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FACTORS INFLUENCING THE BODY CONDITION OF YELLOW PERCH IN MINNESOTA LAKES

by

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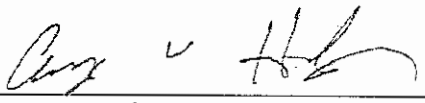

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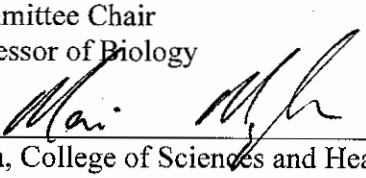

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FACTORS INFLUENCING THE BODY CONDITION OF YELLOW PERCH IN MINNESOTA LAKES

Georgina F. Leramo

Abstract.- Yellow Perch *Perca flavescens* is a key species in Minnesota lakes, fulfilling ecological roles as both an important forage fish and a harvested sport species. Understanding factors influencing body condition can provide insight into population health and ecosystem dynamics. In this study, we assessed relative condition (Kn) of Yellow Perch from 27 Minnesota lakes sampled between 2017 and 2021 and evaluated environmental and biological predictors of variation in Kn. Relative condition was calculated using sex-specific length-weight relationships, and mixed-effects models were used to assess predictors of Kn with lake included as a random effect. Model selection was based on Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). We found that males exhibited higher Kn than females across lakes. Body condition declined with increasing age and surface temperature in both sexes, with a strong temperature effect observed in females. Kn varied by gear types, likely reflecting biological differences, gear selectivity, or habitat use during sampling. There was a gradual decline in female Kn from 2019 to 2021, with no effect in males. Secchi depth, Age/length at maturity, and Walleye Kn showed no influence on Yellow Perch condition. These results indicate that Yellow Perch body condition varied among lakes and was primarily influenced by biological factors and thermal conditions, suggesting that sex-specific effects and variation among lakes should be considered when assessing Yellow Perch populations in Minnesota.

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Introduction

The recent decline in fisheries resources has been a subject of global concern (Teh and Sumaila 2020). This decline has resulted in a significant shift into a new state of many fisheries affecting not only livelihood but also the gross domestic product (GDP) of countries that depend on these resources (Abdul and Adekoya 2016). As defined by Bradley et al. (2019), fisheries management is a complex socio-political process, and currently, there is no consensus on the best way to improve global fisheries. Worldwide, various management systems have been put in place to address the global decline in fisheries such as catch quotas and gear restrictions. Regardless of the management system, having access to reliable, consistent data about the state

of a fishery along with details on the types, locations, and quantities of species being caught is essential for establishing effective fishery management (Wilson et al. 2018).

Meristic and morphometric data are essential for monitoring factors that influence fish populations, playing a key role in fisheries management (Otuu et al. 2023). Morphometric data are used to determine the growth characteristics of a species through the length-weight relationship (Morato et al. 2001). This relationship provides information about life history, growth patterns, general health, stock assessment, and fish population dynamics. It is also useful in ascertaining morphological characteristics, comparing life history traits of populations from different regions, and evaluating suitability of the environment (Le Cren 1951; Froese 2006; Jisr et al. 2018). Among these life-history traits, reproductive investment (e.g., gonadal development, oocyte size, fecundity) provides deeper insights into species ecology and can be used to estimate recruitment potential (Armstrong and Witthames 2012). Accurate evaluation of gonadal development during the reproductive cycle is essential for assessing reproductive strategies in fishes, including size at sexual maturity, fecundity, spawning time, and seasonality (Murua and Motos 2006).

Another essential component in fisheries management is assessing fish body condition, which provides insight into the health of fish population by examining the relative plumpness or fatness of individual fish (Le Cren 1951; Ricker 1975; Ogle 2016). Body condition serves as a useful indicator for understanding fish survival, reproduction, maturity, and overall health. It can also reflect water quality and general health of fish populations within specific habitats or ecosystems (Ridanovic et al. 2015). The body condition of fish can be affected by factors related to length, sex, and other long-term features such as food supply and degree of parasitism. Given these factors, the body condition is frequently quantified by fisheries biologists through indices such as Fulton's condition factor (K), relative weight (Wr), or relative condition factor (Kn). Kn is expressed as the ratio of observed weight of a fish to its expected weight derived from population specific length-weight relationships, which serves as a standardized measure of body condition. This index provides insight into the well-being and energy reserves of individual fish and is widely used to assess habitat quality, food availability, and population health (Le Cren 1951; Anderson and Neumann 1996; Froese 2006). While body condition describes the overall state of a fish, Kn provides a standardized, numerical way to measure and compare condition among individuals, populations, and habitats.

Body condition is not only useful for monitoring the health of fish, but it can also provide insights into the environment in which the fish are living (Chapman et al. 2021). Fish exploitation can significantly alter the condition of a population by decreasing the abundance, biomass, and mean size (Nicholson and Jennings 2004). Under moderate exploitation, body condition may initially improve due to reduced intraspecific competition and greater food availability. However, as exploitation increases, it may lead to the selective removal of high condition individuals, potentially causing shifts in life history (e.g., earlier maturation at smaller sizes) that may result in declining mean condition, particularly when populations are simultaneously affected by environmental stressors (Pierce et al. 2006; Holbrook et al. 2022). These observed changes in body condition highlight the complex relationship between fishing pressures, environmental factors, and population dynamics (Rouyer et al. 2008).

Body condition can also be affected by factors other than exploitation because significant shifts in the condition of previously unexploited or lightly fished populations are well-documented, particularly for species with long lifespans (Wyanski et al. 2000). Large-scale biological factors like climate change, habitat degradation, and the introduction of invasive species are increasingly impacting fisheries across traditional regulatory boundaries (Havel et al. 2015; Huang et al. 2021). Additionally, changes in land use practices, such as increased agricultural area, lakeshore development, and urbanization, have led to elevated nutrient loading and alterations in hydrological processes within lakes, causing potentially adverse physiological and morphological impacts on fish and their overall body condition (Kissoon et al. 2013). Yellow Perch populations have shown significant fluctuations in size, largely due to instability with recruitment and the impacts of recreational and commercial fishing (Marsden and Robillard 2004). The mechanisms governing Yellow Perch recruitment are complex and influenced by multiple environmental and ecological factors (Dembkowski et al. 2017; Brandt et al. 2022).

Similar environmental factors, such as habitat availability, water temperature, and predation may influence recruitment of both Yellow Perch and the closely related percid, Walleye (*Sander vitreus*). Observed declines in Walleye recruitment across parts of the Upper Midwest and Great Lakes regions have raised concerns about the potential implications for Yellow Perch recruitment (Honsey et al. 2016; Brandt et al. 2022). Water clarity is an important environmental factor for percids. Hansen et al. (2022) highlighted that Walleye and Yellow Perch respond differently to changes in their environment, including water clarity. This variation

occurs across different lakes and shows the complexity of these systems. Their review found that higher water clarity is often linked to lower Walleye abundance, biomass, and production. However, these responses differ based on lake productivity, habitat structure, and food web interactions. However, in turbid waters, fish may benefit from protection against predators, despite being smaller due to reduced foraging capacity (Pangle et al. 2012; Bunnell et al. 2021). Skolte et al. (2021) found an opposite pattern in Lake Shaokatan, Minnesota, where increased water clarity resulted in Yellow Perch exhibiting smaller total lengths and lower relative weights. Similarly, Holbrook et al. (2022) also found that increased water clarity was correlated with a smaller female length at 50% maturity in 17 Minnesota lakes. These contrasting findings suggest that the effect of water clarity on Yellow Perch growth may vary across ecosystems and can be influenced by additional interacting factors.

In the past, Yellow Perch populations in Minnesota exhibited significant fluctuations in both abundance and individual growth rates. Bethke and Staples (2015) documented a decline in gill net catch rates of Yellow Perch in Minnesota since 1970s, which Holbrook et al. (2022) linked to a shift toward smaller size structure and reduced catchability, likely indicating life history characteristics have changed over time. Yellow Perch body condition is affected by various environmental, biological, and ecological factors in Minnesota lakes. Skolte et al. (2021) found that the abundance of Yellow Perch increased, leading to intraspecific competition, reduced the length and body condition of Yellow Perch. Roberts et al. (2012) demonstrated that hypoxia can impact the foraging behavior of Yellow Perch, potentially affecting their prey consumption and distribution in lakes, while Chabot and Dutil (1999) found that hypoxia can reduce feeding and growth in fish. Similarly, Thambithurai et al. (2019) showed that under low-oxygen conditions, fish reduce activity, which limits foraging and decreases energy intake. These findings suggest that hypoxia can decrease Yellow Perch body condition, as restricted access to prey reduces the energy available for growth, thereby decreasing weight relative to length.

Interactions with other fish species, such as Walleye, can lead to shifts in Yellow Perch population and size structure due to predation dynamics (Ivan et al. 2011). For example, Mille Lacs Lake, Minnesota, has experienced a decline in its Walleye population, which occurred simultaneously with a reduction in thermal-optical ecosystem area (Hansen et al. 2019). This change is likely driven by warming water temperatures and enhanced water clarity (Hansen et al.

2019). As a co-occurring species, Yellow Perch may also be indirectly affected by these ecosystem changes through reduced predation from Walleye, altered habitats, and food web changes, which may influence their body condition (Jacobson et al. 2010; Strayer et al. 1999). Stocking practices can also affect predator-prey relationships within lakes, consequently impacting Yellow Perch populations (Pierce et al. 2006). Additionally, Yellow Perch also exhibits seasonal variation in habitat use (Feucht et al. 2023), which may influence exposure to biotic interactions. Experimental evidence suggests that interspecific interactions can influence fish growth rates (Yao et al. 2024).To better understand how predation dynamics, competition, habitat, and environmental factors influence the body condition of Yellow Perch in Minnesota lakes, the objective of this study was to characterize patterns in the relative condition (Kn) of Yellow Perch from 27 lakes by sex, age/length of maturity, year, Julian day and gear type (gill net fine-mesh, gill net, and standard electrofishing). Additionally, we examined the relationship between relative condition (Kn) of Yellow Perch and Walleye, and the influence of water clarity on the body condition of Yellow Perch.

Methods

Sampling design

All field data were collected by the Minnesota Department of Natural Resources (MN DNR) and a detailed description of collection methods can be found in Holbrook et al. (2022). Field data were collected using gill net fine-mesh and standard electrofishing from 26 August 2019 through 27 September 2021 in 27 lakes selected across Minnesota.

A minimum of three fine mesh gill nets were set at various lake locations to collect samples of at least 300 Yellow Perch from depths of 4.6 - 7.6 m. Nets were set overnight during a 24- hour soak time, avoiding highly vegetated areas and hypoxic water. Nets were lifted the next day with fish sorted according to mesh sizes. Sex, maturity, and lengths were measured for a subsample of 25 fish, or all fish if less than 25 fish were captured. To facilitate data collection, fish were sorted into the following four categories according to gonad development: immature male, mature male, immature female, mature female. Otoliths were collected from five individuals of each sex per 10 mm length group. Weights for each fish with an aging structure

were collected to the nearest 0.1 g. Walleye samples that were caught as bycatch were measured and weighed.

Standard electrofishing was conducted at a minimum of two sites for up to 60 minutes or until a minimum of 250 Yellow Perch were collected. Yellow Perch were captured using small mesh (~6 mm) dip nets. All Yellow Perch samples were processed in the laboratory, where lengths (± 1 mm), weights (± 0.1 g), sex, and maturity were recorded for each fish. Otoliths were collected from five individuals of each sex per 10 mm length group for age assessment.

Standard gill nets were also set at least once on all study lakes between 2017 and 2021 as part of a standard MNDNR lake survey following the standardized lake survey protocol (MNDNR 2017). Secchi depth measurements were collected at established water quality stations on each lake. Mean Secchi depth for each sampling year was calculated from measurements collected in July, August, and September, using data from the MPCA (Minnesota Pollution Control Agency) and MN DNR.

For age assessments, otoliths were removed, cleaned, and stored individually. For Yellow Perch less than 5 years old, ages were estimated by placing dried whole otoliths in a solution of 70% isopropyl alcohol and using a stereomicrocope with transmitted light. For Yellow Perch age 5 years and older, or where the whole otolith age was not definitive, otoliths were cracked, toasted on a hot plate, mounted in clay, and a drop of immersion oil was used on the surface prior to viewing through a stereomicroscope with a polarized ring light. All otoliths were evaluated by a minimum of two independent readers and otoliths were reexamined until an age was mutually agreed upon. Initial agreement in age estimates was > 90%. Surface temperature was the average surface temperature in June, July, and August modeled using meteorological inputs and multiple modeling frameworks based on work by Corson-Dosch et al. (2023).

Body Condition

Body condition was estimated from the calculation of relative condition (Kn) indices for Yellow Perch and Walleye (Le Cren 1951). The relative condition (Kn) of individual Yellow Perch was calculated directly from the study dataset, making it appropriate for populations sampled across a wide size range, including smaller individuals. Length-weight regressions were

developed from all valid lengths and weights of Yellow Perch collected during sampling. Kn was calculated for individual Yellow Perch and Walleye using the formula:

$$K_n = W/W'$$

where W is the weight of an individual fish and W' is the length-specific expected weight for a fish as predicted by a weight-length regression equation calculated for all study lakes combined. A similar approach was applied to Walleye to generate lake-year averages.

Sex-specific length-weight regressions were developed for males and females. These regressions were then used to recalculate Kn for each sex separately, accounting for sex-related differences. The relative condition (Kn) was chosen over other indices (e.g., Fulton's K) as it is suitable for species exhibiting allometric growth patterns, whereas Fulton's K assumes isometric growth and may not accurately reflect condition under allometric growth (Hards et al. 2019).

Statistical analysis

To evaluate the influence of biological and environmental predictors on Yellow Perch relative condition (Kn), linear mixed-effects models (LMMs) were used. Kn was tested as a response variable, with lake included as a random effect to account for repeated measures and unequal sample sizes among lakes. Fixed effects included sex, surface temperature, age, year, gear type (fine-mesh gill net (GFM), gill net (GN), and standard electrofishing (SEF)), water clarity (Secchi depth), age/length of maturity (A50, L50), and Walleye Kn.

The effect of sex was tested to determine whether it had a significant influence by comparing a null model (Kn ~ (1|Lake)) with a model that included sex as a fixed effect (Kn ~ Sex + (1|Lake)). Once sex was confirmed to have a significant influence on Kn, sex-specific models were fitted separately for males and females, using lake as a random effect and other predictors as fixed effects. Additional sex-specific models were fitted by adding gear type as a fixed effect to predictors that showed support in the initial analyses (temperature, age, year, and Julian Day).

All analyses and figures were conducted in R version 4.4.2 (R Core Team, 2024). Mixed-effects models were fit using the lme4 package (Bates et al., 2015), and model comparisons were based on Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC)

selection criteria. The lme4 package does not provide denominator degrees of freedom or p-values for mixed-effects models, p-values were approximated using the standard normal distribution based on the model t-statistics ($P=2(1-\Phi(|t|))$). Finally, a one-way analysis of variance (ANOVA) was used to compare mean summer surface temperatures across lakes and years to determine if there were significant differences.

Results

The effect of sex on body condition using Kn was evaluated using 9,516 individual Yellow Perch from 27 Minnesota lakes sampled between 2017 and 2021. Of these, 5,856 were females and 3,660 were males (Tables 1 and 2). A mixed-effect model revealed sex significantly influenced Kn, with model including sex (Kn ~ sex + (1|Lake)) showing improved fit over the null model (ΔAIC = -234.16; ΔBIC = -227.0; Table 1). Males exhibited higher values than females (Coefficient = 0.035, 95% Cl = 0.031 - 0.039, P < 0.001; Table 3; Figure1). Based on this result, subsequent mixed-effects models were conducted separately for females and males, with each predictor compared against its corresponding null model (Tables 1 and 2).

For female Yellow Perch, the model including age was best supported predictor of Kn (ΔAIC = -179.98; ΔBIC = -173.67; Table 1), with a significant negative slope associated with increasing age (Coef. = -0.018, 95% Cl = -0.021 to -0.016, P < 0.001; Table 3). Gear type influenced Kn (ΔAIC = -90.69; ΔBIC = -77.34), with GN and SEF gears exhibiting higher values (Coef. = 0.045, 95% Cl = 0.033 - 0.056, P < 0.001; and 0.029, 95% Cl = 0.023 - 0.036, P < 0.001, respectively). Models including surface temperature were also supported (ΔAIC = -15.45; ΔBIC = -8.84), with a significant negative slope and Kn declining with warmer summer temperatures (Coef. = -0.025, 95% Cl = -0.034 to -0.015, P < 0.001; Figure 2). Models testing the effect of year (ΔAIC = -22.4; ΔBIC = -2.37) showed moderate support, with Kn declining slightly over time with significant negative slope (2019 Coef. = -0.026, P = 0.009; 2020: -0.045, P < 0.001; 2021: -0.064, P < 0.001). Secchi depth (Coef. = 0.002, 95% CI = -0.007 to 0.010, P = 0.70), Walleye Kn (Coef. = -0.010, 95% CI = -0.116 to 0.096, P = 0.85), L50 (Coef. = 0.001, 95% CI = 0.00 - 0.001, P = 0.009), and A50 (Coef. = 0.025, 95% CI = 0.002 - 0.049, P = 0.04) showed weak effects and did not improve model fit (Table 1 and 3).

For male Yellow Perch, model including age was also the best supported predictor of Kn (ΔAIC = -89.68; ΔBIC = -83.92; Table 2), with a significant negative slope associated with increasing age (Coef. = -0.020, 95% CI = -0.024 to -0.017, P < 0.001; Table 4; Figure 3). The model including gear type provided moderate support (ΔAIC = -32.47; ΔBIC = -20.06), with GN and SEF gears exhibiting higher values (Coef. = 0.029, 95% CI = 0.012 - 0.046, P = 0.001; and 0.030, 95% CI = 0.022 - 0.039, P < 0.001; Table 4; Figure 4). Surface temperature showed minimal support and was not supported by BIC (ΔAIC = -5.16; ΔBIC = 0.95), although the negative slope remained significant (Coef. = -0.024, 95% CI = -0.036 to -0.012, P < 0.001; Figure 2). Models including Secchi depth (ΔAIC = 10.47; ΔBIC = 16.57) and year (ΔAIC = 11.52; ΔBIC = 30.13) were not supported. Year effects were weak and not significant (2019 Coef. = 0.016, P = 0.42; 2020: -0.005, P = 0.78; 2021: -0.014, P = 0.55; Figure 5), and other biological predictors (A50, L50, Walleye Kn) showed no improvement in model fit (Table 2).

Relationship slopes between Yellow Perch Kn and Secchi depth, L50, and Walleye Kn were near zero for both sexes, with ΔAIC and ΔBIC values indicating poor model fit. A50 showed a weak positive relationship with Kn in females and a weak effect in males (Figures 6 - 9).

To evaluate whether the sampling method influenced model performance, gear type was added as a predictor to models that showed support in the initial analysis. For both sexes, including gear type improved model support for temperature, age, and year, as indicated by lower AIC and BIC values compared with models without gear type (Tables 8 and 9). In contrast, adding gear type to the Julian Day model produced little improvement, particularly for males.

Lake-specific Intercepts

Intercept values for female and male Yellow Perch varied across lakes, with no consistent pattern. Confidence intervals suggested spatial differences in condition after accounting for fixed effects (Figures 10 and 11). For females, the intercept varied across lakes, with Big Sandy, Big Stone, and Bemidji showing the highest intercepts, while Pelican, Minnie-Belle, and Bald Eagle showed the lowest intercepts (Figure 10). For males, the intercept varied across lakes, with Big

Sandy, Big Stone, and Cloquet showing the highest intercepts, while Pelican, Minnie-Belle, and Bald Eagle showed the lowest intercepts (Figure 11).

Interannual Variation in Mean Summer Surface Temperature

Mean summer surface temperature differed significantly among years (one-way ANOVA: $F_{2,32} = 3.98$, $p = 0.029$; Figure B1). Assumptions of normality (Shapiro-Wilk test: $W = 0.94$, $p = 0.053$) and homogeneity of variance (Bartlett's test: $K^2 = 4.99$, $p = 0.083$) were met. Tukey's post hoc comparisons indicated that summer temperature was significantly higher in 2020 than in 2019 (mean difference = 1.67°C, $p = 0.024$), whereas temperatures in 2021 did not differ significantly from those in 2019 or 2020.

Discussion

The findings of this study indicate that Yellow Perch body condition differs among lakes, with lake-specific effects accounting for variation in condition factor (Kn). Observed differences between lakes suggest that lake-specific factors likely have a greater impact than any of the predictors. Previous research similarly demonstrates that Yellow Perch ecological responses, including growth, condition, and trophic interactions, vary among lake systems and environmental factors (Vander Zanden et al. 2017; Hansen et al. 2020). Variation in lakes likely reflects unmeasured environmental and biological differences among systems, including variation in prey community composition, productivity, and habitat.

Body condition differed between males and females, as indicated by the substantial improvement in model fit when sex was included as a fixed effect. Sex related differences in condition are well documented in teleost fishes and mostly reflect variation in growth patterns, energy allocation, and reproductive investment (Nikolsky 1963; Wootton 1998). Hayes and Taylor (1994) demonstrated that males and females Yellow Perch differ in gonadal development timing, with males finishing mid-October, while females develop gradually through winter, this reflects a trade-off in energy allocation between reproduction and body reserves, driving differences in body condition. Field observations were consistent with this pattern, as some males appeared reproductively developed in September, whereas most females were only beginning to develop their eggs. Hayes and Taylor (1994) reported that gonadal development in both sexes coincided with declines in somatic fat and energy reserves. Similarly, condition

indices vary seasonally in association with changes in energy allocation among body tissues during the reproductive cycle (Brown and Murphy 2004). Consequently, reproductive differences at the time of sampling may have contributed to the observed sex-specific variation in Kn. Sex was therefore included as fixed effect in the full dataset following recommended linear mixed effects modeling practices (Zuur et al. 2009).

In this study, age was a significant predictor of Kn in Yellow Perch and explained a substantial proportion of the variation in body condition across lakes for both sexes, with the model including age performing substantially better than the null model. Condition factor (Kn) declined with age, a trend that may reflect underlying energy allocation trade-offs between somatic maintenance and reproductive investment (Roff 1983; Morgan and Colbourne 2004). As Yellow Perch mature, more energy may be allocated to gonadal development and spawning activities, which may diminish lipid stores through the breeding season and into the period after reproduction (Henderson et al. 2000). According to Beverton and Holt (1957) and Weatherley and Gill (1987), age reflects ecological experiences and physiological changes a fish undergoes over its lifetime. Therefore, declining Kn with age may also result from the accumulation of ecological stressors, including prolonged environmental fluctuations, competition, and foraging (Lloret et al. 2013; Luhring and Holdo 2015). Growth rate can decline with age (Post and Parkinson 2001), as older fish typically exhibit slower growth rates and lower feeding efficiency, which can contribute to declining body condition (Headley and Lauer 2008).

Higher summer temperatures may cause earlier maturity in Yellow Perch and reduce longevity, as temperature has been shown to influence age at maturation independently of fish growth (Kuparinen et al. 2012). Hokanson (1977) documented that growth and survival in percids are strongly influenced by temperature and are typically maximized near species thermal optima within their physiological tolerance limit. In this study, surface temperature was a significant predictor of Yellow Perch Kn, with female fish showing stronger negative effects than male. These findings support previous research, which showed that the physiology of fish relative to metabolism and energy budget is influenced by thermal condition (Hokanson 1977; Easwaramoorthy et al. 2025).

Water temperature is the primary driver of spawning onset/duration in Yellow Perch, and as regional climate warms, spawning is likely to occur earlier (Starzynski and Lauer 2014).

Overwinter thermal conditions influence female Yellow Perch somatic composition (Feiner et al. 2016), and elevated temperature disturbs larval metabolism and swimming performance in Yellow Perch (Easwaramoorthy et al. 2025). Recent evidence also suggests northern lakes, including Minnesota lakes, are experiencing long-term changes in thermal patterns due to climate change, although rate of warming varies by season (Winslow et al. 2017; Schoenebeck et al. 2026). These findings suggest that climate change may alter physiological and reproductive processes that influence body condition. Elevated summer temperature may increase metabolic demand, leading to earlier maturation and potentially reducing lifespan due to life history trade-offs between reproduction and survival (Audzionyte and Richards 2018). In addition, ovarian development in females requires substantial energetic investment (Wootton 1998; Peng et al. 2025). In contrast, males showed less sensitivity to temperature as their Kn indicate a weak temperature response within the tested ranges. The study lakes showed linear decline in condition with increasing summer temperature, while earlier studies reported a nonlinear growth response (Neuheimer and Taggart 2007), suggesting that observed temperature in Minnesota study lakes (approximately 19-27 °C) may extend beyond the optimal thermal range for Yellow Perch (approximately 20-23 °C) (Duxbury 2020).

Fish habitat use shows a trade-off between food availability and predation risk, with nearshore habitats providing higher food resources but potentially higher predation (Werner and Hall 1988; Bystrom et al. 2003). Both sexes and gear types showed differences in Kn, with female Yellow Perch exhibiting higher Kn for gill net and electrofishing sampling than gill net fine-mesh. Electrofishing typically captures fish nearshore, whereas gillnets are set offshore (Bonar 2012). Yellow Perch undergoes seasonal movements between nearshore and offshore (Tabor et al. 2025). Yellow Perch occupying these habitats may differ in body condition due to variation in prey availability and habitat quality. Gill nets often capture active fish, whereas electrofishing efficiency varies with size and environmental factors (Fischer and Quist 2014). Freshwater sampling gears capture fish non-randomly with respect to size, behavior, and habitat (Guy and Brown 2007; Bonar et al. 2012). The observed differences in Yellow Perch Kn likely show a combination of gear selectivity, seasonal differences, and biological differences. However, because electrofishing and gill net fine-mesh sampling were both conducted at the same time of year, seasonal differences are unlikely to explain the observed difference. The consistently lower body condition with gill net fine-mesh in both sexes, together with the higher

body condition observed in gill net and electrofishing samples, suggests gear selectivity, habitat use, or both may have contributed to the observed variation.

Previous research has shown that water clarity can influence fish ecology and performance, but responses differ among freshwater bodies (Manning et al. 2013; Bunnell et al. 2021). Surprisingly, Secchi depth did not have a significant effect on Yellow Perch Kn, suggesting that body condition may be maintained across the normal environmental optical range of the study lakes. Similar relationships have been observed in western Lake Erie, age-0 Yellow Perch growth and abundance varied with water clarity in complex ways that were not directly explained by Secchi depth (Manning et al. 2013). Water clarity impacts fish foraging behavior and their habitat structure, but its effect on fish condition is inconsistent (Bunnell et al. 2021). However, water clarity can alter predator-prey interactions and feeding efficiency (Utne-Palm 2002). The lack of a detectable effect on condition suggests that Yellow Perch may maintain energetic balance across the observed water clarity ranges, with factors such as prey availability, habitat structure, and temperature showing stronger influences. The relationship between water clarity and condition is highly system-specific (Bunnell et al. 2021).

Yellow Perch are important forage species for predators such as Walleye and Northern Pike (Glade et al. 2023), and successful management of their population is likely complex due to the influence of multiple interacting environmental and biological factors. The results of this study indicate that Yellow Perch body condition in Minnesota lakes is influenced by age, surface temperature, gear type, year, and Julian day, with these predictors differing between male and female sex-specific models. As body condition is linked to growth, survival, and reproduction, it may have an important effect on their productivity. Understanding how environmental and biological predictors interact to influence Yellow Perch body condition will help improve our ability to anticipate future climate changes and support effective management and conservation of Yellow Perch populations across Minnesota lakes.

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TABLES

Table 1: Definitions of variables and terms used in linear mixed-effects models of Yellow Perch relative condition factor (Kn) across 27 study lakes (2017-2021).

Variable	Description
Kn	Relative condition factor of Yellow Perch
Age	Age of Yellow Perch (years)
Sex	Sex of Yellow Perch (male and female)
Temp	Mean surface water temperature (°C)
Secchi	Secchi depth (m), used as an index of water clarity
Geartp	Capture method (gill net, standard electrofishing, and gill net fine-mesh
JD	Julian Day
Year	Year of sampling (2017-2021)
A50	Age at 50% maturity of Yellow Perch (years)
L50	Length at 50% maturity of Yellow Perch (mm)
WAE	Walleye relative condition

Table 2. Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), change in AIC (ΔAIC), change in BIC (ΔBIC), and sample size (n) for linear mixed-effects regression model of the effect of sex on Yellow Perch relative condition (Kn) using the full dataset for all 27 Minnesota lakes (2017-2021). Lake was included as a random effect.

	Models	**AIC**	**ΔAIC**	**BIC**	**ΔBIC**	**n**
Sex effect	Kn ~ (1|Lake)	-15762.1	0	-15740.6	0	9516
	Kn ~ sex + (1|Lake)	-15996.3	-234.16	-15967.6	-227	9516

Table 3: Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), change in AIC (ΔAIC), change in BIC (ΔBIC), and sample size (n) for linear mixed-effects regression models evaluating environmental (Env) and biological (Bio) predictors of female Yellow Perch relative condition (Kn) for all 27 study lakes. Each model was compared with its corresponding null model, with lake as a random effect.

	Models	**AIC**	**ΔAIC**	**BIC**	**ΔBIC**	**n**
Env predictors	Kn ~ (1|Lake)	-9981.05	0	-9961.03	0	5856
	Kn ~ Geartp +(1|Lake)	-10071.7	-90.69	-10038.4	-77.34	5856
	Kn ~ (1|Lake)	-9307.67	0	-9287.84	0	5485
	Kn ~ Temp + (1|Lake)	-9323.12	-15.45	-9296.68	-8.84	5485
	Kn ~ (1|Lake)	-9981.05	0	-9961.03	0	5856
	Kn ~ JD + (1|Lake)	-9991.74	-10.692	-9965.04	-4.016	5856
	Kn ~ (1|Lake)	-9981.05	0	-9961.03	0	5856
	Kn ~ Year + (1|Lake)	-10003.4	-22.4	-9963.4	-2.37	5856
	Kn ~ (1|Lake)	-9307.67	0	-9287.84	0	5485
	Kn ~ Secchi + (1|Lake)	-9296.78	10.89	-9270.34	17.50	5485
Bio Predictors	Kn ~ (1|Lake)	-6781.75	0	-6762.85	0	4030
	Kn ~ Age + (1|Lake)	-6961.73	-179.98	-6936.52	-173.67	4030
	Kn ~ (1|Lake)	-9119.32	0	-9099.55	0	5394
	Kn ~ A50 + (1|Lake)	-9114.71	4.61	-9088.34	11.20	5394
	Kn ~ (1|Lake)	-9119.32	0	-9099.55	0	5394
	Kn ~ L50 + (1|Lake)	-9107.93	11.39	-9081.56	17.98	5394
	Kn ~ (1|Lake)	-8920.79	0	-8901.14	0	5179
	Kn ~ WAE+ (1|Lake)	-8914.83	5.96	-8888.62	12.52	5179

Table 4. Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), change in AIC (ΔAIC), change in BIC (ΔBIC), and sample size (n) for linear mixed-effects regression models evaluating environmental (Env) and biological (Bio) predictors of male Yellow Perch relative condition (Kn) for all 27 study lakes. Each model was compared with its corresponding null model, with lake as a random effect.

	Models	**AIC**	**ΔAIC**	**BIC**	**ΔBIC**	**n**
Env Predictors	Kn ~ (1|Lake)	-5865.74	0	-5847.13	0	3660
	Kn ~ Geartp +(1|Lake)	-5898.21	-32.47	-5867.18	-20.06	3660
	Kn ~ (1|Lake)	-5139.52	0	-5121.22	0	3294
	Kn ~ Temp +(1|Lake)	-5144.68	-5.16	-5120.28	0.95	3294
	Kn ~ (1|Lake)	-5865.74	0	-5847.13	0	3660
	Kn ~ JD + (1|Lake)	-5848.52	17.225	-5823.69	23.431	3660
	Kn ~ (1|Lake)	-5139.52	0	-5121.22	0	3660
	Kn ~ Year + (1|Lake)	-5134.75	4.78	-5104.24	16.98	3660
	Kn ~ (1|Lake)	-5139.52	0	-5121.22	0	3294
	Kn ~ Secchi + (1|Lake)	-5129.06	10.47	-5104.66	16.57	3294
Bio Predictors	Kn ~ (1|Lake)	-3650.83	0	-3633.56	0	2340
	Kn ~ Age + (1|Lake)	-3740.51	-89.68	-3717.48	-83.92	2340
	Kn ~ (1|Lake)	-5053.33	0	-5035.09	0	3239
	Kn ~ A50 + (1|Lake)	-5044.68	8.65	-5020.35	14.74	3239
	Kn ~ (1|Lake)	-5053.33	0	-5035.09	0	3239
	Kn ~ L50 + (1|Lake)	-5037.08	16.26	-5012.74	22.34	3239
	Kn ~ (1|Lake)	-5005.41	0	-4987.24	0	3160
	Kn ~ WAE+ (1|Lake)	-5000.23	5.19	-4975.99	11.25	3160

Table 5. Coefficients (Coef.), Standard error (SE), T-statistic (T-stat), and 95% confidence intervals from linear mixed-effects models of relative condition (Kn) for Yellow Perch. The combined model included sex as a predictor using the full dataset, with lake as a random effect.

Predictors	**Term**	**Coef.**	**SE**	**T-stat**	**95% CI (Lower)**	**95% CI (Upper)**
Combined (Sex)	Intercept	0.981	0.014	70.012	0.954	1.009
Combined (Sex)	SXM	0.035	0.002	15.803	0.031	0.039

Table 6. Coefficients (Coef.), Standard error (SE), T-statistic (T-stat), and 95% confidence intervals from linear mixed-effects models of relative condition (Kn) for female Yellow Perch. Lake was included as a random effect.

Predictors	**Term**	**Coef.**	**SE**	**T-stat**	**95% CI (Lower)**	**95% CI (Upper)**
Age	Intercept	1.029	0.012	83.037	1.005	1.053
Age	Age	-0.018	0.001	-14.074	-0.021	-0.016
Gear Type	Intercept	0.982	0.013	75.221	0.957	1.008
Gear Type	Gill net	0.045	0.006	7.568	0.033	0.056
Gear Type	Standard electrofishing	0.029	0.003	9.289	0.023	0.036
Julian Day	Intercept	1.190	0.039	30.7	1.110	1.270
Julian Day	Julian Day	-0.001	0.000	-5.36	-0.001	-0.001
Year	Intercept	1.01	0.014	72.30	0.98	1.040
Year	Year2020	-0.019	0.007	-2.62	-0.033	-0.005
Year	Year2021	-0.038	0.006	-6.70	-0.049	-0.027
Temperature	Intercept	1.586	0.116	13.719	1.359	1.812
Temperature	Temperature	-0.025	0.005	-5.134	-0.034	-0.015
Secchi Depth	Intercept	0.991	0.019	51.959	0.954	1.029
Secchi Depth	Secchi	0.002	0.004	0.387	-0.007	0.010
A50	Intercept	0.967	0.020	48.759	0.928	1.006
A50	A50	0.025	0.012	2.106	0.002	0.049
L50	Intercept	0.921	0.031	29.361	0.859	0.982
L50	L50	0.001	0.000	2.641	0.000	0.001
Walleye_Kn	Intercept	1.002	0.057	17.500	0.890	1.114
Walleye_Kn	Walleye_Kn	-0.010	0.054	-0.189	-0.116	0.096

Table 7. Coefficients (Coef.), Standard error (SE), T-statistic (T-stat), and 95% confidence intervals from linear mixed-effects models of relative condition (Kn) for male Yellow Perch. Lake was included as a random effect.

Predictors	Term	Coef.	SE	T-stat	95% CI (Lower)	95% CI (Upper)
Age	Intercept	1.019	0.013	77.763	0.993	1.045
Age	Age	-0.020	0.002	-10.222	-0.024	-0.017
Gear Type	Intercept	0.984	0.014	71.547	0.957	1.011
Gear Type	Gill net	0.029	0.009	3.417	0.012	0.046
Gear Type	Standard electrofishing	0.030	0.004	7.087	0.022	0.039
Julian Day	Intercept	0.978	0.050	19.700	0.881	1.070
Julian Day	Julian Day	0.000	0.000	0.353	-0.000	0.000
Year	Intercept	1.01	0.015	67.10	0.977	1.040
Year	Year2020	-0.021	0.012	-1.790	-0.043	0.002
Year	Year2021	-0.029	0.008	-3.730	-0.045	-0.14
Temperature	Intercept	1.575	0.148	10.661	1.286	1.865
Temperature	Temperature	-0.024	0.006	-3.944	-0.036	-0.012
Secchi Depth	Intercept	0.998	0.022	44.880	0.955	1.042
Secchi Depth	Secchi	-0.001	0.006	-0.201	-0.012	0.010
A50	Intercept	0.993	0.022	44.302	0.949	1.037
A50	A50	0.002	0.014	0.136	-0.026	0.030
L50	Intercept	0.992	0.036	27.304	0.920	1.063
L50	L50	0.000	0.000	0.103	-0.001	0.001
Walleye_Kn	Intercept	0.978	0.083	11.737	0.815	1.142
Walleye_Kn	Walleye_Kn	0.011	0.080	0.130	-0.147	0.168

Table 8. Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), change in AIC (ΔAIC), change in BIC (ΔBIC), and sample size (n) for linear mixed effects regression models of effects of gear type on female Yellow Perch condition factor (Kn) for all 27 study lakes. Models included environmental and biological predictors that showed support, with lake as a random effect.

Predictors	Model	AIC	ΔAIC	BIC	ΔBIC	n
Julian Day	Kn ~Geartp + (1|Lake)	-10071.7	0	-10038.4	0	5856
	Kn ~JD + Geartp + (1|Lake)	-10057.9	13.89	-10017.8	20.56	5856
	Kn ~JD + (1|Lake)	-9991.74	66.11	-9965.04	52.76	5856
Temperature	Kn ~Temp + Geartp + (1|Lake)	-9437.15	0	-9397.49	0	5485
	Kn ~Geartp + (1|Lake)	-9419.62	17.53	-9386.57	10.92	5485
	Kn ~Temp + (1|Lake)	-9323.12	114.03	-9296.68	100.81	5485
Age	Kn ~Age + Geartp + (1|Lake)	-7084.84	0	-7047.03	0	4030
	Kn ~Age + (1|Lake)	-6961.73	123.12	-6936.52	110.51	4030
	Kn ~Geartp + (1|Lake)	-6842.28	242.56	-6810.78	236.26	4030
Year	Kn ~Year + Geartp + (1|Lake)	-9431.14	0	-9384.84	0	5506
	Kn ~Geartp + (1|Lake)	-9403.4	27.74	-9370.33	14.51	5506
	Kn ~Year + (1|Lake)	-9343.92	87.21	-9310.86	73.99	5506

Table 9. Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), change in AIC (ΔAIC), change in BIC (ΔBIC), and sample size (n) for linear mixed-effects regression models of effects of gear type on male Yellow Perch condition factor (Kn) for all 27 study lakes. Models included environmental and biological predictors that showed support, with lake as a random effect.

Predictors	Model	AIC	ΔAIC	BIC	ΔBIC	n
Julian Day	Kn ~Geartp + (1|Lake)	-5898.21	0	-5867.18	0	3660
	Kn ~JD + Geartp + (1|Lake)	-5897.86	0.35	-5860.62	6.56	3660
	Kn ~JD + (1|Lake)	-5848.52	49.69	-5823.69	43.49	3660
Temperature	Kn ~Temp + Geartp + (1|Lake)	-5195.19	0	-5158.59	0	3294
	Kn ~Geartp + (1|Lake)	-5192.35	2.84	-5161.85	3.26	3294
	Kn ~Temp + (1|Lake)	-5144.68	50.51	-5120.28	38.31	3294
Age	Kn ~Age + Geartp + (1|Lake)	-3770.34	0	-3735.79	0	2340
	Kn ~Age + (1|Lake)	-3740.51	29.83	-3717.48	18.32	2340
	Kn ~Geartp + (1|Lake)	-3672.6	97.74	-3643.81	91.98	2340
Year	Kn ~Geartp + (1|Lake)	-5187.69	0	-5157.19	0	3660
	Kn ~Year + Geartp + (1|Lake)	-5179.14	8.55	-5136.44	20.75	3660
	Kn ~Year + (1|Lake)	-5134.75	52.95	-5104.24	52.95	3660

FIGURES

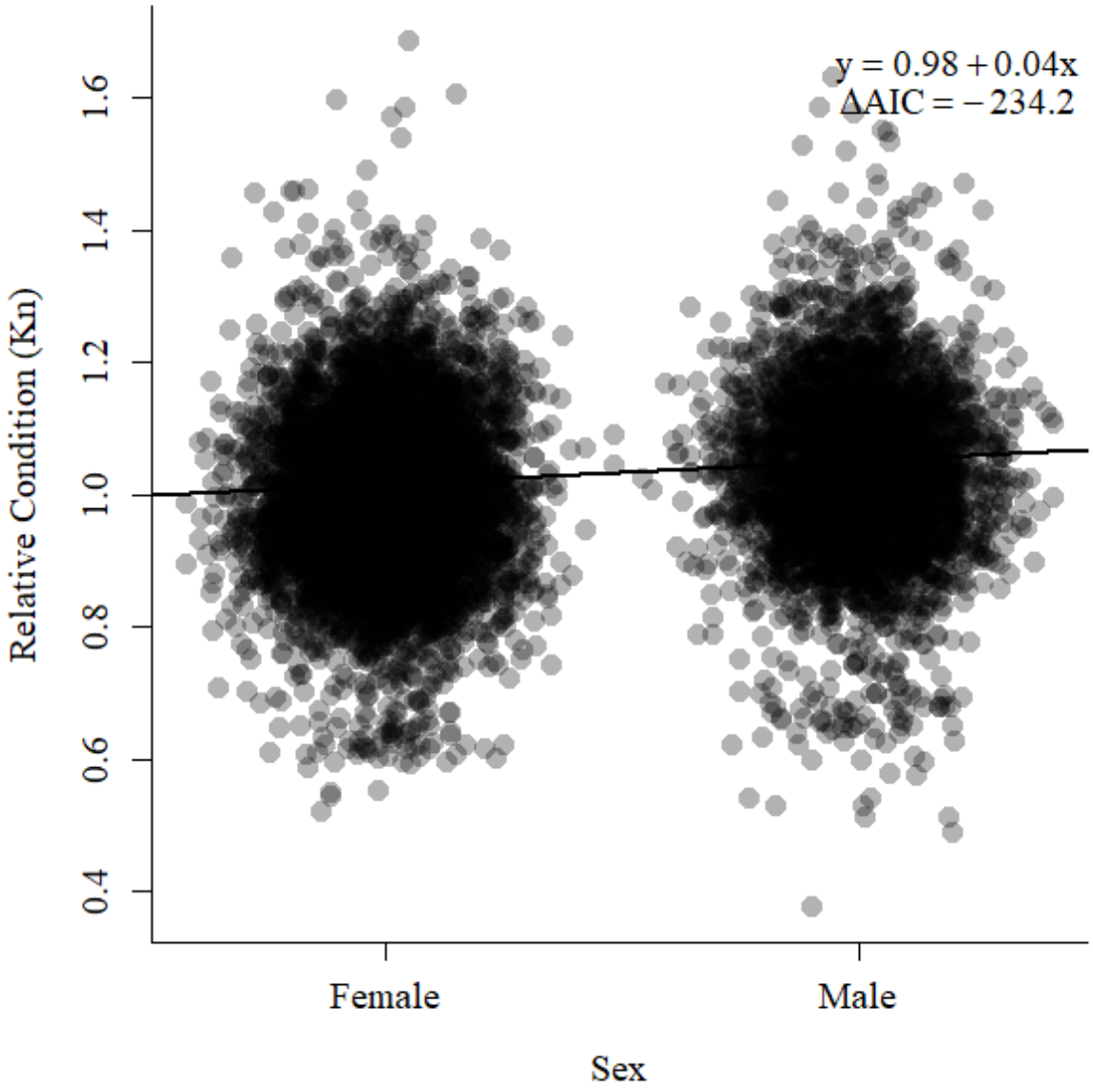

Figure 1. Linear model of Yellow Perch relative condition (Kn) by sex. Each point represents an individual fish with jitter added to reduce overlap. The solid line shows the fitted regression line from the fixed-effect regression model including sex.

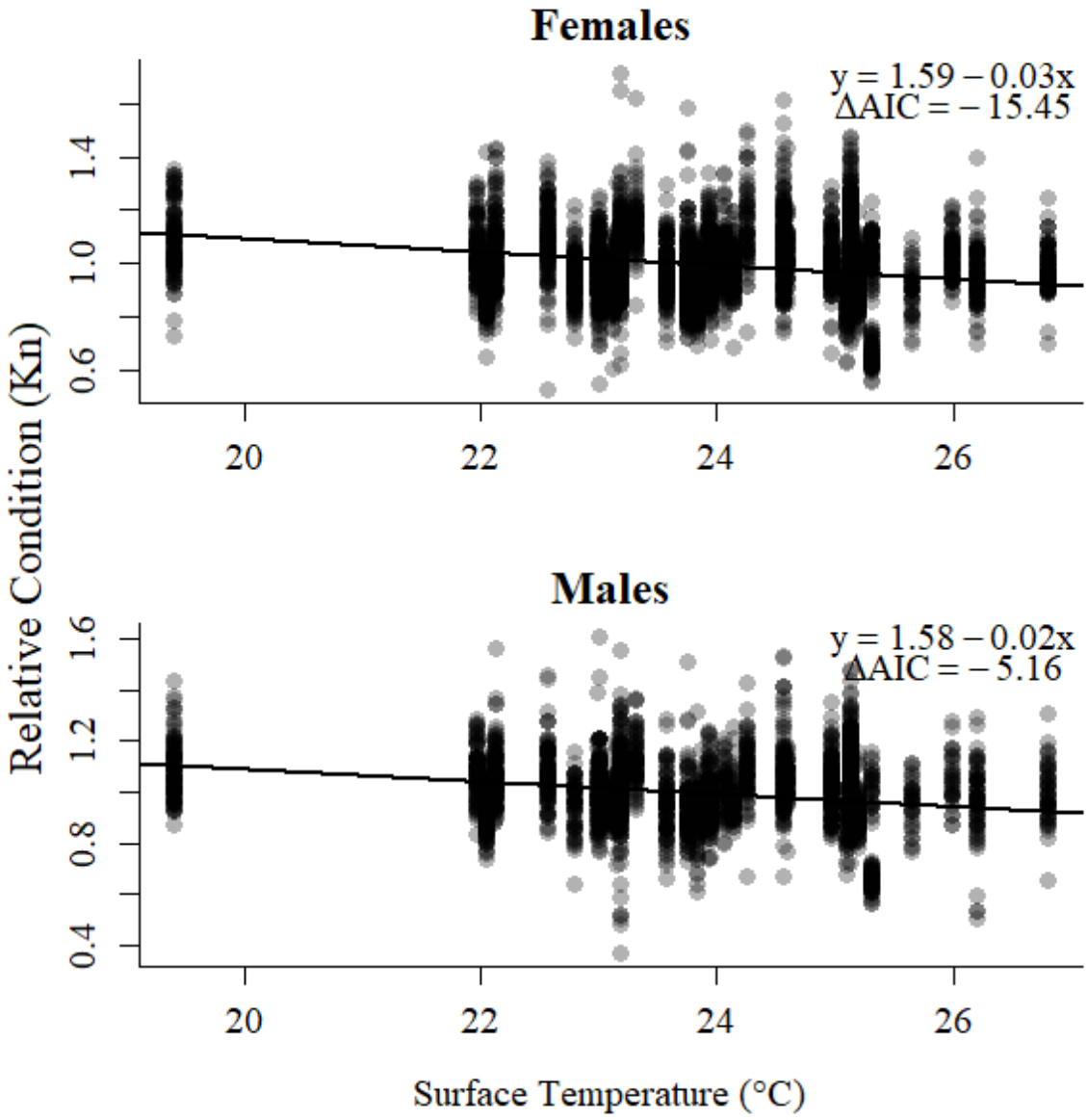

Figure 2. Linear model of Yellow Perch relative condition (Kn) by mean summer surface temperature (°C) for female and male Yellow Perch. Each point represents an individual Yellow Perch Kn, with lake-year mean summer surface temperature. Solid lines show the fixed-effect slopes from mixed-effects regression models fitted separately for each sex.

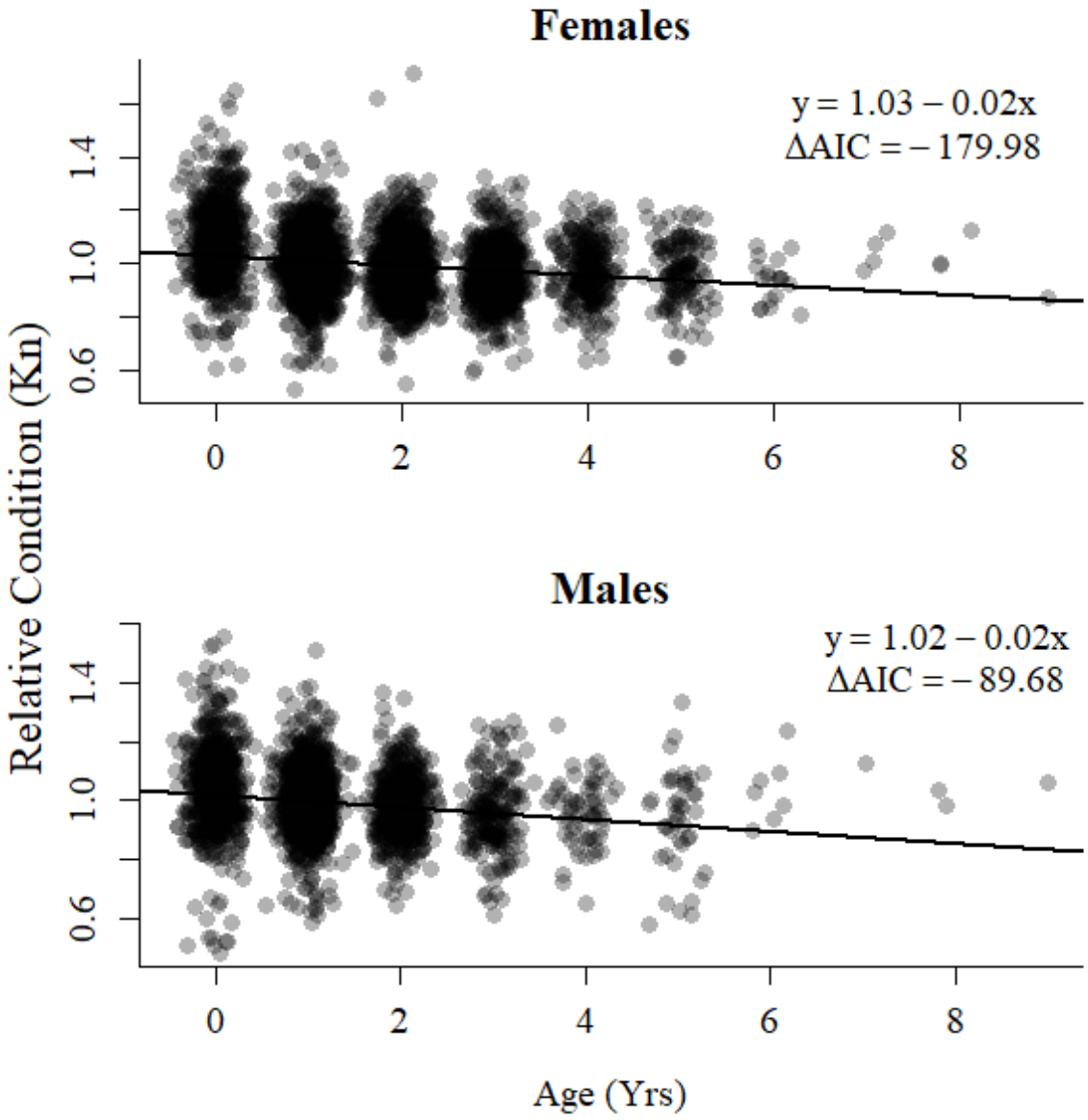

Figure 3. Linear model of Yellow Perch relative condition (Kn) by age (years) for female and male Yellow Perch. Each point represents an individual Yellow Perch Kn, with individual age values slightly jittered to reduce overlap. Solid lines show the fixed-effect slopes from mixed-effects regression models fitted separately for each sex.

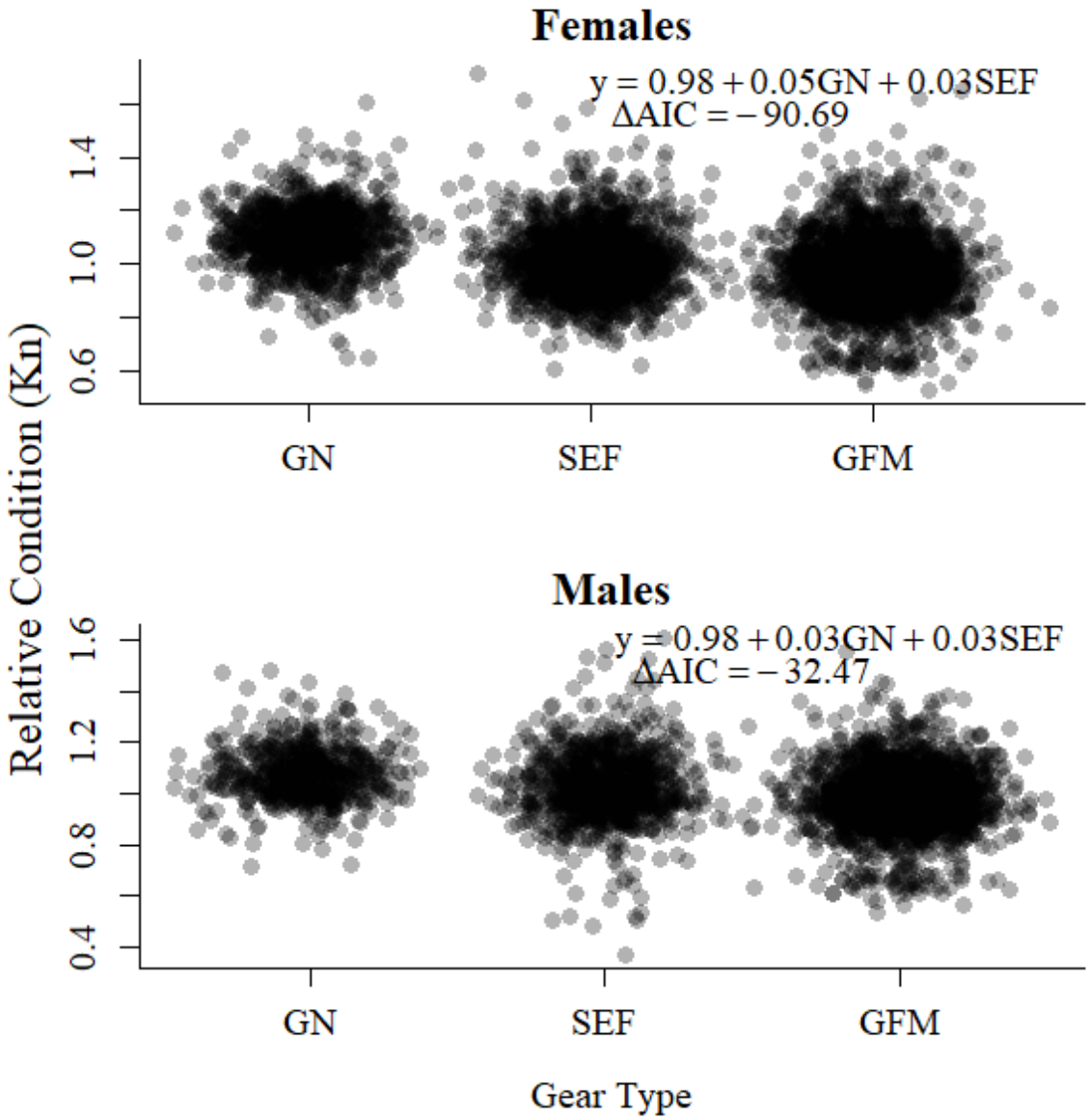

Figure 4. Relationship between Yellow Perch relative condition (Kn) and gear type for female and male. Gear types include gill net fine mesh (GFM), gill net (GN), and standard electrofishing (SEF). Each point represents an individual Yellow Perch Kn, with gear type slightly jittered to reduce overlap.

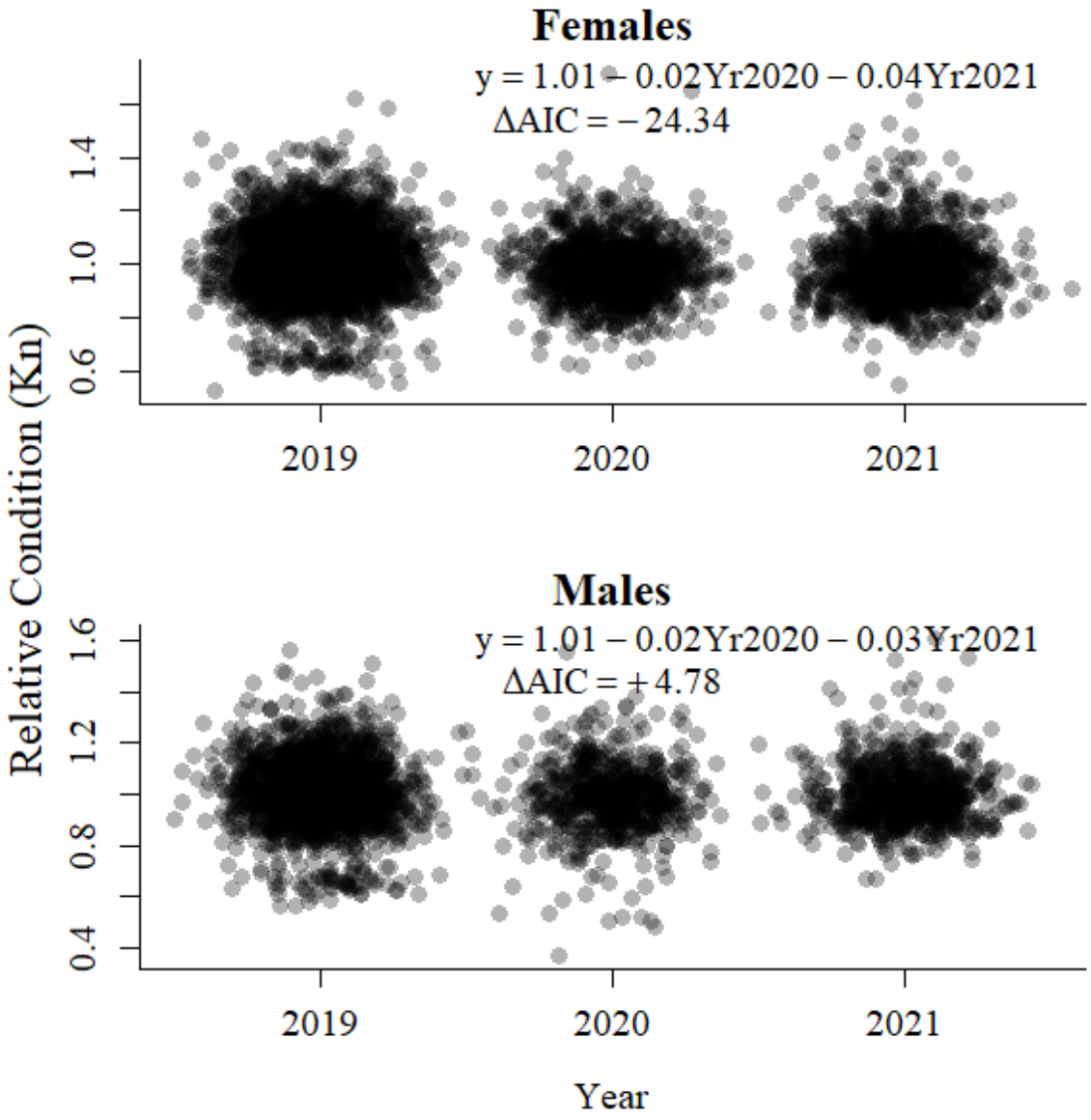

Figure 5. Relationship between Yellow Perch relative condition (Kn) and year for female and male Yellow Perch. Each point represents Kn of an individual Yellow Perch. Data from 2017 were excluded because sampling was limited to a single lake.

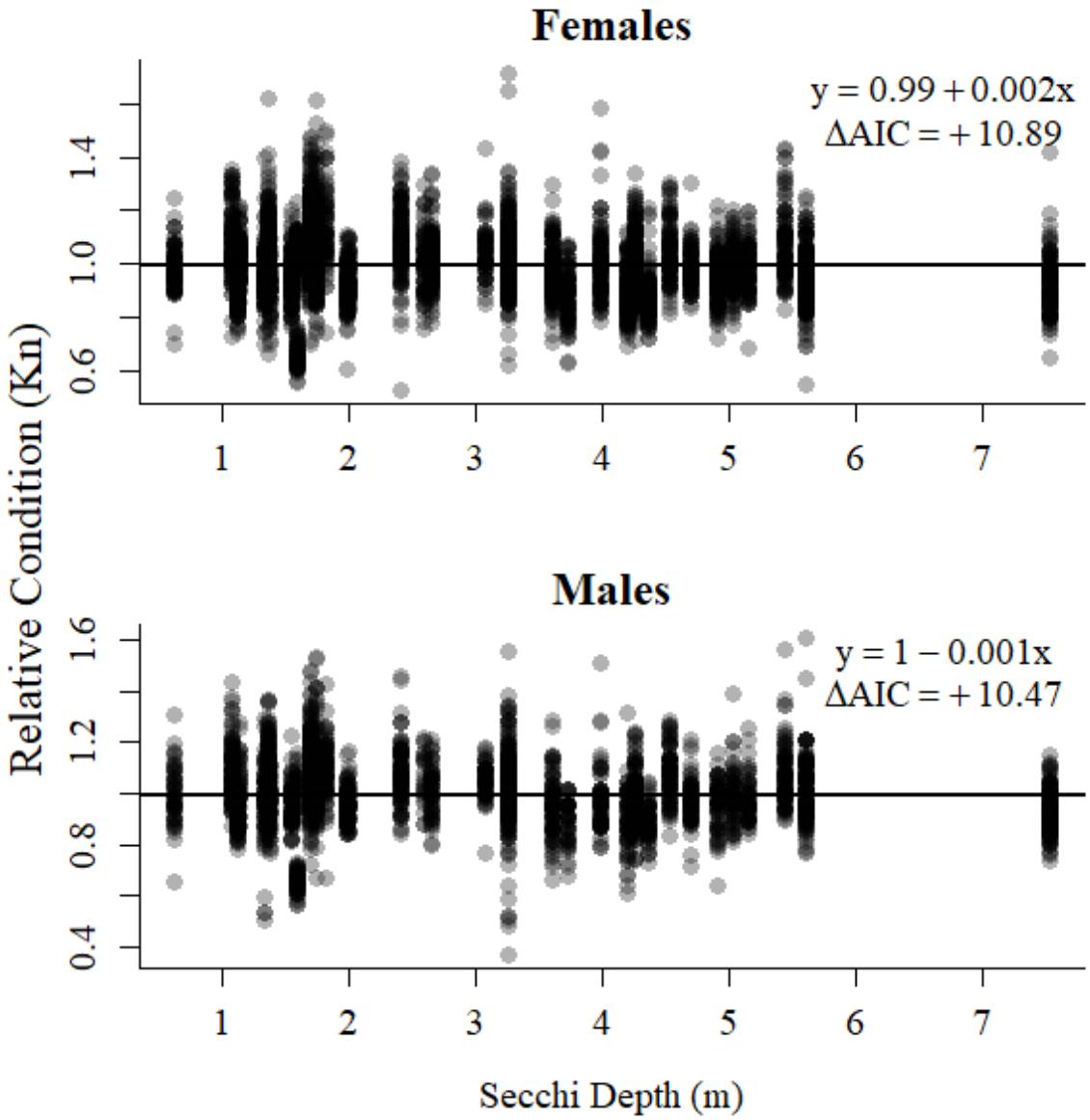

Figure 6. Linear model of Yellow Perch relative condition (Kn) by mean Secchi depth (m) for female and male Yellow Perch. Each point represents an individual Yellow Perch Kn, with lake-year mean Secchi depth (m). Solid lines show the fixed-effect slopes from mixed-effects regression models fitted separately for each sex.

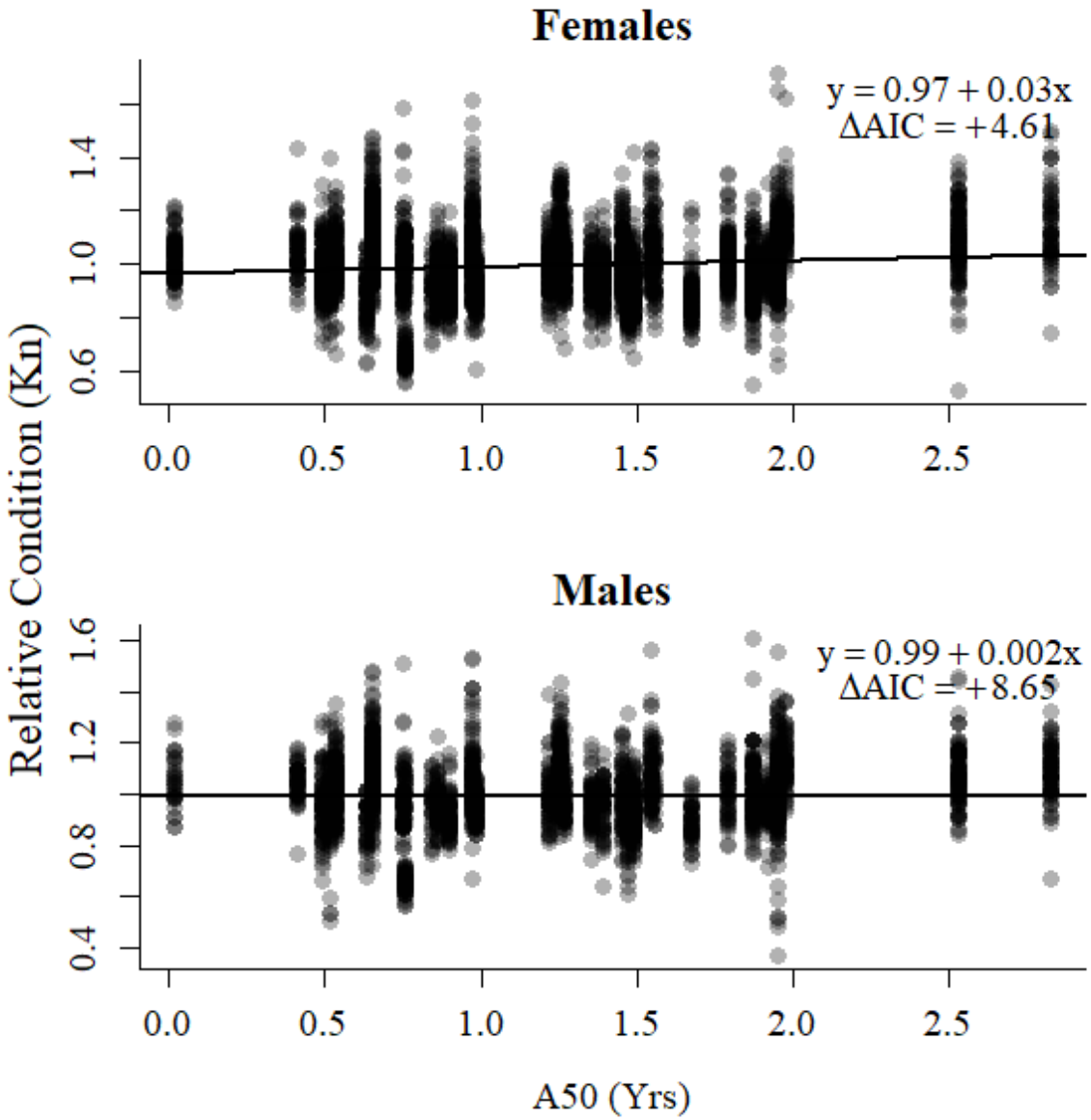

Figure 7. Linear model of Yellow Perch relative condition (Kn) by age at 50% maturity (A50) for female and male Yellow Perch. Each point represents an individual Yellow Perch Kn, with lake-year mean A50. Solid lines show the fixed-effect slopes from mixed-effects regression models fitted separately for each sex.

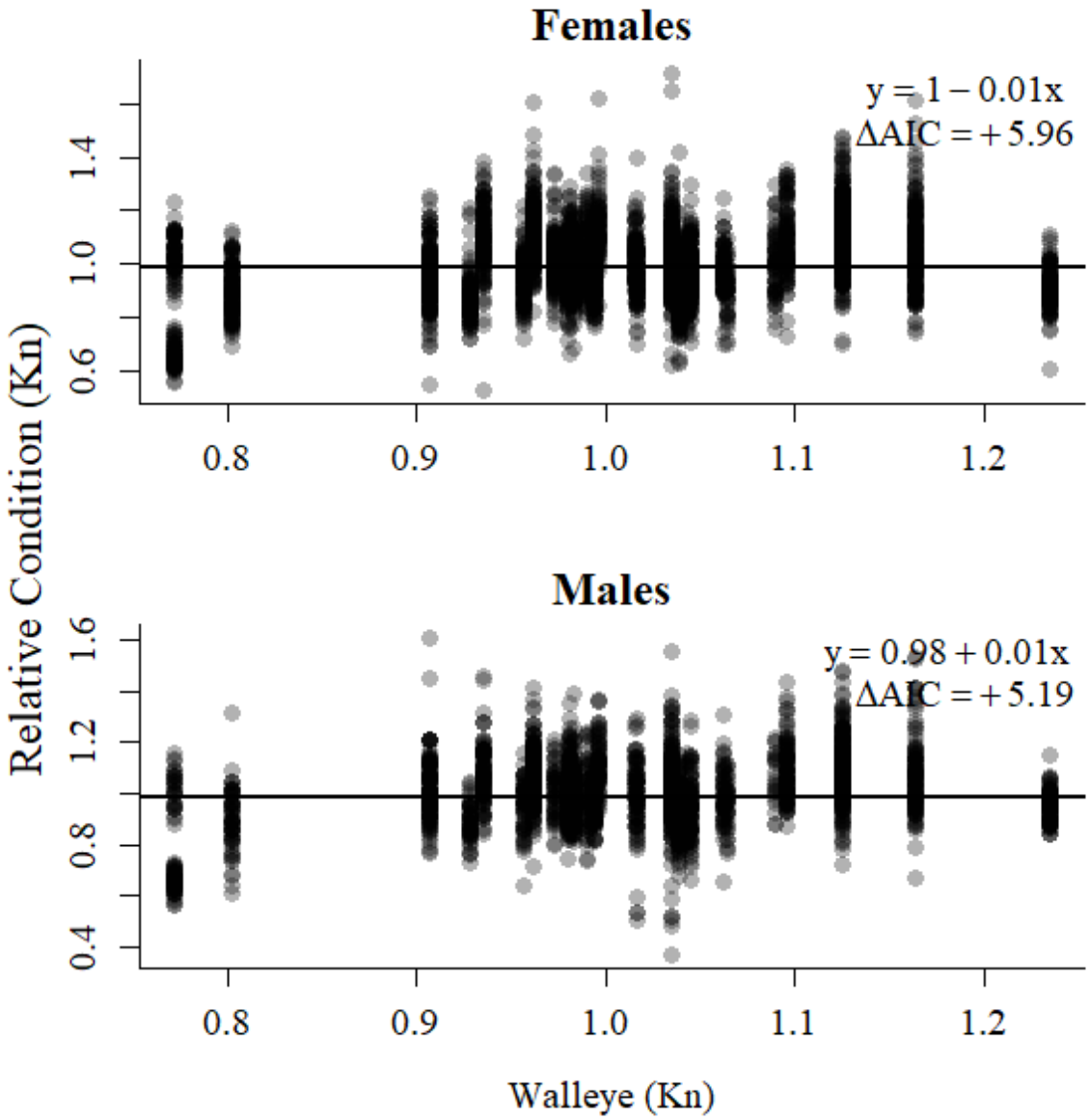

Figure 8. Linear model of Yellow Perch relative condition (Kn) by Walleye Kn for female and male Yellow Perch. Each point represents an individual Yellow Perch Kn, with lake-year mean Walleye Kn. Solid lines show the fixed-effect slopes from mixed-effects regression models fitted separately for each sex.

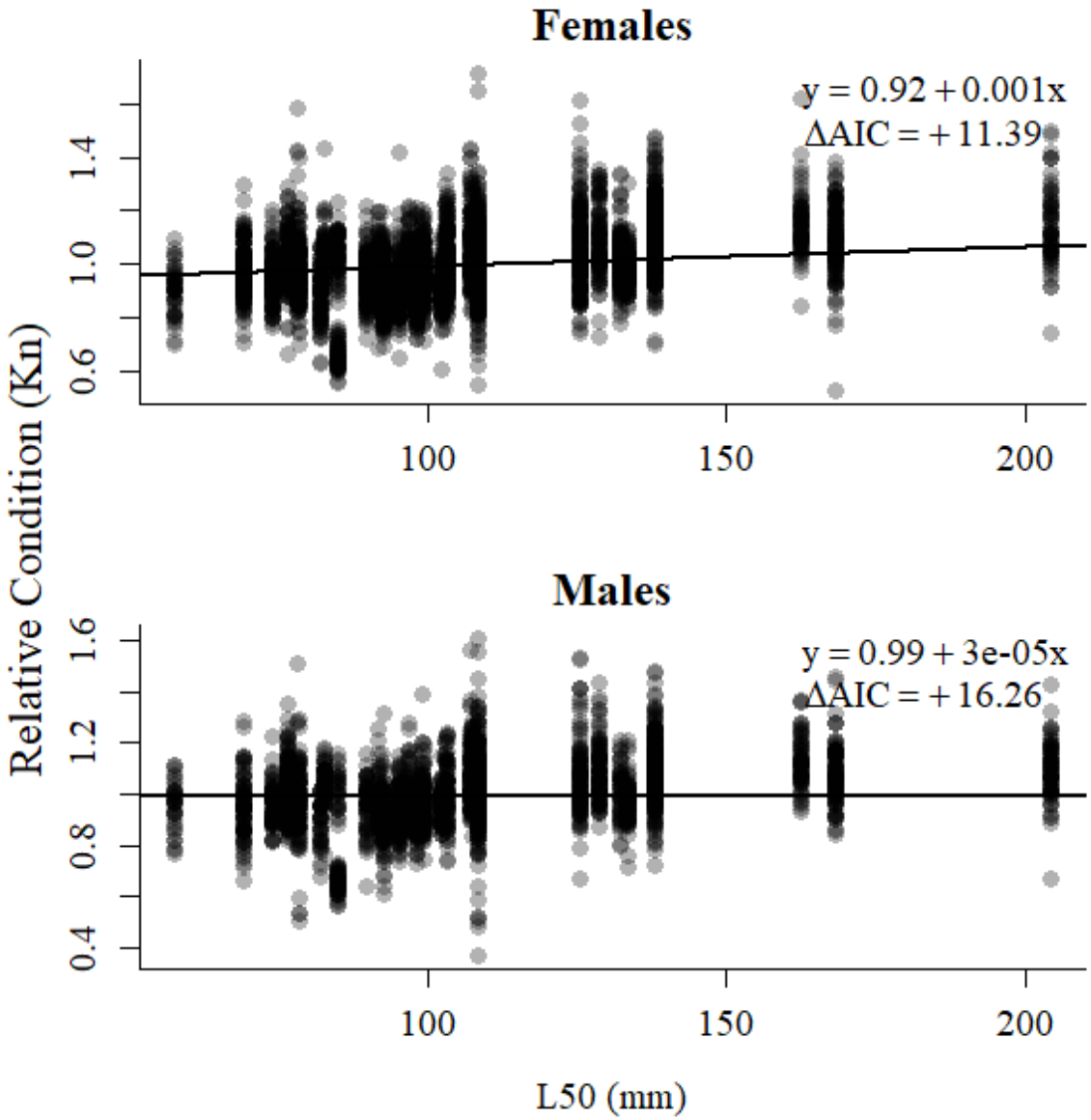

Figure 9. Linear model of Yellow Perch relative condition (Kn) by length at 50% maturity (L50) for female and male Yellow Perch. Each point represents an individual Yellow Perch Kn, with lake-year mean L50. Solid lines show the fixed-effect slopes from mixed-effects regression models fitted separately for each sex.

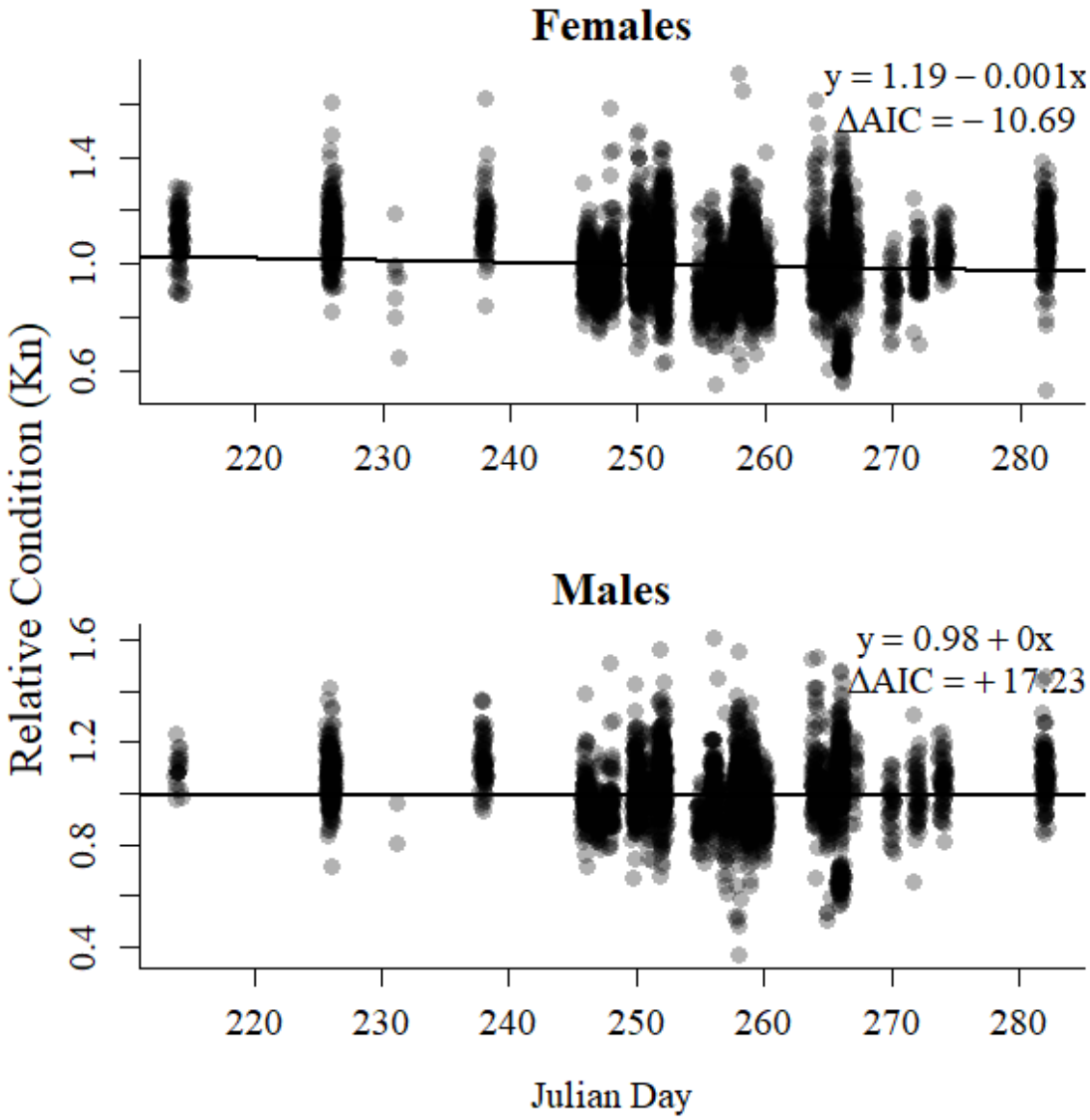

Figure 10. Linear model of Yellow Perch relative condition (Kn) by Julian Day for female and male Yellow Perch. Each point represents an individual Yellow Perch Kn. Solid lines show the fixed-effect slopes from mixed-effects regression models fitted separately for each sex.

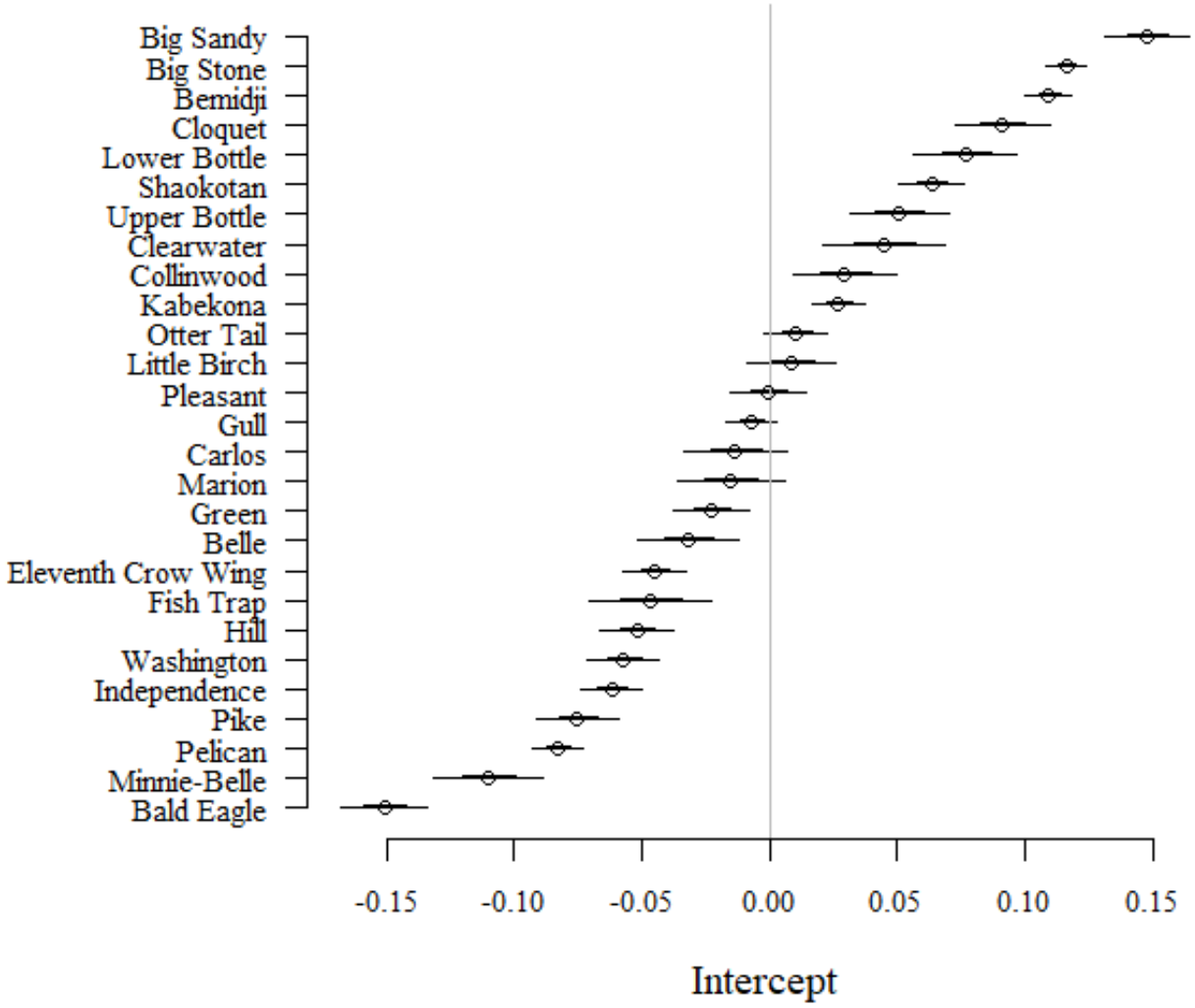

Figure 11. Estimated intercepts of relative condition factor (Kn) for female Yellow Perch. Each point represents the lake-specific intercept from a null mixed-effects model with lake as a random effect, and horizontal lines indicate 95% confidence intervals. Lakes are ordered from highest to lowest intercept values, illustrating variation in Kn among lakes.

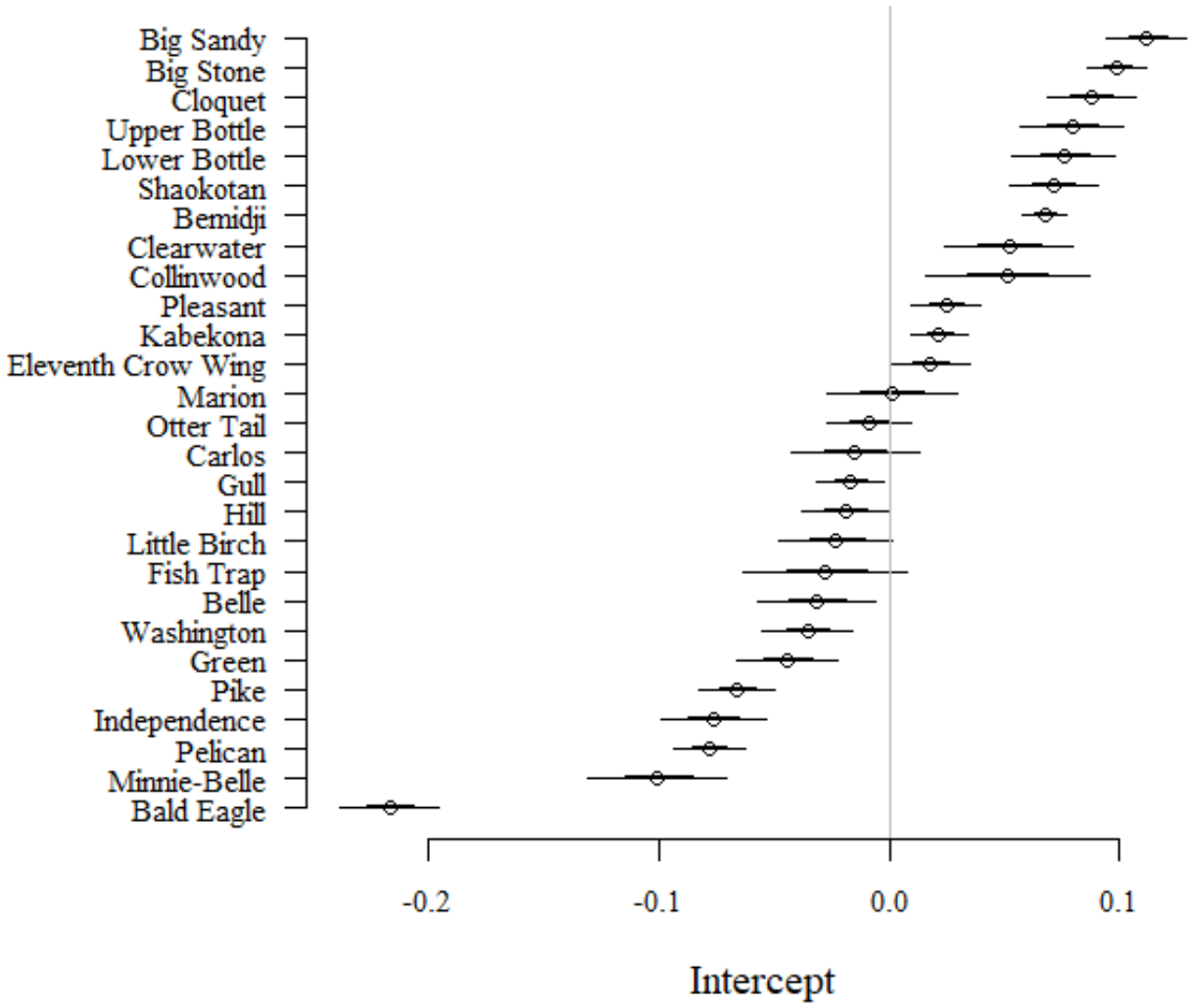

Figure 12. Estimated intercepts of relative condition (Kn) for male Yellow Perch. Each point represents the lake-specific intercept from a null mixed-effects model with lake as a random effect, and horizontal lines indicate 95% confidence intervals. Lakes are ordered from highest to lowest intercept values, illustrating variation in Kn among lakes.

APPENDIX A

Table A1. Mean relative condition (Kn) values for all Female Yellow Perch in each of the 27 study lakes. Included are standard deviation (SD), sample size (n), minimum and maximum relative condition (Kn).

Lake	Mean Kn	SD	N	Min	Max
Bald Eagle	0.83	0.20	147	0.55	1.21
Belle	0.95	0.10	107	0.68	1.36
Bemidji	1.09	0.10	506	0.52	1.59
Big Sandy	1.12	0.12	151	0.72	1.60
Big Stone	1.10	0.10	684	0.70	1.46
Carlos	0.96	0.08	98	0.68	1.16
Clearwater	1.02	0.09	69	0.84	1.40
Cloquet	1.07	0.11	120	0.73	1.32
Collinwood	1.01	0.07	103	0.85	1.20
Eleventh Crow Wing	0.93	0.09	275	0.55	1.23
Fish Trap	0.93	0.07	71	0.82	1.08
Green	0.95	0.09	191	0.69	1.28
Gull	0.97	0.09	428	0.71	1.30
Hill	0.93	0.09	201	0.60	1.27
Independence	0.92	0.07	307	0.74	1.18
Kabekona	1.01	0.11	377	0.61	1.69
Little Birch	0.99	0.11	134	0.77	1.54
Lower Bottle	1.05	0.12	102	0.82	1.40
Marion	0.97	0.08	91	0.69	1.22
Minnie-Belle	0.87	0.09	88	0.62	1.05
Otter Tail	0.99	0.08	273	0.76	1.30
Pelican	0.90	0.09	419	0.69	1.20
Pike	0.90	0.09	162	0.64	1.39
Pleasant	0.98	0.10	192	0.64	1.26
Shaokotan	1.05	0.13	243	0.72	1.57
Upper Bottle	1.03	0.10	110	0.81	1.27
Washington	0.92	0.08	207	0.69	1.17

Table A2. Mean relative condition (Kn) values for all Male Yellow Perch in each of the 27 study lakes. Included are standard deviation (SD), sample size (n), minimum and maximum relative condition (Kn).

Lake	Mean Kn	SD	N	Min	Max
Bald Eagle	0.79	0.18	99	0.58	1.19
Belle	0.98	0.15	70	0.51	1.30
Bemidji	1.10	0.09	473	0.74	1.47
Big Sandy	1.13	0.10	154	0.68	1.45
Big Stone	1.13	0.12	284	0.75	1.53
Carlos	1.00	0.08	57	0.86	1.27
Clearwater	1.07	0.07	57	0.78	1.20
Cloquet	1.11	0.10	122	0.90	1.46
Collinwood	1.08	0.10	34	0.89	1.31
Eleventh Crow Wing	1.03	0.11	164	0.79	1.63
Fish Trap	0.99	0.07	34	0.87	1.18
Green	0.97	0.11	96	0.68	1.31
Gull	1.00	0.10	218	0.76	1.42
Hill	1.00	0.08	128	0.86	1.23
Independence	0.95	0.07	85	0.81	1.19
Kabekona	1.04	0.14	312	0.38	1.59
Little Birch	0.99	0.12	74	0.81	1.54
Lower Bottle	1.10	0.11	91	0.92	1.58
Marion	1.02	0.11	55	0.67	1.33
Minnie-Belle	0.91	0.08	48	0.70	1.03
Otter Tail	1.01	0.09	133	0.73	1.23
Pelican	0.94	0.10	187	0.62	1.34
Pike	0.95	0.08	160	0.75	1.17
Pleasant	1.04	0.10	199	0.83	1.39
Shaokotan	1.10	0.14	124	0.69	1.55
Upper Bottle	1.10	0.10	89	0.86	1.30
Washington	0.98	0.08	113	0.79	1.26

APPENDIX B

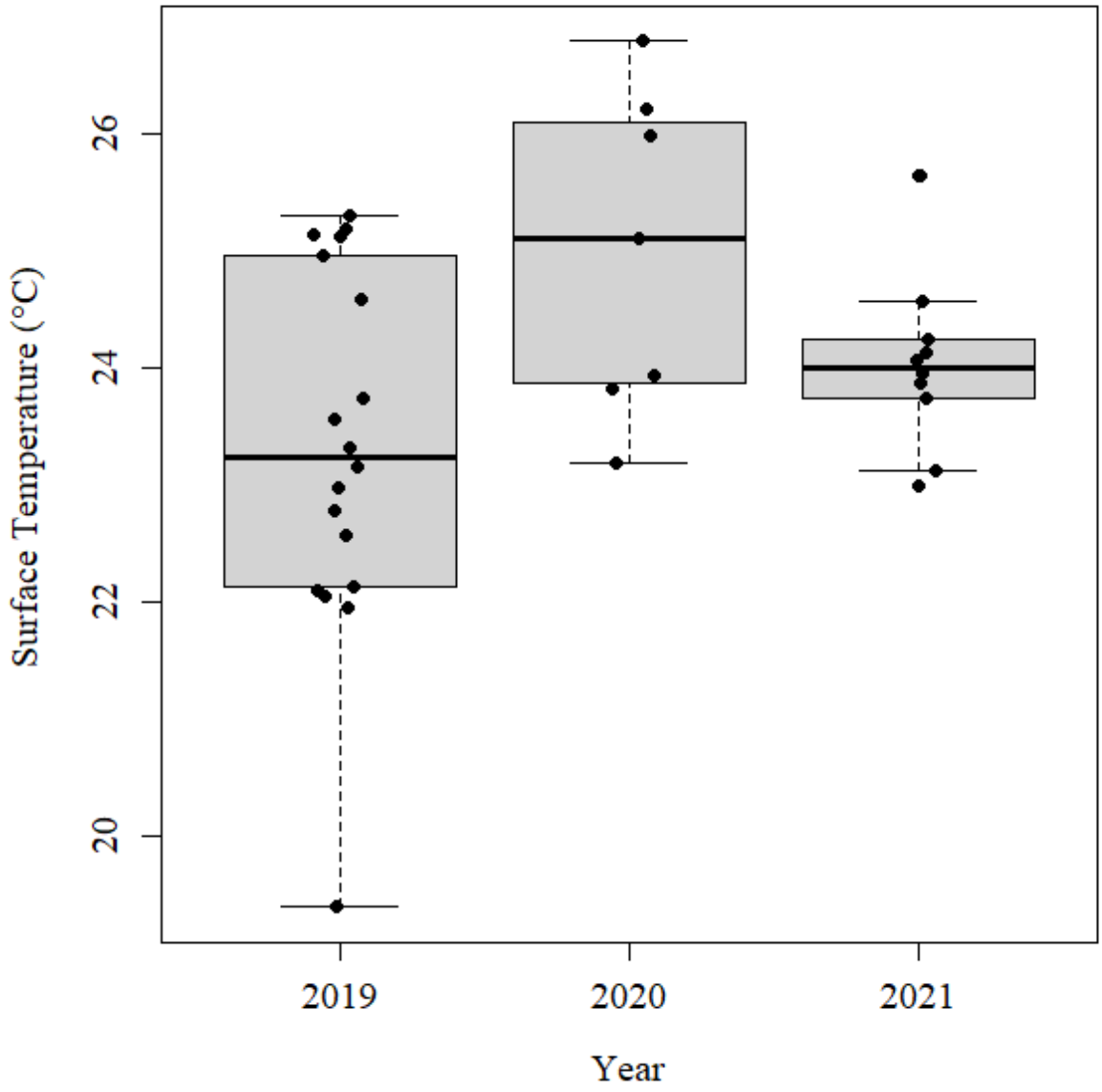

Figure B1. Box and whisker plots of mean summer surface temperature (°C) among Minnesota lakes from 2019-2021. Mean summer surface temperature was calculated for each study lake. For each year, the median is shown with a dark horizontal bar, and the shaded boxes represent the upper and lower quartiles. Black circles represent individual lake mean summer surface temperature.