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Estimating Somatic Weight From Total Weight in the European Eel (*Anguilla anguilla*)

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ABSTRACT

Data on the size of an animal is essential when analysing population dynamics, growth rates or the body condition of individuals for size-structured populations. Two common weight measurements are total body weight and somatic weight. Compared to total weight, somatic weight needs lethal sampling and is more time-consuming to assess, but can provide a more standardised measure. Hence, the choice between measuring total or somatic weight should be carefully adapted to data needs for each specific species and monitoring program. In this study, we assessed the need to collect somatic weight compared to total weight for the European eel (*Anguilla anguilla*) from a monitoring perspective. Total weight was compared to two somatic measurements: removal of digestive tract and stomach or removal of digestive tract, stomach and gonads. Based on data from 6999 female eels and 20 males collected along the Swedish coasts, we show that for females, life stage influenced the somatic to total weight ratio, with yellow eels showing the lowest ratios. The weight ratios increased slightly with increasing length and weight. For the male yellow eel, neither length nor weight influenced the weight ratio. With the conversion factors from the linear relationship between somatic and total weight for each life stage presented here, we show that it is possible to estimate somatic weight from total weight. We also demonstrate that using the conversion factors to estimate somatic weight does not distort condition estimates—such as relative condition (Rc), Fulton's K, and Le Cren's K_n—compared to calculations based on observed somatic weight. We conclude that lethal sampling of eels can be avoided while still retaining the ability to use somatic weight estimates for various end-user purposes.

1 | Introduction

Within monitoring programs, it is essential to evaluate sampling schemes and the usage of sampled biological variables to ensure efficient and cost-effective sampling that fulfils end-user needs (Lovett et al. 2007). Sampling schemes can be designed for specific species or apply to many species, geographical areas, or ecosystems (Lindenmayer and Likens 2010). Continuous evaluation of sampling methods ensures that sampling schemes and methods stay updated and avoid the risk of lingering inefficient monitoring programs that may persist unchanged despite method development and changes in end-user needs (reviewed in Radinger

et al. 2019). To keep sampling programs updated also ensures consensus among practitioners regarding method and technique choices, which can otherwise be an issue, even for programs monitoring the same species (e.g., Francis 2006). Also, the status of populations and/or stocks can change over time, which may alter end user data needs or potentially affect the possibilities to sample individuals, for example, via restrictions in lethal sampling methods or due to the need to implement replacement, reduction, refinement (3R) strategies, which also require updates of sampling programs. This is the case for the European eel (*Anguilla anguilla*). As it has become a critically endangered species (Pike et al. 2020), there is a great need to reduce lethal

sampling, while at the same time, there is a great data need. For example, data is needed within monitoring programs, such as the EU Data Collection Framework (DCF), which plays a crucial role in providing standardised, high-quality data to support both national and international assessments (van Gemert et al. 2024; ICES 2025). These assessments are essential to understand the species' status and to inform effective conservation measures aimed at ensuring the survival of the species (ICES 2025).

Data on size are essential when analysing, for example, population dynamics or growth rates of individuals (Ricker 1975; Bolger and Conolly 1989; Froese et al. 2016). Body weight (herein equal to body mass) is therefore one important biological variable typically sampled within monitoring programs and in basic and applied science (Neuman et al. 1997; Verreycken et al. 2011; Radinger et al. 2019). Body weight can be used to calculate various condition indices (Bolger and Conolly 1989), as well as a range of organo-somatic indices (Mallett et al. 2024). These indices serve as biological indicators of energy investment and allocation, as well as overall fish health. Because body condition is closely linked to both mortality and productivity, and can sometimes show stock-dependent patterns and respond to temporal and spatial variability, the use of such indices is increasingly recognised as an important tool in conservation management (Lloret et al. 2014; Cooke et al. 2022). There are, however, different types of weight measurements used for fish, with two common types being total body weight and somatic weight. The somatic weight is the weight of an individual excluding the viscera (organs, gut content and/or gonads), hence a lethal sampling method, but it is used to obtain a more standardised measure of weight as compared to total weight (Hansson et al. 2017). The organs that are removed to record somatic weight vary depending on what data are of interest for the specific species and/or monitoring program. As an example, prey items of predatory fish with large mouths can be large and thus constitute a great part of the total weight of the animal being measured, thereby resulting in erroneous data on total weight (Mittelbach and Persson 1998; Scharf et al. 2000). Furthermore, the size of gonad tissue generally varies depending on when in time the measurement was collected in relation to spawning time, reflecting fluctuations in gonadal investment, maturation and reproductive strategies such as skipped spawning (the latter for species that reproduce multiple times during their life span (Galloway and Munkittrick 2006; Skjæraasen et al. 2012). In some cases, and for some species, however, data on somatic weight might not be particularly useful. In such instances, collecting data on somatic weight would imply unnecessary lethal sampling and increase sampling time and costs. This can be the case for anguillids, such as the European eel, because the somatic weight will likely be relatively similar to the total weight due to their complex semelparous life history, long-distance oceanic spawning migration, and feeding patterns. European eel can feed on a variety of organisms, but most prey items are relatively small and include insects, worms, shellfish and small fish (Mann and Blackburn 1991; Denis et al. 2022). Although broad-headed phenotypes of eels can tear off chunks from larger prey (De Meyer et al. 2016), eels have a relatively small mouth, constraining them from swallowing whole prey items (Lammens and Visser 1989). Given their semelparous reproductive strategy, eels invest in gonadal development only once in life during the silver eel stage (Trischitta et al. 2013), developing their gonads while migrating to the Sargasso Sea to spawn (Palstra et al. 2005; Palstra and Thillart

2010). Our hypothesis is therefore that neither prey items nor the gonad tissue will affect the total weight significantly for eels caught in their residential waters. Hence, somatic weight might not be a useful measure for eel compared to other fish species, which is also reflected by the limited usage in the scientific literature, mainly found in papers studying effects of parasites and contaminants (Höglund et al. 1992; Svedäng et al. 1996; Lefebvre et al. 2004, 2013). Despite this, and the need to kill individuals to record somatic weight, somatic weight is still collected within certain monitoring programs (along with additional lethal sampling such as otoliths for ageing), for example, in the Swedish program monitoring eel along the coast, which is part of the EU DCF (Neuman et al. 1997; Swedish DCF Work Plan).

In Sweden, both total weight and two types of somatic weight have been recorded for yellow and silver eels as part of national coastal monitoring programs in the Baltic Sea and the North Sea (specifically, the Skagerrak and Kattegat regions). These efforts have generated a substantial dataset covering both total and somatic weight across a wide size range of both yellow and silver eel. In this study, we used these monitoring data to evaluate differences among these weight measurements and whether such differences vary with size and life stage. In addition, we examined the potential to accurately estimate somatic weight from observed total weight using linear regression models. Based on these estimates, we evaluated the use of estimated somatic weight to calculate body condition in comparison with using observed somatic weight, applying several commonly used body condition indices within science: the residual condition index (Fechhelm et al. 1995), Fulton's condition factor (Ricker 1975; Nash et al. 2006), and Le Cren's relative condition index (Le Cren 1951).

2 | Materials and Methods

2.1 | Study Species

The European eel is a long-lived, facultative catadromous species with a life history involving long migrations. Adults presumably spawn once in the Sargasso Sea, after which the larvae drift towards the coasts of Europe and northern Africa (Schmidt 1912, 1922). Upon arrival at the coasts, some eels ascend rivers while other individuals stay at the coast or in estuaries where they grow larger as yellow eels (Aprahamian 1988; Tesch 2003; Williamson et al. 2023). After their growth period, as yellow eels, they transition into silver eels, initiating maturation and ceasing to feed on their migration back to their presumed spawning grounds in the Sargasso Sea (Pankhurst and Sorensen 1984; Tesch 2003; Wright et al. 2022). The European eel is considered a panmictic population across the entire distribution range (Palm et al. 2009; Enbody et al. 2021).

2.2 | Database Extraction

Individual data on eels were downloaded from the publicly available Swedish Database for Coastal Fish (KUL) (KUL 2025), hosted by the Swedish University of Agricultural Sciences, Department of Aquatic Resources (SLU Aqua). All individuals with data on total length, total weight, somatic weight, life stage (yellow or silver eel) and sex (male or female) were extracted from the

database (on 19 April 2025) using R and a database connection via the R-package odbc() (Wickham et al. 2023). The extracted data included eels sampled from commercial fisheries or from fisheries-independent monitoring programs along the Swedish west and east coasts, using various gear types (fyke nets or pound nets), between the years 2007 and 2024.

2.3 | Individual Level Dissection Data

All dissections (generating the data in the database) had been performed in laboratory facilities on frozen (−18°C, 1–3 months) and thawed eels. We corrected weight and length using a freeze-shrinking correction factor (Sundin et al. 2025) before further analyses. Total length had been measured using a standard measuring board (±0.5 mm), life-stage (yellow or silver eel) had been assessed by ocular inspection of body colour and eye size, and sex (male or female) had been determined by gonad inspection. Most eels in the dataset were females, since not many male eels are caught in the gear types used in these monitoring programs.

2.4 | Somatic Weight Sampling Methods

In the database, there was data on two different types of somatic weight: one type where the digestive tract and stomach had been removed (here called: Type DS, collected 2021–2024), and another type where the digestive tract, stomach and gonads had been removed (here called Type DSG, collected 2007–2017). The total weight (±0.5 g) of the eel had been measured before collecting either of the two somatic weight measurements (±0.5 g).

2.5 | Data Filtering

In total, dissection data on 7027 individuals were downloaded from the KUL database. To find and remove potential errors in the data, we calculated the somatic to total weight ratio by dividing the somatic weight by the total weight (for both somatic weight types). Individuals with a weight ratio lower than 0.5 (i.e., meaning that the somatic weight would have been 50% or less of the total weight) were removed (excluded: $n = 3$). This was done since such large differences are likely due to measurement or data entry errors, since the stomach, digestive tract and gonads do not make up 50% or more of an eel's total weight, given their relatively small size compared to the eel's body size. We also identified another error regarding total length, where the total length was recorded as 10–24 mm, which is much smaller than the total length of a yellow or silver eel and hence an error rather than an actual measure (excluded: $n = 3$). This yielded a sample size of $n = 6999$ female eel individuals, out of which $n = 4442$ had data on Type DS somatic weight, and $n = 2557$ on Type DSG somatic weight (Table 1). In addition to the females, there were 22 males in the dataset, out of which $n = 20$ had data on Type DS and $n = 2$ had Type DSG. The two males with data on Type DSG somatic weight were excluded from further analyses due to the low sample size.

2.6 | Statistical Analysis

For all analyses, males and females were analysed separately, given the large difference in sample size. The analyses were performed similarly between the sexes, with the difference that life stage could not be included in any analyses for males (since all males were yellow eel), and the different types of somatic weight could not be analysed for males (since all males had Type DS somatic weight).

To evaluate whether total weight differs from somatic weight (Type DS or Type DSG), and whether this difference is influenced by individual traits, we calculated the somatic to total weight ratio and used this weight ratio as the response variable in our analyses. The two somatic weight types measured (Type DS and Type DSG) were associated with slightly different temporal and, to some extent, spatial sampling windows. To assess whether this could bias our results, we examined potential differences across regions and time periods. Although small differences were observed, the overall data distribution did not permit reliable inclusion of temporal or spatial parameters in subsequent analyses, and the observed differences appeared minor. Consequently, time (year or month) and space (sampling location on the Swedish west or east coast) were not considered further (see Figures S1–S5). The impact of life stage (yellow eel and silver eel), and somatic weight type (Type DS and DSG) on the weight ratio was analysed using a Wilcoxon rank test, using the R-function wilcox.test(). The effects of length and weight on the weight ratio was analysed using robust generalised linear models (GLMrob) implemented in the R-package robustbase (Maechler et al. 2024). Models tested the effects of total length and life stage (yellow or silver eel) or the effects of total weight (g) and life stage (yellow or silver eel) on the weight ratio. A gamma distribution with a log link was used, as the response variable was strictly positive and right-skewed, and relationships were multiplicative rather than additive. p values and confidence intervals were estimated using robust standard errors and normal z-distributions.

To determine whether somatic weight can be estimated from total weight, we fitted separate linear models, using the R function lm(), with somatic weight as the response variable and total weight as the predictor. For these and subsequent analyses involving estimated somatic weight, eels were categorised into four groups based on their life stage (yellow or silver eel) and type of somatic weight (Type DS or DSG). Model coefficients were then used to estimate the somatic weight. The estimated somatic weight and the observed somatic weight were used to calculate and compare three commonly used condition indices: the residual condition index (Rc), Fulton's condition factor (K), and Le Cren's relative condition index (K_n):

Residual condition index (Rc) computed using linear regressions between log-transformed weight (total weight, somatic weight or estimated somatic weight) and log-transformed total length. The residuals from these regressions were used as a length-independent index of body condition (Fechhelm et al. 1995).

Fulton's condition factor (K) is computed as $K = M \times 10^5 / L^3$, where M (g) is the weight measurement (total weight, somatic weight or

TABLE 1 | Descriptive data of the eels included in the analysis, including sex, life stage (yellow or silver eel), type of somatic weight (Type DS: removal of digestive tract and stomach or Type DSG: removal of digestive tract, stomach and gonads), number of eels within each sampling group (n), freeze-shrinking corrected mean total body length, mm (±1SD), mean total body weight, g (±1SD) and mean somatic weight, g (±1SD).

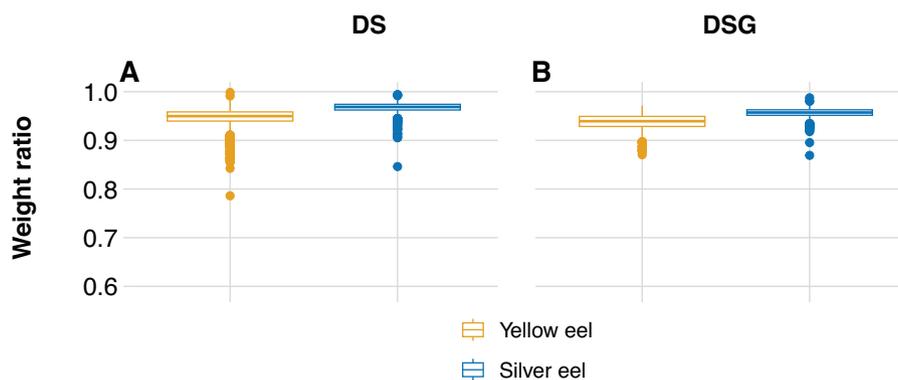| Sex	Life-stage	Som. type	n	Length, mm	Total weight, g	Som. weight, g
Female	Yellow eel	DS	2920	512 (±106)	242 (±164)	230 (±157)
Female	Yellow eel	DSG	655	605 (±104)	429 (±246)	401 (±231)
Male	Yellow eel	DS	20	377 (±28)	93 (±21)	88 (±20)
Female	Silver eel	DS	1522	769 (±81)	972 (±320)	941 (±312)
Female	Silver eel	DSG	1902	753 (±82)	883 (±304)	844 (±292)

FIGURE 1 | Boxplots showing the distribution of somatic to total weight ratio in female yellow eels (yellow boxes) and silver eels (blue boxes), for two different types of somatic weight: Panel A Type DS; weight excluding digestive tract and stomach, Panel B Type DSG; weight excluding digestive tract, stomach, and gonads. Boxes indicate the median (bold horizontal line), interquartile range (IQR), and whiskers extend to $1.5 \times$ IQR and outliers as points. N = Type DS yellow eel: 2920, silver eel: 1522, Type DSG: yellow eel: 655, silver eel: 1902. The y-axis starts at 0.6.

estimated somatic weight) and L (mm) is total length (Ricker 1975; Nash et al. 2006).

The relative condition (K_n) is computed as the observed weight measurement (M) (total weight, somatic weight or estimated somatic weight) divided by the calculated weight (M'), $K_n = M/M'$. The calculated weight was derived from coefficients from the linear relationship between weight and total length (both log-transformed) for each group ($M' = aLb$) (Le Cren 1951).

These indices allowed us to examine how the choice of weight metric affects estimates of body condition. To assess potential systematic differences among condition estimates derived from observed and estimated somatic weight, we conducted Welch's t-test using the R-function t.test().

For the male data, additional t-tests between condition indices calculated with somatic weights estimated by using conversion factors for females or conversion factors for males were performed to analyse if a sex-agnostic conversion factor could be applied to yellow eel type DS (see Table S1; Figure S6).

Data handling, filtering and visualisations were performed using the tidyverse (Wickham et al. 2019), and ggplot2 (Wickham 2016) R-packages. Significance level was set to $p = 0.05$.

Language model software was used to generate and optimise some of the R code drafts, to aid interpretation of R outputs, and

language editing (OpenAI 2025; Google 2025). All AI-generated outputs were reviewed and edited by the authors.

3 | Results

3.1 | Females

When comparing the somatic to total weight ratio for Type DS somatic weight, it ranged between 0.785 and 0.999 (including both yellow and silver eels), and for Type DSG somatic weight, it ranged between 0.869 and 0.988. The median weight ratio (±1 SD) for the yellow eel was 95 (±2) for Type DS somatic weight and 0.94 (±0.2) for Type DSG somatic weight (Figure 1). For silver eel, the median weight ratio was 0.97 (±0.1) for Type DS somatic weight and 0.96 (±0.1) for Type DSG somatic weight (Figure 1). The Wilcoxon rank test showed a difference in weight ratio between the two life stages (yellow and silver eel), ($W = 9716$, $p < 0.001$) and between the two types of somatic weight (Type DS and DSG) ($W = 6386$, $p < 0.001$).

3.1.1 | Weight Ratio—Length and Stage, Females

The analysis of the effect of total length and life-stage on the somatic to total weight ratio showed that for somatic weight Type DS and DSG, total length was a positive predictor (Table 2;

TABLE 2 | Results from robust generalised linear models examining the effects of total length (TL) or total weight (TW), life stage (yellow eel vs. silver eel), and their interaction on somatic to total weight ratio (Type DS; weight excluding digestive tract and stomach or Type DSG; weight excluding digestive tract, stomach and gonads) for female eels.

Weight ratio type	Coefficient	Estimate	Std Error	z	Pr(<|z|)
Type DS	Intercept	−6.380e−02	2.820e−03	−22.625	**< 0.001**
	TL	4.073e−05	3.649e−06	11.161	**< 0.001**
	Yellow eel	−8.135e−03	3.007e−03	−2.706	**0.007**
	TL × yellow eel	−2.368e−06	4.159e−06	−0.569	0.569
Type DSG	Intercept	−5.247e−02	2.062e−03	−25.445	**< 0.001**
	TL	1.123e−05	2.722e−06	4.126	**< 0.001**
	Yellow eel	−1.164e−02	3.050e−03	−3.490	**< 0.001**
	TL × yellow eel	−1.053e−05	4.562e−06	−2.309	**< 0.021**
Type DS	Intercept	−3.950e−02	9.600e−04	−41.151	**< 0.001**
	TW	7.247e−06	9.384e−07	7.723	**< 0.001**
	Yellow eel	−1.792e−02	1.035e−03	−17.313	**< 0.001**
	TW × yellow eel	1.428e−05	1.623e−06	8.802	**< 0.001**
Type DSG	Intercept	−4.510e−02	6.890e−04	−65.465	**< 0.001**
	TW	1.259e−06	7.379e−07	1.707	0.088
	Yellow eel	−1.576e−02	1.032e−03	−15.268	**< 0.001**
	TW × yellow eel	−5.602e−06	1.721e−06	−3.255	**0.001**

Note: Model coefficients estimated effect sizes, standard errors, z values and associated p values are reported. N = Type DS yellow eel: 2920, silver eel: 1522, Type DSG: Yellow eel: 655, silver eel: 1902. Significant results are indicated in bold ($p < 0.05$).

Figure 2A,B). For both types of somatic weight measures, yellow eels exhibited a lower weight ratio compared to silver eels—indicating a larger difference between somatic and total weight for yellow eel compared to silver eel (Table 2; Figure 2A,B). Importantly, however, the magnitude of this difference was modest; for example, the ratio is expected to increase by only 0.011 for an eel (both yellow and silver) measured using Type DS somatic weight, if it increases in length from 600 to 900 mm (i.e., smaller difference between somatic and total weight with increasing length) (Figure 2A). The effect on the weight ratio was of an even smaller magnitude for Type DSG compared to Type DS somatic weight, with an expected increase of 0.0032 for a silver eel, and 0.0003 for a yellow eel, calculated for the same increase in length (i.e., a length increase from 600 to 900 mm, Figure 2B). The statistically significant effects detected despite the small differences for both somatic weight types are probably due to the large sample size (Type DS: $n = 4442$, Type DSG: $n = 2557$).

For somatic weight Type DSG, the interaction between total length and life stage was statistically significant, suggesting that the positive relationship between total length and the weight ratio was weaker in yellow eels compared to silver eels (Table 2; Figure 2B). For somatic weight Type DSG, no statistically significant interaction was found between total length and life stage (Table 2; Figure 2A).

3.1.2 | Weight Ratio—Weight and Stage, Females

For the analysis on the effects of weight and stage on the weight ratio, total weight was a positive predictor of Type DS somatic weight, but not for Type DSG (Table 2, Figure 2C,D). The interaction between total weight and life stage was statistically significant for both Type DS and DSG, indicating that the relationship between total weight and Type DS and DSG somatic weight differed by life stage. For Type DS, there was a stronger effect on yellow eels (Table 2; Figure 2C), meaning that, for example, an increase in weight from 500 to 1000 g is associated with an expected increase in the weight ratio of 0.010 for a yellow eel and 0.0035 for a silver eel. For Type DSG, the interaction showed that in yellow eels, the effect of total weight was associated with a decrease in Type DSG weight ratio with increased total weight. Also here, the effect is modest; the weight ratio is expected to decrease by 0.0020 for yellow eels but increase by 0.0006 for silver eels, with an increase in weight from 500 to 1000 g (i.e., a larger difference between somatic and total weight for larger yellow eels).

3.1.3 | Conversion Factors—Females

The linear relationship between somatic weight and total weight was strong for female eels, regardless of the type of somatic weight used and regardless of life stage of the eel (Figure 3; Table 3).

3.1.4 | Body Condition Indices—Females

A Welch's t-test showed no difference between residual condition indices (Rc) based on estimated somatic weight, or observed somatic weight, irrespective of type of somatic weight or life stage (Table 4; Figure 4). The result was the same for both Fulton's
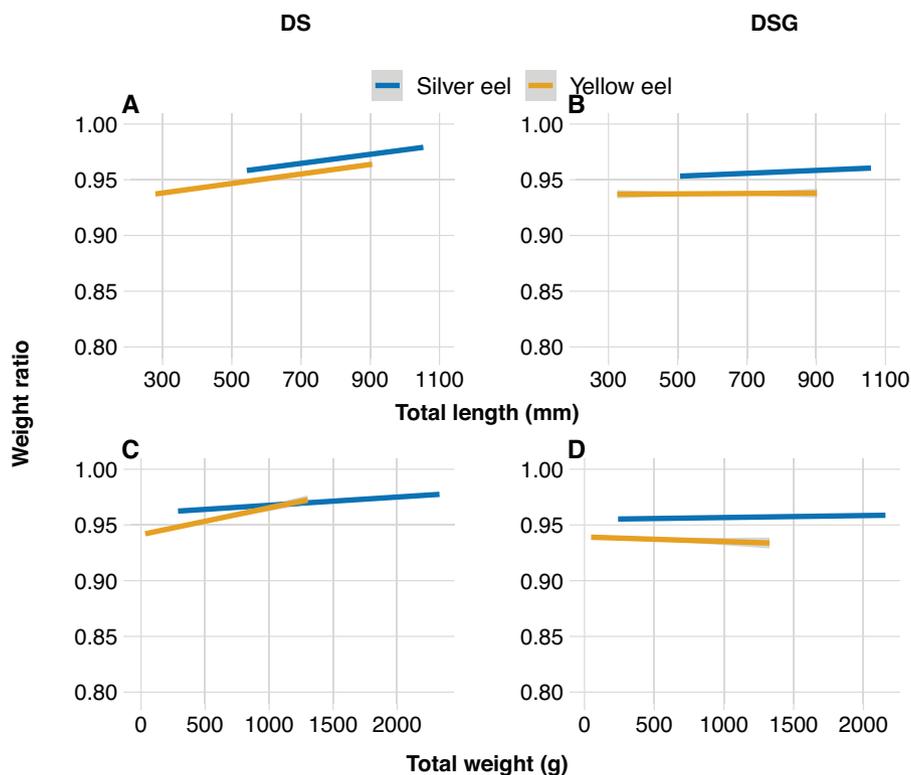
FIGURE 2 | Somatic to total weight ratio over the total span of length (Panels A and B) or total weight (Panels C and D) for female silver (blue lines) and yellow (yellow lines) eels, and 95% confidence intervals in grey (which are very narrow and therefore difficult to see in all groups). Panel A and C show the Type DS somatic weight ratio (removal of digestive tract and stomach), and Panels B and D show the Type DSG somatic weight ratio (removal of digestive tract, stomach and gonads). N = Type DS yellow eel: 2920, silver eel: 1522, Type DSG: yellow eel: 655, silver eel: 1902. All the y-axes start at 0.8 and the x-axes for length start at 250.

TABLE 3 | Coefficients from linear regression models relating somatic weight to total weight for female yellow and silver eels. Two types of somatic weight were used: Type DS (excluding digestive tract and stomach) and Type DSG (excluding digestive tract, stomach and gonads).

Life-stage	Som. weight type	Intercept, a	Slope, b	Adj. R^2	p
Yellow eel	DS	−1.507	0.956	0.999	**< 0.001**
	DSG	0.060	0.937	0.999	**< 0.001**
Silver eel	DS	−7.060	0.976	0.999	**< 0.001**
	DSG	−0.741	0.957	0.999	**< 0.001**

Note: Reported values include life stage, somatic weight type, intercept, slope, adjusted R^2 and p value for each model. N = Type DS yellow eel: 2920, silver eel: 1522, Type DSG: Yellow eel: 655, silver eel: 1902. Significant results are indicated in bold ($p < 0.05$).

condition index (K) and Le Cren's relative condition index (K_n) for all t-tests (Table 4; Figure 4).

3.2 | Males

When comparing the somatic to total weight ratio for the males, Type DS somatic weight ratio ranged between 0.904 and 0.980. The median weight ratio ($\pm$1SD) for Type DS somatic weight was 0.95 ($\pm$0.2) (only yellow eels).

3.2.1 | Weight Ratio—Length or Weight, Males

Neither total length nor total weight had any effect on the somatic to total weight ratio for somatic weight Type DS males (Table 5; Figure 5A,B).

3.2.2 | Conversion Factors—Males

The linear relationship between somatic weight and total weight was strong for male yellow eels using Type DS somatic weight (adjusted $R^2 = 0.989$, $F_{(1,18)} = 1724$, $p < 0.001$) (Figure 6). The model indicated that somatic weight increased proportionally with total weight, with an intercept of 1.086 and a slope of 0.933.

3.2.3 | Body Condition Indices—Males

A Welch's t-test showed no difference between residual condition indexes (Rc) based on estimated somatic weight, or observed somatic weight (Table 6; Figure 7). The result was the same for both Fulton's condition index (K) and Le Cren's relative condition index (K_n) for all t-tests (Table 6; Figure 7).

TABLE 4 | Results from Welch's t-test between condition indices based on estimated somatic weight and observed somatic weight for female eels.

CI	Somatic weight type	Stage	Mean diff.	95% Conf. Int	T (df)	p
Rc	DS	Yellow eel	1.39e−17	−0.006–0.006	−4.49e−15 (5836)	1.000
Rc	DSG	Yellow eel	4.27e−17	−0.017–0.017	−5.02e−15 (1306)	1.000
Rc	DS	Silver eel	4.85e−18	−0.009–0.009	−1.06e−15 (3041)	1.000
Rc	DSG	Silver eel	1.73e−18	−0.007–0.007	4.94e−16 (3802)	1.000
Fulton's K	DS	Yellow eel	9.03e−5	−0.001–0.001	0.18 (5836)	0.86
Fulton's K	DSG	Yellow eel	9.03e−05	−0.003–0.003	−0.06 (1307)	0.95
Fulton's K	DS	Silver eel	5.78e−5	−0.002–0.002	−0.06 (3041)	0.99
Fulton's K	DSG	Silver eel	−3.97e−5	−0.001–0.001	−0.06 (3802)	0.95
Le Cren's K_n	DS	Yellow eel	0.00	−0.005–0.006	0.23 (5836)	0.82
Le Cren's K_n	DSG	Yellow eel	0.00	−0.015–0.014	−0.074 (1305)	0.94
Le Cren's K_n	DS	Silver eel	0.00	−0.001–0.008	−0.06 (3041)	0.95
Le Cren's K_n	DSG	Silver eel	0.00	−0.006–0.006	−0.06 (3802)	0.95

Note: Condition index (CI), type of somatic weight (somatic weight type); Type DS with removal of digestive tract and stomach and Type DSG with removal of digestive tract, stomach and gonads, 95% confidence interval (95% Conf. Int.), mean difference (mean diff.), t value (degrees of freedom) and p value. Significant results are indicated in bold ($p < 0.05$).
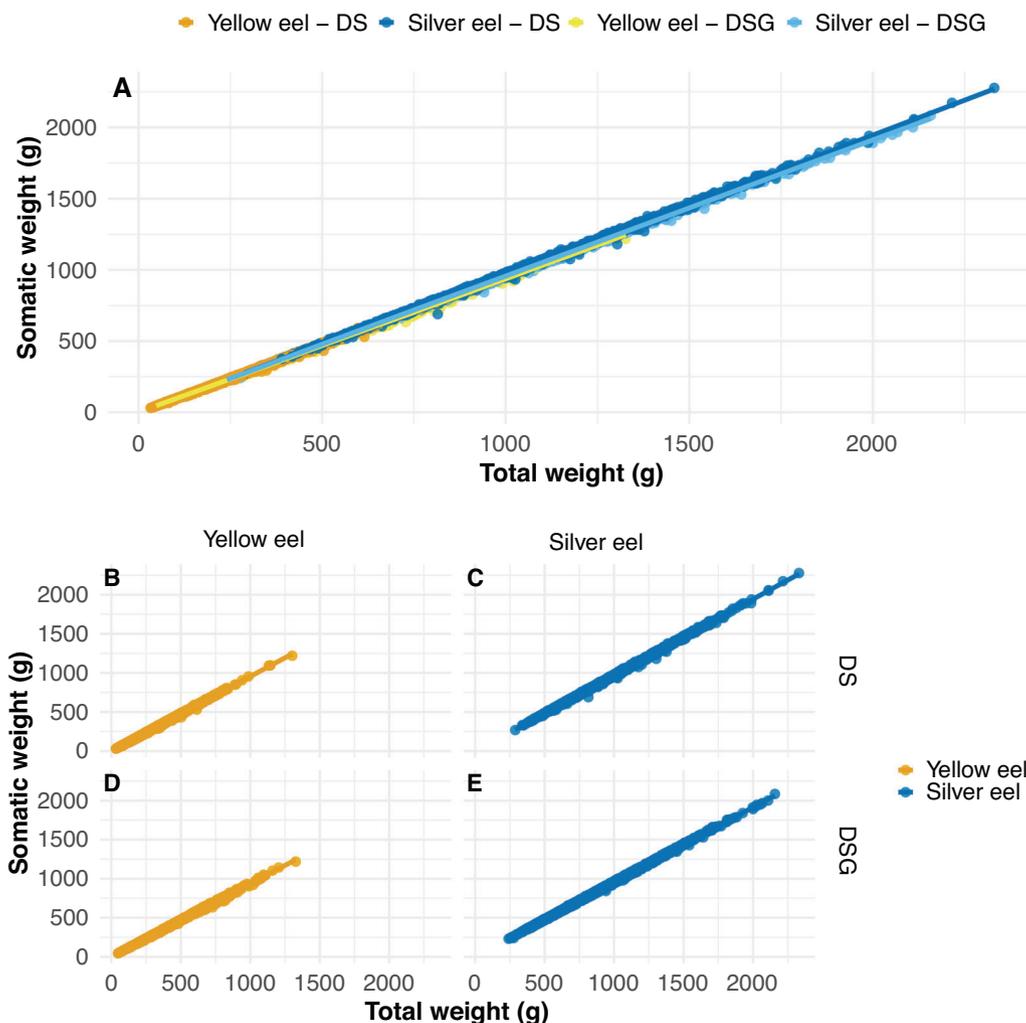
FIGURE 3 | Linear relationship between somatic weight and total weight (Type DS: removal of digestive tract and stomach and Type DSG: removal of digestive tract, stomach and gonads) for female yellow and silver eel in (A) a plot jointly displaying both stages and types and in separate plots divided by somatic weight type (Type DS: Panels B and C, and Type DSG: Panels D and E) and by life stage (yellow eels: Panels B and D and silver eel: Panels C and E). N = Type DS yellow eel: 2920, silver eel: 1522, Type DSG: yellow eel: 655, silver eel: 1902.

TABLE 5 | Results from robust generalised linear models examining the effects of total length (TL) or total weight (TW) on somatic to total weight ratio (Type DS; weight excluding digestive tract and stomach).

Weight ratio type	Coefficient	Estimate	Std. error	z	$\Pr(<|z|)$
Type DS	Intercept	−5.588e−02	7.584e−02	−0.461	0.461
	TL	2.652e−07	2.006e−04	0.001	0.999
Type DS	Intercept	−0.045	0.024	−1.863	0.062
	TV	−0.113 e−03	0.253e−03	−0.446	0.656

Note: Model coefficients estimated effect sizes, standard errors, z values and associated p values are reported. N = 20 Type DS yellow eel males. Significant results are indicated in bold ($p < 0.05$).

4 | Discussion

In this study, using individual length and weight data from 6999 female eels and 20 male eels, we show that the difference between total weight and somatic weight—expressed as the somatic to total weight ratio—was minimal for both female yellow and silver eel and for male yellow eel. For females, this was true regardless of which type of somatic weight was used (Type DS: excluding digestive tract and stomach; Type DSG: excluding digestive tract, stomach and gonads) (for male eel, only Type DS was measured). Female yellow eels exhibited slightly lower weight ratios compared to female silver eels, and the ratios tended to increase with increasing body length and weight. These differences were, however, very small. For males, neither length nor weight affected the weight ratios, but it should be acknowledged that the sample size was rather small ($n = 20$),
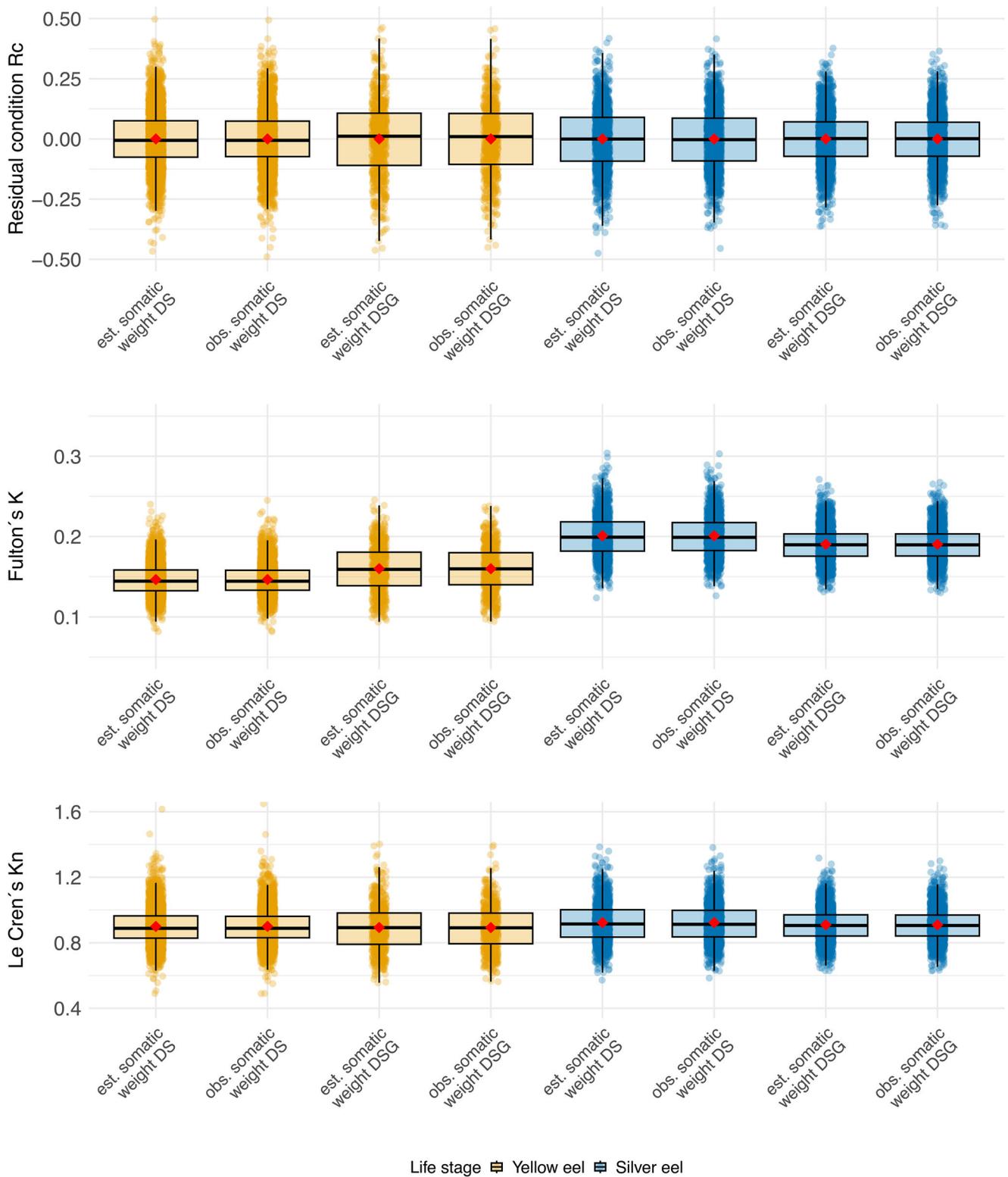
FIGURE 4 | Boxplots showing residual condition index (Rc), Fulton's condition index (K) and Le Cren's relative condition index (K_n) calculated on estimated somatic weight or observed somatic weight for Type DS somatic weight (removal of digestive tract and stomach) or Type DSG somatic weight (removal of digestive tract, stomach and gonads). Boxes are divided by life stage (yellow eels: yellow data points and silver eels: blue data points). Boxes indicate median (bold horizontal line), interquartile range (IQR), whiskers extend to 1.5 × IQR and mean (red diamonds). The *y*-axis does not start at 0.
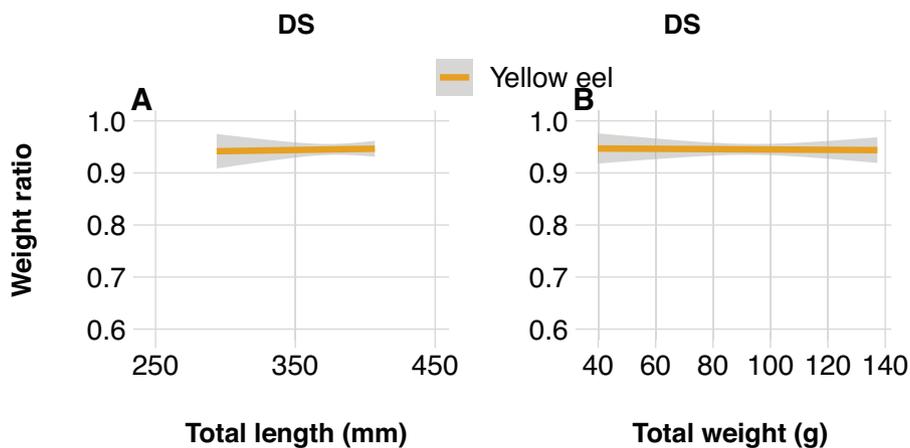
FIGURE 5 | Somatic to total weight ratio over the total span of (A) length or (B) weight for male yellow eels (yellow lines) with Type DS somatic weight (removal of digestive tract and stomach) with 95% confidence intervals in grey. $N = 20$. All the y-axes start at 0.8, and neither of the x-axes start at 0.
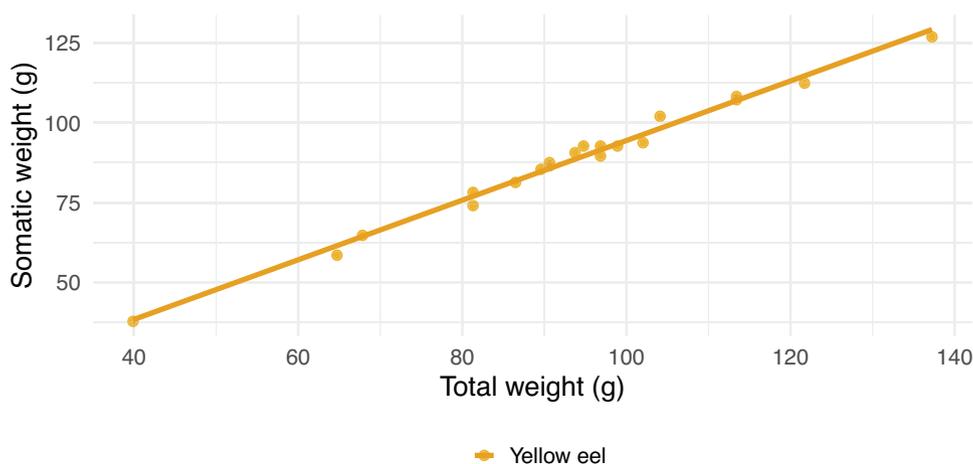

FIGURE 6 | Linear relationship between somatic weight and total weight (Type DS: removal of digestive tract and stomach) for male yellow eels ($N = 20$).

and our dataset only contained yellow eel. Hence, additional data on males would be useful to confirm the results found here. We further show that using somatic weight estimated from total weight using linear models and conversion factors does not distort condition indices for female yellow and silver eels compared to using observed somatic weight. This was also true for male yellow eels (for all three condition indices). Based on these results, we suggest that measuring somatic weight for monitoring purposes for the European eel might be redundant, since it is similar to total weight, and since it can be estimated using total weight and the conversion factors presented in this study.

Although we conclude that it may be unnecessary to measure somatic weight, we did detect some small differences between observed somatic weight and total weight. The most common explanation for these differences, and the rationale for measuring both somatic and total weight, is that they partly reflect the contribution of prey weight to total weight and partly reflect fluctuations in gonad size (Galloway and Munkittrick 2006; Skjæraasen et al. 2012). For eel, the amount and weight of prey items in the stomach and gut could lead to the small observed

difference between total weight and somatic weight (weight ratio) in our result, at least in part. In females, the small difference between the two measures corresponds to a relatively high weight ratio, indicating that prey items likely contribute less than in some other species (Mittelbach and Persson 1998; Scharf et al. 2000). One might instead expect any difference in weight ratio to be driven by the presence of gonadal tissue in female silver eels. However, this explanation appears unlikely, as our results indicate similar weight ratios regardless of whether gonads were included or excluded from the somatic weight of female eels. It should be noted that DS and DSG were derived from different sampling years, such that any differences between them may reflect a combination of biological and temporal or spatial effects that could not be explicitly accounted for.

The somatic to total weight ratios were also expected to be higher in yellow eel than in silver eel since the eel is a semelparous species which invests in gonadal development only once, during the silver eel stage, and therefore some gonad development could have potentially started in the silver eels even though they are sampled early in this process (Trischitta et al. 2013).
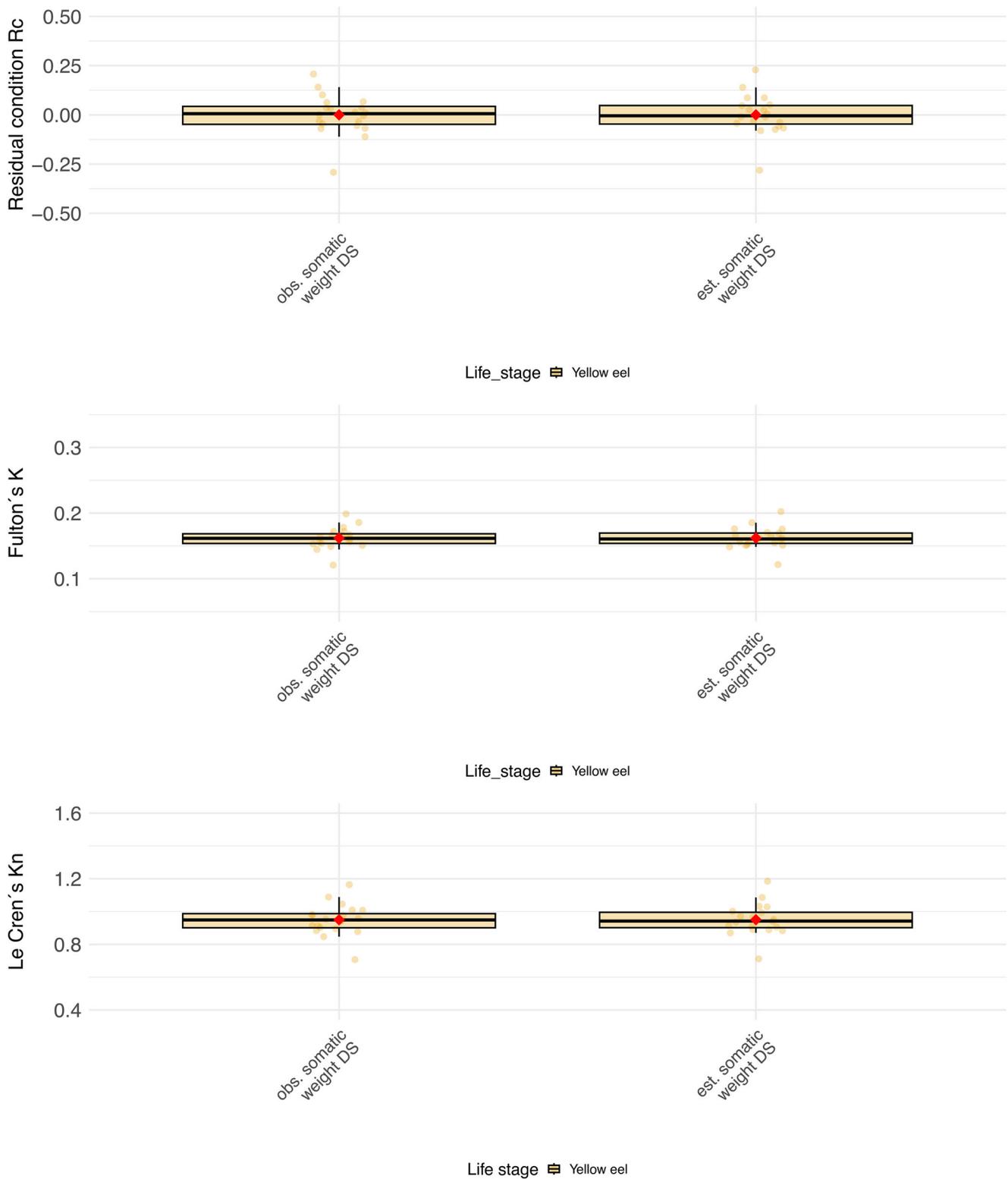
FIGURE 7 | Boxplots showing residual condition index (Rc), Fulton's condition index (K) and Le Cren's relative condition index (K_n) calculated on observed somatic weight or estimated somatic weight for Type DS somatic weight (removal of digestive tract and stomach) for male yellow eels. Boxes indicate median (bold horizontal line), interquartile range (IQR), whiskers extend to $1.5 \times$ IQR and mean (red diamonds). The y-axes do not start at 0.

On the contrary, we found slightly lower weight ratios in female yellow eels compared to silver eels. We interpret the differences in weight ratios between the life stages as more likely to be attributed to the generally higher fat content, as well as muscle increase found in silver eels compared to yellow eels (Boëtius

and Boëtius 1980; Pankhurst 1982; Parzanini et al. 2021), which could reduce the proportional impact of viscera removal in silver eels. This is further strengthened by the fact that the weight ratio increased (difference between somatic and total weight was less obvious) with increasing length and weight in both

TABLE 6 | Results from Welch's t-test between condition indices based on estimated somatic weight and observed somatic weight for male eels.

CI	Somatic weight type	Stage	95% Conf. Int	Mean diff.	T (df)	p
Rc	DS	Yellow eel	−0.065–0.065	1.214e−17	3.76e−16 (38)	1
Fulton's K	DS	Yellow eel	−0.011–0.010	0.143e−3	−0.028 (38)	0.978
Le Cren's K_n	DS	Yellow eel	0.950–0.951	−0.843e−3	−0.028 (38)	0.978

Note: Condition index (CI), type of somatic weight (somatic weight type); Type DS with removal of digestive tract and stomach, 95% confidence interval (95% Conf. Int.), mean difference (Mean diff.), t value (degrees of freedom) and p value. Significant results are indicated in bold ($p < 0.05$).

yellow and silver female eels. However, this hypothesis requires further investigation to be confirmed, as well as the inclusion of male silver eels (for this study, we only had data on 20 male yellow eels). The silver transformation is also characterised by a gradual decline and eventual cessation of feeding, along with degeneration of the stomach and other digestive organs (Pankhurst and Sorensen 1984). This could also affect the weight ratio and might explain why the ratios were lower in yellow than in silver female eel in our results (i.e., if the silver eel were less likely to have eaten). Since sampling of adult silver eel far out at sea, during their migration towards the Sargasso Sea to spawn, has not yet been successful for European eel (which it has been for Japanese eel (*Anguilla japonica*) (Chow et al. 2009; Tsukamoto et al. 2011), any eel, also silver eel, are sampled before the onset or at an early stage of gonad development and digestive tract degradation. This is hence another reason why sampling of somatic weight in the European eel is likely redundant, a conclusion supported by our results.

Although our results show that it is likely redundant to measure somatic weight in the European eel, there could be specific reasons or circumstances where such data is needed. This is why we estimated somatic weight using total weight and then tested whether condition factors calculated using the observed or estimated somatic weight would differ. We employed several condition indices that are commonly applied in fish research. Although there are varying opinions about which indices are the most appropriate in various situations (e.g., Blackwell et al. 2000; Schulte-Hostedde et al. 2005; Froese 2006), our aim was not to evaluate the relative merits of these indices. Rather, we demonstrate that, irrespective of using the estimated or the observed somatic weight in the calculations, the results are similar when assessing the body condition of female and male European eel. Although analysing a fairly large number of eel individuals, the spatial distribution of samples was limited to Swedish coastal waters. Provided the large distribution area of the European eel (i.e., all of Europe and northern parts of Africa), it would be desirable to include data from other regions to investigate if the suggested conversion factors to estimate somatic weight from total weight in this study are valid for eels from different regions as well.

Somatic weight is a lethal sampling method and reducing unnecessary lethal sampling is important from a 3R perspective, both in monitoring and fundamental research. For the European eel, minimising unnecessary lethal sampling is particularly critical due to the dramatic population decline since the 1960–1979 period (ICES 2025) and its classification as Critically Endangered (Pike et al. 2020). In addition, collecting data on somatic weight is time-consuming and therefore costly compared to measuring total weight. Since we show that it is possible to estimate somatic weight from total weight by applying a linear regression model, it is hence possible to retain the ability to use somatic weight while avoiding the need for lethal sampling. In the data used in this study, sex had been determined through ocular inspection of the gonads which requires lethal sampling. If the sex-specific conversion factors derived in this study are to be used, there are optional methods to determine the sex that do not require lethal sampling. Genetic methods (Geffroy et al. 2016) are most likely still too expensive to use in monitoring. Visual methods to distinguish between the two sexes might, on the other hand,

be useful. These methods are, however, most reliable for mature silver eels, as eye size and colour changes with maturation and European eels exhibit sex-size dimorphism (Tesch 2003). Because sex differences in weight ratios are likely mainly driven by differences in gonad size (with females generally having larger gonads), and because the difference between somatic and total weight were found to be minimal in female silver eels, this difference is likely even smaller in male silver eels. A sex agnostic conversion factor could be justified (see Supporting Information for tests on male yellow eel data) and may well be sufficient for most monitoring purposes, but since no male silver eels were included in this study and the sample size of yellow male eels was rather small, this needs to be further strengthened in other studies. Together with other improved sampling methods for measuring length and maturation stage without the need to anaesthetise the eel (Höhne et al. 2023), using estimated somatic weights can decrease the overall handling of eel even more, thereby reducing the stress of the fish and increasing sampling efficiency. This said, any modifications to long-term data series within monitoring programs should be approached with caution, as future data requirements from end users may change. One potential future need related to somatic weight in eel could involve monitoring of gonad development and reproductive strategies in silver eel during their migration to the Sargasso Sea, should oceanic sampling of silver eels become feasible, as it has been for Japanese eels (Chow et al. 2009; Tsukamoto et al. 2011). Another alternative to completely halting lethal sampling is reducing the frequency and number of individuals sampled for somatic weight and other related metrics. That would also allow other lethal data collection, such as the collection of otoliths for age analysis and otolith microchemistry. This approach would help balance an eventual need for long-term data continuity with the goal of reducing lethal sampling.

Author Contributions

P.J. and J.S. conceived the study. E.M. and P.J. performed the statistical analyses and created figures. E.M. and P.J. wrote the manuscript draft with substantial contributions from J.S. All co-authors contributed to the final draft of the manuscript and gave final approval for submission.

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Ethics Statement

Animal ethical approval was not required for this study since we analysed publicly available data downloaded from the Swedish Database for Coastal Fish (KUL) (KUL 2025), hosted by the Swedish University of Agricultural Sciences, Department of Aquatic Resources (SLU Aqua). The original data used here had been collected between the years 2007 and 2024, as part of several different monitoring programs, in accordance with the animal ethical legislation valid at that time, with the latest permit being valid from 2019 to 2024 (Dnr 5.8.18-10169/2019). The data collection complied with The Swedish Board of Agriculture's animal welfare laws, guidelines and policies as approved by The Swedish Board of Agriculture. Fisheries-dependent data collection complied with fisheries regulations and fisheries-independent data collection was performed under fisheries regulation exempts.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data and script used for statistical analyses are archived in the figshare repository (https://figshare.com/s/a941fee7162a53249f1f and https://figshare.com/s/603c27c06b7699127796), following best practices guidelines for public data archiving (Roche et al. 2015).

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary Figure: aff270203-sup-0001-figureS1.pdf **Supplementary Figure**: aff270203-sup-0002-figureS2.pdf **Supplementary Figure**: aff270203-sup-0003-figureS3.pdf **Supplementary Figure**: aff270203-sup-0004-figureS4.pdf **Supplementary Figure**: aff270203-sup-0005-figureS5.pdf **Supplementary Figure**: aff270203-sup-0006-figureS6.pdf **Supplementary Table**: aff270203-sup-0007-tableS1.docx **Supplementary Material**: aff270203-sup-0008-SuppMat.docx