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Evaluation of Trophic States Through Zooplankton Communities: A Comprehensive Methodology

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Abstract

This study introduces a novel index for assessing the trophic status of aquatic environments, leveraging the zooplankton community as a bioindicator. The assessment was conducted across three distinct regions: the southern sections of the Eastern Al-Hammar, Al-Chebiyesh Marshes and the Euphrates River, over a period from November 2020 to October 2021. Employing Carlson's methodology as a foundation, the research aimed to validate the efficacy of zooplankton abundance as a metric for trophic state evaluation. Through systematic sampling of zooplankton across selected sites, data on individual counts per liter and biomass (wet weight in mg/L), alongside the biomass-to-individual ratio, were subjected to linear regression analysis against Carlson's trophic status indices. This process facilitated the derivation of formulae capable of deducing the trophic state from zooplankton metrics. Findings revealed that the trophic status, as indicated by the Zooplankton-based Trophic State Index (TSIZOO), predominantly classified the aquatic environments within the mesotrophic category, with values ranging between 43.37 and 43.39. The biomass-to-individual ratio of zooplankton further suggested a Meso-eutrophic classification, marked by a value of 46.3. This study underscores the utility of zooplankton communities as reliable indicators for the trophic classification of water bodies, providing a nuanced understanding of aquatic ecosystem health.

Keywords: Trophic State, Zooplankton, Water Bodies, TSIZOO, Bioindicator

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Introduction

Aquatic ecosystems, encompassing over two-thirds of Earth's surface, are crucial for maintaining global climate equilibrium and provide a multitude of services vital for human welfare. However, anthropogenic activities have adversely impacted these systems, manifesting detrimental effects on their functionality and biodiversity (Hader et al., 2020). The classification of these ecosystems' trophic states is fundamental to understanding their health and productivity. This classification typically segments the trophic continuum into three primary states: Oligotrophic, Mesotrophic, and Eutrophic, each reflecting varying levels of nutrient enrichment and biological productivity.

Environmental indicators, including biological organisms and aquatic communities, serve as essential tools for assessing the impacts of human activities on these ecosystems. Among these, zooplankton stand out as significant bioindicators due to their sensitivity to environmental changes, offering prompt insights into alterations within aquatic environments (De-Carli et al., 2019). Their rapid response to environmental variables makes zooplankton an advantageous option for monitoring aquatic ecosystem health, providing a more immediate reflection of changes compared to larger organisms, such as fish, which require longer periods to manifest detectable alterations (Tuba and Sevim, 2015).

Nutrient levels directly influence the abundance and composition of zooplankton communities, rendering them critical indicators of trophic status changes and eutrophication processes in aquatic environments. This study opts for a holistic approach by utilizing the entire zooplankton community as an indicator for trophic status estimation. This methodology is preferred over previous methods that focused solely on specific subsets of the zooplankton community, such as Rotifers (Ejsmont-Karabin, 2012) or Crustacea (Ejsmont-Karabin, 2013). The comprehensive assessment provided by analyzing the complete zooplankton community offers a more accurate and encompassing evaluation of the aquatic ecosystems' trophic states, ensuring a thorough understanding of their ecological health and the impacts of environmental stressors.

The principal objective of this research is to address the existing gap by utilizing the entire zooplankton community as a comprehensive bioindicator for assessing the trophic states across diverse aquatic settings. This methodology aims to refine the precision and thoroughness of evaluations concerning trophic conditions, thereby advancing our comprehension of eutrophication effects and additional human-induced impacts on aquatic ecosystems. Through an encompassing examination of zooplankton populations, this study aspires to significantly inform the creation and implementation of effective surveillance

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and management practices. These efforts are directed towards safeguarding and sustaining the vitality and rich biodiversity of global aquatic ecosystems.

Materials and Methods

Study Area Description

Wetlands represent ecosystems of immense productivity and biodiversity, making them critical subjects for biological research (Mitsch and Gosselink, 2000). This study focuses on three aquatic environments within the northern portion of the Basra Province, specifically the southern sections of the Eastern Al-Hammar Marsh, Al-Chebiyesh Marsh, and a segment of the Euphrates River.

Al-Hammar Marsh: Situated as one of the principal marshlands in Iraq's southern terrain, Al-Hammar Marsh experiences a division due to tectonic activities beneath the Earth's crust, leading to distinct eastern and western sections (Al-Sakini, 1992). The western marsh lies southward of the Euphrates River, extending into Dhi Qar Province and receiving its water supply from the river's right bank. Conversely, the eastern marsh falls within Basra Province, with its southern end linking to the Shatt al-Arab through the Karmat-Ali Canal. The marsh's reliance on tidal influxes from the Arabian Gulf via Shatt al-Arab introduces variability in water salinity levels. It showcases a varied concentration of aquatic vegetation, both emerged and submerged. Recognition of its ecological value is underscored by its inclusion in the Ramsar sites as of September 30, 2015, and its addition to the World Heritage List on July 17, 2016. Water depths within the marsh fluctuated between 0.32 to 2.43 meters during the study period, prompting the selection of two study stations within its eastern part.

Al-Chebiyesh Marsh: This marsh stands among the most notable central marshlands, positioned north of Al-Hammar Marsh and the Euphrates River, eastward of Dhi Qar Provinces, and west of the Tigris River. Historically, it received its water supply from the Tigris River, but post-2003, the source shifted to the Euphrates River. Consequently, the water levels and the marsh's ecological dynamics exhibit seasonal variations in response to the Euphrates River's flow patterns.

The choice of these locations for the study reflects a strategic interest in evaluating the trophic states of diverse wetland ecosystems within the Basra region, leveraging their varied ecological characteristics and water sources to enrich the understanding of aquatic biodiversity and health in response to environmental and anthropogenic influences.

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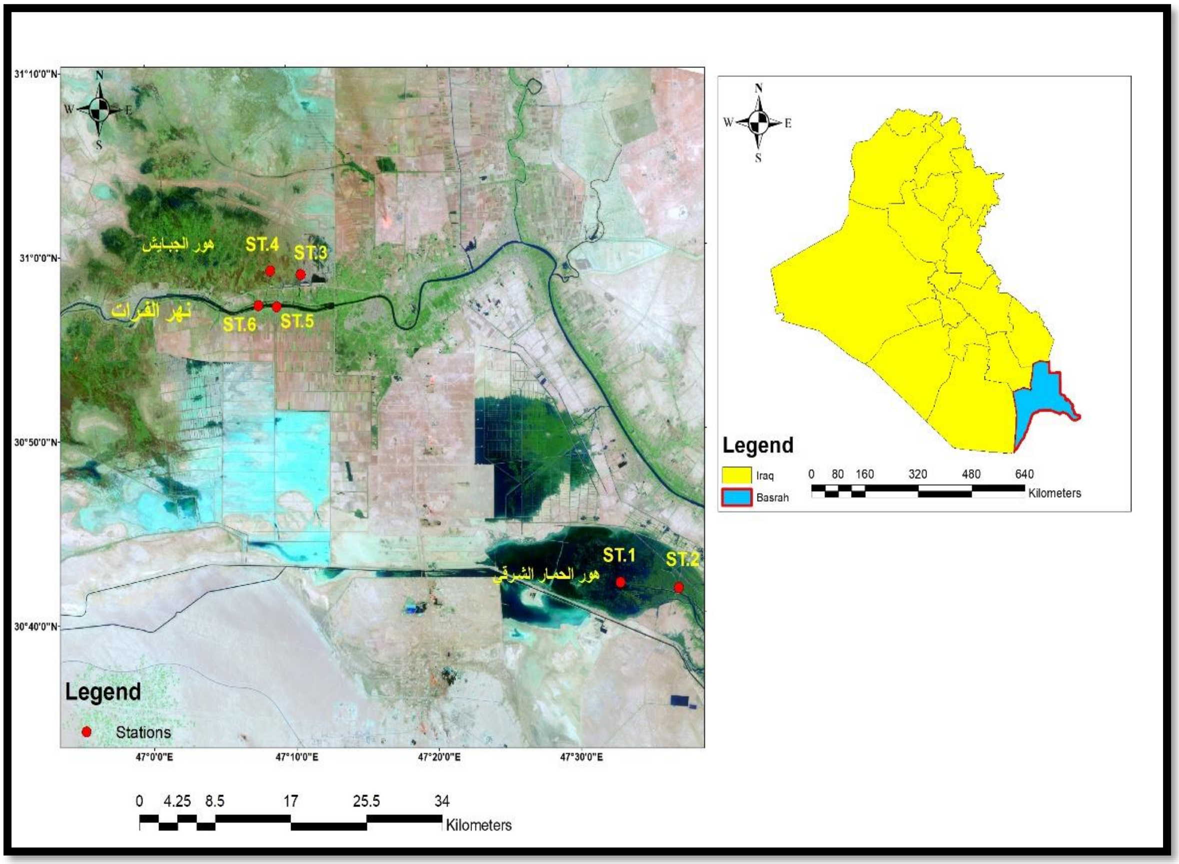

Figure 1. Showing Sampling Stations

Table 1. Location of the sampling area.

Position	Station	GPS Location

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AL- Hammar marshes	St.1	N: 30° 41'45.87" E: 47° 32'59.56"
	St.2	N: 30° 41'22.16" E: 47° 37'4.78"
Al-Chebiyesh marshes	St.3	N: 30° 59'3.45" E: 47° 8'39.80"
	St.4	N: 30° 58'51.04" E: 47° 10'47.90"
Euphrates River	St.5	N: 30° 57'7.18" E: 47° 9'2.74"
	St.6	N: 30° 57′ 8.88″ E: 47° 7′ 42.81″

Collection of Water and Zooplankton Samples

Water and zooplankton samples, alongside various measurements, were systematically collected from six designated study stations over a period spanning from November 2020 to October 2021. The trophic status index (TSI) was determined using concentrations of chlorophyll a, total phosphorus (TP), and visibility as measured by Secchi's disc (SD), following the methodology outlined by Carlson in 1977. The calculation of the TSI was based on the following formulas:

-TSI for Chlorophyll a (TSI Chl. a) = 9.81 * ln(Chla concentration in µg/L) + 30.6
-TSI for Total Phosphorus (TSI TP) = 14.42 * ln(TP concentration in µg/L) + 4.15
-TSI for Secchi's Disc Visibility (TSI SD) = 60 – 14.41 * ln(SD in meters)
-Composite Trophic Status Index (CTSI) = (TSI Chl. a + TSI TP + TSI SD) / 3

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Further analysis involved the application of a linear regression to correlate zooplankton abundance (individuals per liter, ind. $L.^{-1}$) and biomass (mg wet weight per liter, mg w.wt. L^{-1}), as well as the ratio of zooplankton biomass to numbers, with the trophic status as determined by the Carlson TSI equations. This analysis was conducted for three distinct environments, each characterized by differing environmental conditions, with a total of 12 samples collected from each environment. The objective was to elucidate the relationship between zooplankton communities and the trophic state of these environments. The average values obtained were then used to derive formulas capable of indicating the trophic status of water bodies based on zooplankton community metrics, as follows:

-TSI based on Zooplankton Numbers (TSIZOO) = 0.0134 * N + 36.763
-TSI based on Zooplankton Biomass (TSIZOO) = 96.752 * B + 39.567
-TSI based on the Ratio of Biomass to Numbers (TSIZOO) = 18928 * (B/N) + 44.836

Where:
-N represents the number of zooplankton (ind. $L.^{-1}$),
-B denotes total biomass (mg w.wt. $L.^{-1}$),
-B/N is the ratio of biomass to numbers (mg w.wt. $ind.^{-1}$).

The classification of the environmental trophic status, based on Carlson's trophic state index and the zooplankton trophic status index, was then compared. The following table outlines the TSI zoo grades and their ecological attributes, as defined by Ejsmont-Karabin in 2012:
This classification serves to categorize the environments into distinct trophic states based on the impact of zooplankton communities on the overall trophic status.

Table (2): TSIzoo grade and their ecological attributes according to Ejsmont-karabin (2012).

class	TSI_{ZOO}	classification
1	<45	Mesotrophic
2	45<55	Meso-eutrophic
3	55<65	Eutrophic
4	>65	Hypertrophic

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Results

Figures 2, 3, and 4 are illustrative of the regression equations established for the relationship between zooplankton numbers, zooplankton biomass, and the ratio of biomass to numbers, respectively. These figures serve to visually depict the nature of these relationships, highlighting the differential impacts of zooplankton abundance and biomass on the trophic status of water bodies as determined by the CTSI. The stronger correlation between zooplankton numbers and CTSI underscores the importance of considering zooplankton abundance as a key indicator in the assessment of aquatic ecosystem health and trophic status.

The regression analysis conducted between zooplankton indicators and the Carlson Trophic Status Index (CTSI) revealed a positively correlated exponential relationship between these variables. Notably, the correlation between zooplankton numbers and CTSI was found to be stronger than that between zooplankton biomass and CTSI. This indicates that the correlation coefficient for zooplankton numbers is higher than that for biomass, suggesting that zooplankton abundance is a more significant predictor of trophic status compared to biomass in these environments.

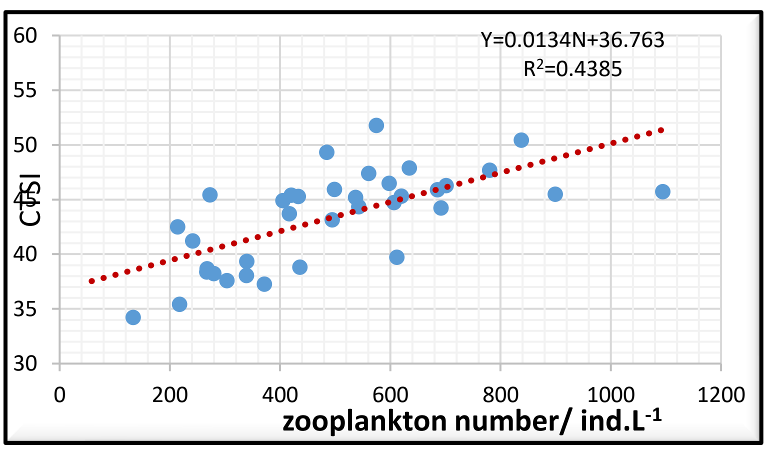

Fig. 2. Relationship between the total density of zooplankton (Numbers; ind. L^{-1}) and the trophic state index (CTSI)

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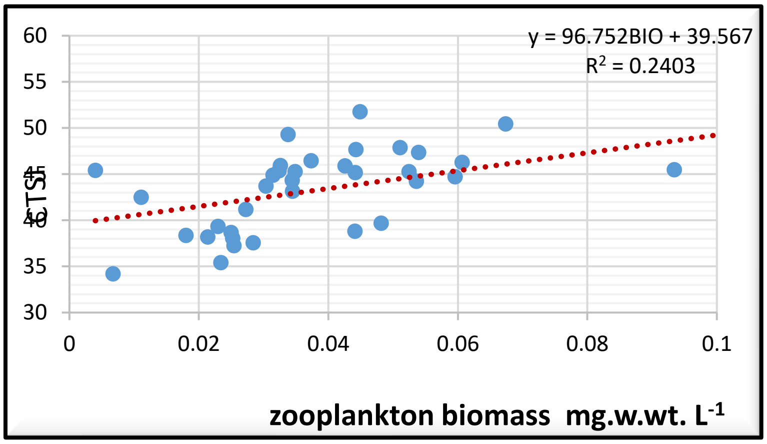

Fig. 3. Relationship between the total biomass of zooplankton (Biomass; mg w.wt. L^{-1}) and the trophic state index (CTSI)

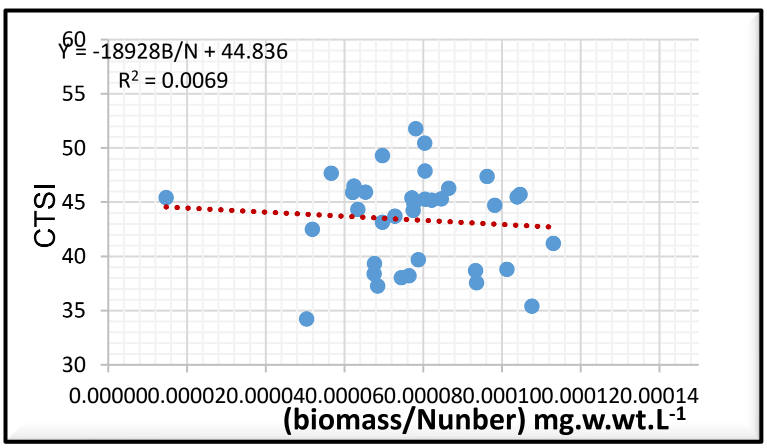

Fig. 4. Relationship between biomass to numbers ratio of zooplankton (B:N) mg w.w. ind^{-1})

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Table (3): Comparison of Trophic status of aquatic environment in general in terms of CTSI and TSIzoo values.

CTSI	TSI_{zoo} **(N, ind. L^{-1})**	TSI_{zoo} B (mg w.wt. L^{-1})	**TSIzoo** B:N (mg w.wt. ind. $^{-1}$)
43.1	43	42.6	46.2
42.46	43.1	42.7	46.1
42.2	44.1	42.9	46
40.4	39.5	40.2	45.5
41.2	41.5	42.4	46.4
43.9	42.5	43.2	46.5
42	45.8	45.7	46.6
42.1	42.7	43.2	46.4
43	43.5	43.6	46.3
43.4	42.8	43.1	46.3
45.9	43.6	43.4	46.2
45.19	48.1	46.9	46.5

Figure 5 showcases the monthly fluctuations in zooplankton numbers across Al-Hammar, Al-Chebiyesh, and the Euphrates, highlighting significant variability in populations. Peak zooplankton counts were observed at 51.4 in Al-Hammar, 48 in Al-Chebiyesh, and 40 in the Euphrates, indicating optimal environmental conditions for zooplankton growth. Conversely, the lowest counts were 40.4, 39.6, and 28.5, respectively, suggesting adverse conditions such as limited food or poor water quality.
Figure 6 illustrates the monthly shifts in the zooplankton index, focusing on zooplankton biomass across Al-Hammar, Al-Chebiyesh, and the Euphrates. The data reveal notable fluctuations in biomass, with the highest values recorded at 50.6 in Al-Hammar, 46.1 in Al-Chebiyesh, and 44.2 in the Euphrates, indicating periods of peak zooplankton productivity. The lowest biomass values were observed at 40 in Al-Hammar and the Euphrates, and slightly higher at 40.6 in Al-Chebiyesh, pointing to times of reduced zooplankton activity.

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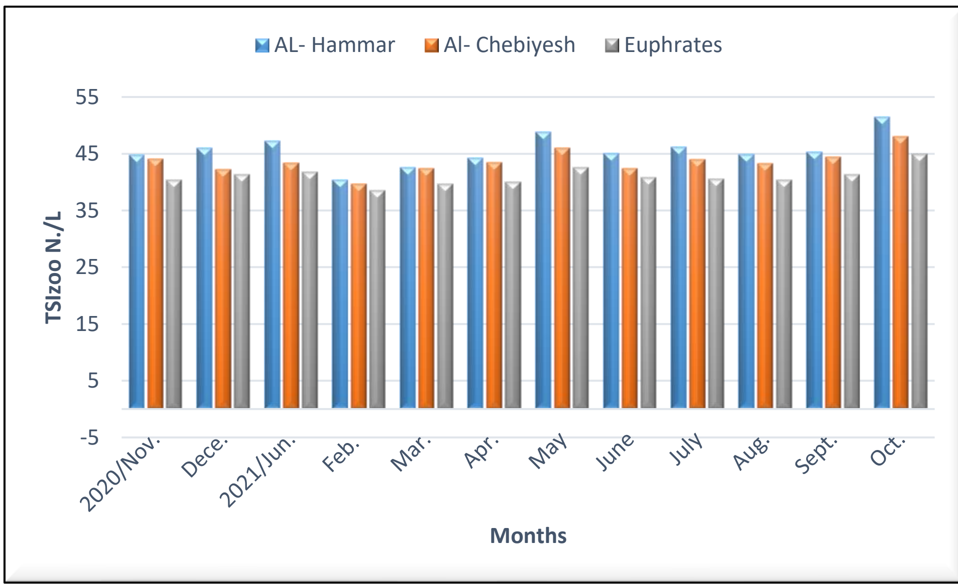

Fig. 6: Monthly changes in the values of the zooplankton index of trophic status as a function of zooplankton biomass

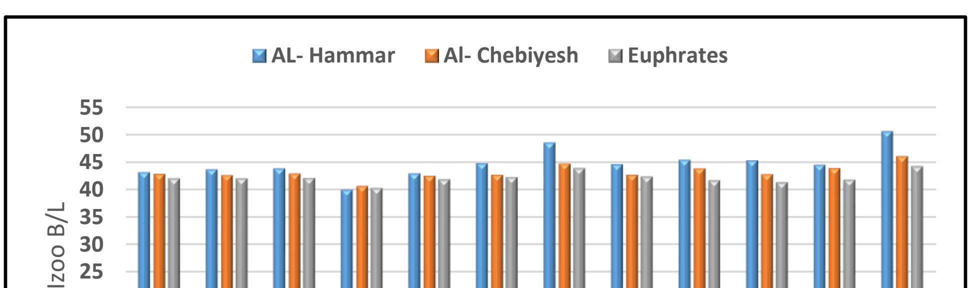

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Fig. 6: Monthly changes in the values of the zooplankton index of trophic status as a function of zooplankton biomass

Figure 7 depicts the monthly variations in the zooplankton index, specifically focusing on the ratio of zooplankton biomass to their numbers across Al-Hammar, Al-Chebiyesh, and the Euphrates. This figure highlights relatively narrow fluctuations in this ratio, with the highest values being 46.8 in Al-Hammar, 46.4 in Al-Chebiyesh, and 47 in the Euphrates, indicating periods where biomass per individual zooplankton was at its peak. Conversely, the lowest values recorded were 45.1 in Al-Hammar, and 45.8 in both Al-Chebiyesh and the Euphrates, suggesting slightly less biomass per zooplankton individual during these times.

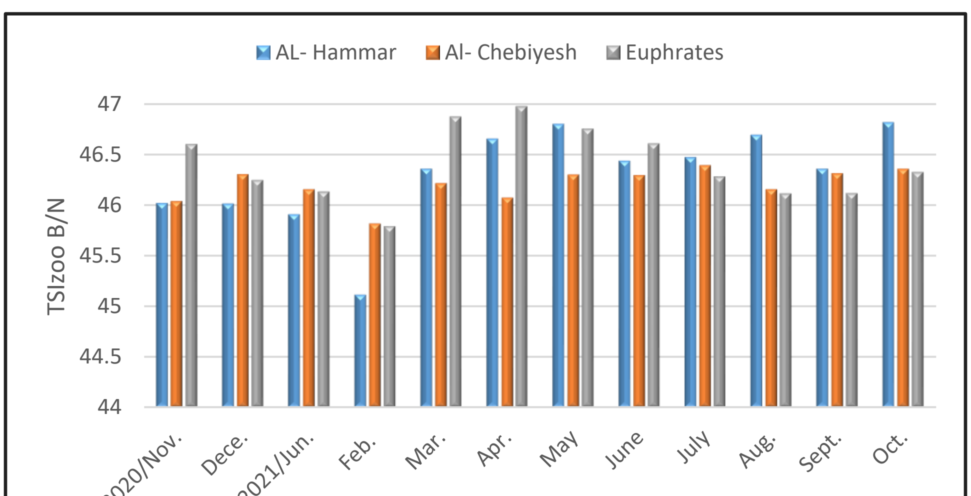

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Figure 8 presents the annual average values of the zooplankton index, indicating the trophic status across three distinct environments. The Eastern Al-Hammar marsh recorded an average value of 45.6, positioning it within the Meso-eutrophic category. In contrast, the Al-Chebiyesh Marsh and the Euphrates River exhibited slightly lower average values of 44.3 and 43.2, respectively, categorizing both environments as Mesotrophic.

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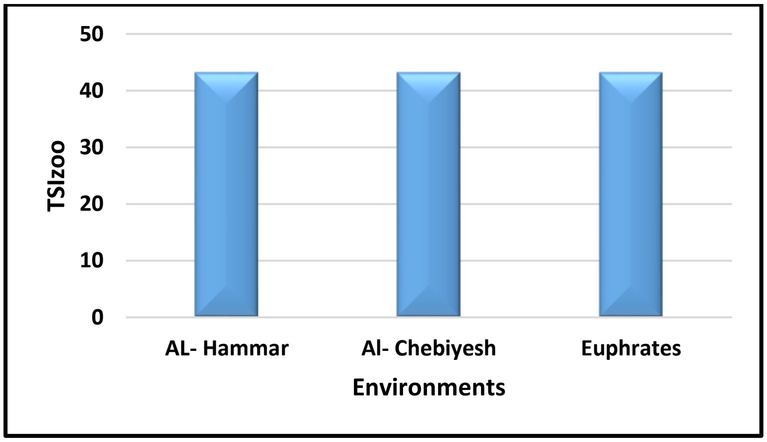

Fig. 8: Annual average values of zooplankton index of trophic state (TSIzoo)

Figure 9 assesses the consistency between the TSIzoo and CTSI, showed how seasonal factors may influence these metrics. This could provide insights into the ecological dynamics of the studied environments and inform decisions on conservation or remediation efforts.

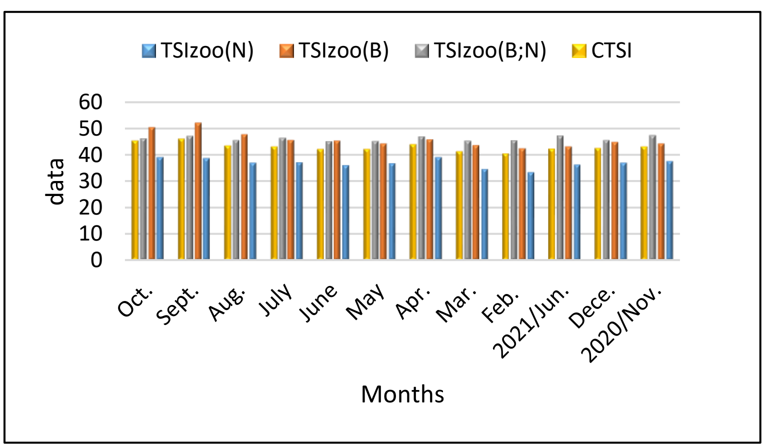

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Fig. 9**:** relationship between zooplankton trophic index (TSIzoo) and the Carlson trophic state index (CTSI)

Discussion

The results present a comprehensive analysis of the relationships between zooplankton communities and the trophic status of various aquatic environments. It underscores the 'bottom-up' ecological model, asserting that nutrient availability and light — essential for photosynthesis — regulate phytoplankton, which in turn influences zooplankton populations. Multiple studies, including those by Jeppesen et al. (2003), Nwankwo (2004), and Chou et al. (2012), have supported this concept.

The statistically significant correlations between zooplankton metrics and nutrient concentrations: nitrate ($r = 0.44$) and phosphate ($r = 0.51$). Furthermore, a substantial positive correlation is noted between zooplankton numbers and the Carlson Trophic Status Index (CTSI) ($r = 0.671$), zooplankton biomass ($r = 0.456$), and the ratio of biomass to numbers ($r = 0.621$), reinforcing the impact of trophic status on plankton communities.

Studies by Duggan et al. (2001), Yoshida et al. (2003), and Tasevska et al. (2010) indicate an increase in zooplankton numbers and biomass with a rise in trophic status. Conversely, Gutkowska et al. (2013) and Munoz-Colmenares et al. (2021) suggest that brackish water bodies and their variable salinity may impede the use of zooplankton communities as a reliable indicator of trophic status.

The strong positive relationship between CTSI and zooplankton numbers ($R^2 = 0.4385$), while the relation with zooplankton biomass was weaker ($R^2 = 0.2403$). The discrepancy may be due to the prevalence of smaller plankton species which, despite their numbers, contribute less to the overall biomass.

It is obvious that zooplankton indices closely align with CTSI values, suggesting that zooplankton can serve as effective indicators of trophic enrichment, as posited by Jekatierynczuk-Rudczyk et al. (2014). This alignment could be attributed to the bottom-up influence of nutrients, particularly phosphorus, on phytoplankton growth, which has a direct connection to chlorophyll-a concentrations.

Shifting primary producer compositions impact zooplankton communities, with their abundance and biomass tied to chlorophyll-a levels and phytoplankton availability, as

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supported by research from Hogsden et al. (2009), Xiong et al. (2016), and Ochocka and Pasztaleniec.(2016)

Classifications of trophic status based on zooplankton indices reveal that the Eastern Al-Hammar marsh falls within the Meso-eutrophic category, while Al-Chebiyesh marshes and the Euphrates River are categorized as Mesotrophic. However, when considering the ratio of biomass to numbers, both Al-Chebiyesh and the Euphrates shift to the Meso-eutrophic category.

This differentiation in classification across environments is likely due to variations in nutrient levels and pollutant concentrations, which are foundational for phytoplankton and subsequent zooplankton growth. The rapid response of zooplankton to changes in the food chain, such as phytoplankton blooms, is noted.

Conclusion

This research clearly categorize the trophic condition of the aquatic systems in question as predominantly Mesotrophic, according to analyses centered on zooplankton count and biomass. Nevertheless, an inclination towards a Meso-eutrophic state is observed when the focus is placed on the ratio of biomass to organism count. The results emphasize the critical role of zooplankton as reliable indicators for assessing ecological integrity and nutrient flux in aquatic ecosystems. These indicators are imperative for precise environmental evaluation and stewardship, offering a deeper understanding of the ecological health and enduring viability of these water bodies.

الخلاصة

لتقييم حالة المسطحات المائية التغذوية وفق دليل جديد يعتمد على مجتمع الهائمات الحيوانية قدرت الحالة التغذوية لثلاث مناطق وفق دليل الحالة التغذوية لكارلسون CTSI شملت الجزء الجنوبي لكل من هوري الحّمار الشرقي والجبايش ونهر الفرات وللمُدة من تشرين الثاني 2020 ولغـاية تشرين الأول 2021.كان الهدف من الدراسة هو اختبار مدى فائدة وفرة مجتمع الهائمات الحيوانية كدليل حيوي لتقدير الحالة التغذوية لذا جمعت عينات الهائمات الحيوانية من محطات الدراسة . طُبِقتْ معادلة الانحدار الخطي بين بيانات كل من أعداد الهائمات الحيوانية فرد/لتر والكتلة الحية للهائمات بدلالة الوزن الرطب وبوحدة ملغم/لتر ونسبة الكُتلة الحية للهائمات الحيوانية إلى أعداد الهائمات الحيوانية مع معادلات الحالة التغذوية لكارلسون CTSI وحولتْ معادلات الانحدار إلى صيغ يمكن من خلالها معرفة الحالة التغذوية للمسطحات المائية، حُسب دليل الحالة التغذوية للمسطحات بدلالة الهائمات الحيوانية اذ صُنِفت الحالة التغذوية للبيئة المائية بصورة عامة بحسب دليل الهائمات الحيوانية TSIZOO وإعتماداً على أعداد الهائمات والكتلة

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الحية لها ضمن الفئة متوسطة التغذية Mesotrophic بقيم بلغت 43.37-43.39 على التوالي، أما اعتماداً على نسبة الكتلة الحية إلى الأعداد فصُنِفت ضِمن الفئة Meso-eutrophic بقيمة بلغتْ 46.3

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