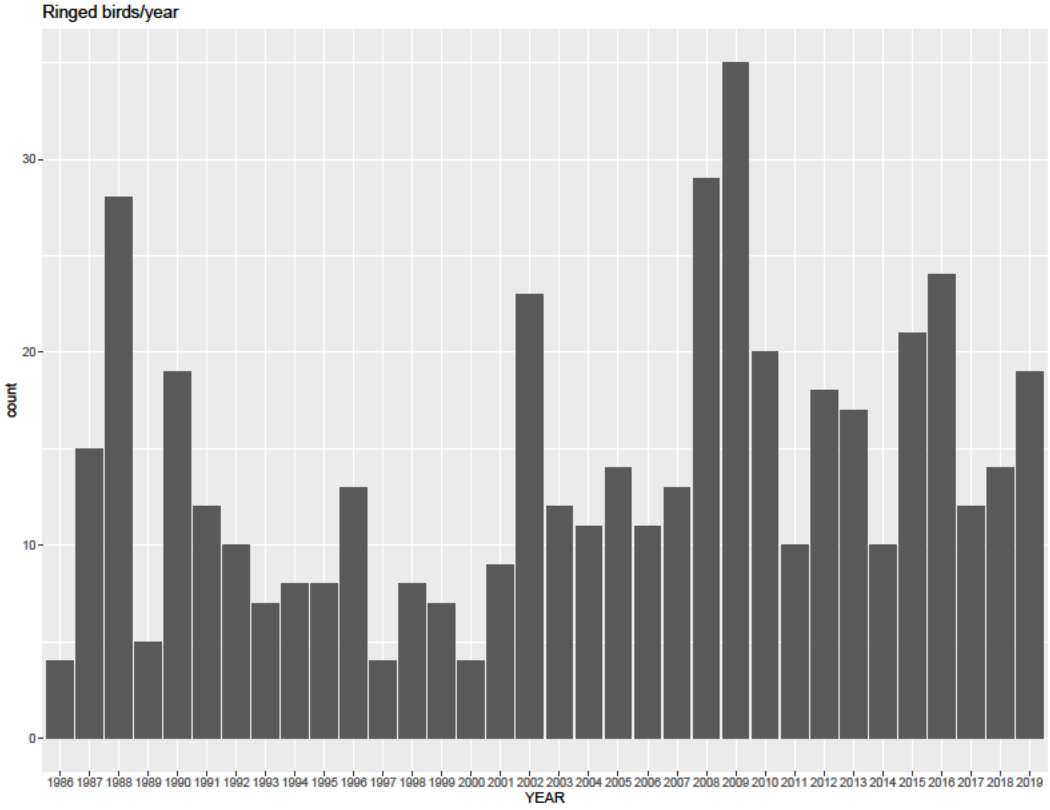

Figure 4: Number of T. merulas ringed per year in Falsterbo.

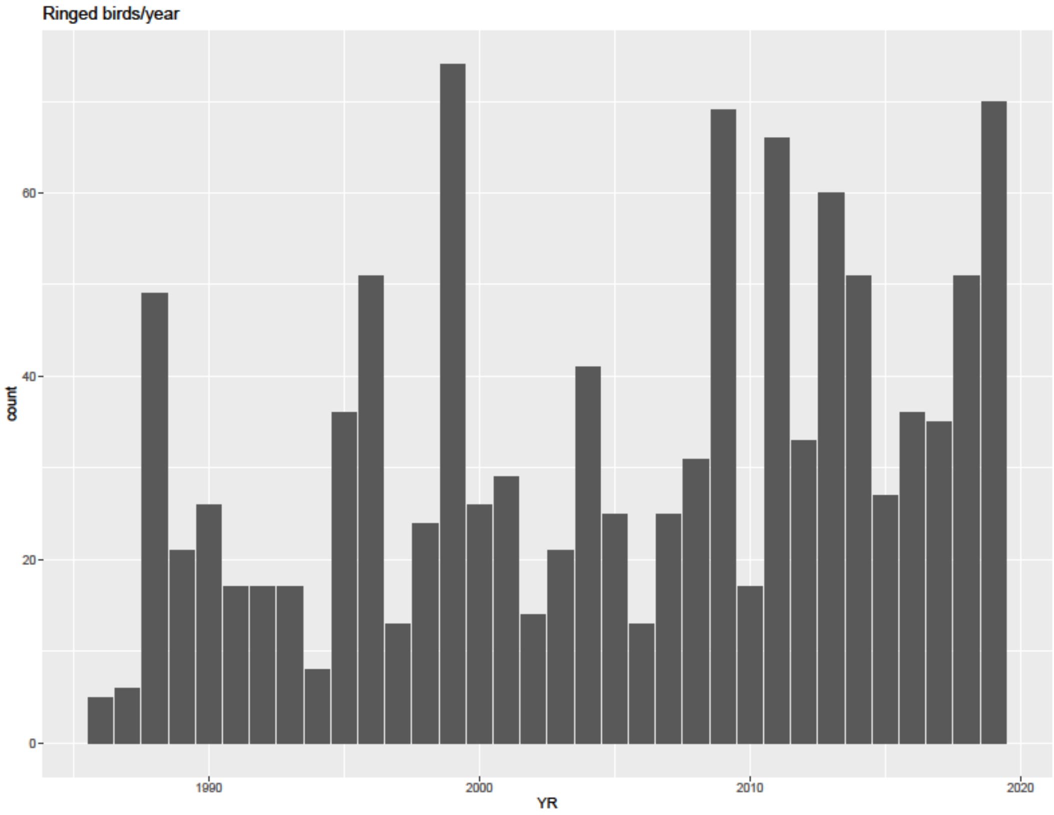

Figure 5: Number of *T. Merulas* ringed per year in Ottenby.

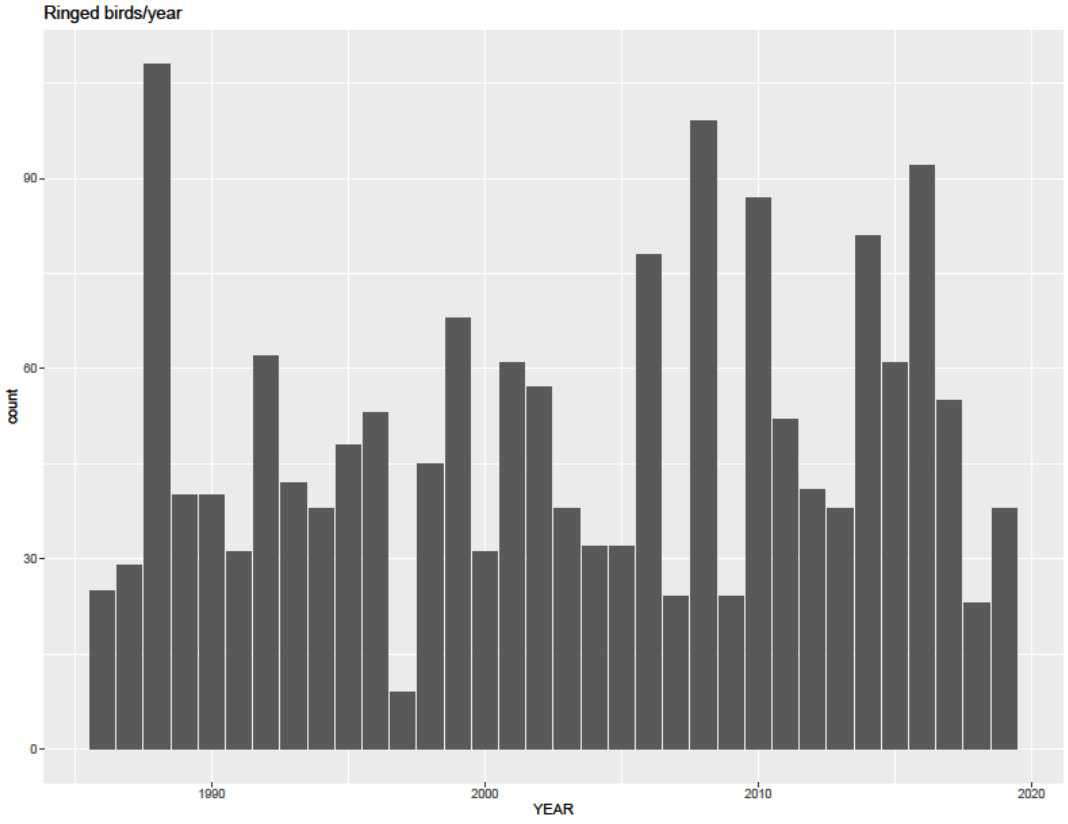

Figure 6: Number of *S. atricapilla* ringed per year in Falsterbo.

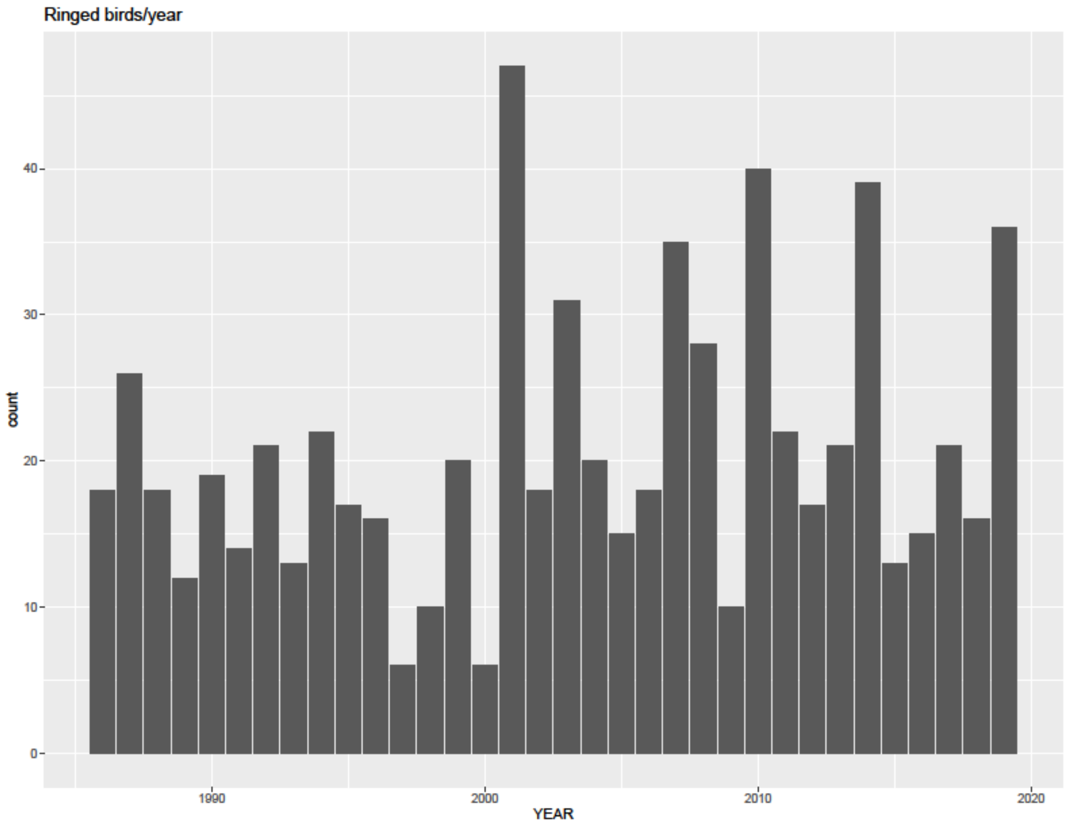

Figure 7: Number of *S. atricapilla* ringed per year in Ottenby.

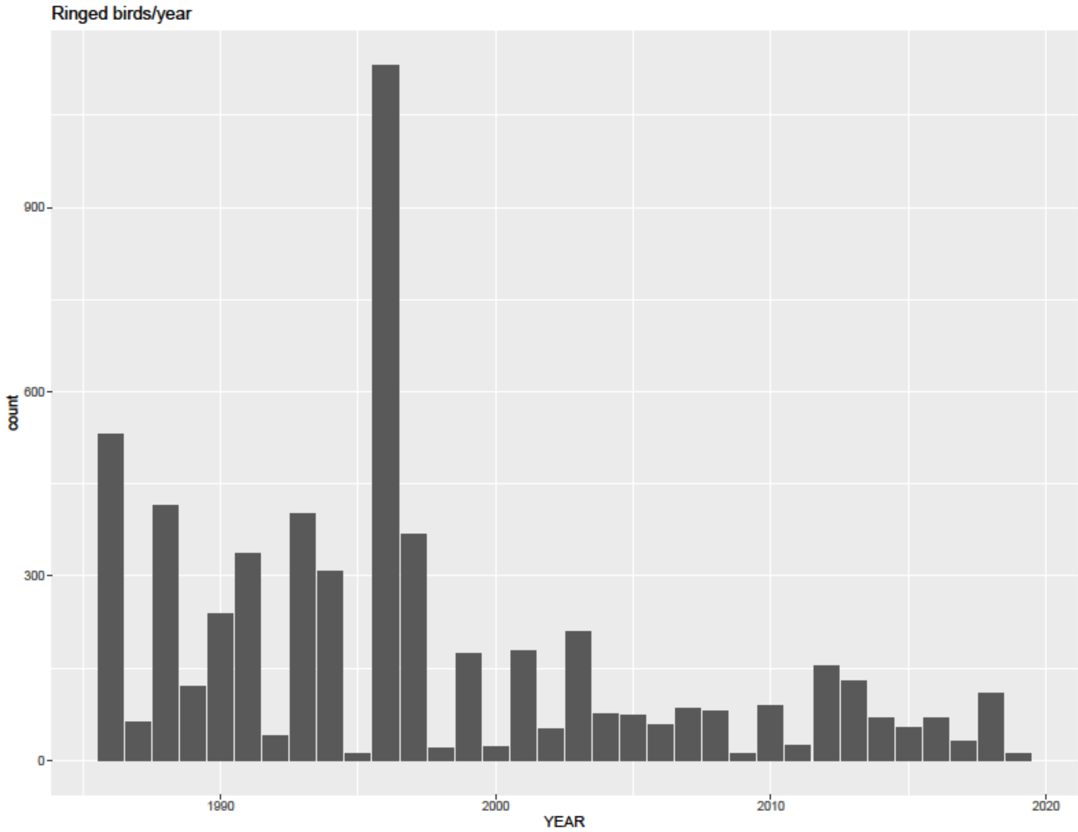

Figure 8: Number of *C. caerulues* ringed per year in Falsterbo.

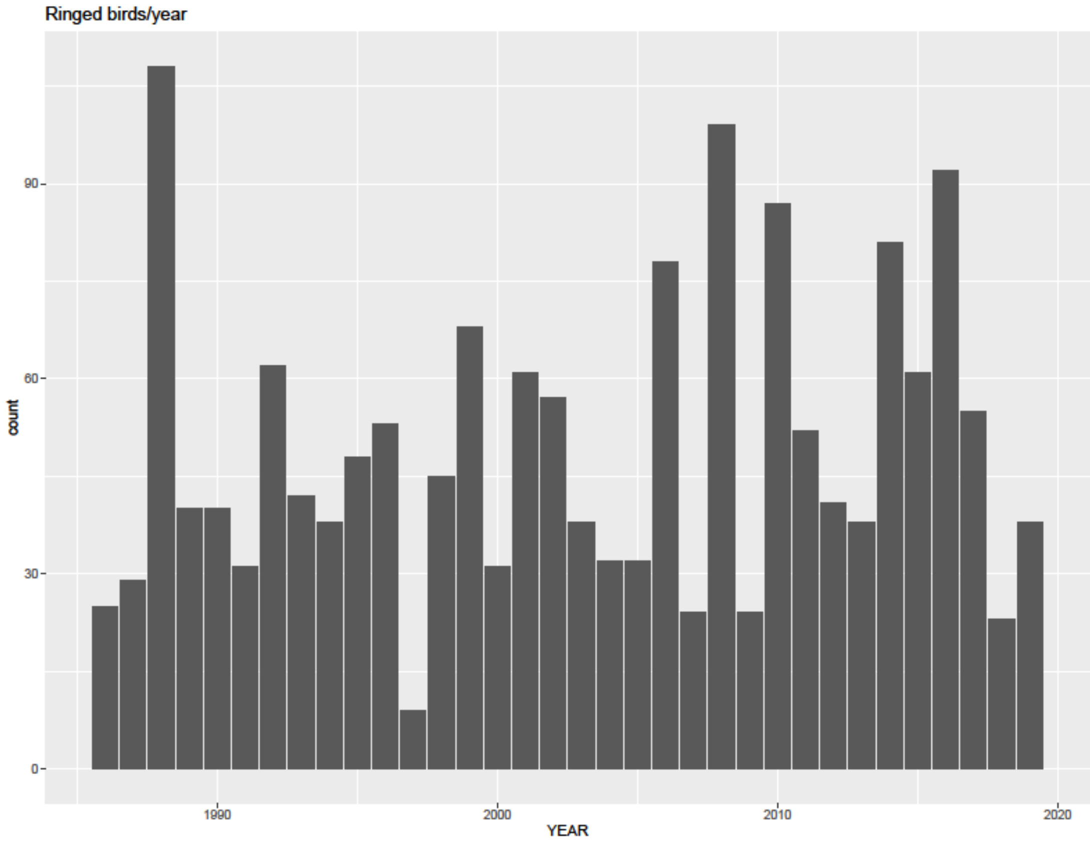

Figure 9: Number of *F. montifringilla* ringed per year in Falsterbo.

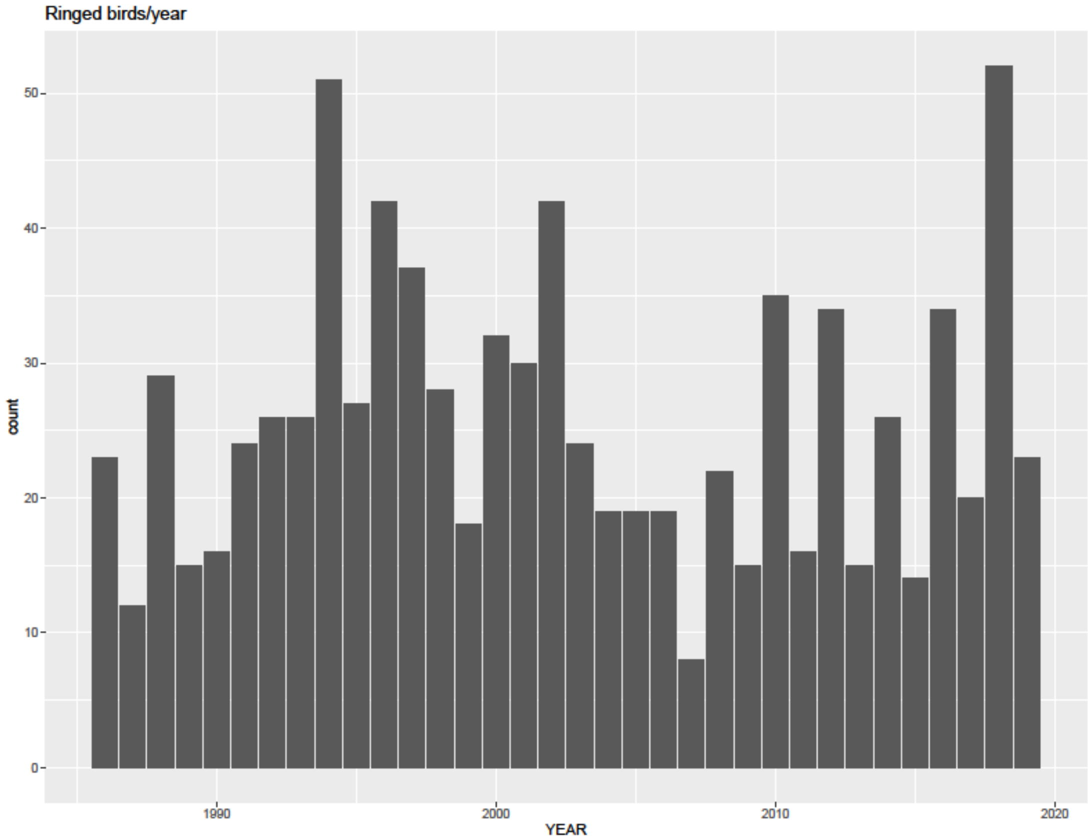

Figure 10: Number of *F. coelebs* ringed per year in Falsterbo.

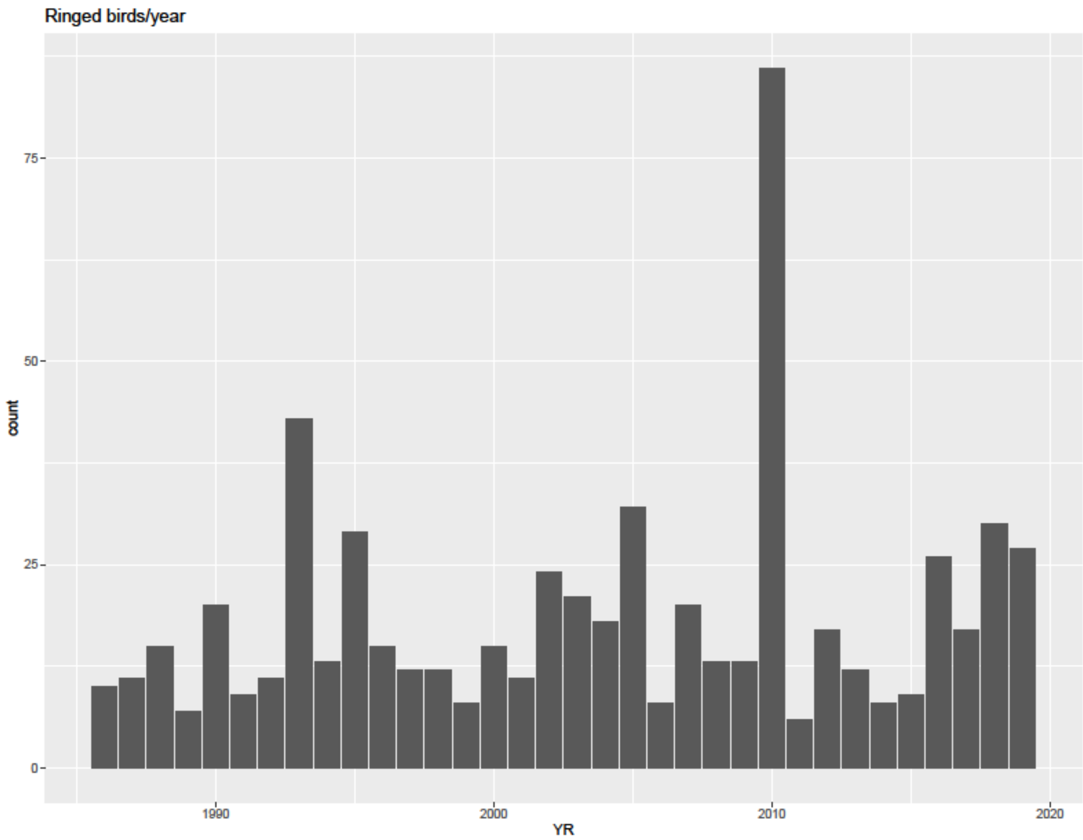

Figure 11: Number of *F. coelebs* ringed per year in Ottenby.

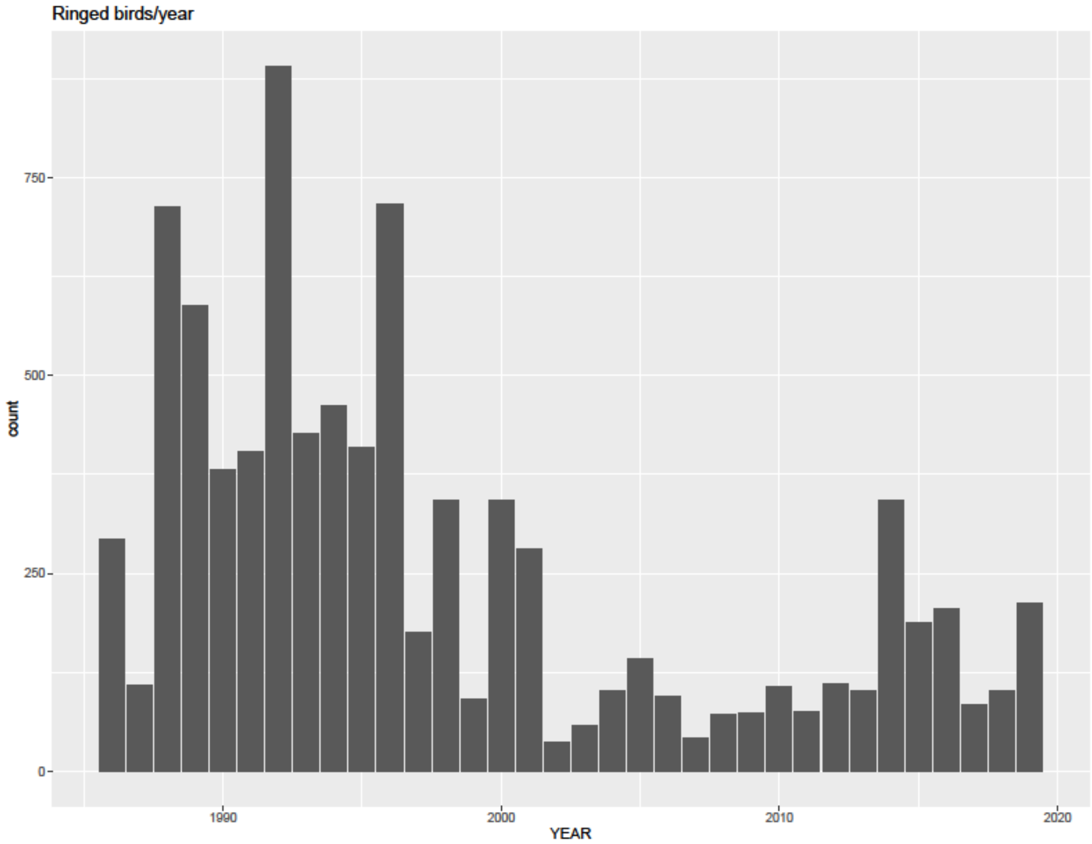

Figure 12: Number of *R. regulus* ringed per year in Falsterbo.

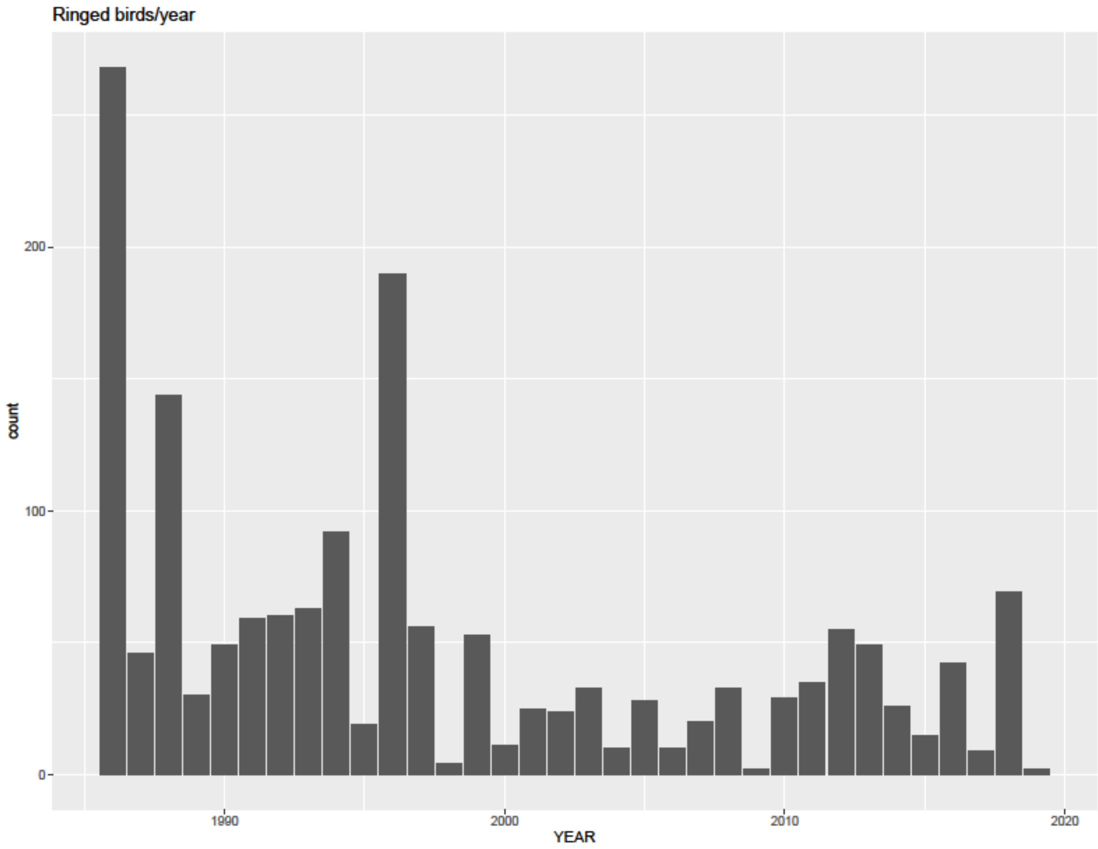

Figure 13: Number of *P. major* ringed per year in Falsterbo.

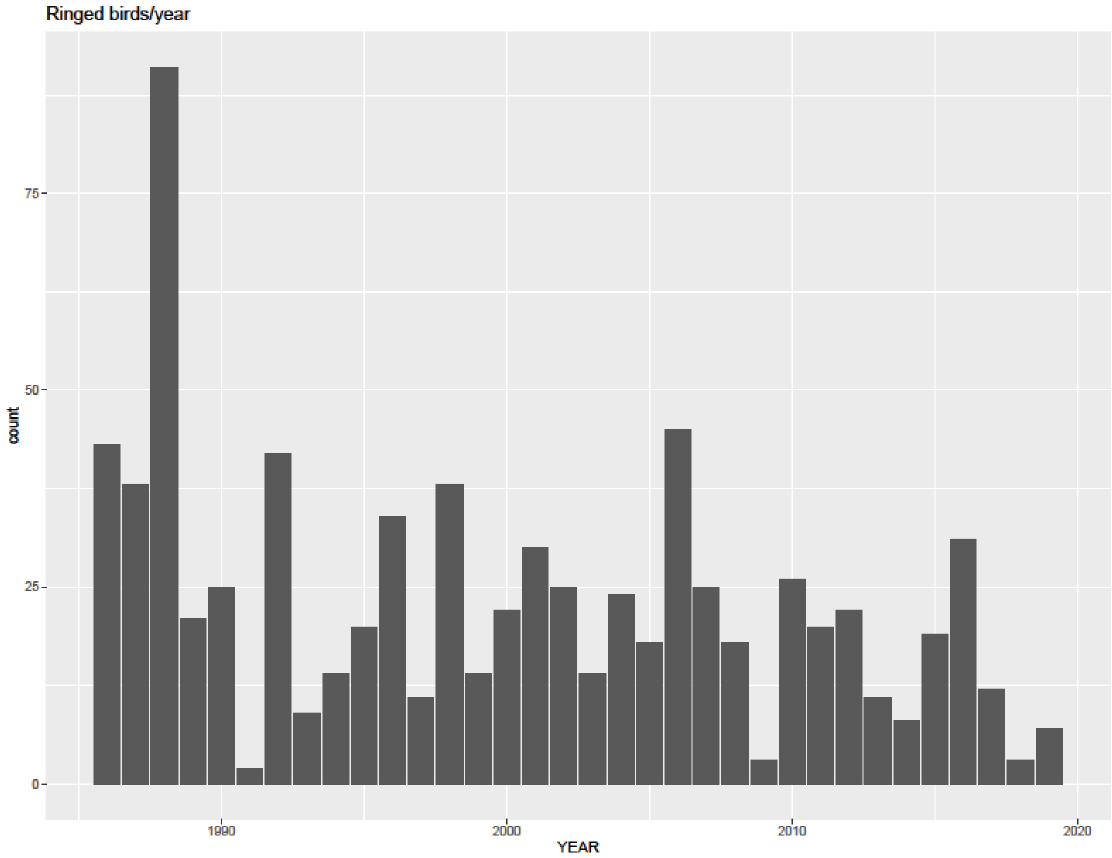

Figure 14: Number of *F. hypoleuca* ringed per year in Falsterbo.

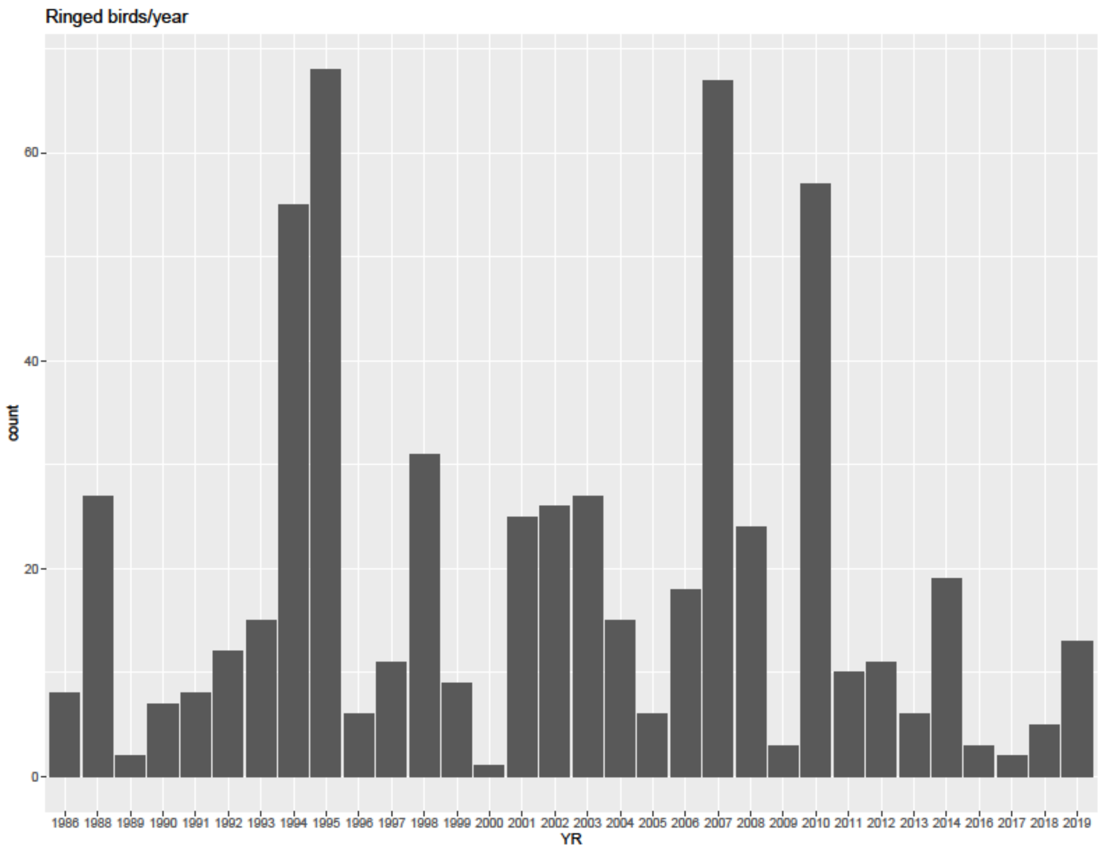

Figure 15: Number of *F. hypoleuca* ringed per year in Ottenby.

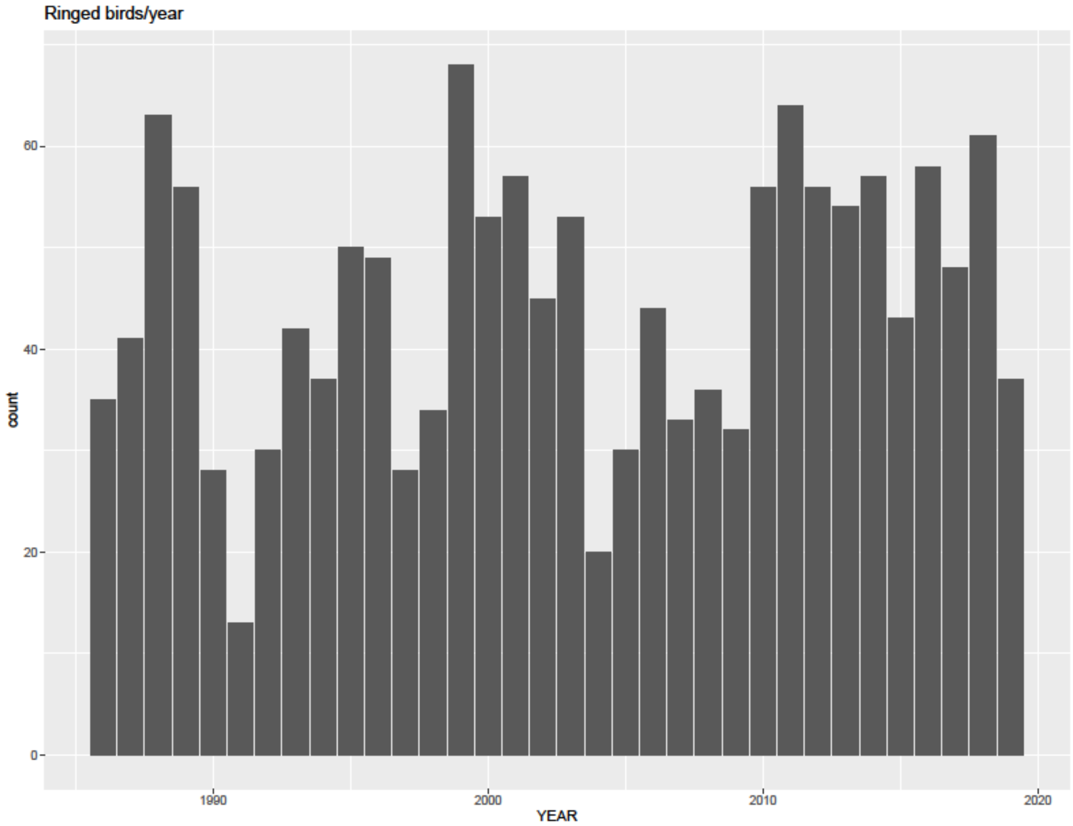

Figure 16: Number of *P. phoenicurus* ringed per year in Falsterbo.

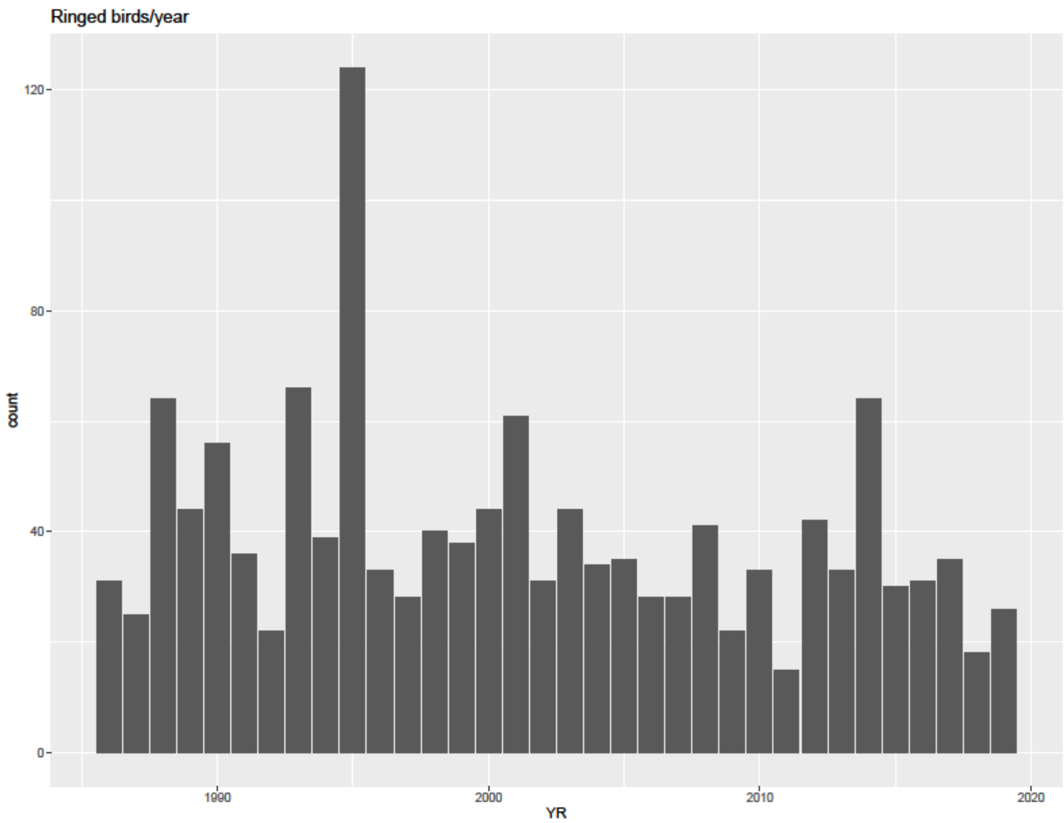

Figure 17: Number of *P. phoenicurus* ringed per year in Ottenby.

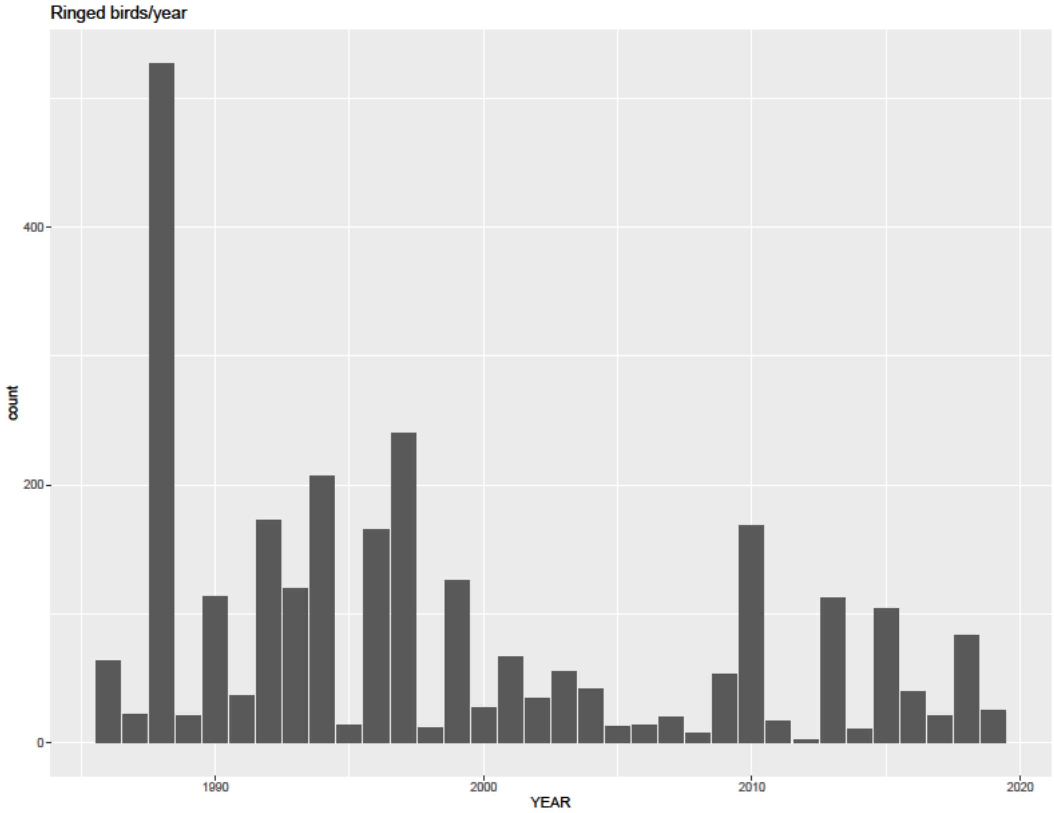

Figure 18: Number of *S. spinus* ringed per year in Falsterbo.

7. Appendix B

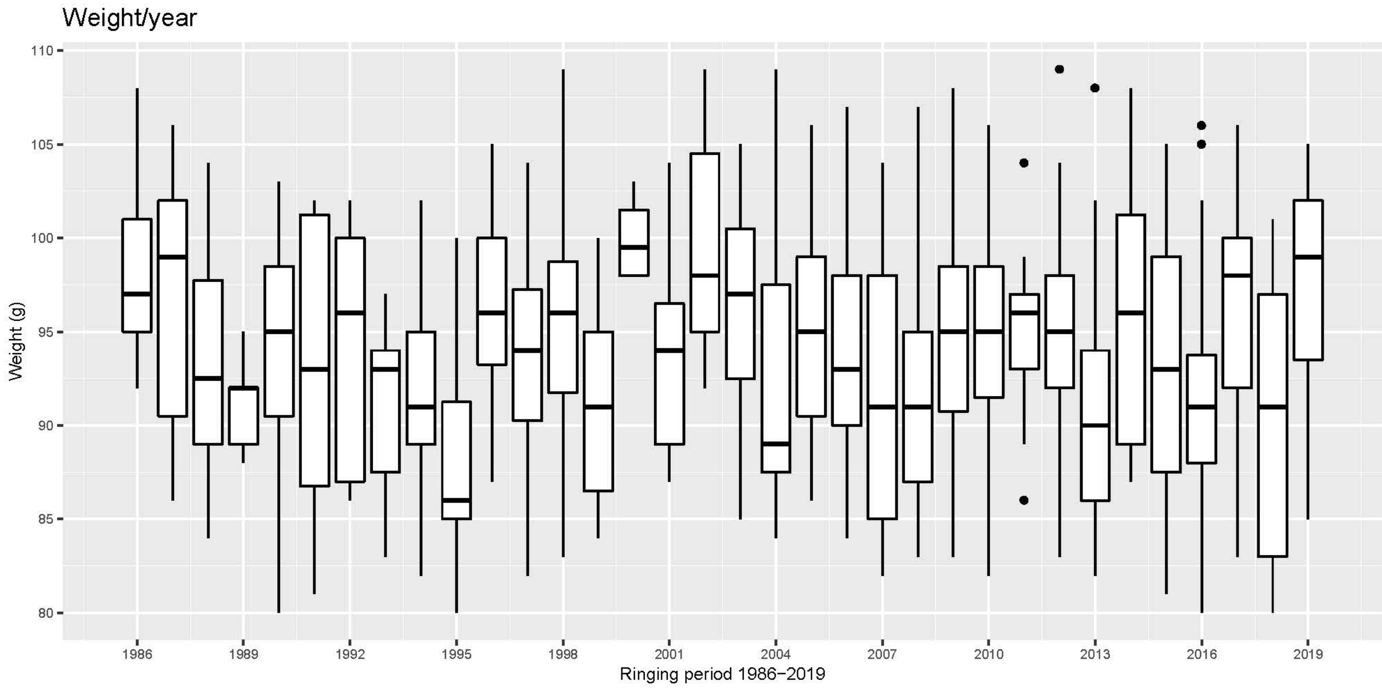

Figure 18: Boxplot showing weight data for ringed *T. merula* from Falsterbo.

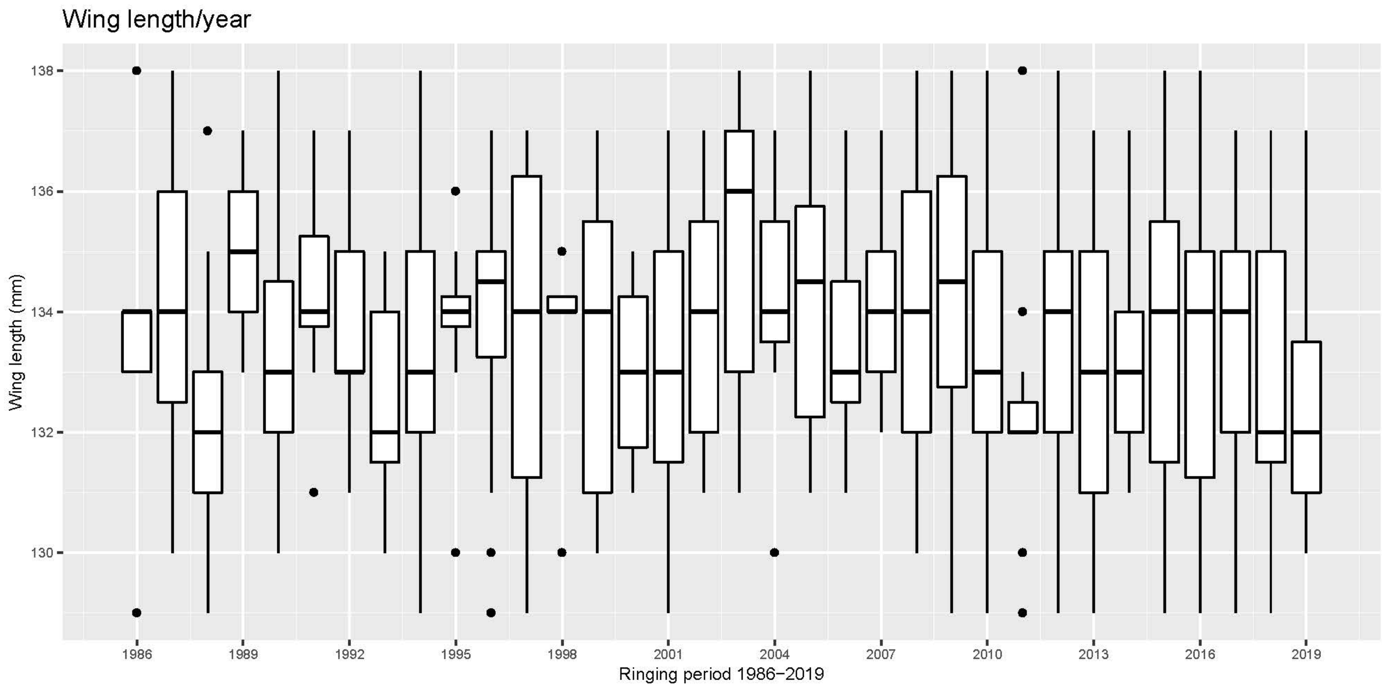

Figure 19: Boxplot showing wing length data for ringed *T. merula* from Falsterbo.

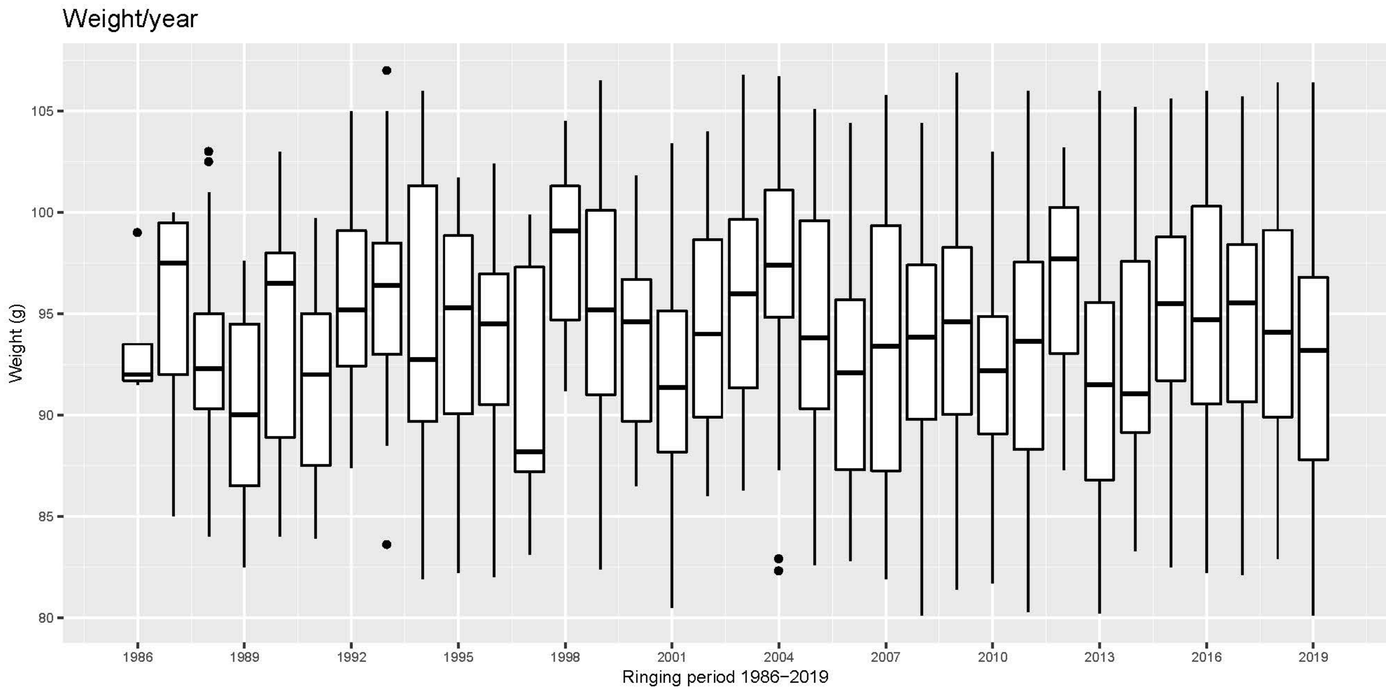

Figure 20: Boxplot showing weight data for ringed *T. merula* from Otenby.

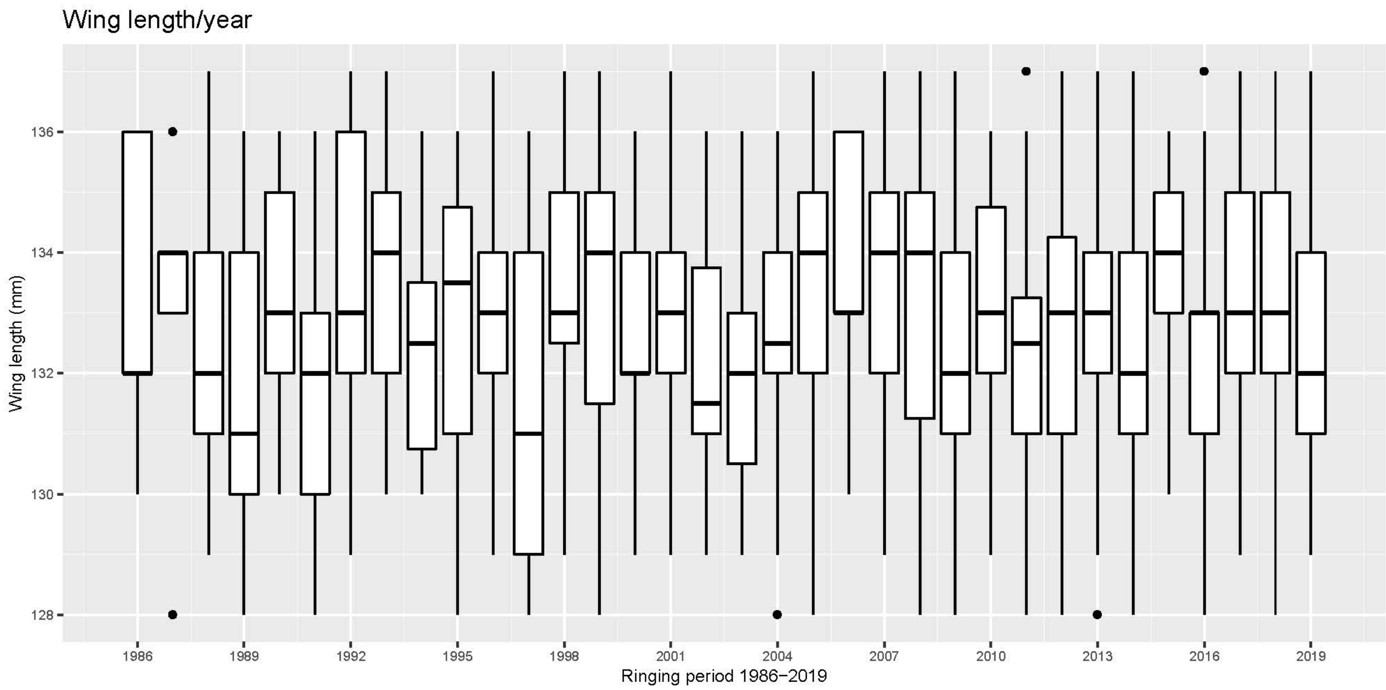

Figure 21: Boxplot showing wing length data for ringed *T. merula* from Ottenby.

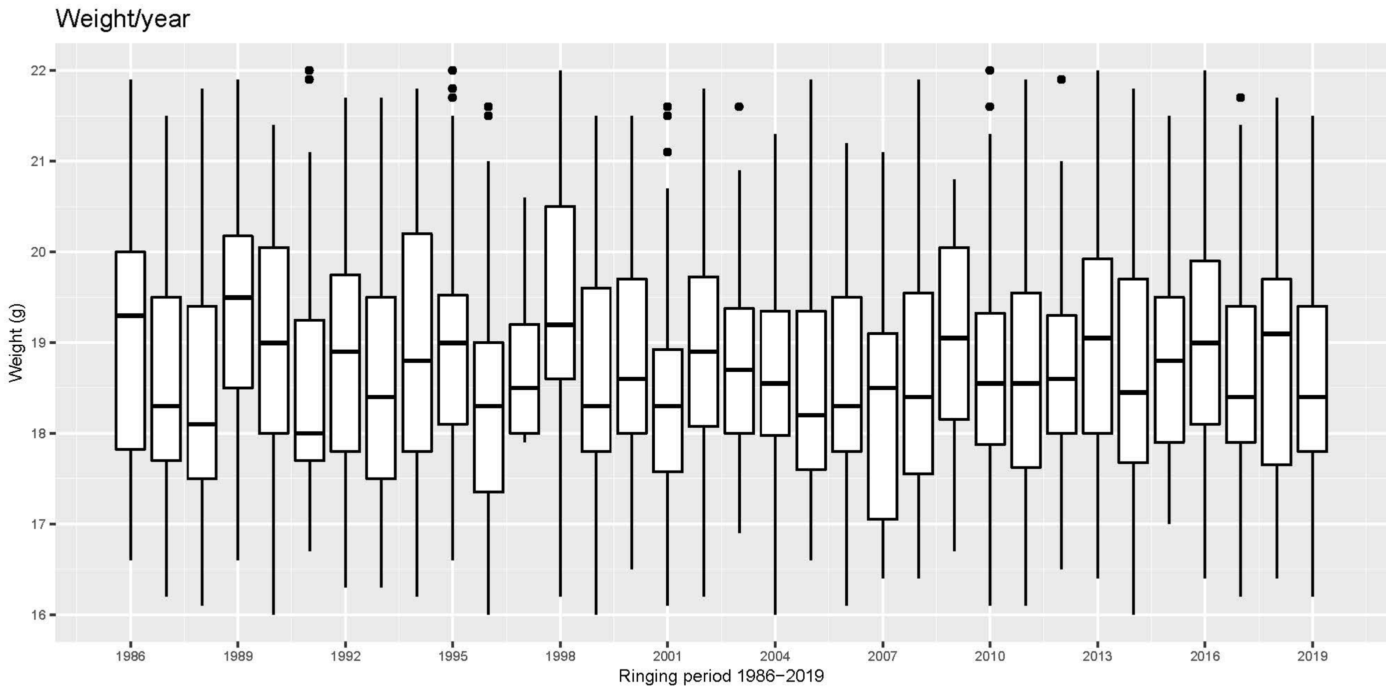

Figure 22: Boxplot showing weight data for ringed *S. atricapilla* from Falsterbo.

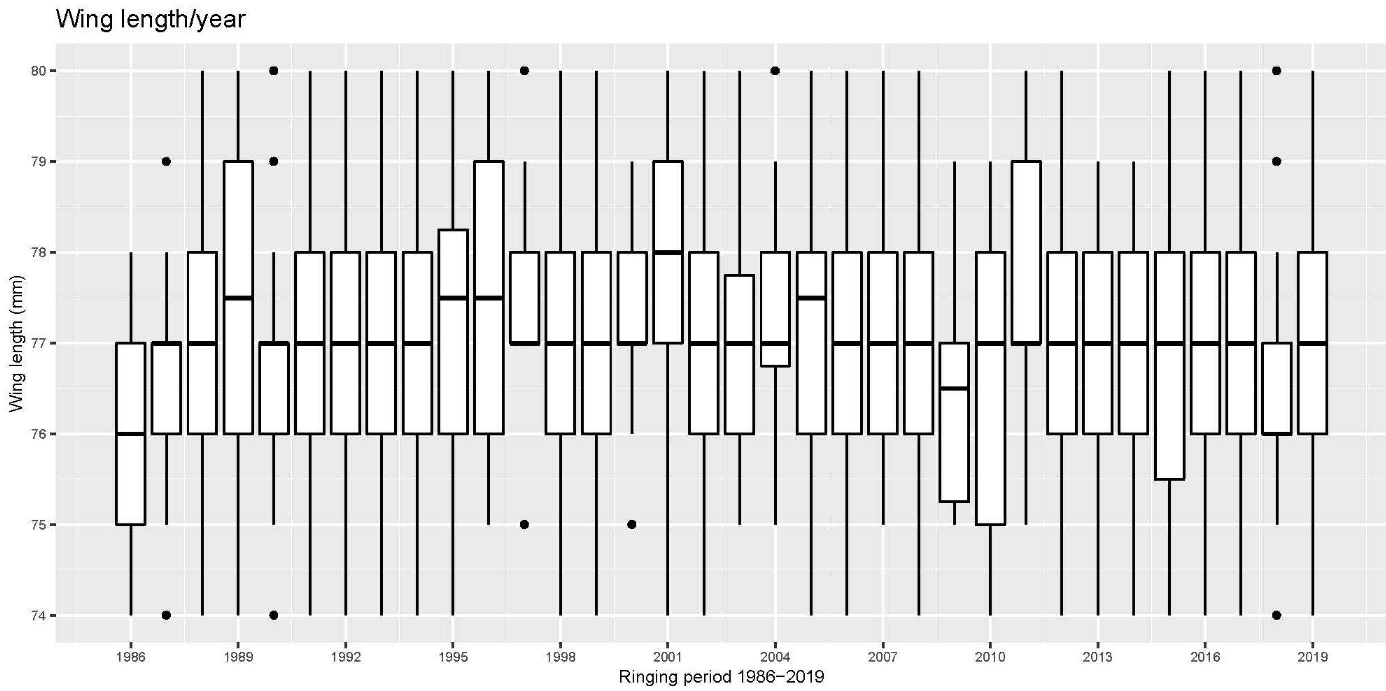

Figure 23: Boxplot showing wing length data for ringed *S. atricapilla* from Falsterbo.

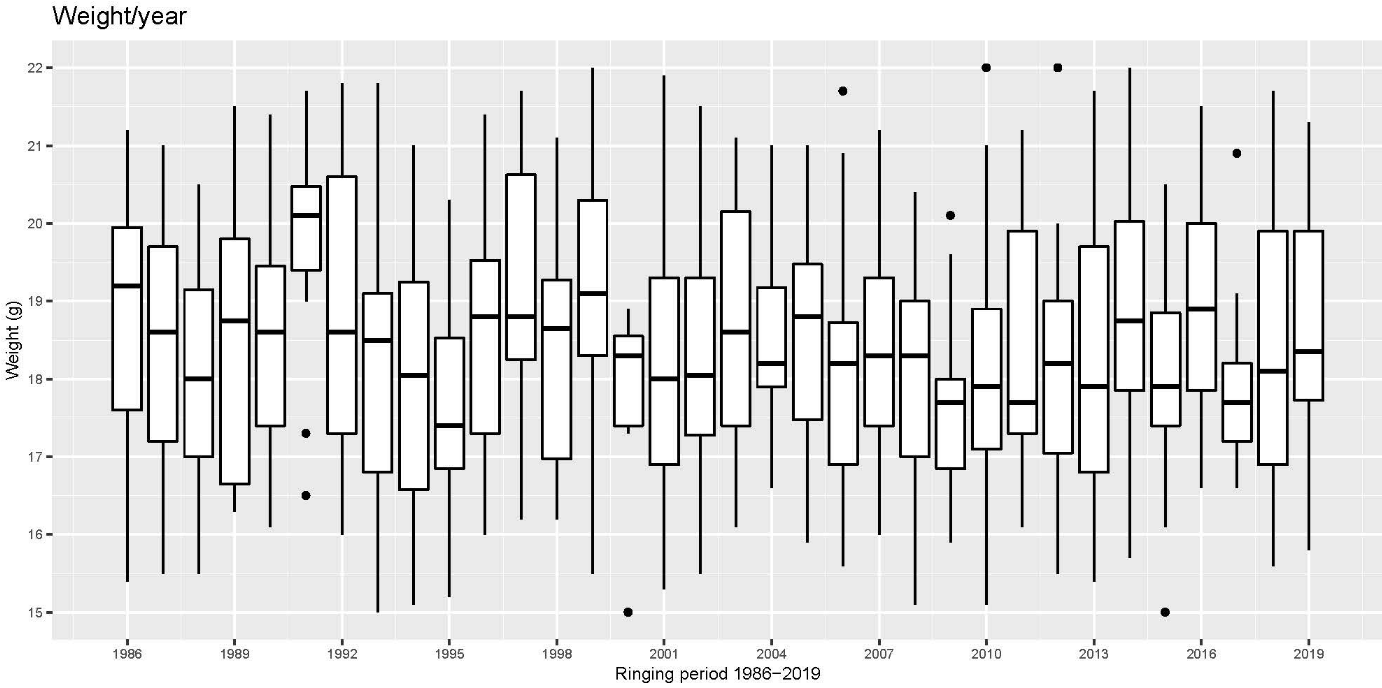

Figure 24: Boxplot showing weight data for ringed *S. atricapilla* from Ottenby.

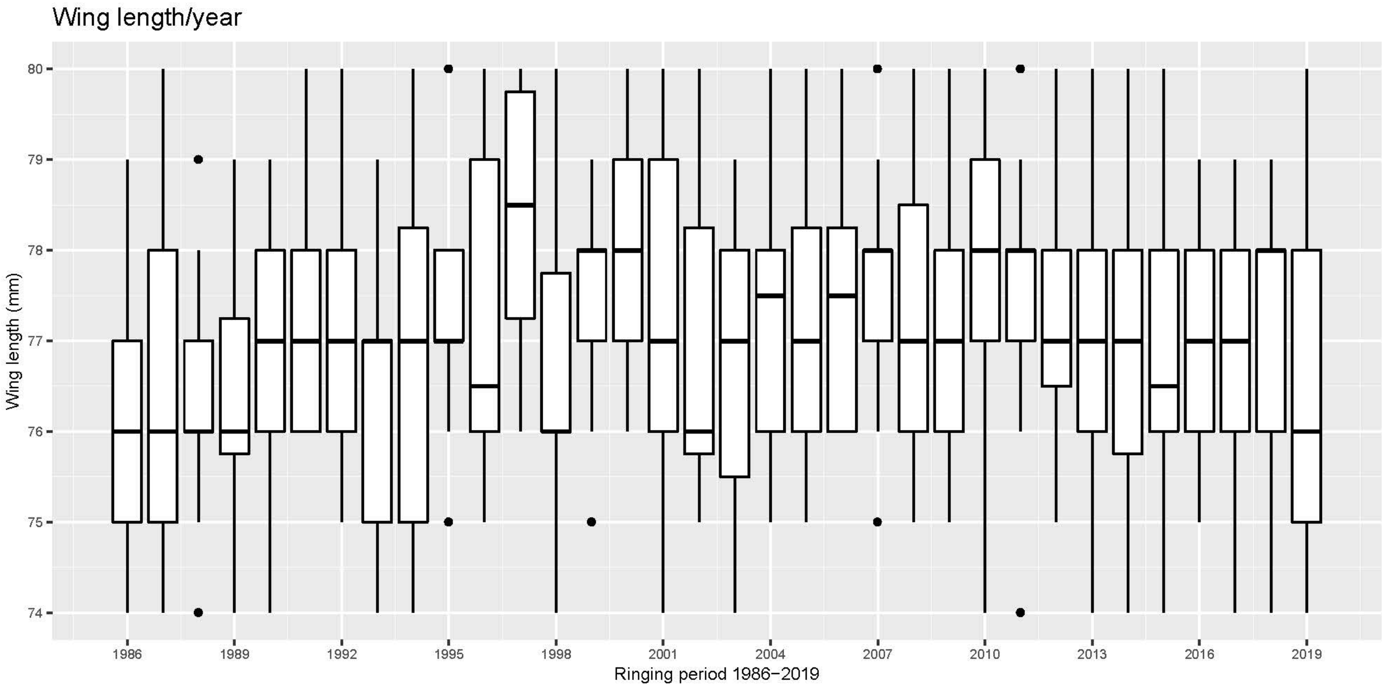

Figure 25: Boxplot showing wing length data for ringed *S. atricapilla* from Ottenby.

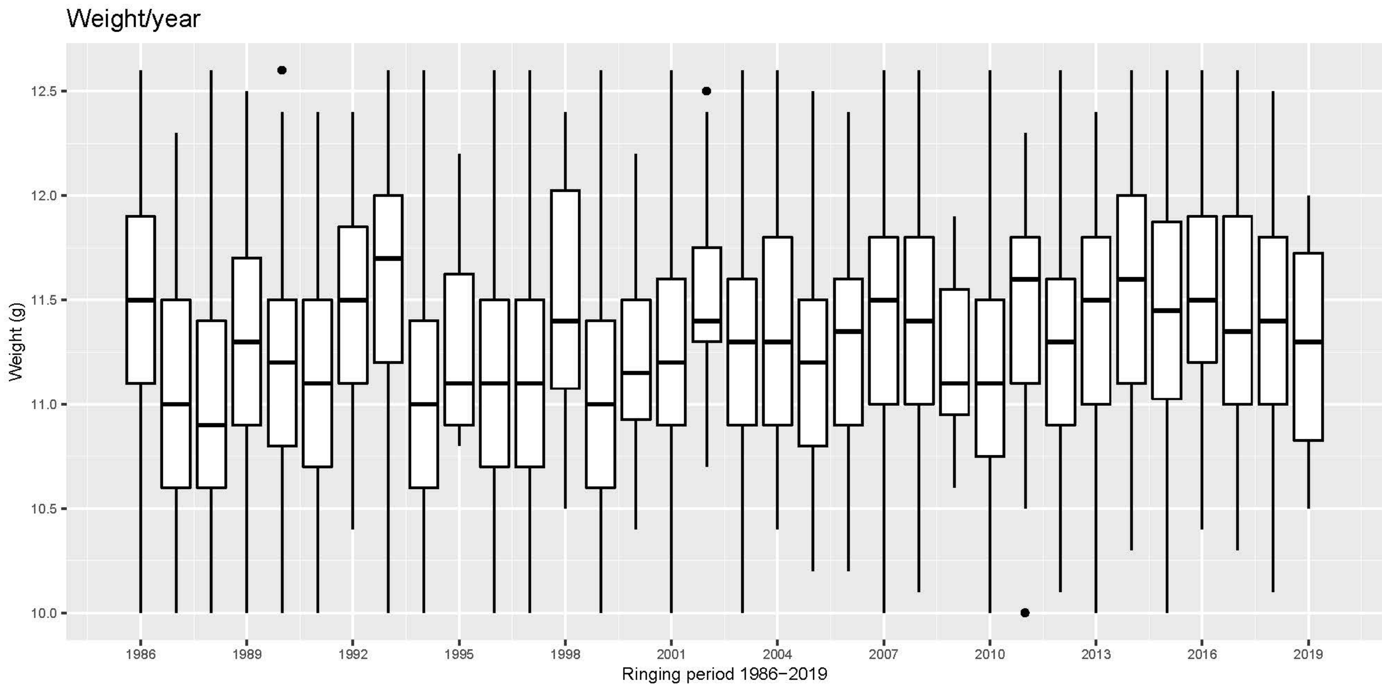

Figure 26: Boxplot showing weight data for ringed *C. caeruleus* from Falsterbo.

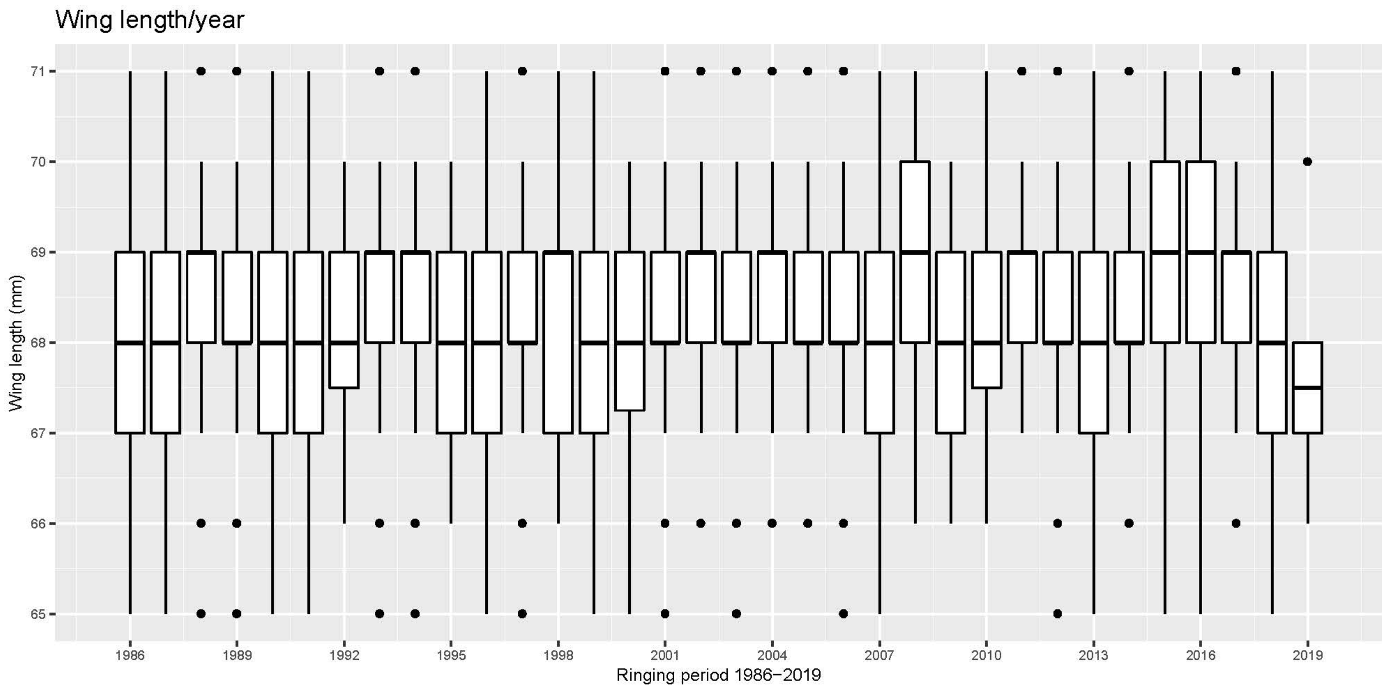

Figure 27: Boxplot showing wing length data for ringed *C. caeruleus* from Falsterbo.

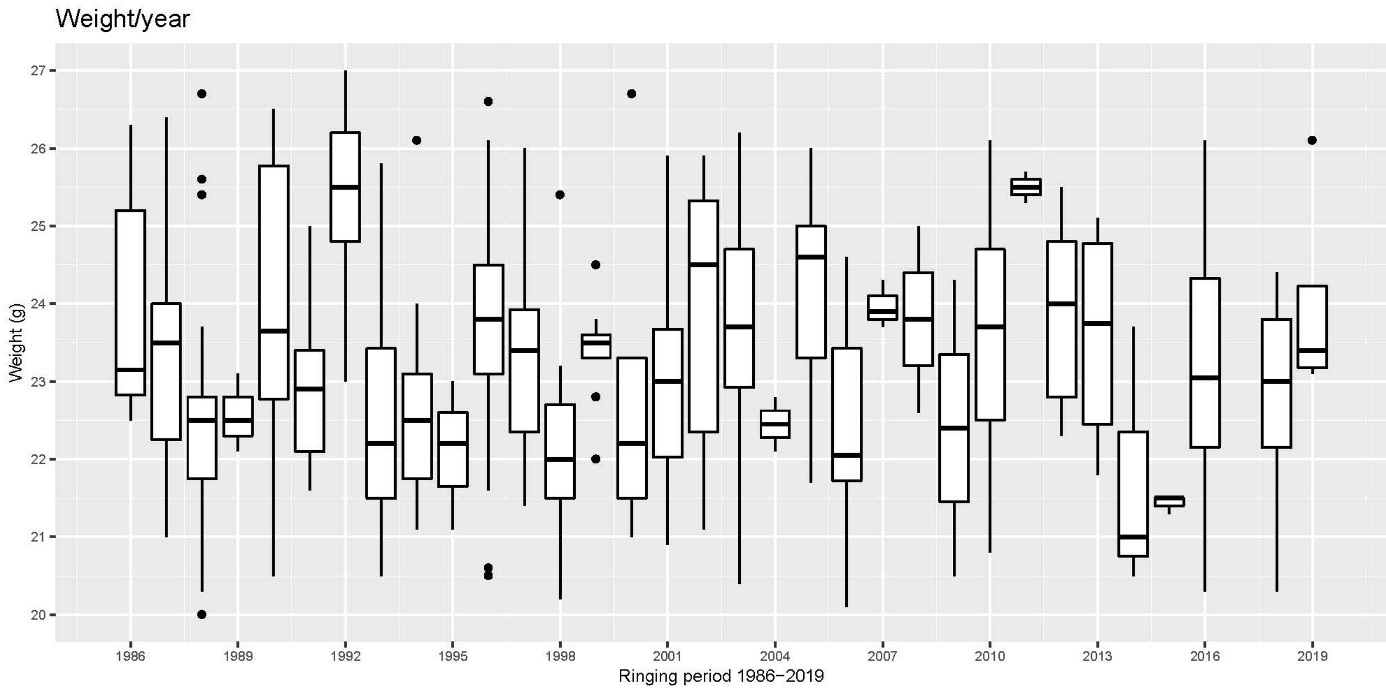

Figure 28: Boxplot showing weight data for ringed *F. montifringilla* from Falsterbo.

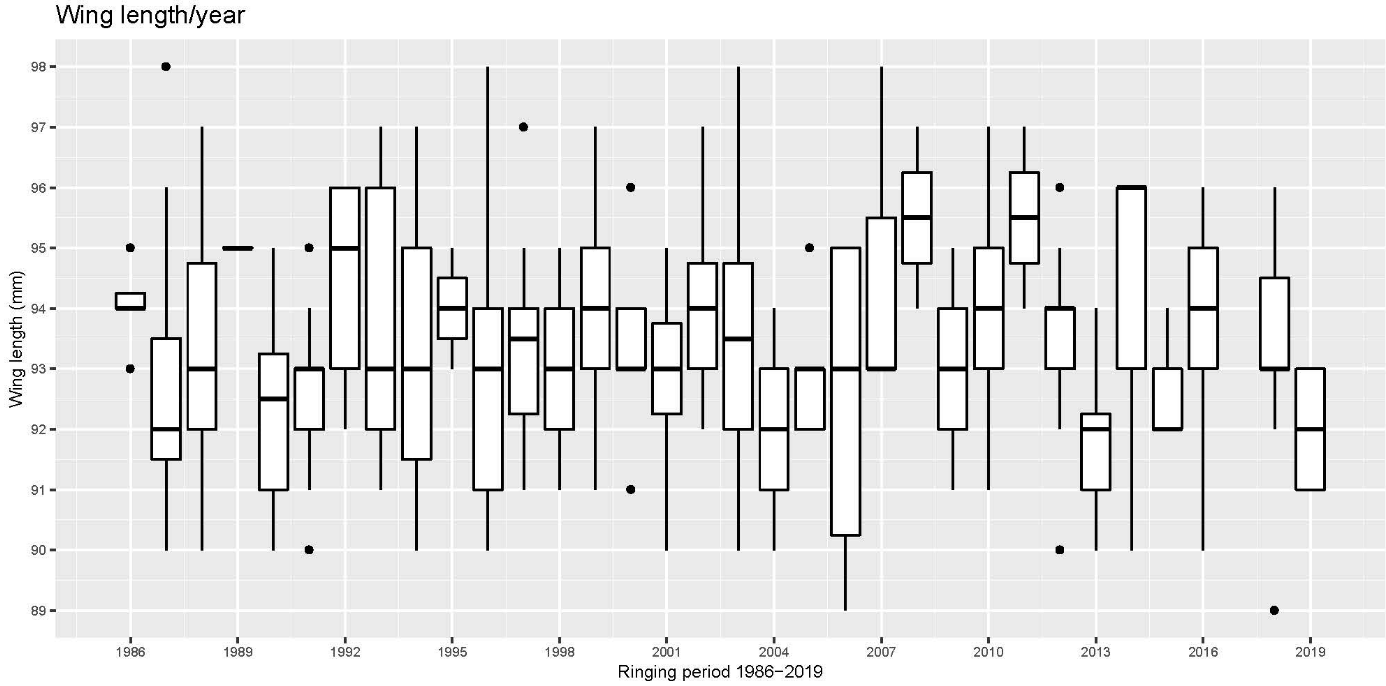

Figure 29: Boxplot showing wing length data for ringed *F. montifringilla* from Falsterbo.

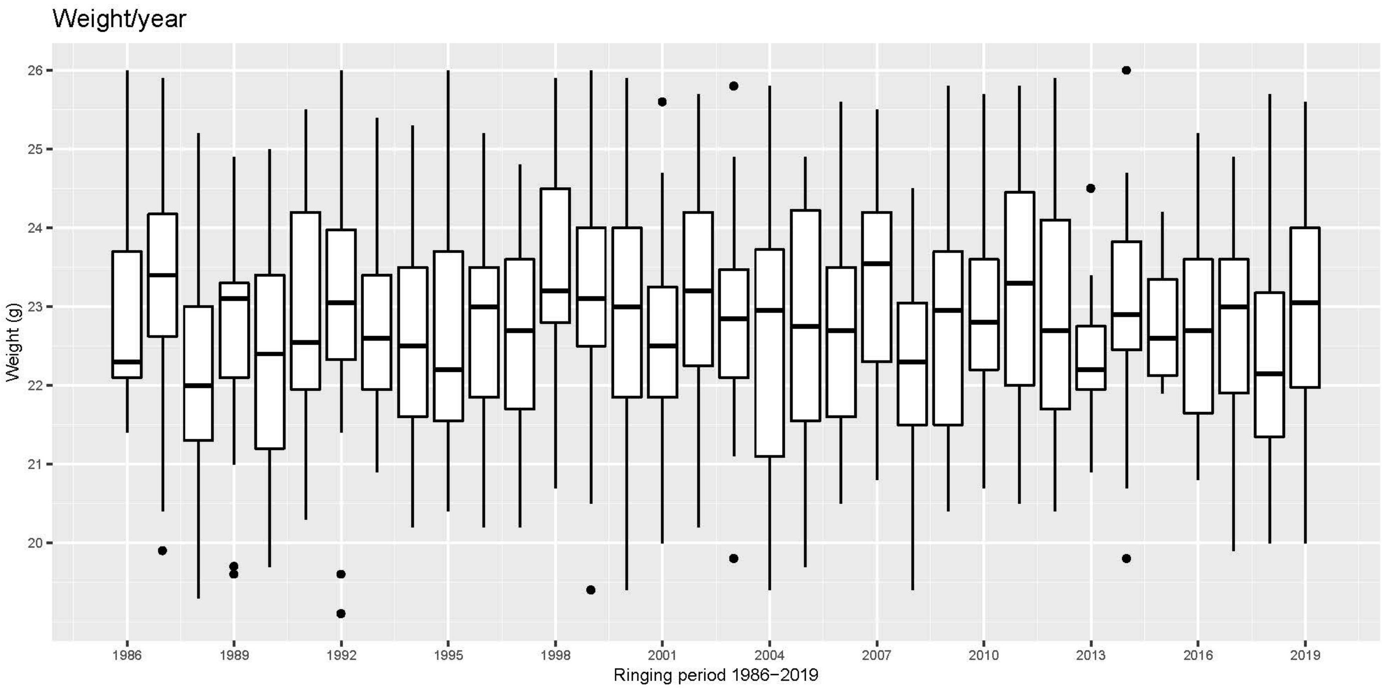

Figure 30: Boxplot showing weight data for ringed *F. coelebs* from Falsterbo.

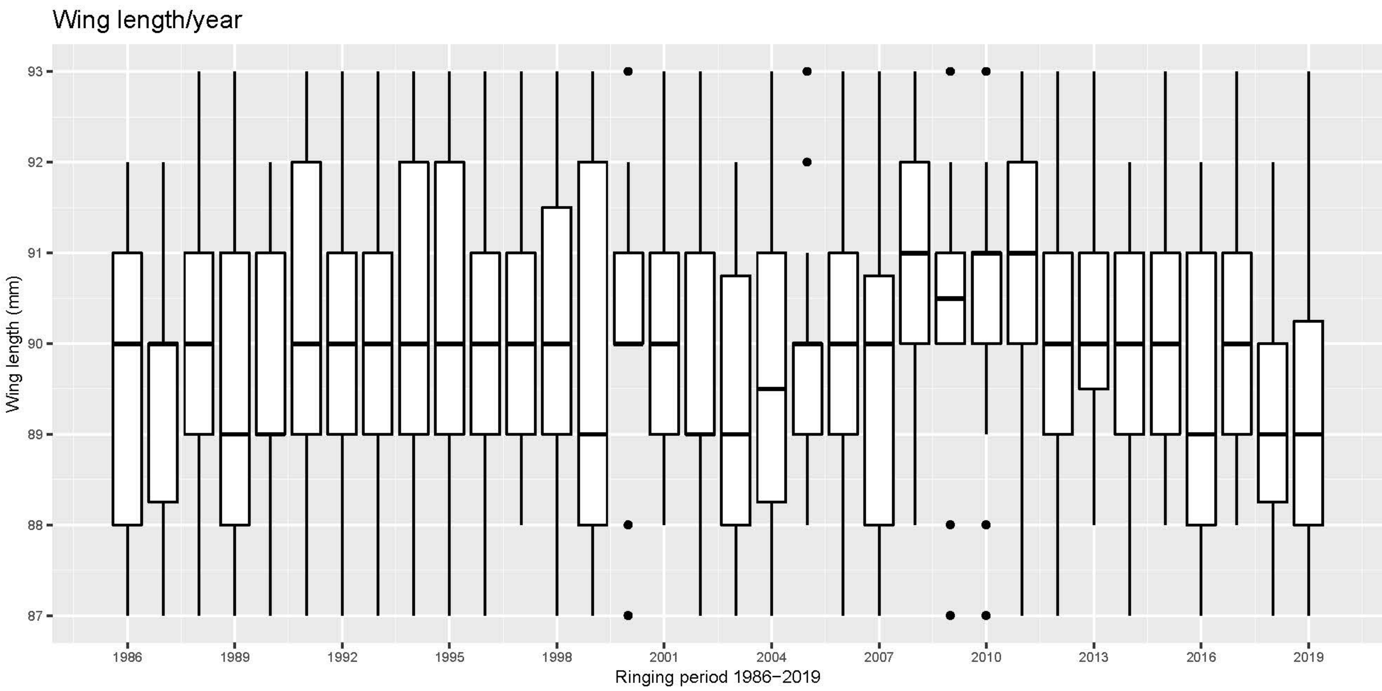

Figure 31: Boxplot showing wing length data for ringed *F. coelebs* from Falsterbo.

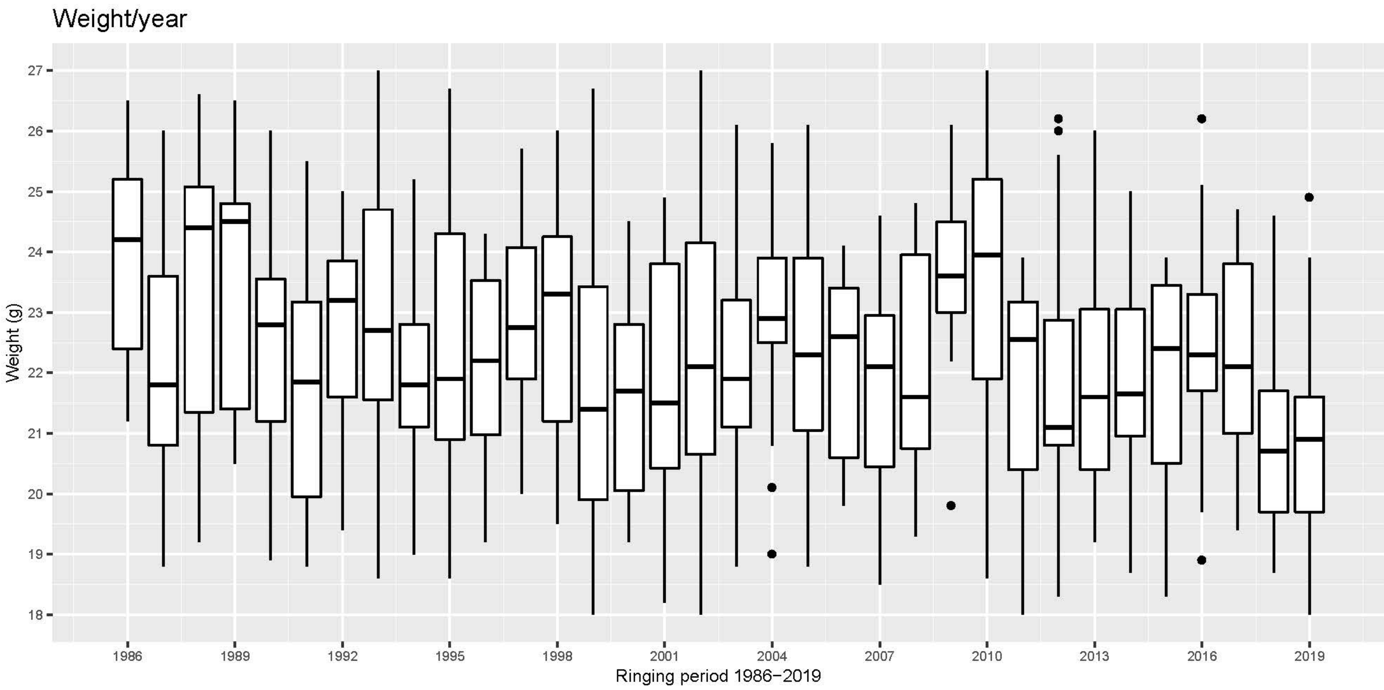

Figure 32: Boxplot showing weight data for ringed *F. coelebs* from Ottenby.

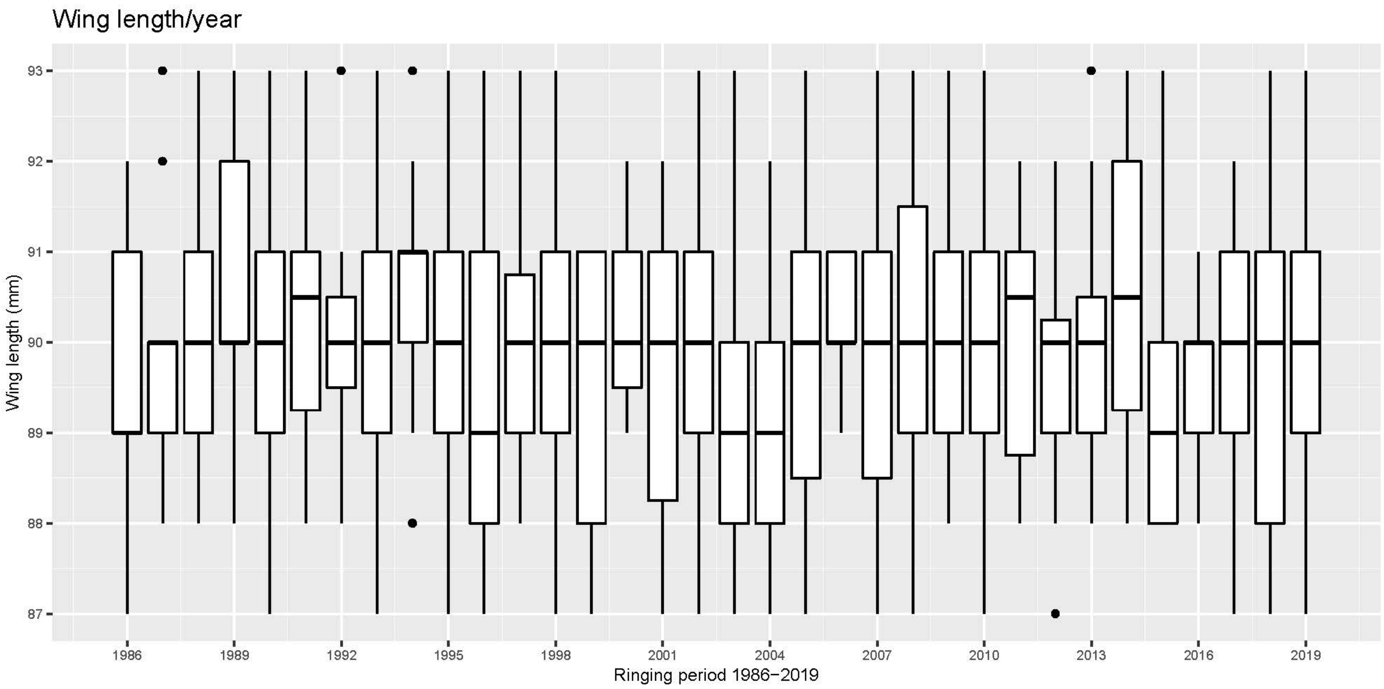

Figure 33: Boxplot showing wing length data for ringed *F. coelebs* from Ottenby.

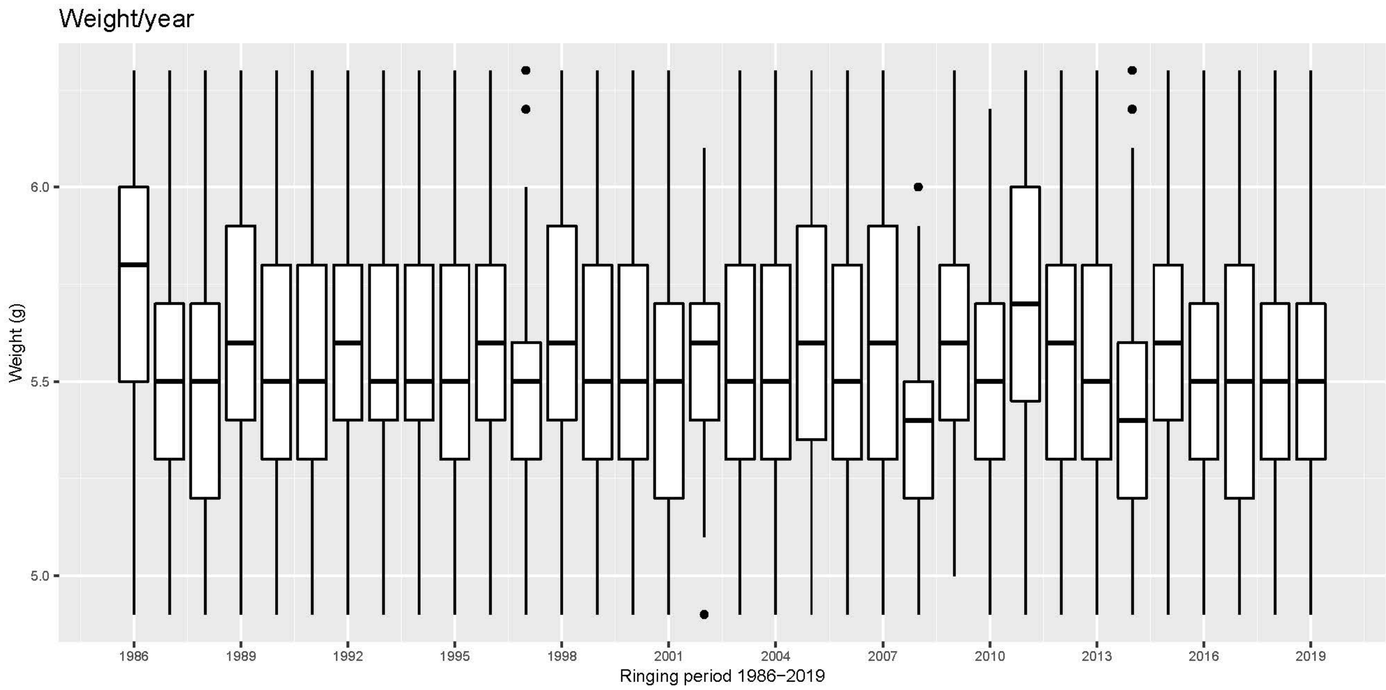

Figure 34: Boxplot showing weight data for ringed *R. regulus* from Ottenby.

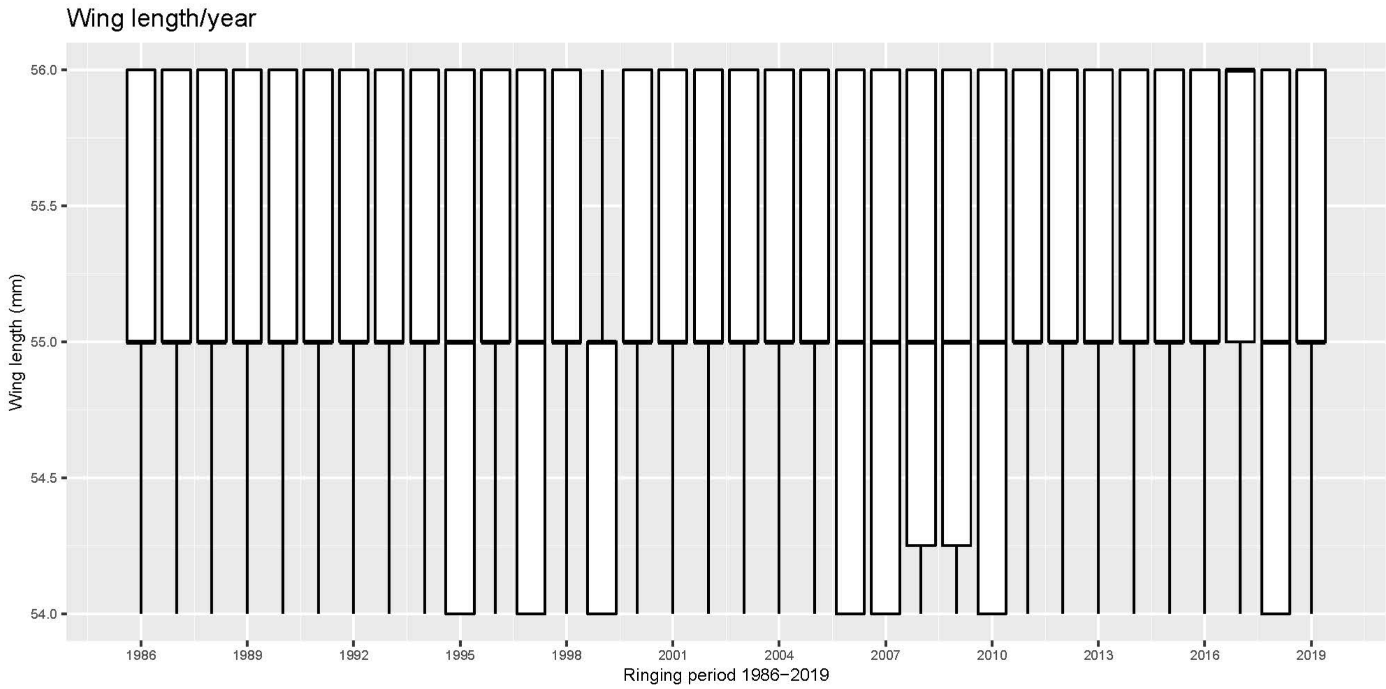

Figure 35: Boxplot showing wing length data for ringed *R. regulus* from Falsterbo.

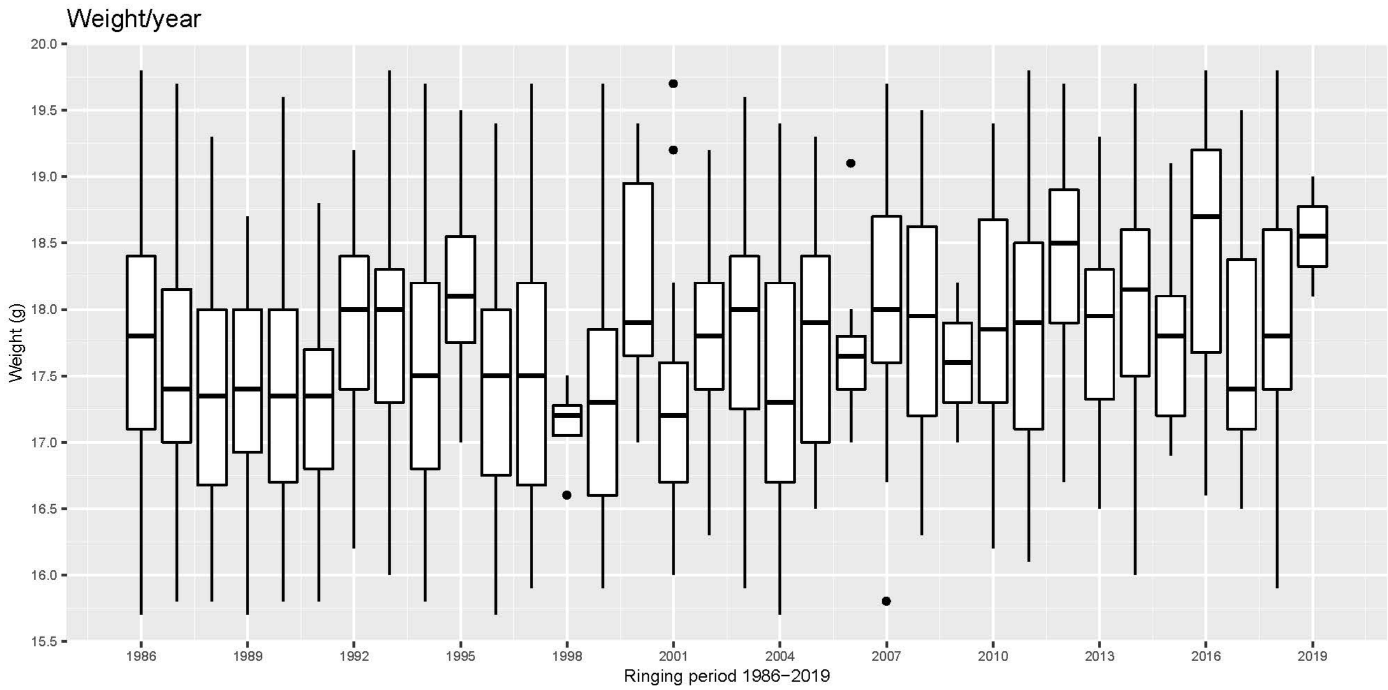

Figure 36: Boxplot showing weight data for ringed *P. major* from Falsterbo.

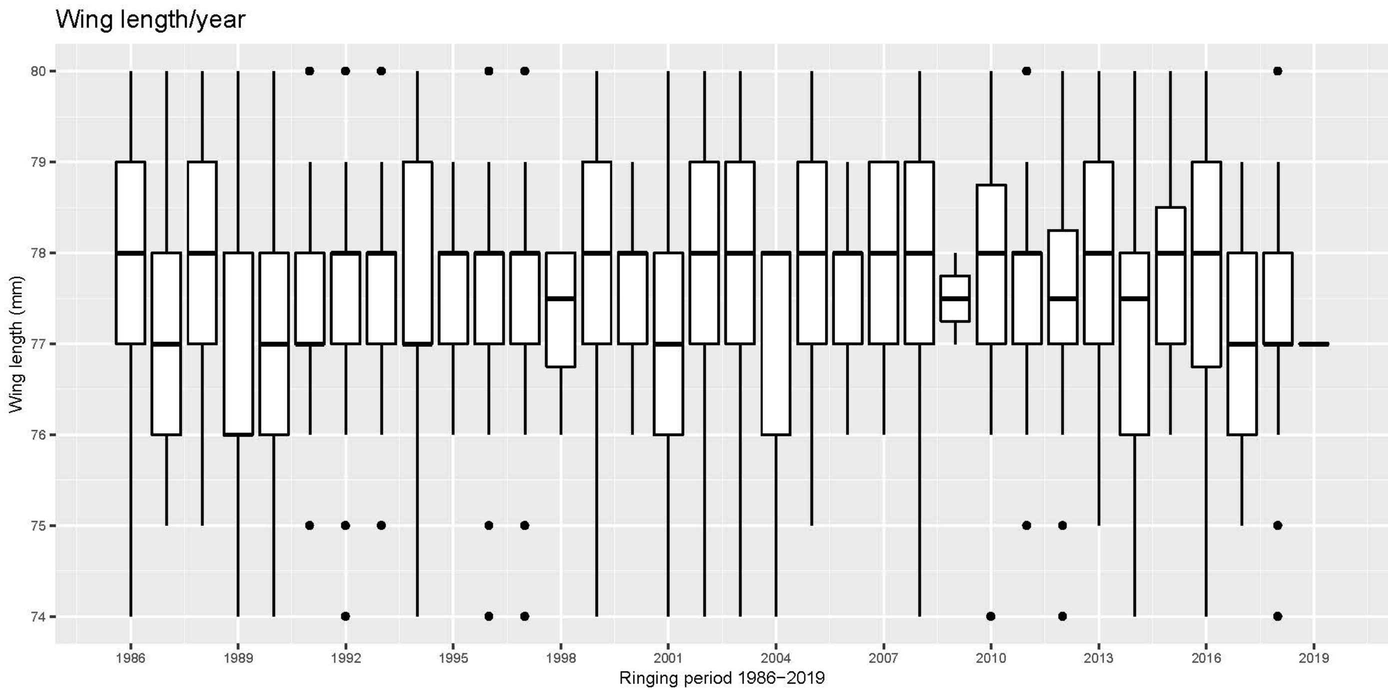

Figure 37: Boxplot showing wing length data for ringed *P. major* from Falsterbo.

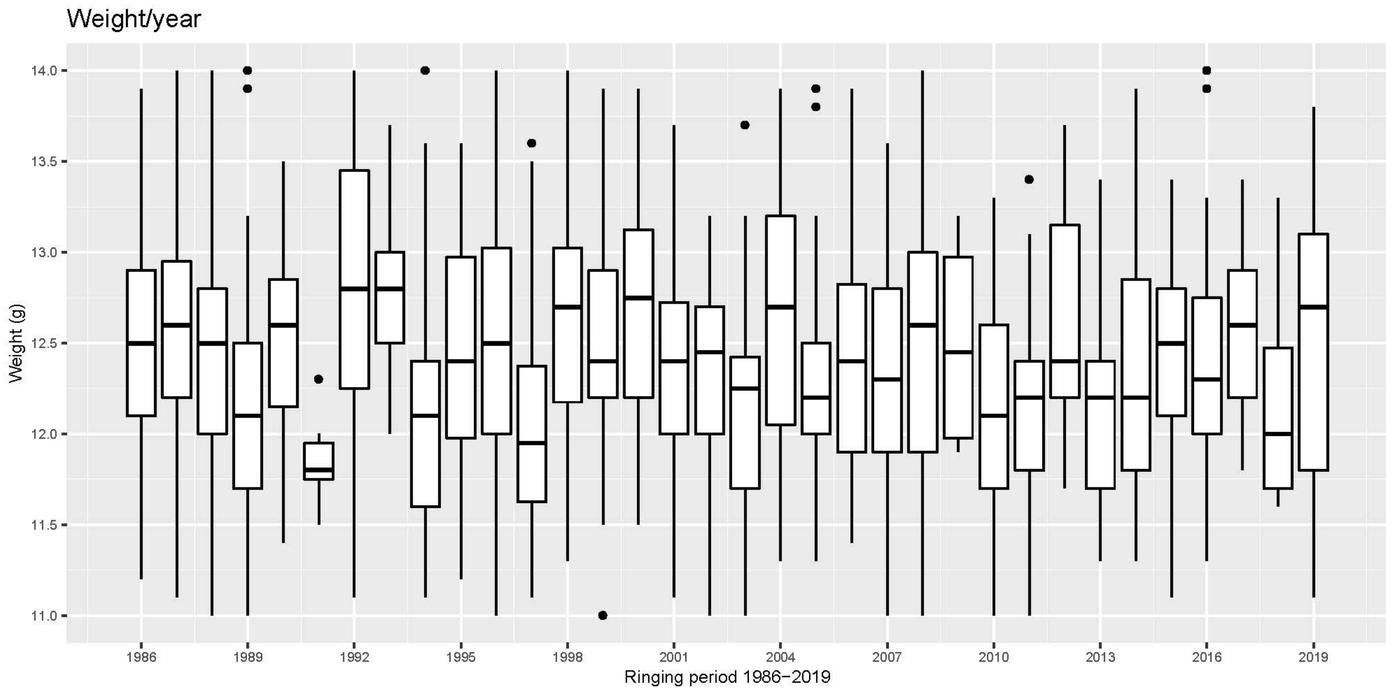

Figure 38: Boxplot showing weight data for ringed *F. hypoleuca* from Falsterbo.

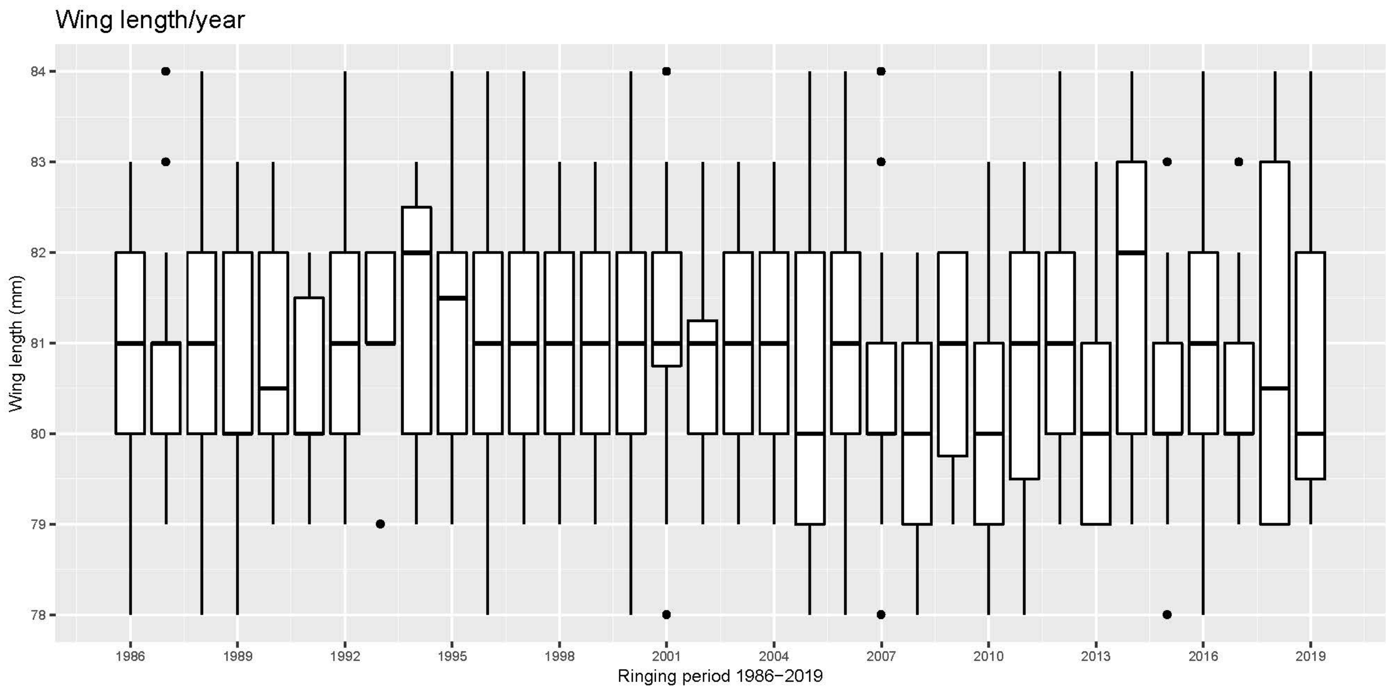

Figure 39: Boxplot showing wing length data for ringed *F. hypolecua* from Falsterbo.

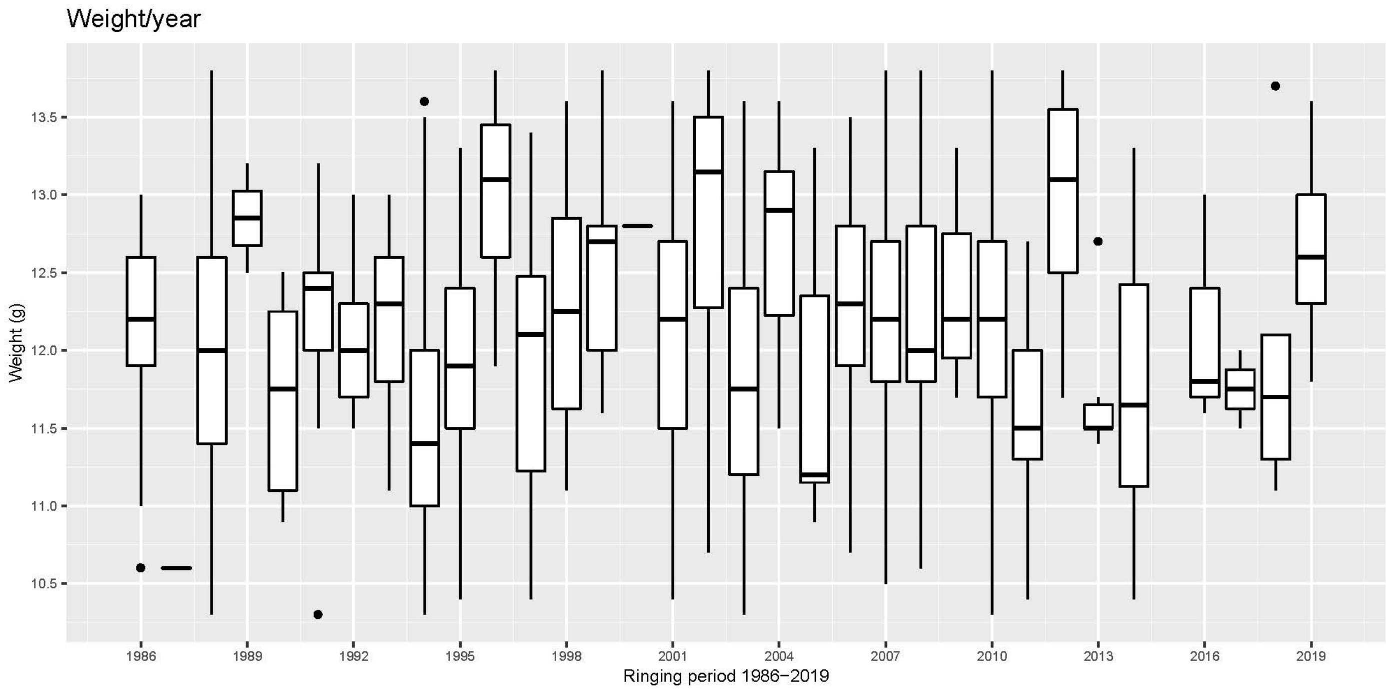

Figure 40: Boxplot showing weight data for ringed *F. hypoleuca* from Ottenby.

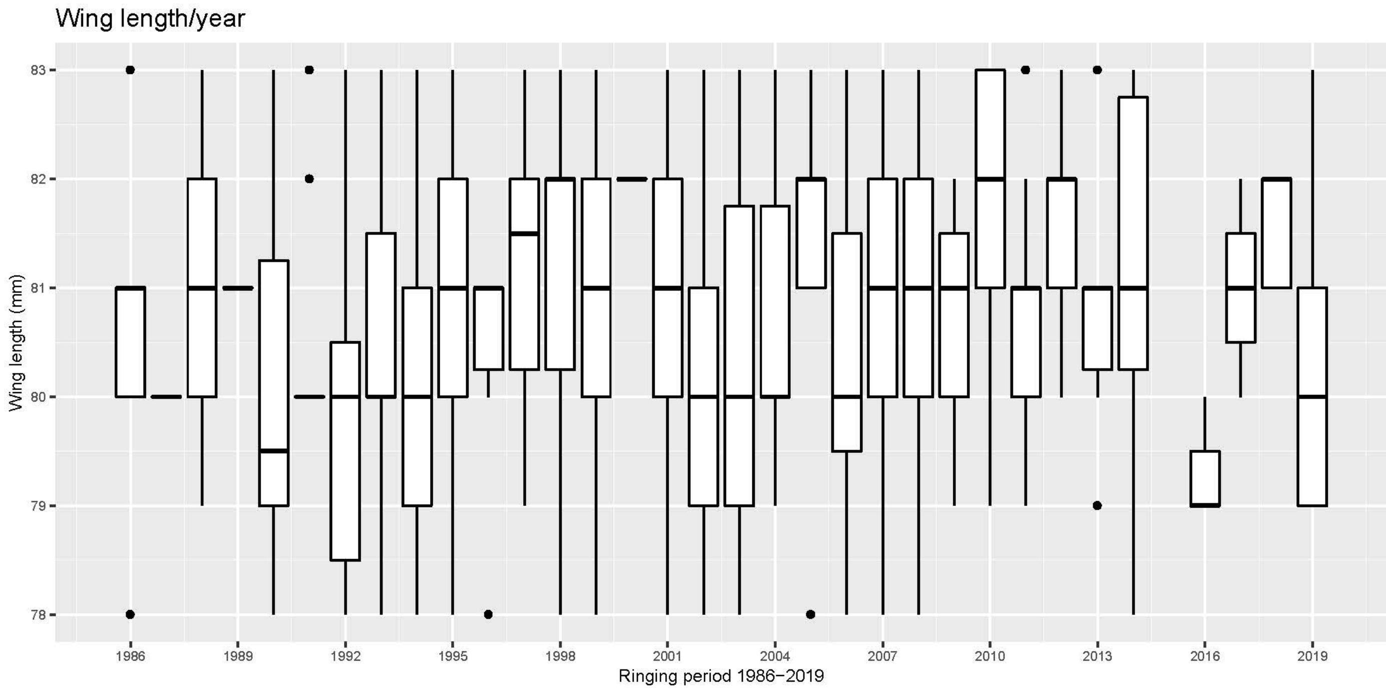

Figure 41: Boxplot showing wing length data for ringed *F. hypoleuca* from Ottenby.

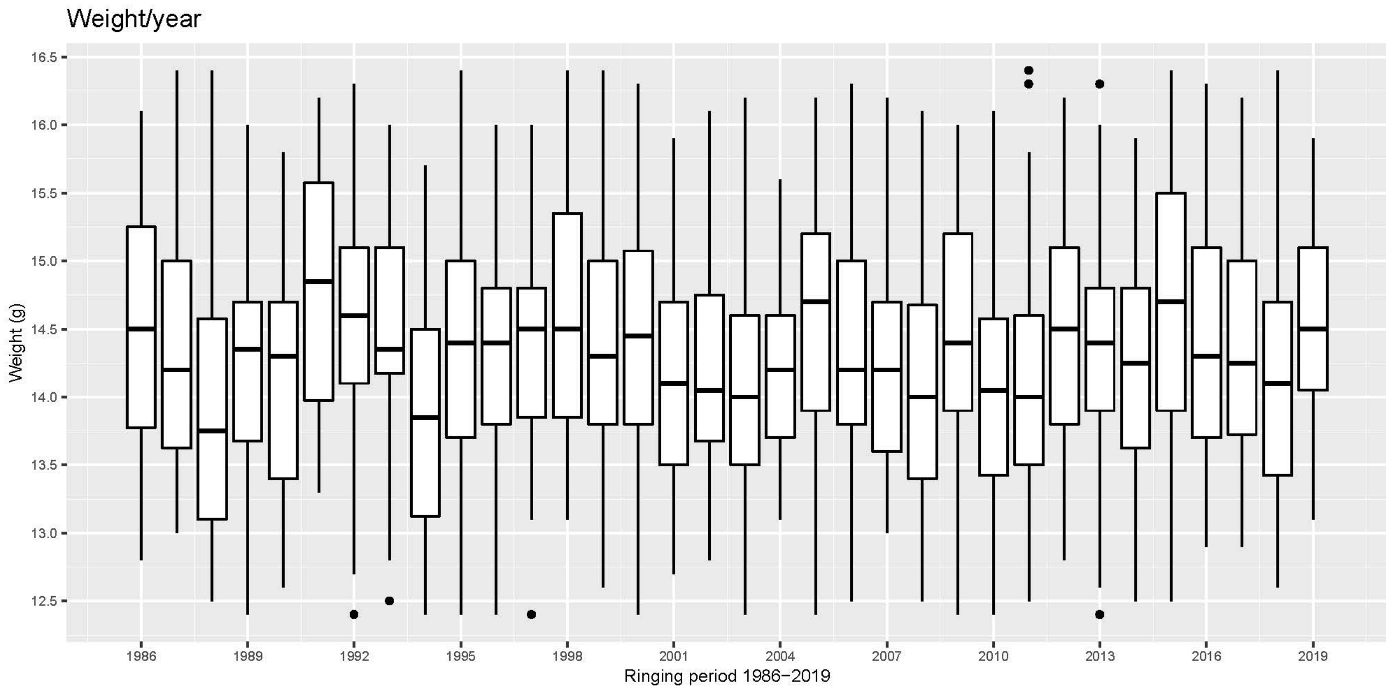

Figure 42: Boxplot showing weight data for ringed *P. phoenicurus* from Falsterbo.

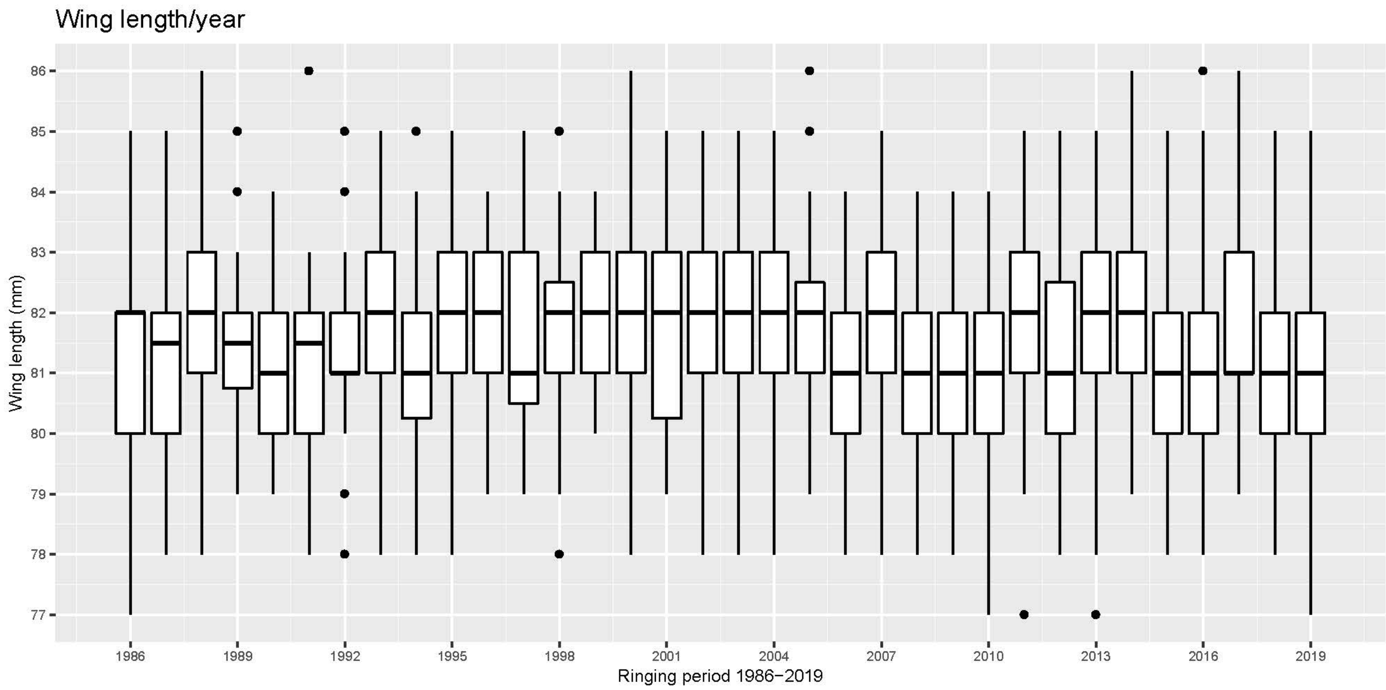

Figure 43: Boxplot showing wing length data for ringed *P. phoenicurus* from Falsterbo.

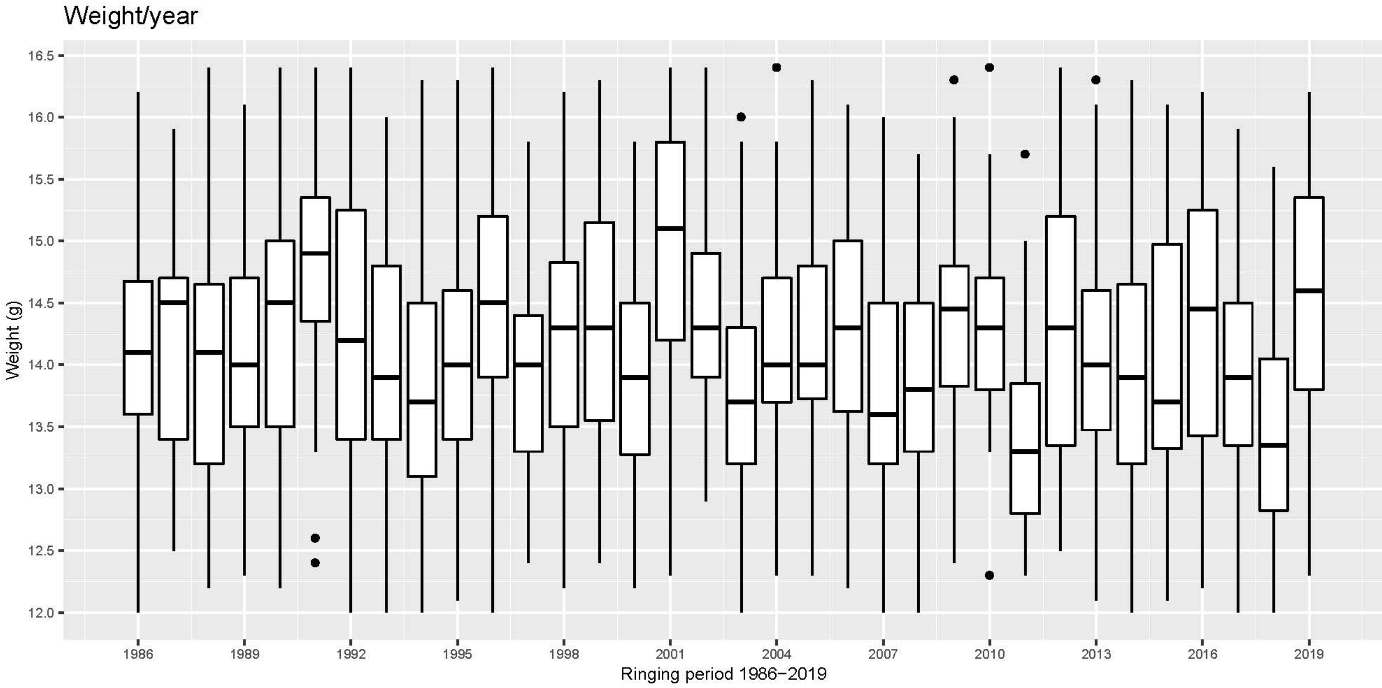

Figure 44: Boxplot showing weight data for ringed *P. phoenicurus* from Ottenby.

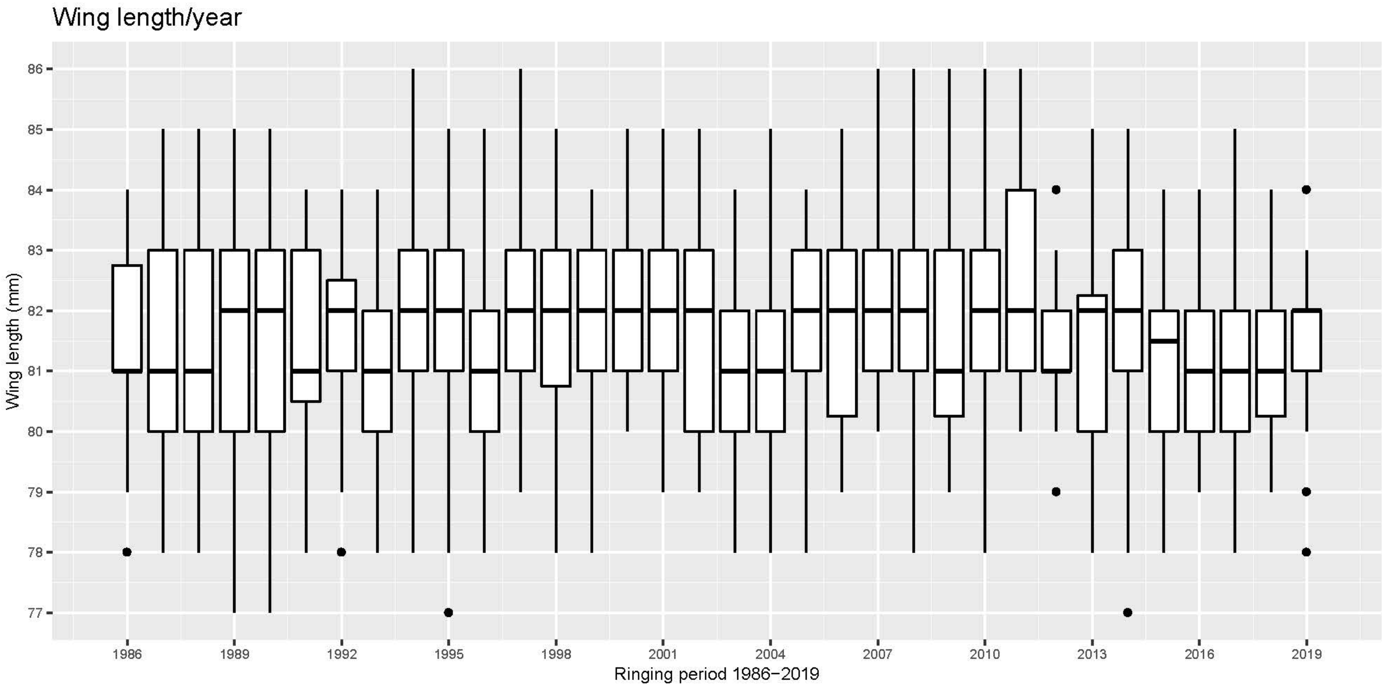

Figure 45: Boxplot showing Wing length data for ringed *P. phoenicurus* from Ottenby.

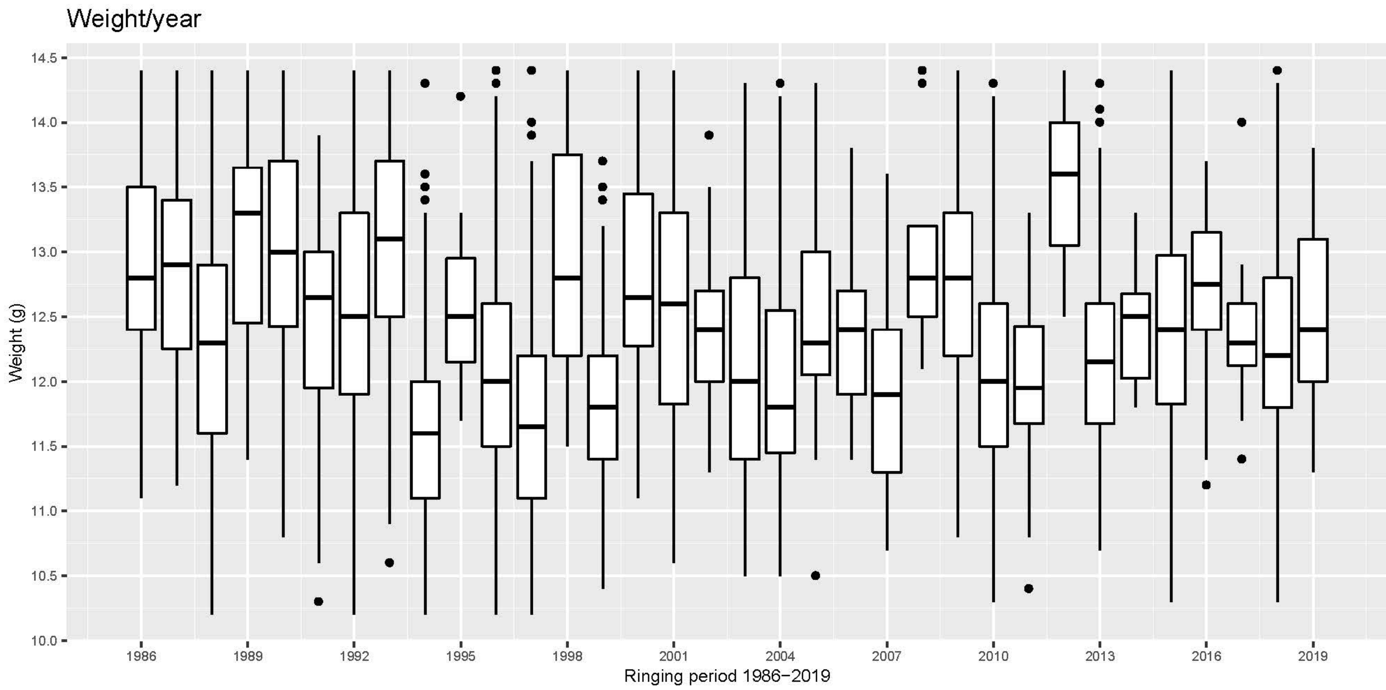

Figure 46: Boxplot showing weight data for ringed *S. spinus* from Falsterbo.

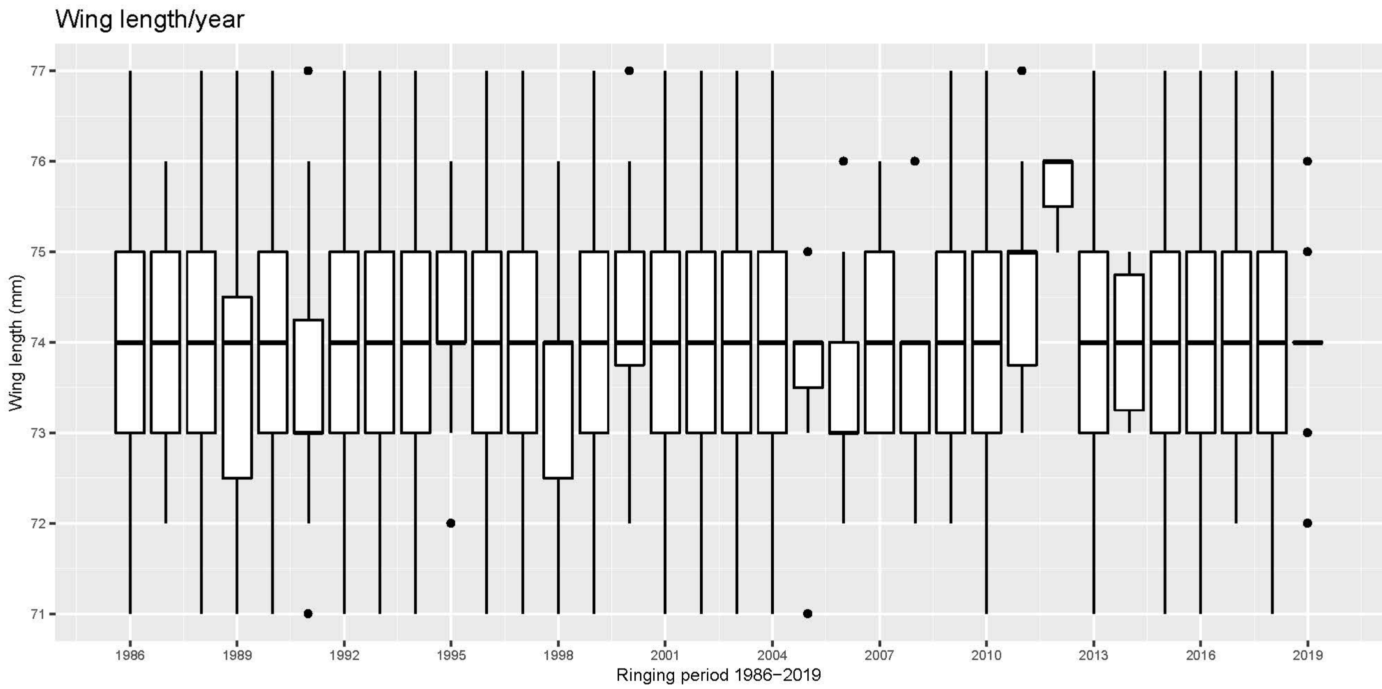

Figure 47: Boxplot showing wing length data for ringed *S. spinus* from Falsterbo.

8. Appendix C

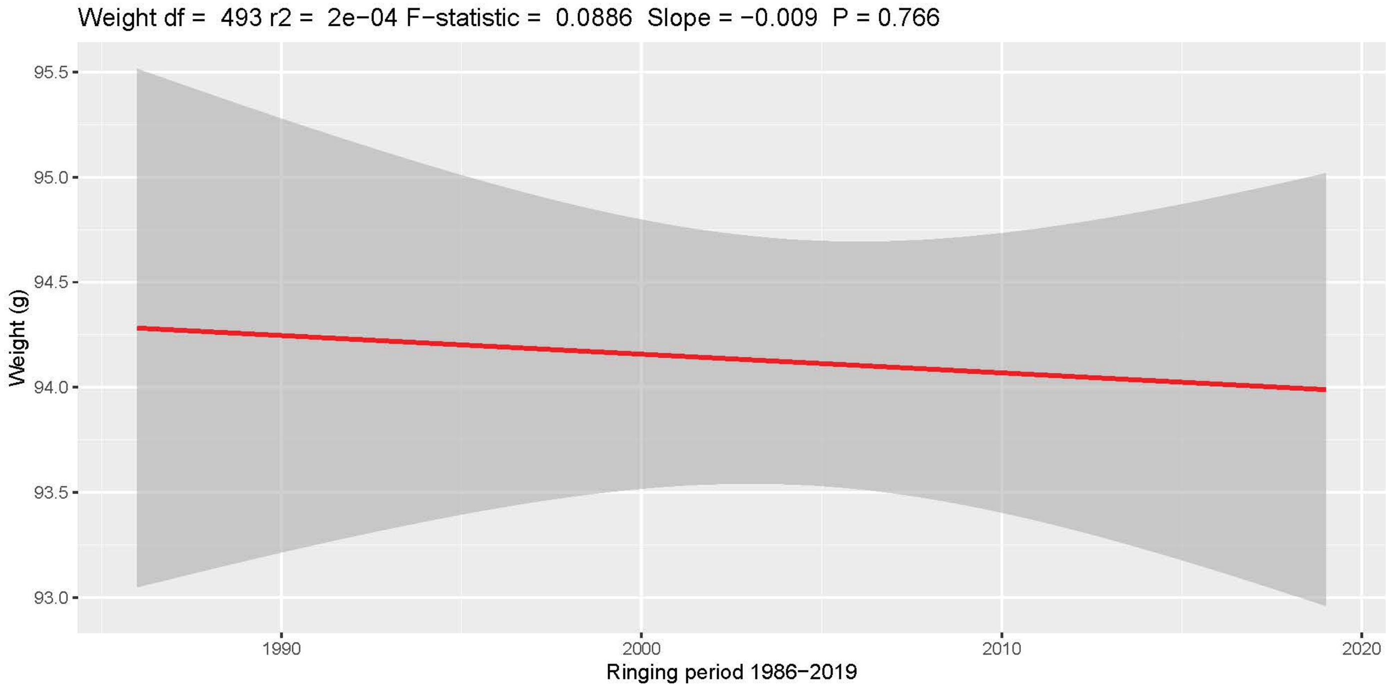

Figure 48: Trend line with confidence interval and statistics from weight analysis for ringed *T. merula* from Falsterbo.

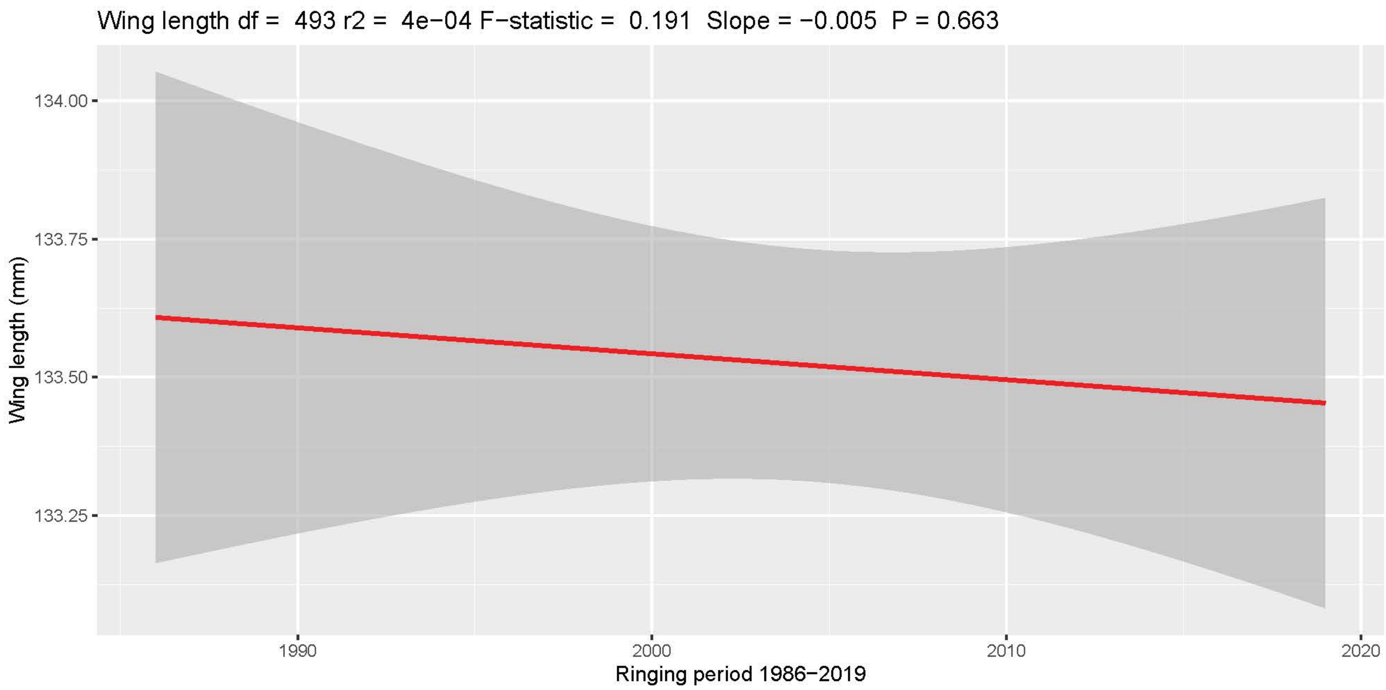

Figure 49: Trend line with confidence interval and statistics from wing length analysis for ringed *T. merula* from Falsterbo.

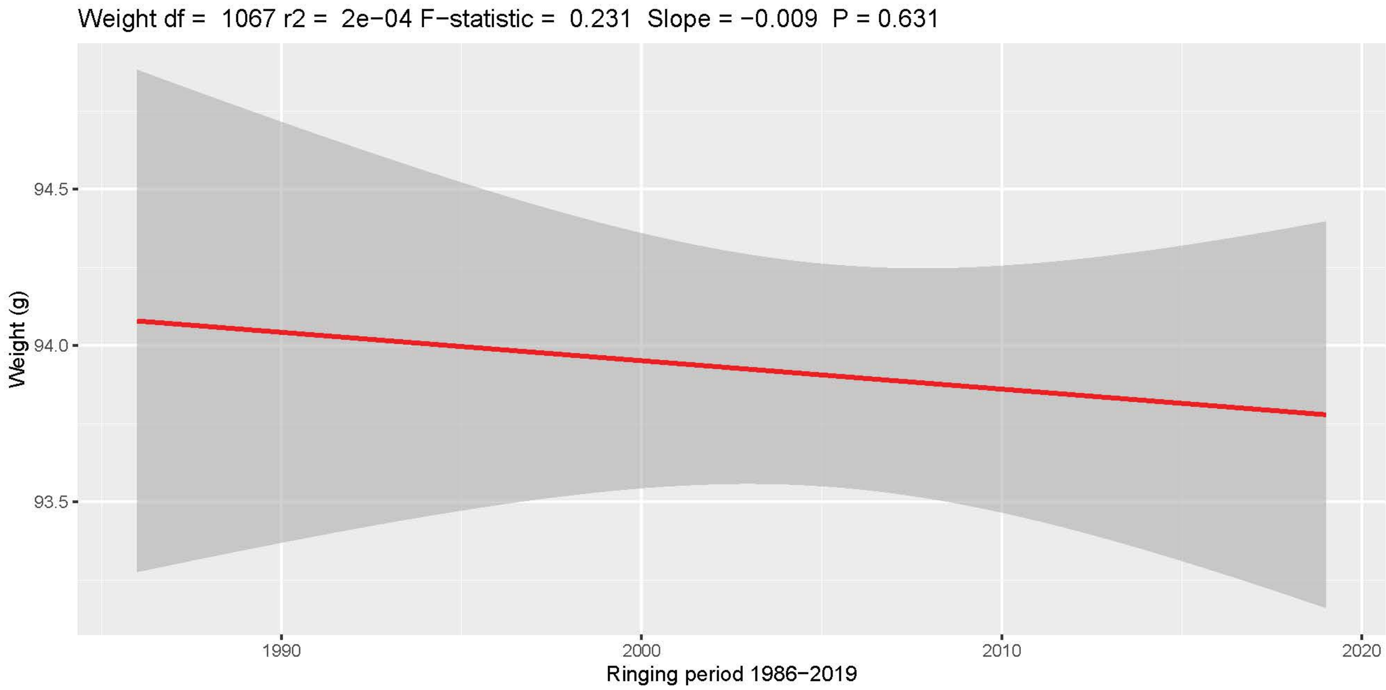

Figure 50: Trend line with confidence interval and statistics from weight analysis for ringed *T. merula* from Ottenby.

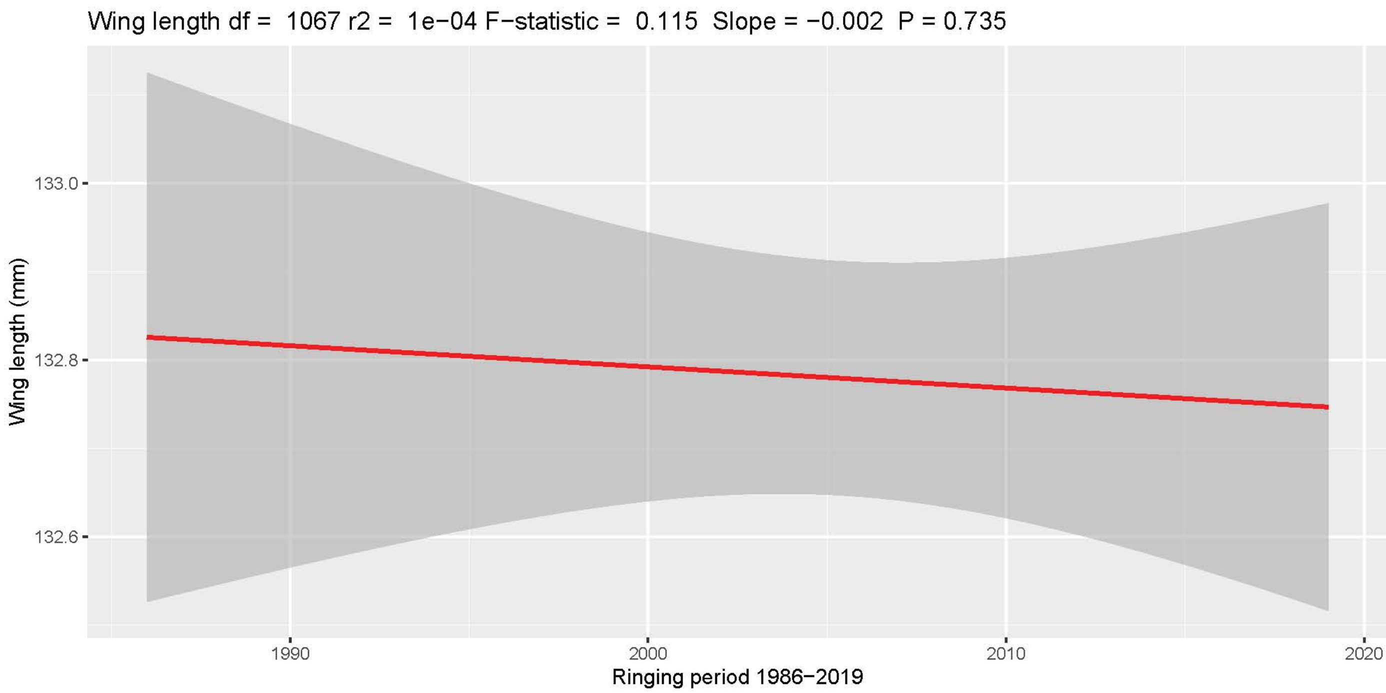

Figure 51: Trend line with confidence interval and statistics from wing length analysis for ringed *T. merula* from Ottenby.

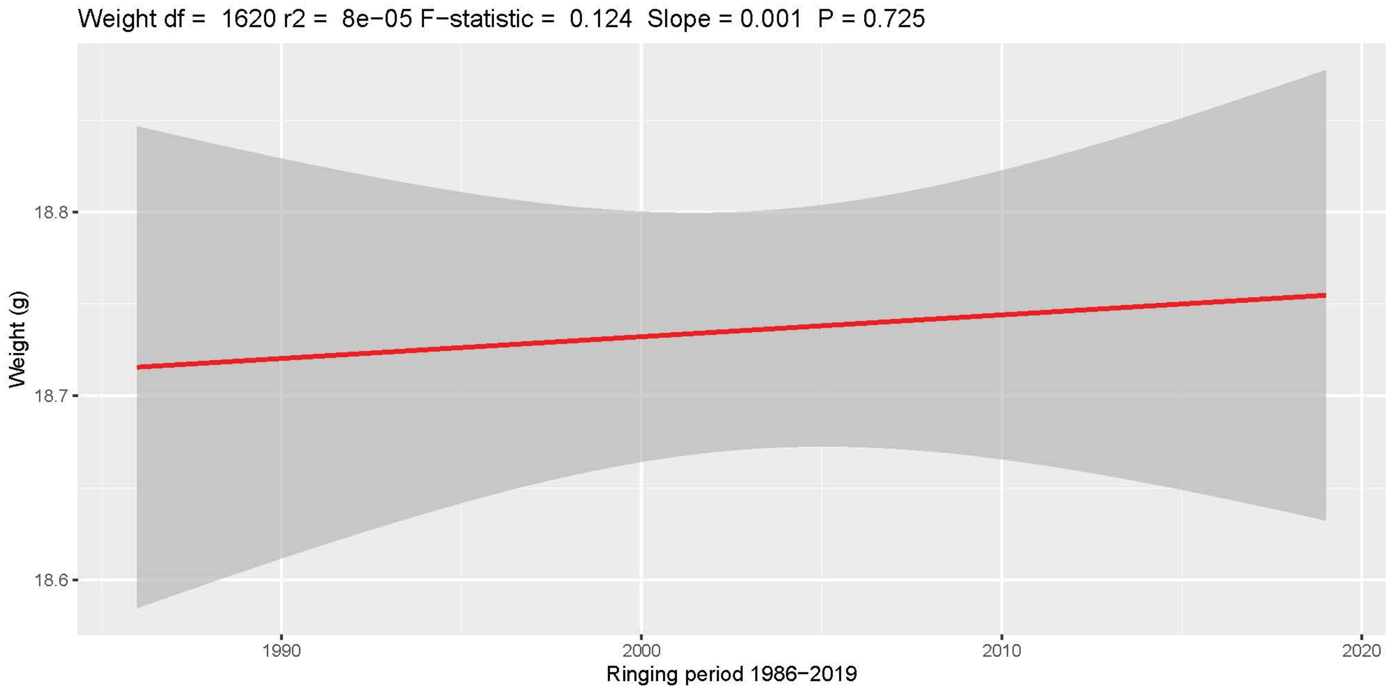

Figure 52: Trend line with confidence interval and statistics from weight analysis for ringed *S. atricapilla* from Falsterbo.

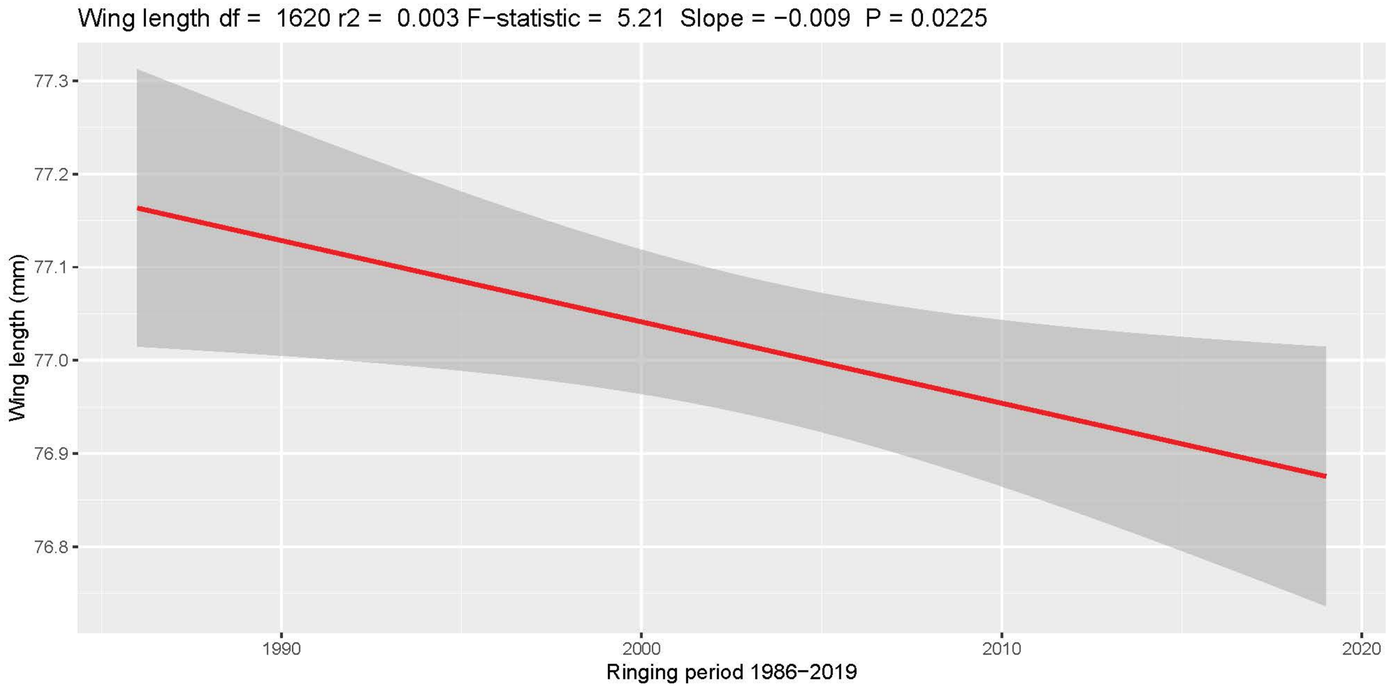

Figure 53: Trend line with confidence interval and statistics from wing length analysis for ringed *S. atricapilla* from Falsterbo.

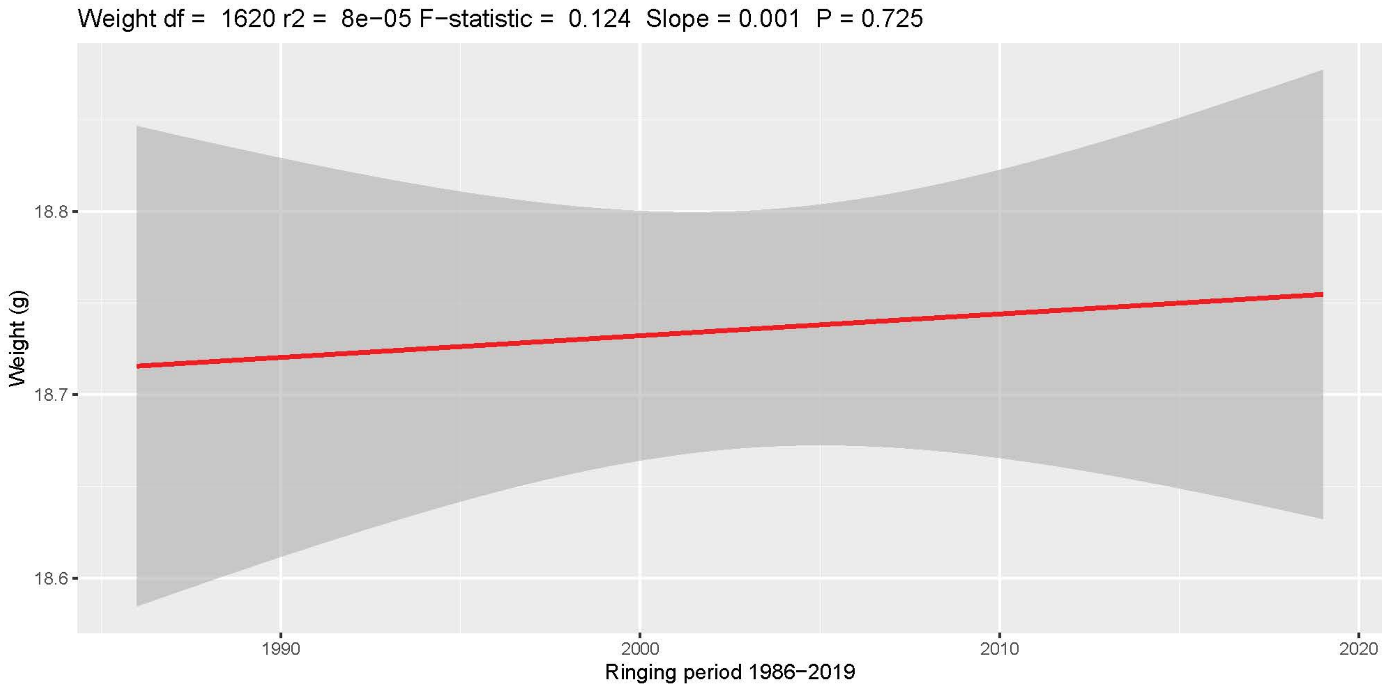

Figure 54: Trend line with confidence interval and statistics from weight analysis for ringed *S. atricapilla* from Ottenby.

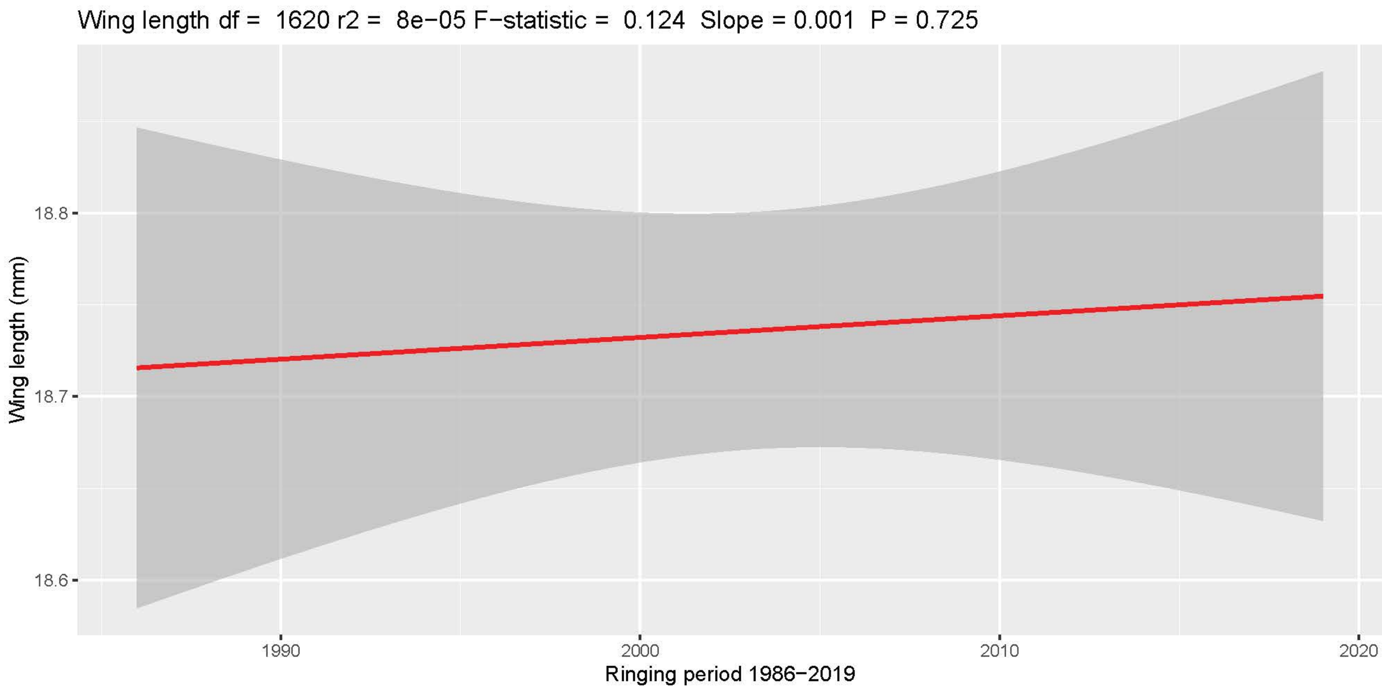

Figure 55: Trend line with confidence interval and statistics from wing length analysis for ringed *S. atricapilla* from Ottenby.

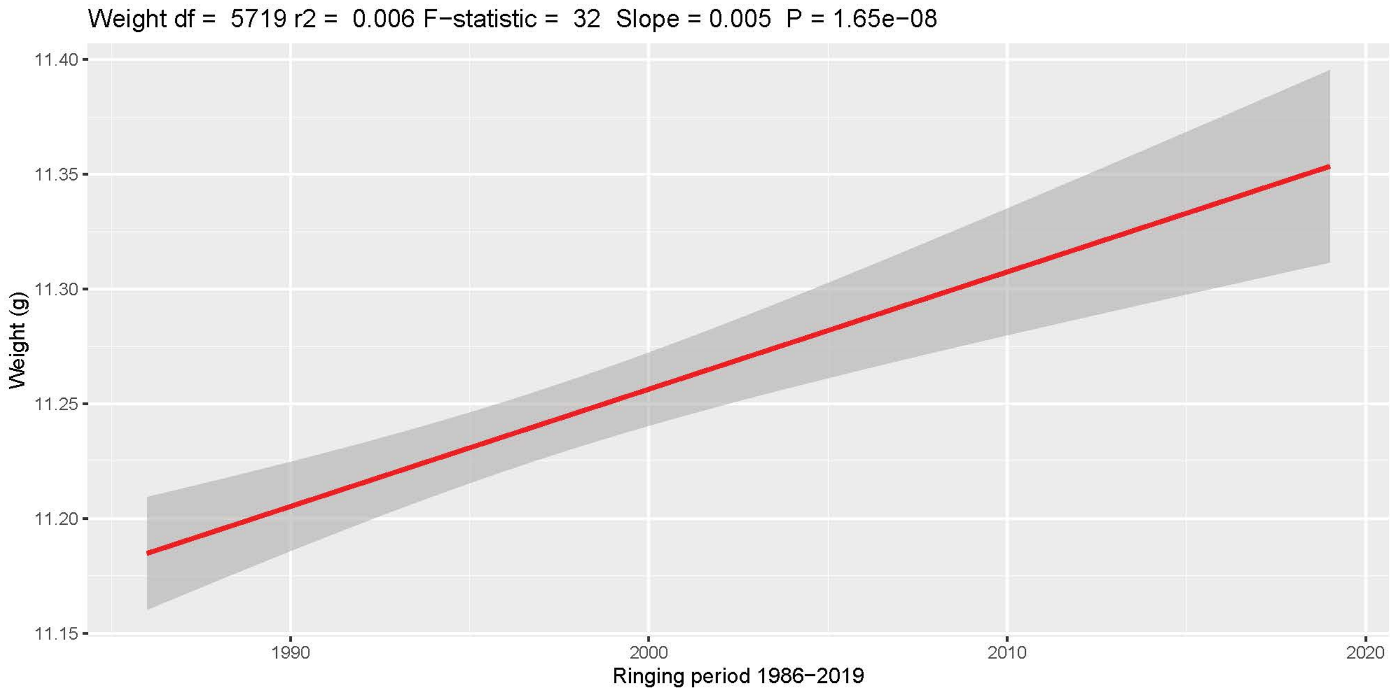

Figure 56: Trend line with confidence interval and statistics from weight analysis for ringed *C. caeruleus* from Falsterbo.

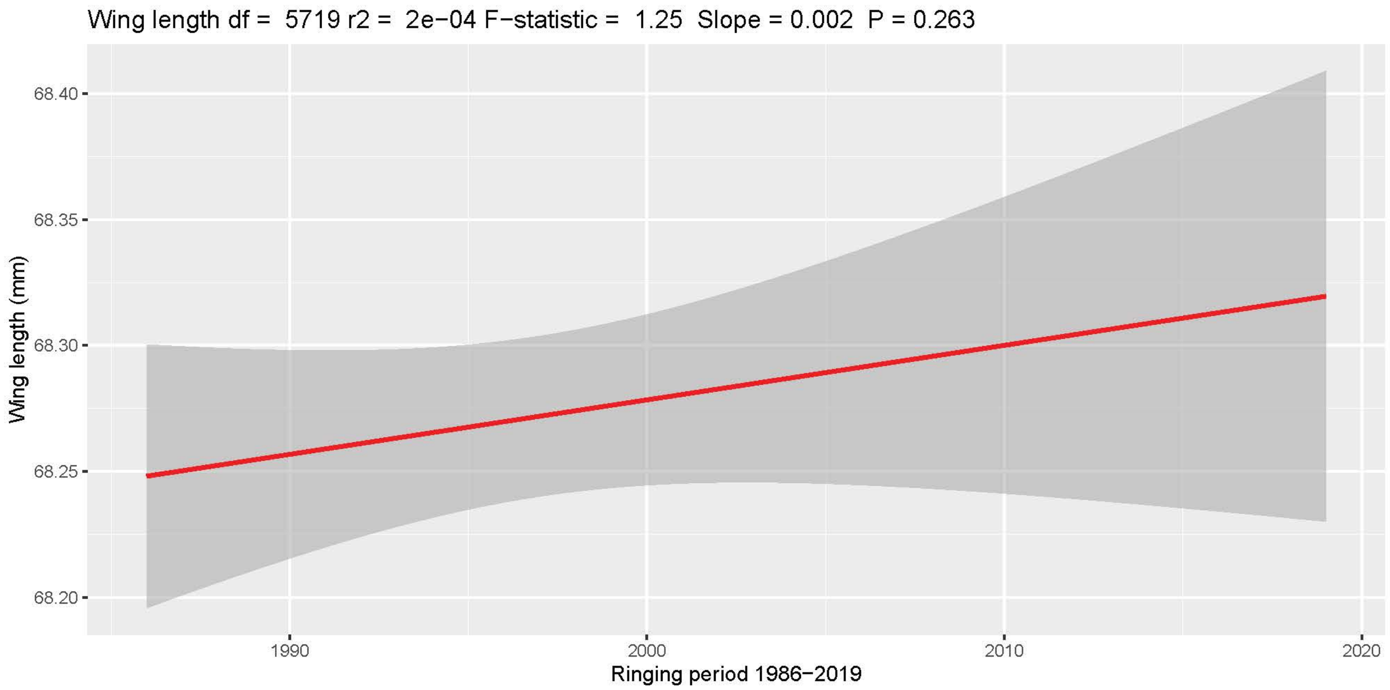

Figure 57: Trend line with confidence interval and statistics from wing length analysis for ringed *C. caeruleus* from Falsterbo.

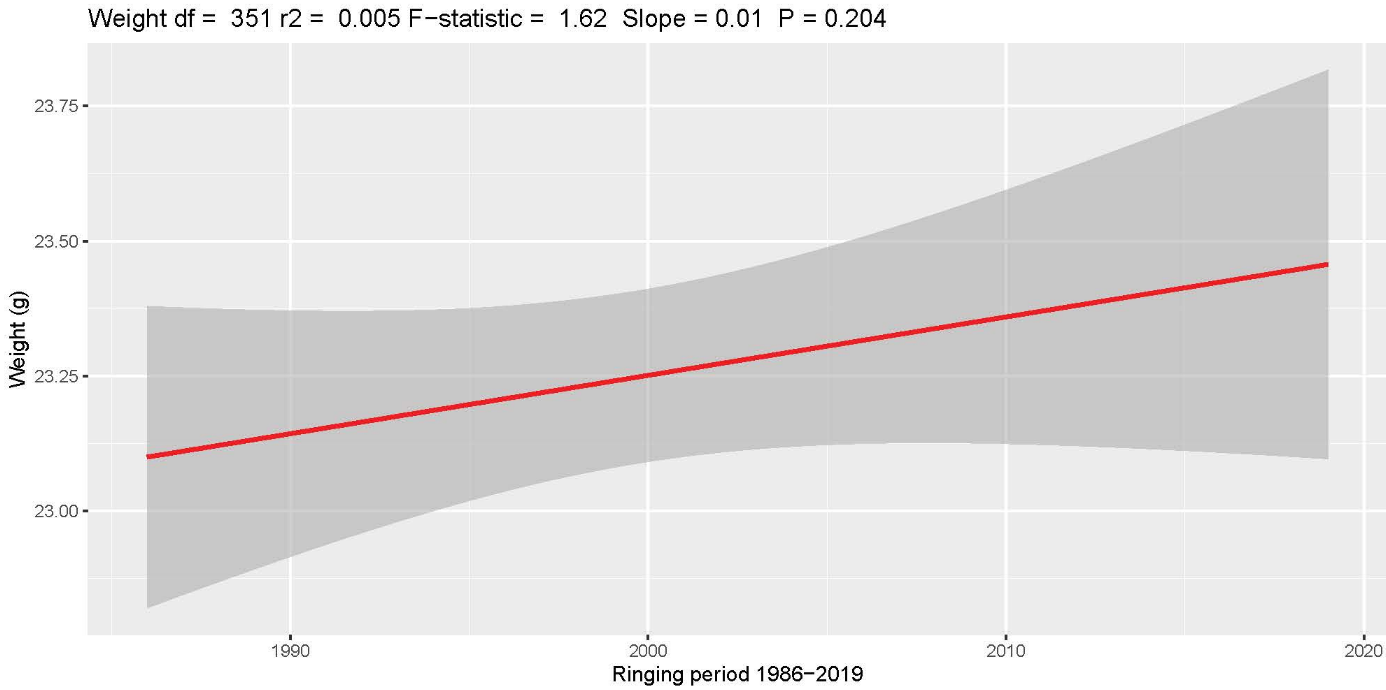

Figure 58: Trend line with confidence interval and statistics from weight analysis for ringed *F. montifringilla* from Falsterbo.

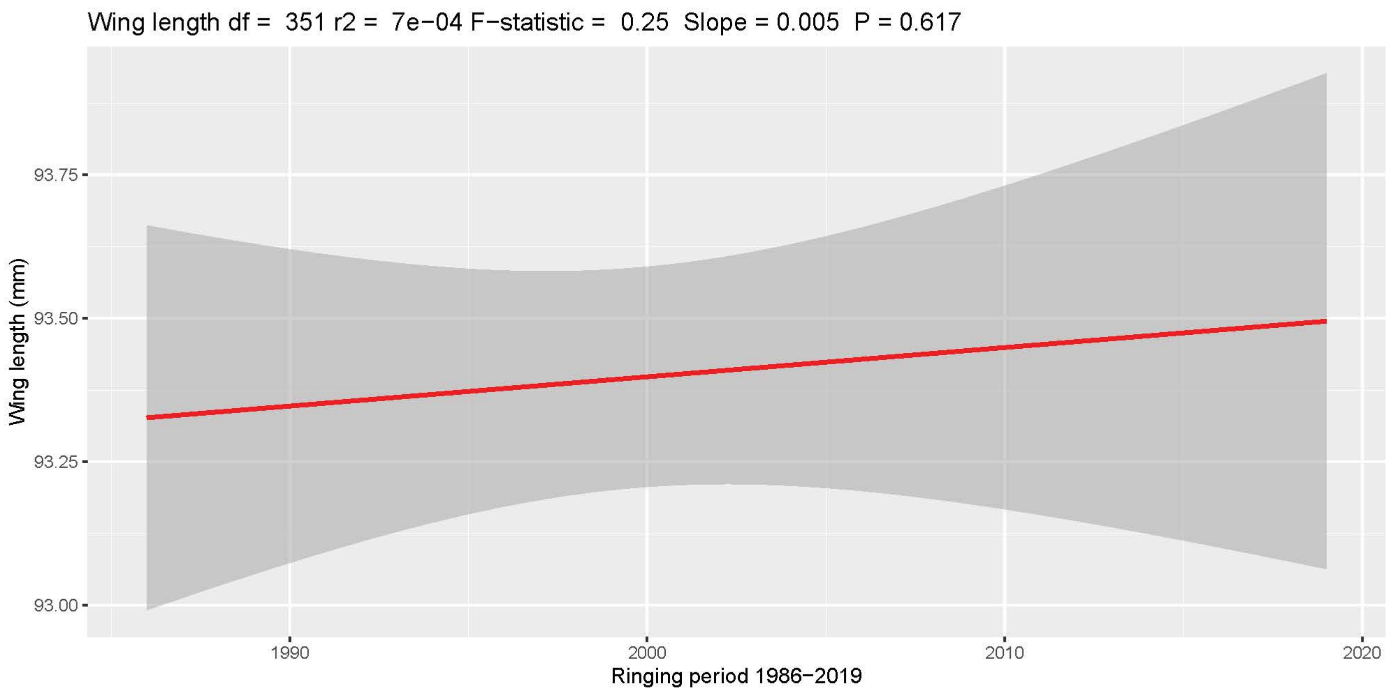

Figure 59: Trend line with confidence interval and statistics from wing length analysis for ringed *F. montifringilla* from Falsterbo.

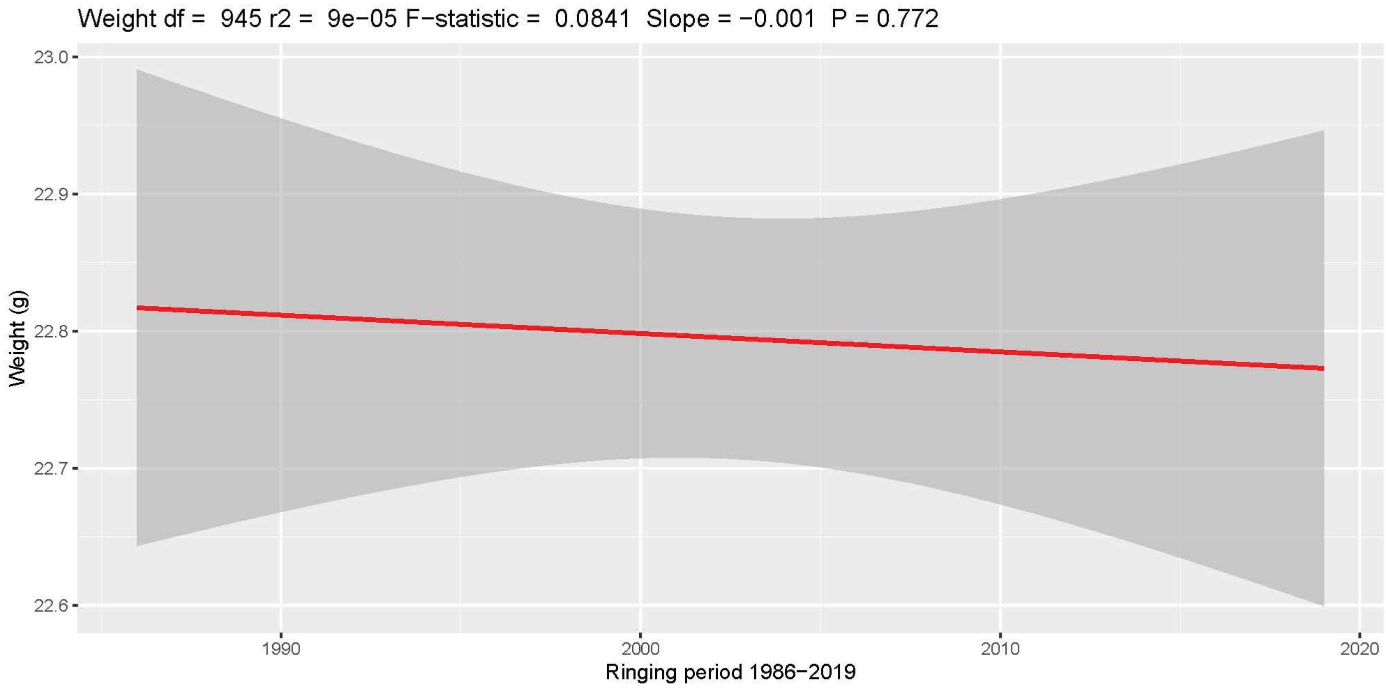

Figure 60: Trend line with confidence interval and statistics from weight analysis for ringed *F. coelebs* from Falsterbo.

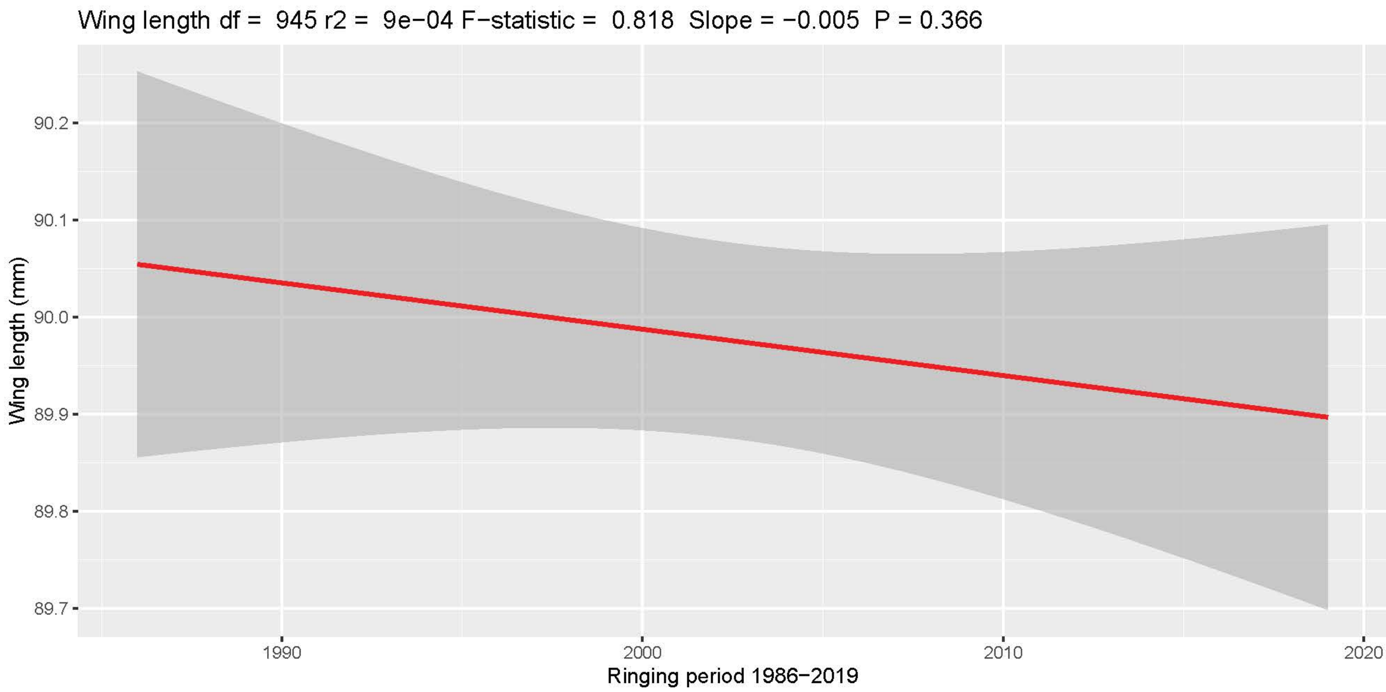

Figure 61: Trend line with confidence interval and statistics from wing length analysis for ringed *F. coelebs* from Falsterbo.

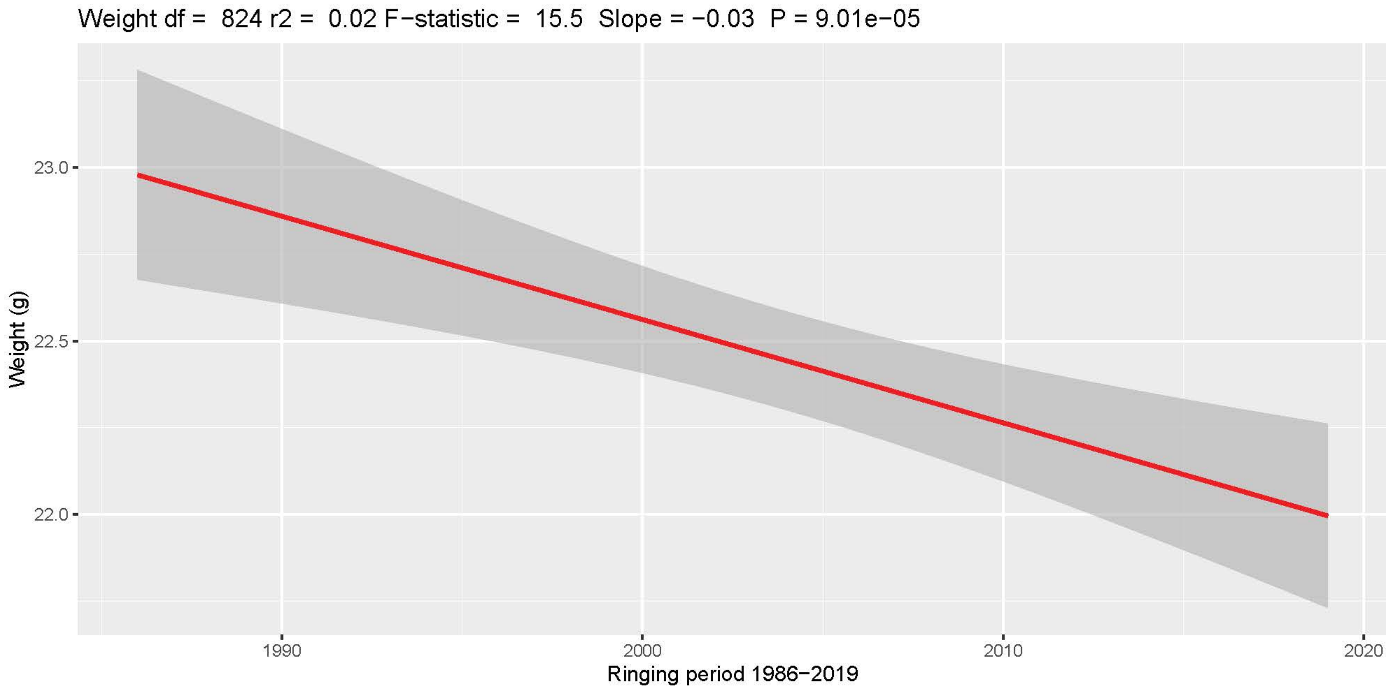

Figure 62: Trend line with confidence interval and statistics from weight analysis for ringed *F. coelebs* from Ottenby.

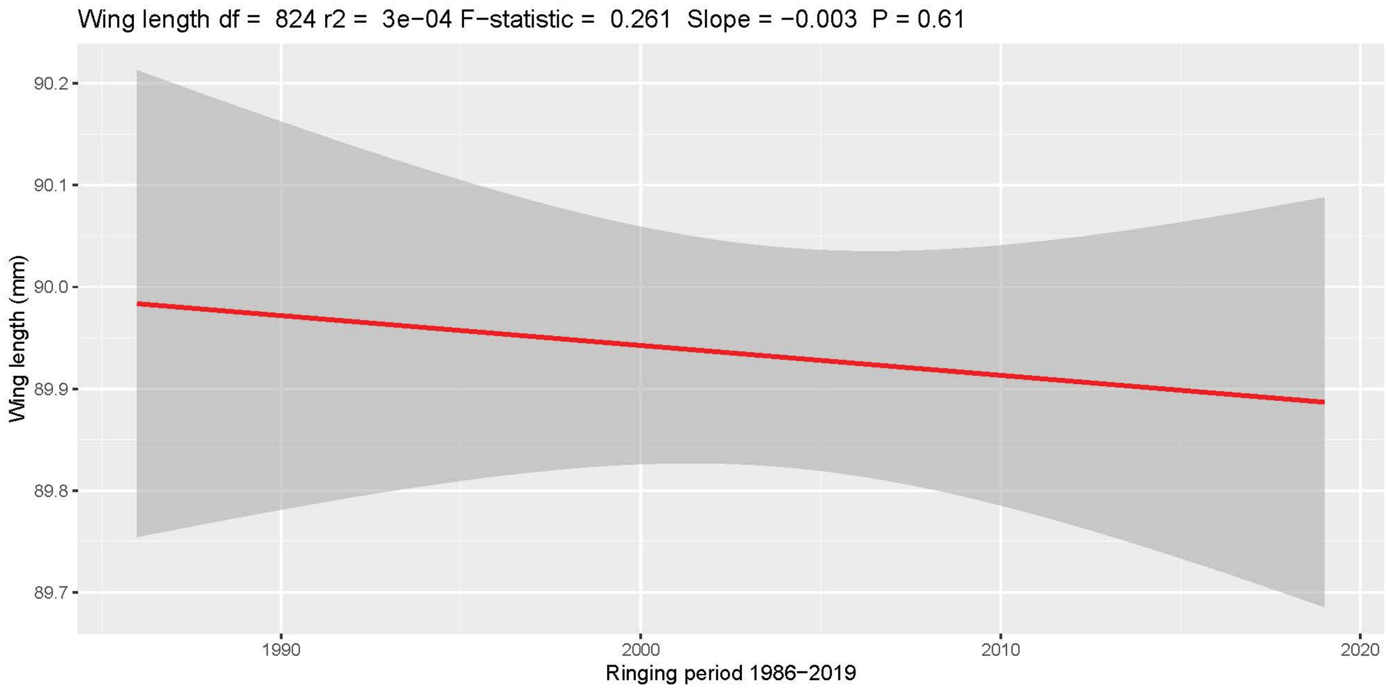

Figure 63: Trend line with confidence interval and statistics from wing length analysis for ringed *F. coelebs* from Ottenby.

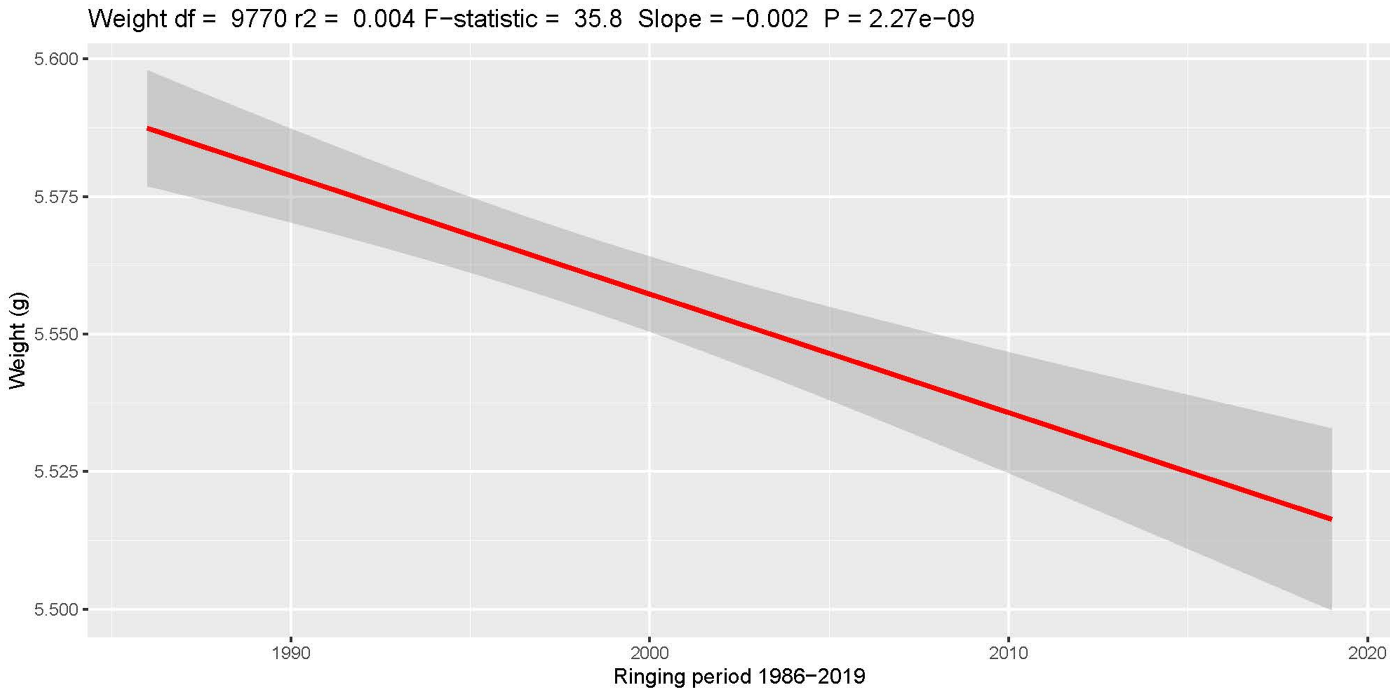

Figure 64: Trend line with confidence interval and statistics from weight analysis for ringed *R. regulus* from Falsterbo.

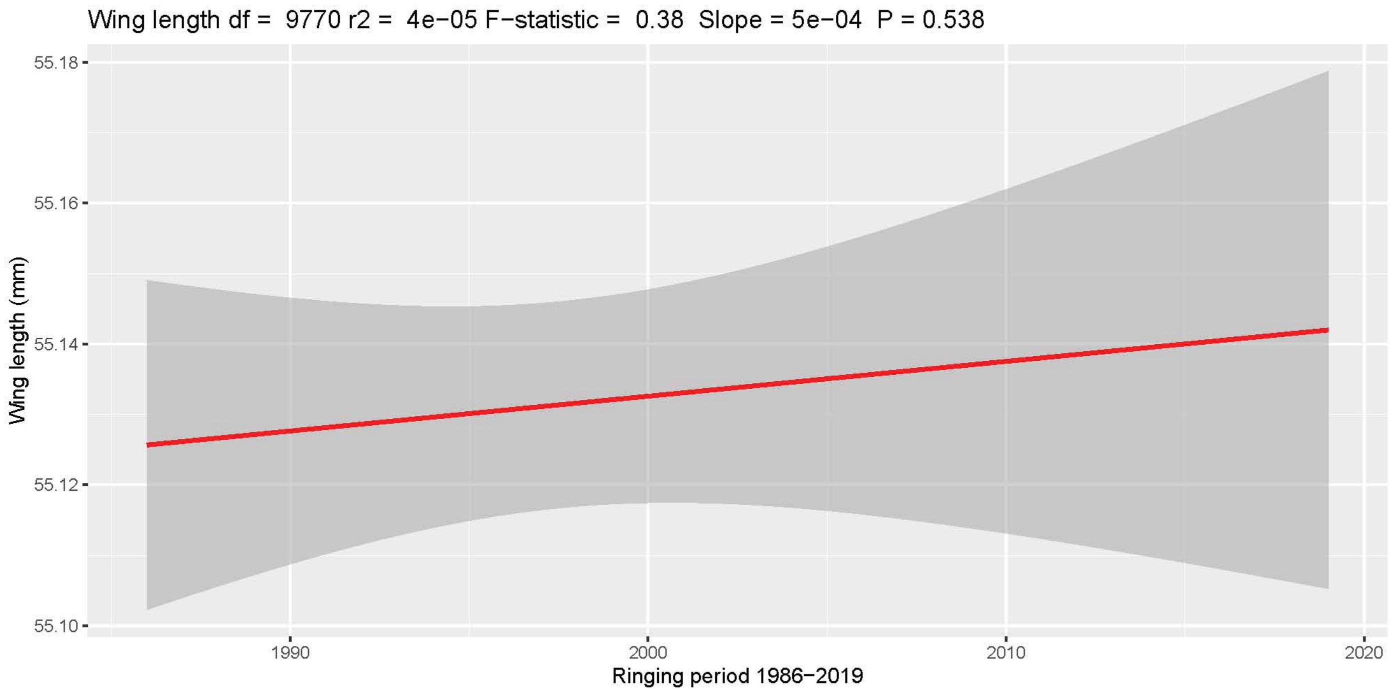

Figure 65: Trend line with confidence interval and statistics from wing length analysis for ringed *R. regulus* from Falsterbo.

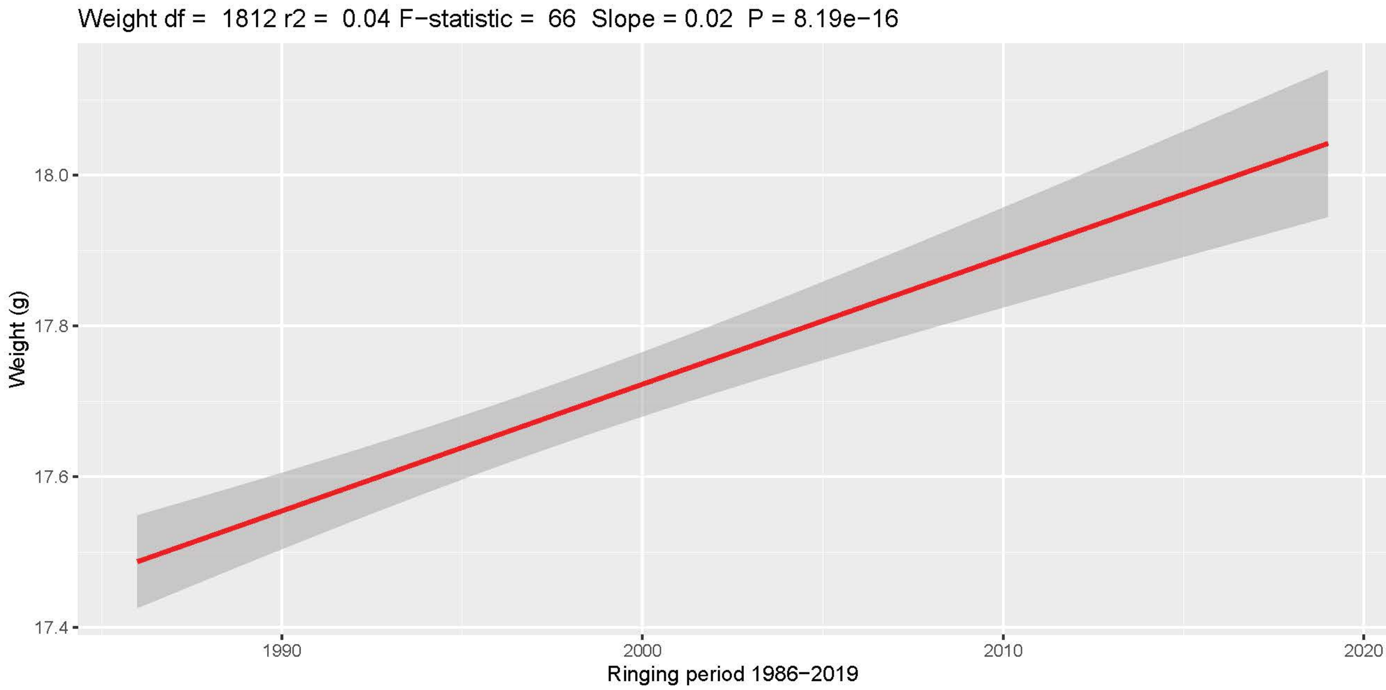

Figure 66: Trend line with confidence interval and statistics from weight analysis for ringed *P. major* from Falsterbo.

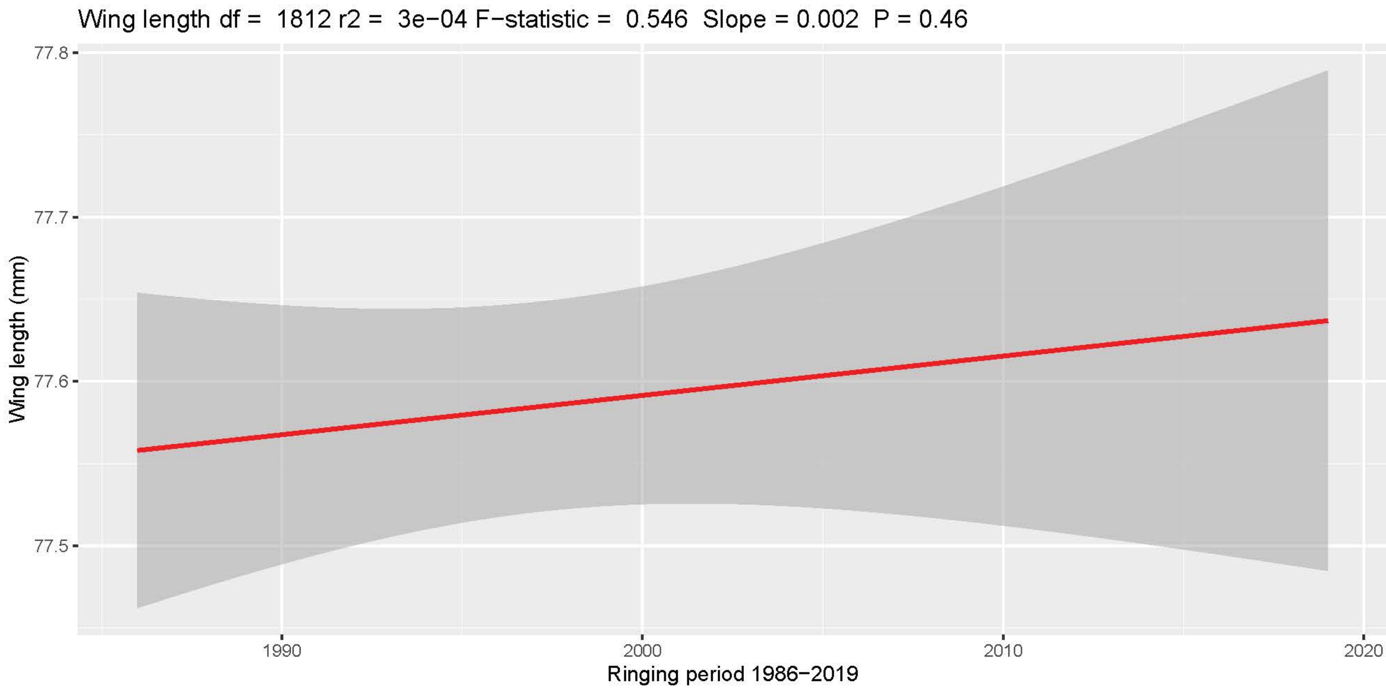

Figure 67: Trend line with confidence interval and statistics from wing length analysis for ringed *P. major* from Falsterbo.

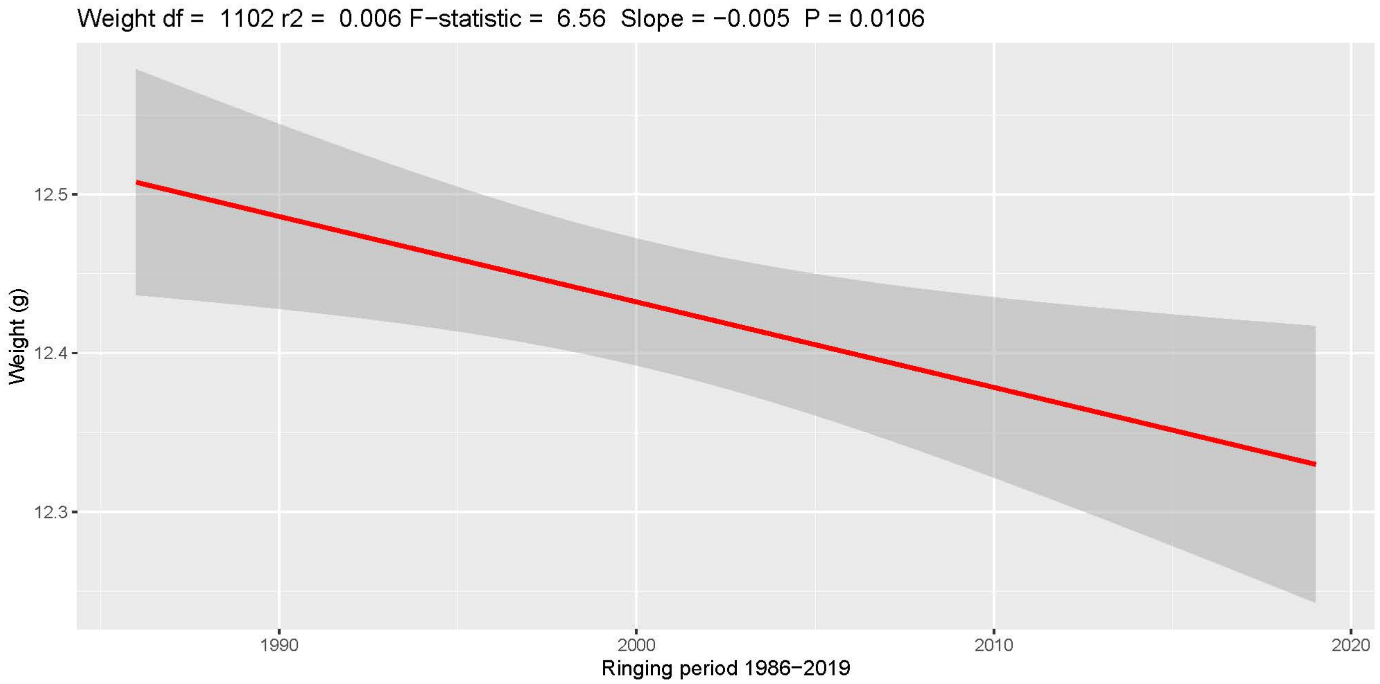

Figure 68: Trend line with confidence interval and statistics from weight analysis for ringed *F. hypoleuca* from Falsterbo.

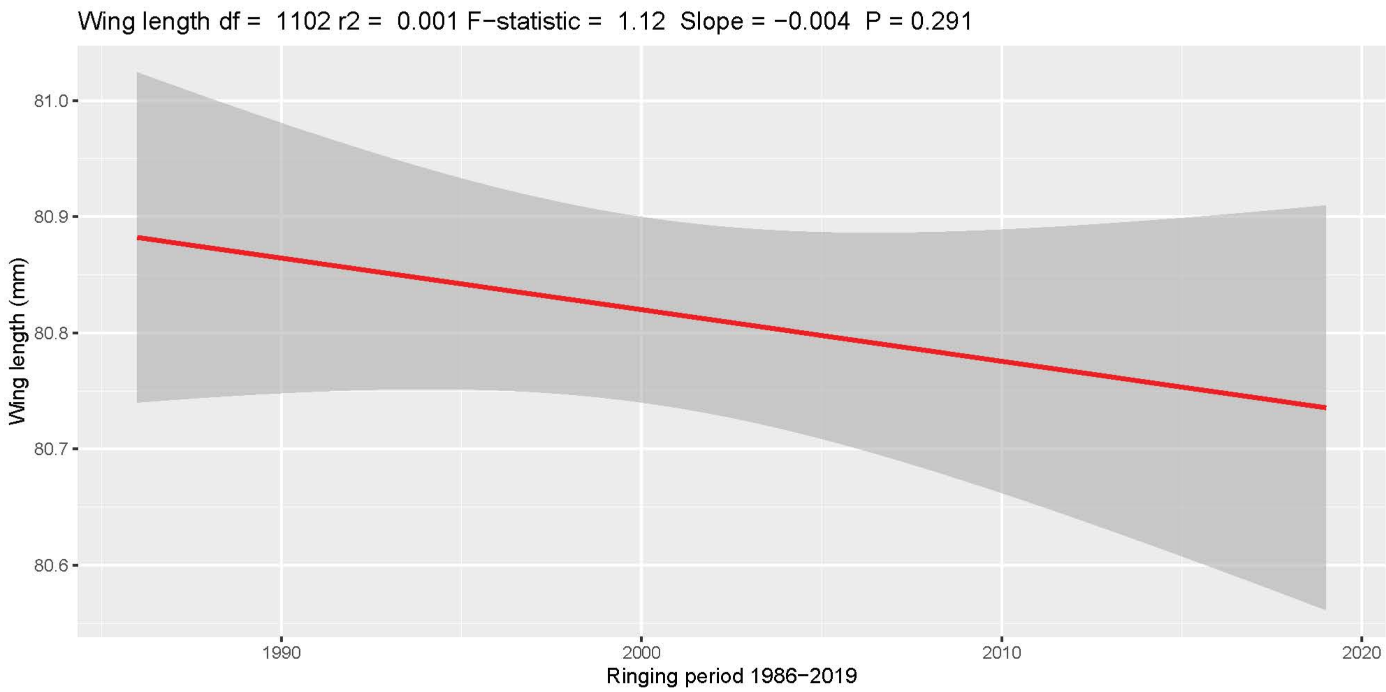

Figure 69: Trend line with confidence interval and statistics from wing length analysis for ringed *F. hypoleuca* from Falsterbo.

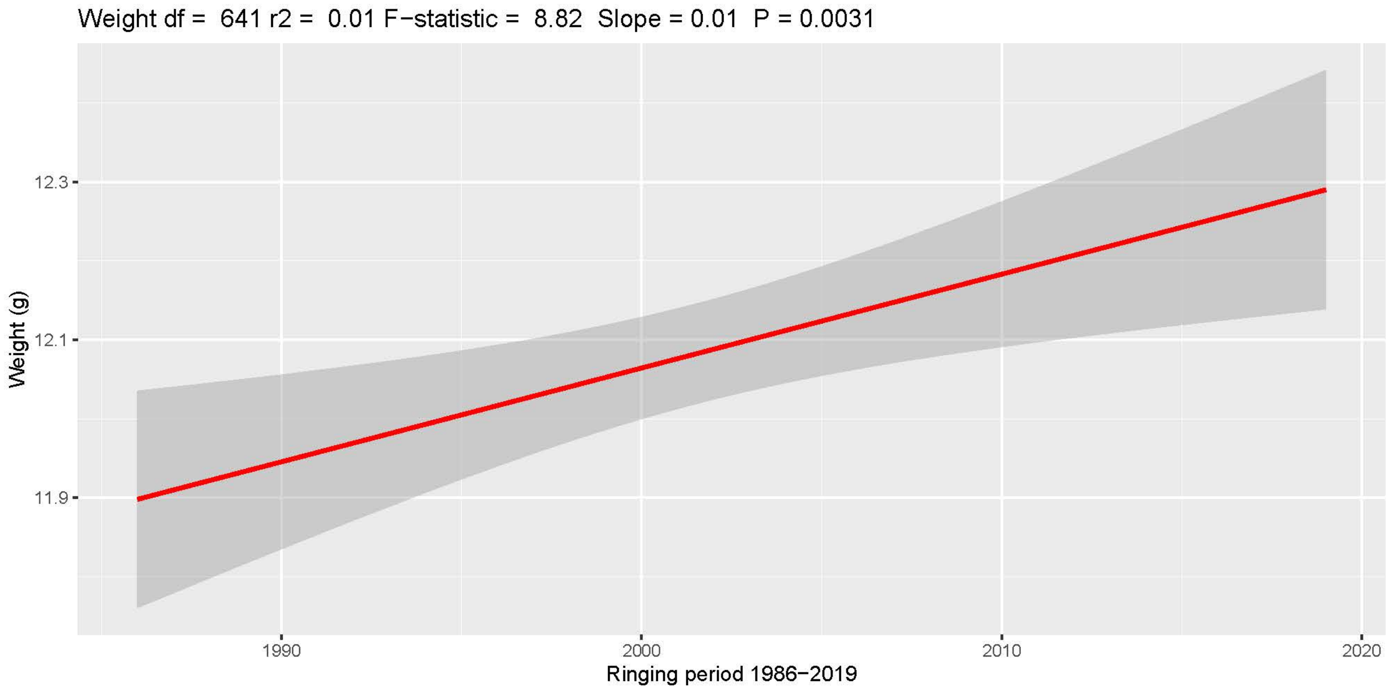

Figure 70: Trend line with confidence interval and statistics from weight analysis for ringed *F. hypoleuca* from Ottenby.

Figure 71: Trend line with confidence interval and statistics from wing length analysis for ringed *F. hypoleuca* from Ottenby.

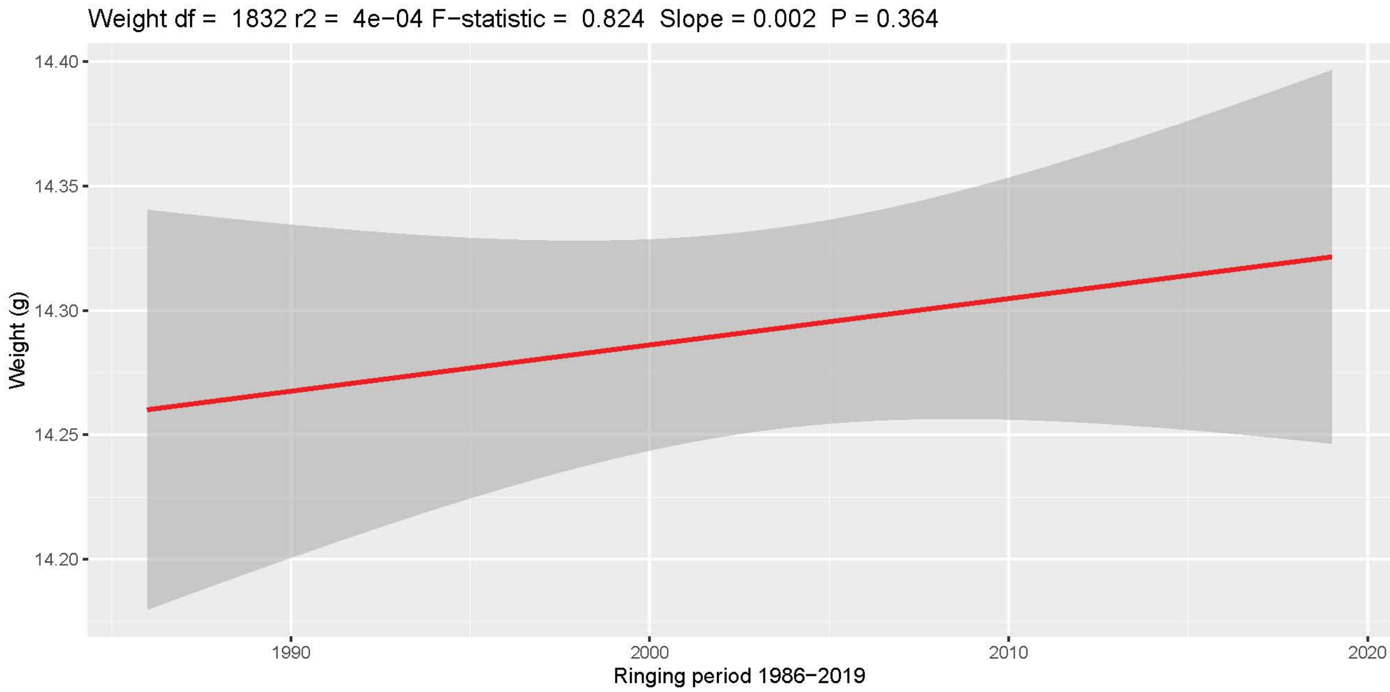

Figure 72: Trend line with confidence interval and statistics from weight analysis for ringed *P. pheonicurus* from Falsterbo.

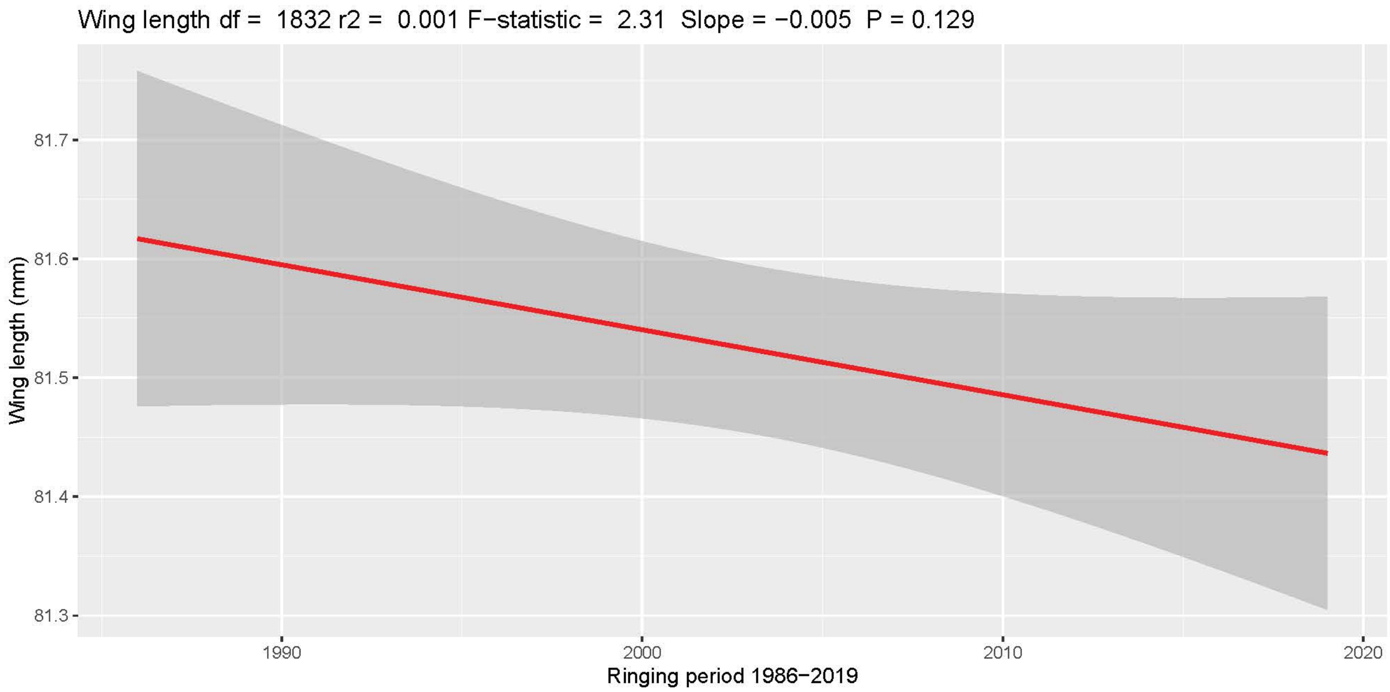

Figure 73: Trend line with confidence interval and statistics from wing length analysis for ringed *P. pheonicurus* from Falsterbo.

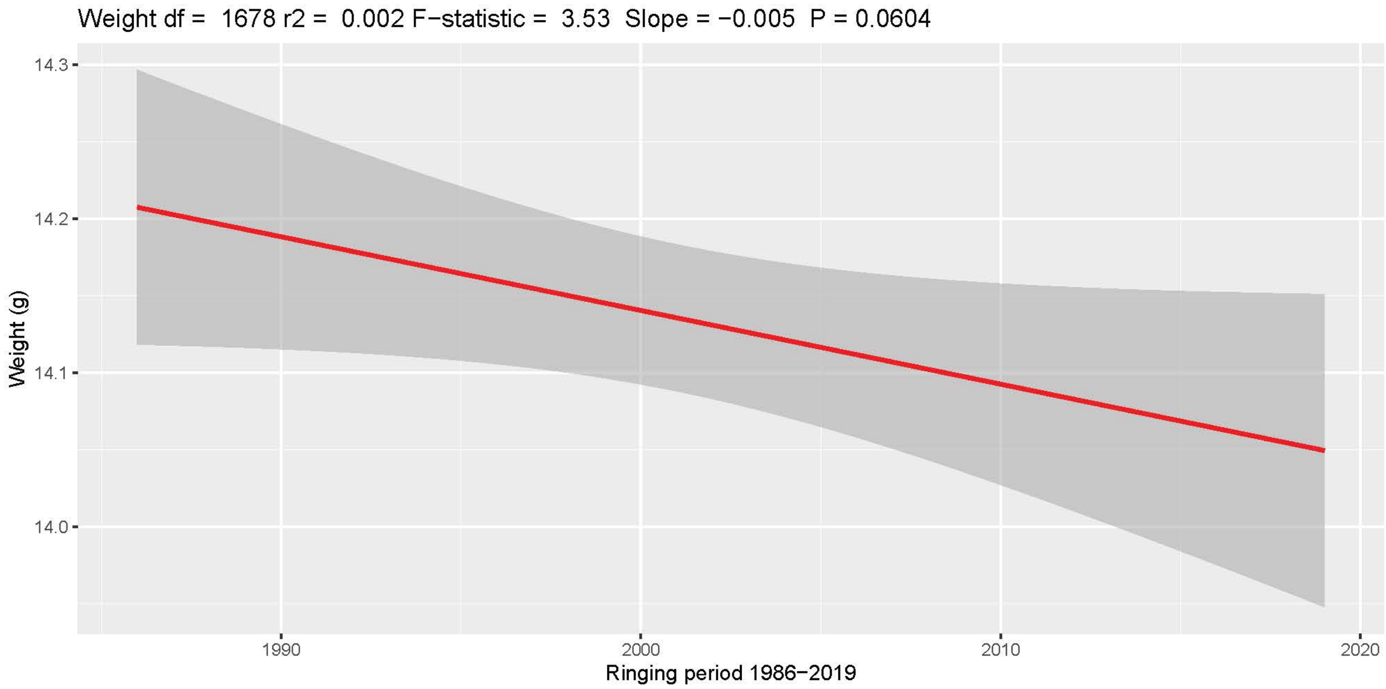

Figure 74: Trend line with confidence interval and statistics from weight analysis for ringed *P. pheonicurus* from Ottenby.

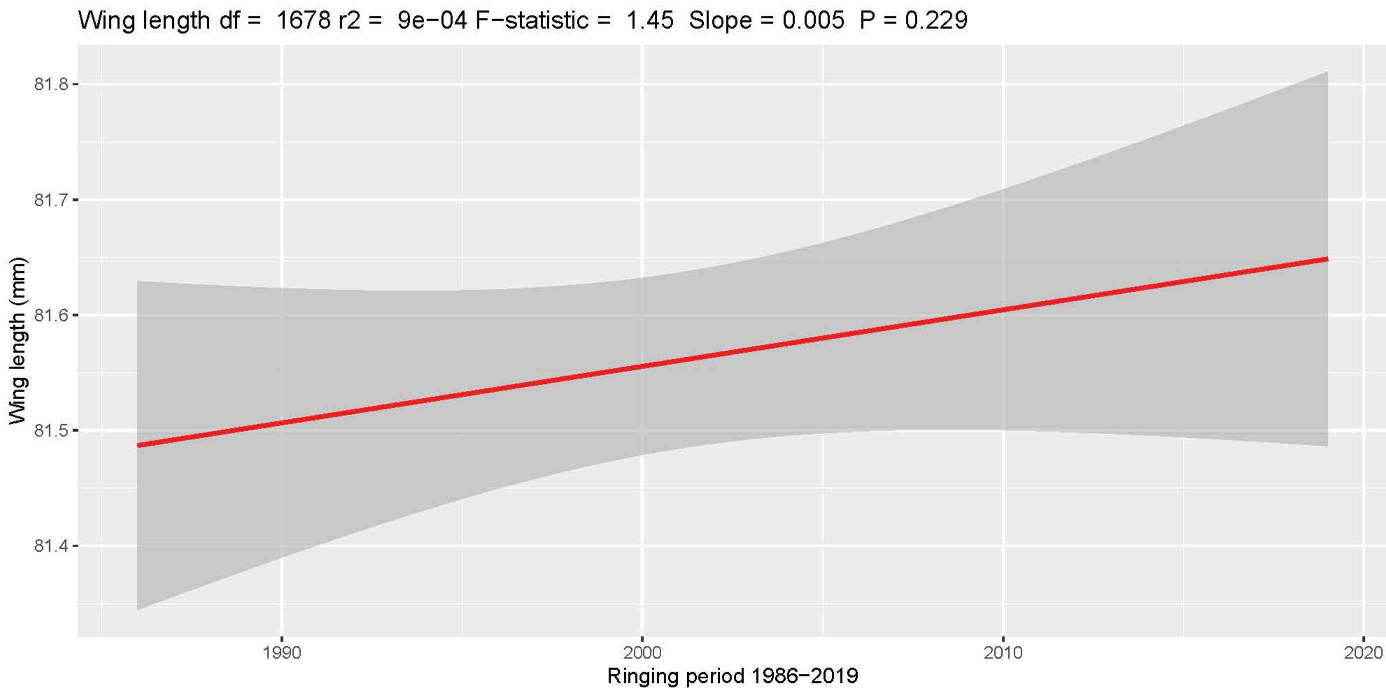

Figure 75: Trend line with confidence interval and statistics from wing length analysis for ringed *P. pheonicurus* from Ottenby.

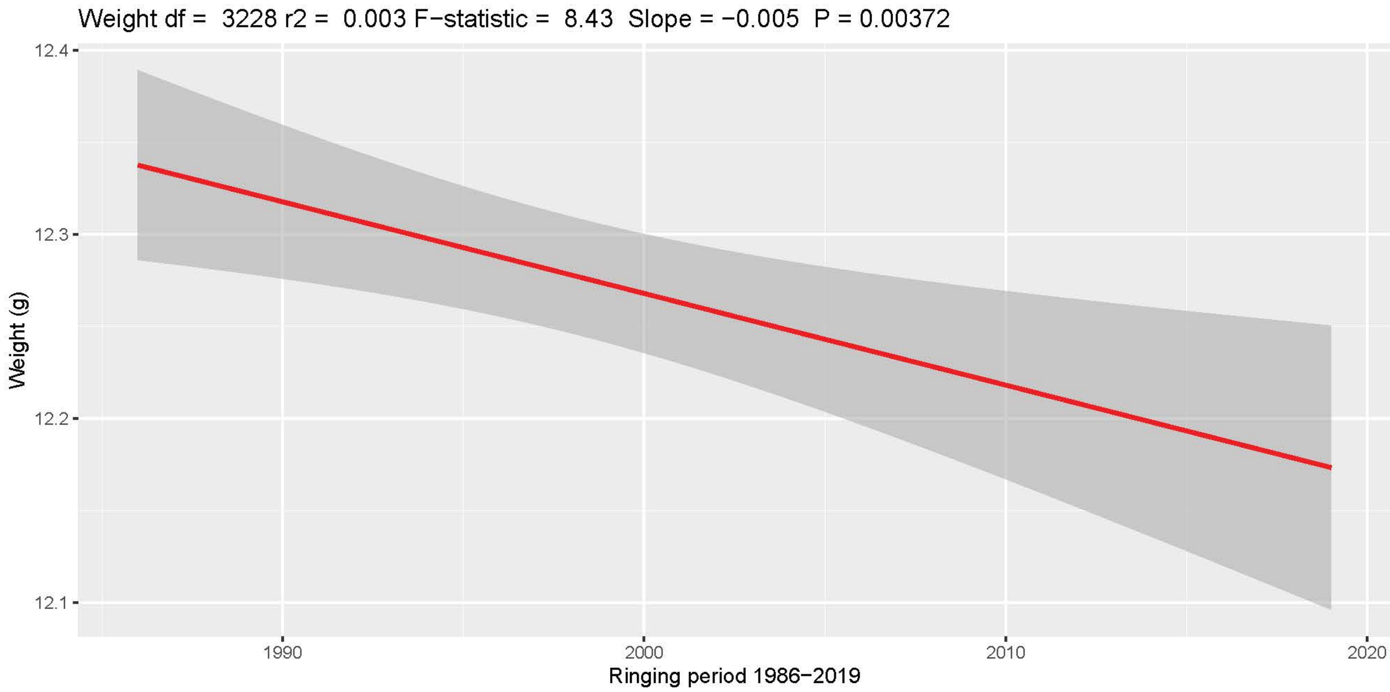

Figure 76: Trend line with confidence interval and statistics from weight analysis for ringed *S. spinus* from Falsterbo.

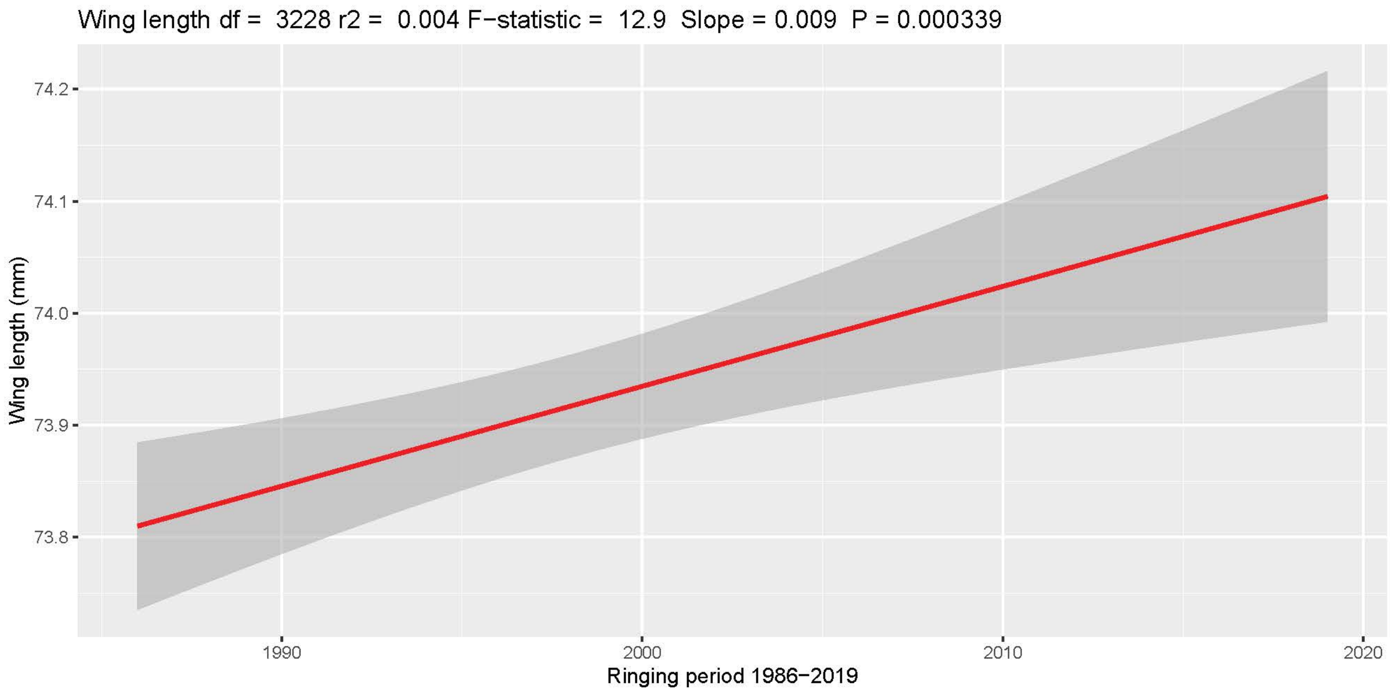

Figure 77: Trend line with confidence interval and statistics from wing length analysis for ringed *S. spinus* from Falsterbo.