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ECOLOGY

Body condition as an ecological stress indicator in coastal fish before, during, and after the largest oil spill in Brazil

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ABSTRACT. The body condition factor in fish is widely used as a tool to detect variations in individual fitness associated with habitat quality and food availability. In August 2019, one of the most significant environmental disasters in the history of tropical oceans impacted the Brazilian coastline, affecting multiple ecosystems and fishing communities. In this context, the present study aimed to assess the impact of the disaster on 14 fish species by analyzing interannual variations from 2014 to 2020. We tested the hypothesis that the 2019 oil spill significantly affected the condition factor (*K*). The study was conducted along the northern coast of Pernambuco state, in northeastern Brazil, using fixed arrowhead-type traps for fish sampling. *K* estimates for the 14 fish species revealed apparent interannual variability. Notably, all species exhibited variations during or after the 2019 oil spill, particularly in 2020, when *K* values fell below 1, indicating poor body condition. The most pronounced effects were observed in *Archosargus rhomboidalis*, *Caranx bartholomaei*, *Chaetodipterus faber*, *Diapterus auratus*, *Haemulon parra*, *Haemulon plumieri*, *Haemulopsis corvinaeformis*, *Lutjanus analis*, and *Opisthonema oglinum*. These structural changes in the fish assemblage suggest the presence of sublethal effects from oil exposure, capable of compromising physiological integrity even in the absence of direct mortality. This study highlights the value of biometric indicators, such as the *K* factor, as sensitive tools for the early detection of environmental disturbances.

Keywords: Environmental disaster; Coastal monitoring; Bioecological indicators; Condition factor; Artisanal fishing.

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Introduction

The relative condition factor (*K*), derived from the length–weight relationship (LWR), is widely adopted to detect variations in individual fitness associated with habitat quality and food availability (Le Cren, 1951; Gubiani et al., 2020). This index is sensitive to both natural and anthropogenic environmental fluctuations and is particularly relevant in the context of high-impact disturbances such as oil pollution (Claireaux et al., 2004; Holth et al., 2008; Rodgers et al., 2018; Paz-Ríos et al., 2022).

In August 2019, one of the most significant environmental disasters in the history of tropical oceans affected the Brazilian coast, with over 4,000 km of shoreline contaminated by an oil spill of unknown origin (Soares & Rabelo, 2023; Soares et al., 2022) impacting different ecosystems, such as beaches, mangroves, coral reefs, and seagrass meadows, which serve as habitat for several marine species and support local fishing communities (Magalhães et al., 2022; Souza et al., 2024).

This orphan oil spill had extensive ecological consequences, including oil ingestion, morphological abnormalities, immune suppression, altered sex ratios, and changes in community composition across multiple taxonomic groups (Soares & Rabelo, 2023; Campelo et al., 2021). Polycyclic aromatic hydrocarbons (PAHs), the toxic components of crude oil, were detected in edible tissues of fish and shellfish (Magalhães et al., 2022; Melo et al., 2022), as well as in seawater, zooplankton, and benthic organisms along the northeastern coast (Soares et al., 2021). Impacts included oxidative stress responses in fish (Soares et al., 2021), PAH bioaccumulation in fisheries resources (Magalhães et al., 2022), and reduced mesozooplankton richness and abundance (Souza et al., 2024). These findings suggest systemic disruption of the food web structure in affected areas.

Previous large-scale oil spills such as the Exxon Valdez and Deepwater Horizon in 1989 and 2010, respectively, have demonstrated that sublethal effects of oil on fish include developmental abnormalities, endocrine disruption, reproductive failure, and impaired growth, often manifesting years after exposure (Sol et al., 2000; Short et al., 2003; Takeshita et al., 2021). Chronic exposure to PAHs, even at low concentrations, can alter cardiac, neurological, and immune function (Filatova & Abramochkin, 2023) and cause histopathological alterations (Collier et al., 2013). These sublethal effects are particularly severe in early life stages and species dependent on demersal habitats and benthic food webs (Akpan, 2022).

Despite these known risks, the biological responses of tropical fish species, especially those exploited in artisanal fisheries, remain poorly understood. Biometric indices such as *K* offer cost-effective, field-applicable indicators to detect stress and energetic imbalance in fish populations (Jisr, 2018; Sandoval-Huerta et al., 2015). However, few studies have assessed these metrics in the aftermath of major oil spills in tropical coastal ecosystems.

This study aims to evaluate the impact of Brazil's largest oil spill on the *K* of 14 coastal fish species by analyzing interannual variations from 2014 to 2020. We tested the hypothesis that the 2019 oil spill significantly affected the condition factor. By focusing on this biometric index, our findings provide insights into the sublethal effects of oil contamination on tropical marine fish and underscore the utility of the *K* as an early-warning indicator for ecosystem health in oil-impacted coastal areas.

Materials and methods

Study area and data collection

The study was carried out in the district of Ponta de Pedras, Goiana, on the northern coast of the state of Pernambuco, in northeastern Brazil (Figure 1). The district is situated in a socio-economic context marked by sugarcane monoculture and tourism. It remains one of the last areas where traditional fishing with simple arrowhead fixed traps, known locally as 'curral', is practiced (Ferreira et al., 2022). This artisanal activity constitutes an important source of income for the local community.

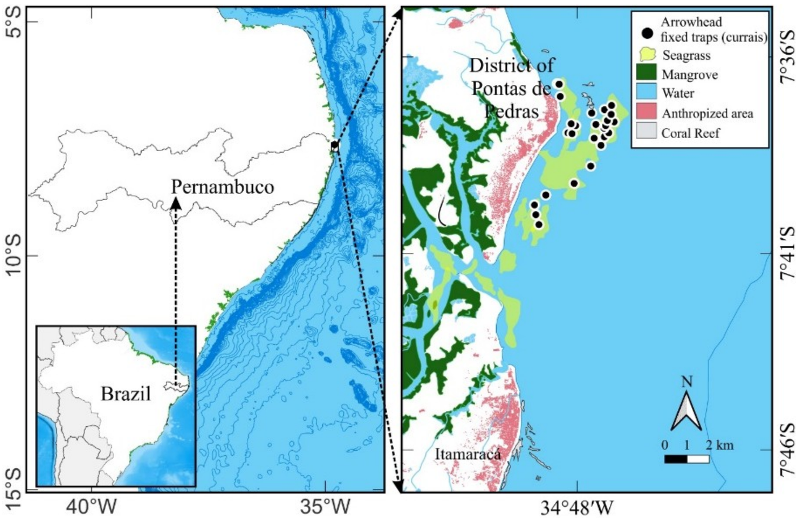

Figure 1. Geographic location of the coastal region of Pernambuco state, northeastern Brazil, within the western tropical South Atlantic. The map highlights the district of Ponta de Pedras and sensitive and highly productive coastal habitats, which play a critical ecological role and are vulnerable to oil contamination.

Ecologically, the region encompasses sensitive and highly productive coastal habitats, including mangroves, coral reefs, and extensive seagrass meadows, among the largest in the northeastern region of Brazil (Magalhães et al., 2022; Deeks et al., 2024). Due to its ecological and socio-economic relevance, Ponta de Pedras was included in the long-term fish monitoring program using fixed traps, coordinated by the Applied Statistical Modeling Laboratory (MOE).

Fish landings were monitored monthly from May 2014 to December 2020, a period that included a significant oil spill that affected more than 4,000 km of the Brazilian coastline. The region of Ponta de Pedras was directly impacted on September 7 and October 17, 2019. Along the coast and nearby areas, 38 arrowhead fixed traps were installed for fish capture. These passive fishing structures consist of two compartments: the first and largest section, called the 'wings,' and the second, the 'trap,' where most fish are retained (Slack-Smith, 2001). Due to their size-selective nature, all individuals above a certain length are retained without the possibility of escape.

During the landings, fish species were identified on site, and individuals were measured for standard length and weight. These biometric data were used to assess temporal changes in body condition in response to oil contamination.

Data analysis

The condition factor was calculated using the equation $K = W/(aL^b)$ (Le Cren, 1951). Although more recent methods for estimating body condition exist, their application remains controversial. Therefore, the Le Cren method was chosen for its well-established utility and consistency, especially in contexts with limited resources (Gubiani et al., 2020). This approach is widely accepted in fisheries science due to its simplicity and robustness (Froese, 2006).

Condition factor (*K*) estimates were derived from the coefficients of the length-weight relationships (LWRs) aggregated for each species, as presented in (Table 1), based on results published by Lima et al. (2024), which were obtained from the same sampling effort as the present study. To assess the potential impacts of the 2019 oil spill on fish health, interannual variations in *K* were analyzed for 14 species commonly captured using fixed arrowhead-type fish traps in the Ponta de Pedras region.

Table 1. Total number of individuals (N), coefficients *a* and *b,* and Pearson r-squared (r) of the length-weight relationship for each of the 14 species frequently captured using arrowhead fixed traps along the northern coast of Pernambuco, Brazil, from 2014 to 2020. Table adapted from Lima et al. (2024).

Species	N	a	b	r
Archosargus rhomboidalis (Linnaeus, 1758)	202	0.0440	2.9082	0.988
Caranx bartholomaei (Cuvier, 1833)	447	0.0411	2.8096	0.957
Chaetodipterus faber (Broussonet, 1782)	568	0.1386	2.6872	0.961
Chloroscombrus chrysurus (Linnaeus, 1766)	380	0.0167	3.0232	0.943
Diapterus auratus (Ranzani, 1842)	817	0.0635	2.7584	0.949
Haemulon parra (Desmarest, 1823)	329	0.0429	2.8325	0.983
Haemulon plumierii (Lacepède, 1801)	808	0.0419	2.8582	0.954
Haemulopsis corvinaeformis (Steindachner, 1868)	235	0.0492	2.7494	0.936
Lutjanus analis (Cuvier, 1828)	130	0.0316	2.9394	0.972
Oligoplites saurus (Bloch & Schneider, 1801)	119	0.0093	3.0517	0.956
Opisthonema oglinum (Lesueur, 1818)	1579	0.0135	3.0966	0.947
Pempheris schomburgkii (Müller & Troschel, 1848)	373	0.0314	2.87500	0.914
Selene brownii (Cuvier, 1816)	292	0.0333	2.9849	0.987
Selene vomer (Linnaeus, 1758)	181	0.0566	2.7782	0.975

Outlier values of the *K* for each species were excluded from the analyses to avoid significant distortions and to enable more precise distinctions between years and among species. According to Jisr et al. (2018), *K* values equal to or greater than one indicate good body condition and adequate growth. In contrast, values below one reflect poor condition relative to individuals of the same length. Based on this classification, the present study adopted the following criteria: individuals with $K > 1.02$ were considered to be in good body condition; those with values between 0.98 and 1.02 were classified as having moderate condition; and individuals with $K < 0.98$ were considered to be in poor body condition.

Cluster analyses with graphical representation through heat maps were conducted based on the *K* values, aiming to identify potential groupings across years and species. Raw data were transformed into a distance matrix to facilitate subsequent multiple comparison analyses, using Euclidean distance as the transformation method. To assess potential statistical differences among groups, Permutational Multivariate Analysis of Variance (PERMANOVA) was applied with 9.999 random permutations, a method used to test the homogeneity of multivariate dispersions (Anderson et al., 2006). Significant PERMANOVA results were subsequently evaluated using Pillai–Bartlett trace tests.

Comparisons of the *K* values across years and among species were performed using Analysis of Variance (ANOVA), followed by Tukey's multiple comparison test when significant differences were detected. A parametric approach was employed, as the model assumptions were satisfied. All statistical analyses and graphical representations were carried out using R software (R Core Team, 2025), with a significance level set at $\alpha = 0.05$. The *Complex Heatmap* (Gu, 2022) and *RVAideMemoire* (Hervé, 2025) packages were used to construct the heatmap and to perform post hoc tests following the PERMANOVA, respectively.

Results

On average, 10.55% of individuals were excluded from the condition factor analyses due to the presence of outlier values. As presented in (Table 2), the species with the lowest proportion of discarded individuals were *A. rhomboidalis* (2.48%), *S. vomer* (4.97%), and *S. brownii* (5.48%), whereas those with the highest exclusion rates were *P. schomburgkii* (26.01%), *O. oglinum* (19.13%), and *C. chrysurus* (16.84%).

Table 2. Annual number of individuals (*N* year), total number of individuals used (*N* used), and percentage of outlier individuals excluded from the condition factor (*K*) estimates for each of the 14 species frequently captured using arrowhead fixed traps along the northern coast of Pernambuco, Brazil, from 2014 to 2020.

Specie	*N* Year							*N* Used	Outlier (%)
	2014	2015	2016	2017	2018	2019	2020		
Archosargus rhomboidalis	18	110	10	7	17	20	15	197	2.48
Caranx bartholomaei	41	99	52	48	42	44	80	406	9.17
Chaetodipterus faber	73	29	24	66	98	118	122	530	6.69
Chloroscombrus chrysurus	13	212	35	3	25	22	6	316	16.84
Diapterus auratus	90	152	26	41	195	180	60	744	8.94
Haemulon parra	42	62	59	78	42	8	19	310	5.78
Haemulon plumierii	33	148	111	91	125	66	174	748	7.43
Haemulopsis corvinaeformis	58	37	10	24	66	4	10	209	11.06
Lutjanus analis	5	18	19	17	5	21	35	120	7.69
Oligoplites saurus	15	15	17	17	12	15	9	100	15.97
Opisthonema oglinum	238	325	345	53	195	66	55	1277	19.13
Pempheris schomburgkii	53	82	21	9	26	50	35	276	26.01
Selene brownii	15	69	22	34	53	64	19	276	5.48
Selene vomer	23	25	35	23	32	22	12	172	4.97

The annual median values of the coefficient *K* were predominantly negative in 2019 and especially in 2020. Cluster analysis revealed a clear separation between two temporal groups, with the years 2019 and 2020 isolated from the others (Figure 2 – vertical axis). The differences between these two groups were statistically significant (PERMANOVA, $p = 0.048$).

Regarding the annual variation of *K* among species, the cluster analysis identified four distinct groups (Figure 2 – horizontal axis). The first group included *H. plumieri* and *L. analis*; the second, *A. rhomboidalis*, *H. corvinaeformis*, *C. faber*, *C. bartholomaei*, and *D. auratus*; the third, *O. oglinum*, *P. schomburgkii*, and *S. brownii*; and the fourth, *C. chrysurus*, *H. parra*, *O. saurus*, and *S. vomer*. Differences between the second group and the first and third groups were statistically significant (PERMANOVA, $p < 0.050$). In contrast, differences between the remaining group pairs were marginal, except between the first and third groups, where no significant differences were observed (PERMANOVA, $p = 0.100$).

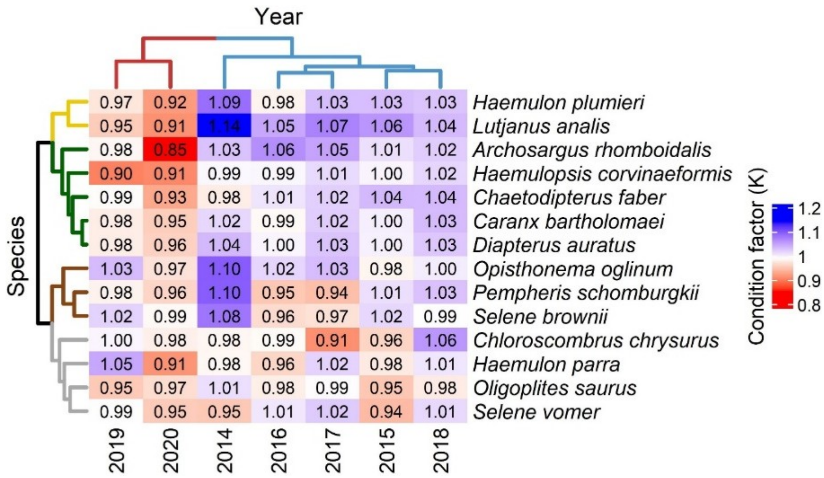

Figure 2. Annual values of condition factor (*K*) for 14 species captured with arrowhead fixed traps on the northern coast of Pernambuco, Brazil, from 2014 to 2020.

In the annual comparisons of the condition factor (*K*), significant differences were observed ($F = 83.460$; $p < 0.01$; $df = 6$), with the year 2020 showing the lowest mean and median values and standing out as significantly different from the other years (Figure 3 A). The mean and median*K* values for 2014, 2017, and 2018 were classified as indicative of good condition, while 2015, 2016, and 2019 were considered moderate, and 2020 reflected poor condition.

Significant differences were also found among species and their annual *K* variations (F = 6.498; $p < 0.01$; *df* = 13). *Opisthonema oglinum* exhibited significantly higher *K* values compared to 11 other species, particularly in relation to *C. chrysurus*, which also differed significantly from *P. schomburgkii*. Most mean and median *K* values across species were classified as indicating moderate condition, except for *O. oglinum*, whose individuals were predominantly in good condition, and *O. saurus*, which showed poor condition levels.

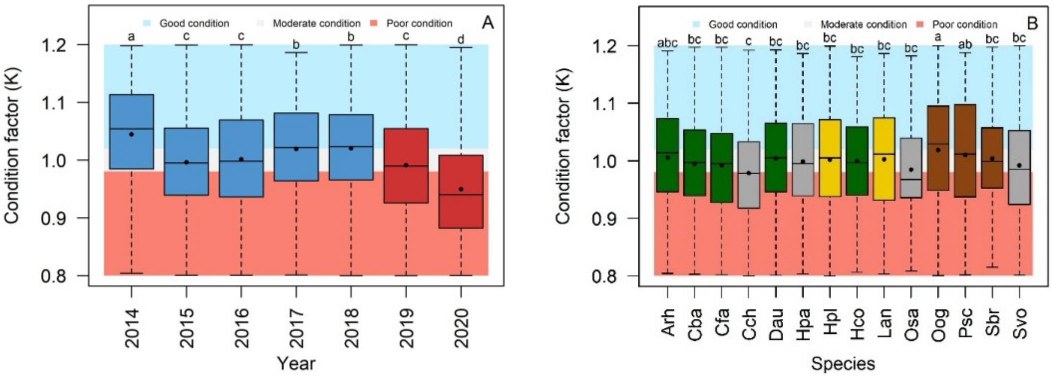

Figure 3. Variations in condition factor (*K*) values for 14 species caught in fish traps along the northern coast of Pernambuco, Brazil. (A) Annual comparison; (B) Species comparison. Different letters indicate statistically significant differences. Box colors correspond to the groups formed in the cluster analysis (Figure 2).

Discussion

The analysis of the *K* for 14 fish species, monitored over seven years, revealed apparent interannual variability. In particular, all species showed variations during or after the 2019 oil spill, especially in 2020, when *K* values fell below one, indicating poor growth conditions in the fish (Jisr et al., 2018). Exposure to oil was greater in the first year and tended to decrease in subsequent years (Sol et al., 2000). These findings suggest a biological response consistent with environmental stress, potentially associated with contamination by petroleum-derived compounds, which affect species development and may compromise reproduction in the long term (Dzwonkowski et al., 2020).

Exposure to polycyclic aromatic hydrocarbons (PAHs) from oil spills affects organisms across different trophic levels, impacting both their physiological and ecological aspects (Ko et al., 2019; Soares & Rabelo, 2023; Rodrigues et al., 2025). This type of contamination is detectable in fish fauna regardless of habitat, impairing the physiology of various species (Shahjahan et al., 2022). Soares et al. (2021) found moderate PAH concentrations in *Diapterus rhombeus*, while Magalhães et al. (2022) reported bioaccumulation in commercially and ecologically important species, such as *H. parra*, *H. plumieri*, and *L. analis*, sampled in the Santa Cruz Channel, approximately 20 km from Ponta de Pedras. In a study conducted along the coast of Bahia, Souza et al. (2024) detected elevated levels of arsenic, barium, chromium, and zinc in juveniles of *Lutjanus synagris* and *Haemulon aurolineatum*.

The species analyzed in the present study exhibited varying levels of impact, influenced by their ecological and physiological characteristics. The literature indicates that exposure to PAHs can impair somatic growth, reproduction, and the overall physiological condition of fish (Collier et al., 2013; Shahjahan et al., 2022; Varol et al., 2022). Polluted environments typically reduce fish condition, possibly due to increased metabolic rates and the mobilization of lipid reserves to cope with the toxic effects of contamination (Javed & Usmani, 2019).

Measurements of body condition, such as the *K* index, have proven to be sensitive indicators of contamination. Even at low concentrations, exposure leads to a decline in body condition (Claireaux et al., 2004; Holth et al., 2008). In *Lutjanus campechanus*, for example, oil spills caused significant sublethal effects on somatic growth (Rodgers et al., 2018). Moreover, juveniles exposed to oil exhibited compromised body condition, with *K* being a reliable indicator of sublethal impacts (Gilliérs et al., 2006; Saborido-Rey et al., 2007). In our study, large numbers of juvenile individuals were observed among the captures of most species.

These studies reinforce that PAH exposure can reduce *K* values, providing strong support for interpreting the observed drop in 2020 in this study as a result of cumulative sublethal effects from the 2019 oil spill along the Brazilian coast. This supports our hypothesis that the 2019 oil spill had adverse ecological effects, particularly impacting fish condition in the following year.

Investigations conducted in 2022 with some species indicated that individuals no longer posed health risks for consumption (Rodrigues et al., 2025), which may signal the beginning of environmental recovery. However, patterns of population renewal in marine fish are often irregular, resulting in fluctuations that challenge management and conservation efforts (Petrik et al., 2021). Even when physical and climatic indicators return to pre-disaster levels, ecosystem responses may not be linear or fully revert to previous conditions due to the complexity of ecological interactions (Suryan et al., 2021).

There is a clear need for long-term environmental monitoring along the Brazilian coast, as the spill also had social and economic repercussions for various fishing communities, reducing income in smaller municipalities and highlighting the vulnerability of these populations to extreme environmental events (Ferreira et al., 2022). Impacts of this magnitude have severe consequences for fishing activities, exacerbating the socio-economic vulnerability of these communities (Sandifer et al., 2021). Therefore, it is essential to identify commercially important species that may have been adversely affected.

Tropical species, especially those along the northeastern coast of Brazil, require priority attention in the coming decades due to the prolonged effects of oil contamination (Soares et al., 2021). In the present study, *A. rhomboidalis*, *C. bartholomaei*, *C. faber*, *D. auratus*, *H. parra*, *H. plumieri*, *H. corvinaeformis*, *L. analis*, and *O. oglinum* were identified as showing greater vulnerability to contamination, as evidenced by lower K values in 2019 and especially in 2020. Among these, *A. rhomboidalis* stands out as a bioindicator of environmental degradation (Kendall et al., 2021). The remaining species are of high economic value to coastal fisheries, with *O. oglinum* and *H. plumieri* being particularly important in Pernambuco, where *O. oglinum* was the most frequently captured species, especially along the northern coast of the state (Oliveira & Andrade, 2018).

Conclusion

The results of this study highlight that the largest oil spill in recent South Atlantic history, which occurred in 2019, was associated with significant alterations in the body condition of 14 coastal fish species monitored between 2014 and 2020. A generalized decline in K values was observed, particularly in 2020, indicating a deterioration in body condition, with more pronounced effects in *A. rhomboidalis*, *C. bartholomaei*, *C. faber*, *D. auratus*, *H. parra*, *H. plumieri*, *H. corvinaeformis*, *L. analis*, and *O. oglinum*. These structural changes in the fish assemblage suggest the presence of sublethal effects from oil exposure, capable of compromising physiological integrity even in the absence of direct mortality.

This study underscores the importance of biometric indicators, such as the *K*, as sensitive tools for the early detection of environmental disturbances. Incorporating this index into long-term monitoring programs can provide essential support for fisheries management and for assessing the health of tropical marine ecosystems affected by oil contamination.

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