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ORIGINAL ARTICLE

THE IMPACT OF MARINE HEAT WAVES AND THEIR TEMPORAL PATTERNS ON THE ABUNDANCE AND DIVERSITY OF FISHERIES Off IRAQI MARINE WATERS

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ABSTRACT

Data from the current study was used to analyse the impact of marine heat waves on the quantity and distribution patterns of Iraqi marine fisheries following the recent change in the climate of the northwestern Arabian Gulf. The average annual water temperature and salinity were 26◦C and 38.6 psu, respectively, higher than the averages recorded during previous decades. The dissolved oxygen average was 8.65 psu, and the pH was 8.23. Principal components analysis (PCA) showed that temperature and salinity accounted for 66.93% of the effect of the studied factors, while the percentage of dissolved oxygen was 32.81% and the pH was 0.27%. The results showed a decrease in the weight, numbers, and diversity of the fish during the summer compared to the data from previous decades. Supplementary variable analysis showed that the number of species, individuals, and weights of commercial marine fisheries' catches were inversely correlated to water temperature and salinity. Autocorrelation analysis revealed temporal changes in the effect of temperature and salinity on the decline in the number of fish during the summer. It is extremely important that significant progress be made in understanding marine heat waves and the risks they pose to marine ecosystems in order to predict how these systems and the products they provide will be affected.

Keywords: Biodiversity, Climate change, Fish populations, Marine fisheries, Marine heat waves.

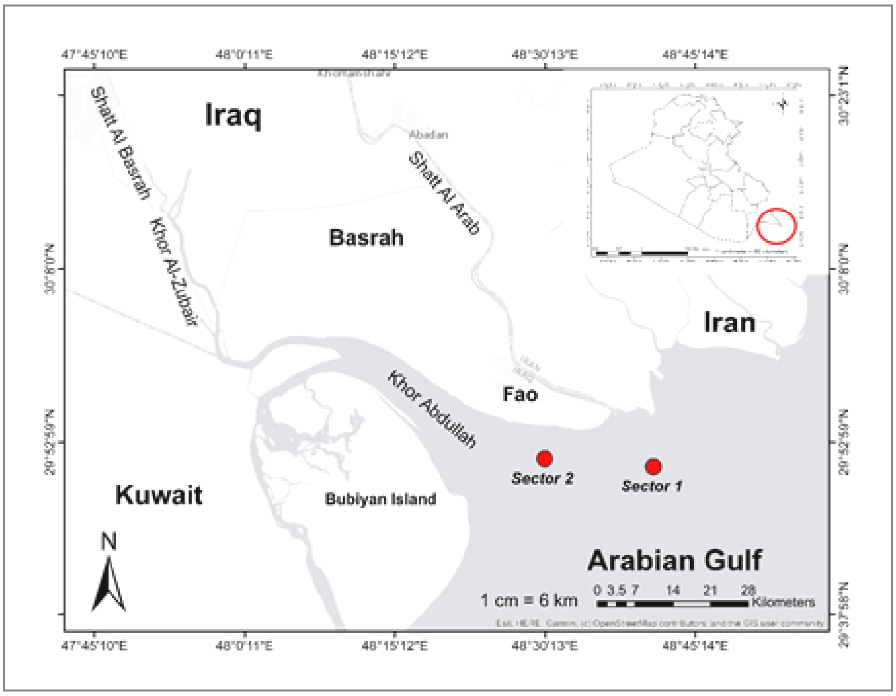
INTRODUCTION

An essential challenge in ecology is understanding patterns of biodiversity distribution and the drives behind them, especially global climate change and biodiversity loss (Weir and Schluter, 2007; Espino *et al.*, 2015). The ecological stability hypothesis indicates that the diversity increases in places with low environmental fluctuations. The fact that more stable environments favor a higher degree of specialization and leads to increased species richness (Sanders, 1968). Climatic phenomena shape the structure of biological systems and affect the biogeochemical functions and services they provide to the community (Frolicher and Laufkotter, 2018). Marine heatwaves are defined as abnormally long periods of warm ocean temperatures or very warm temperatures over short periods. (Harley *et al*., 2006). Evidence indicates that atmospheric heat waves on the Earth's surface are changing due to global warming. This increases the risk of severe and widespread effects, and in some cases, impacts on natural, social, and economic systems are irreversible. In contrast, we know little about how these extreme events change the oceans, especially those related to global warming, and how they will affect marine organisms (IPCC, 2014). This knowledge gap is a source of concern; some recently observed marine heat waves have demonstrated the vulnerability of marine organisms and ecosystems to such extreme weather events (Parmesan *et al*., 2000). Marine heatwaves can cause devastating impacts on warm-water ecosystems with severe social and economic repercussions (Sun *et al*., 2023). Extreme events can cause sudden, dramatic impacts on marine ecosystems, including mass die-offs, coral bleaching, shifts in the distribution of fish communities, and changes in the structure and functions of regional marine ecosystem organisms (Hughes *et al*., 2017; Smale *et al*., 2019).

No previous studies in Iraqi marine waters have been carried out to study this topic. Hence, the current paper is prepared to examine the impact of marine heat waves resulting from climate change on fisheries in the Iraqi territorial’s marine waters.

MATERIALS AND METHODS

Description of the study area: Our territorial waters are located at the northwestern head of the Arabian Gulf; they include the lands through which the Shatt al-Arab flows and extend west to Khor Abdullah and the Kuwaiti borders. Their coastline is 60 kilometers long, and tidal currents are the primary source of movement for marine water currents, in addition to the influence of winds (REF?). Marine hydrology is influenced by fresh water discharge from the Shatt Al-Arab River. This may reduce the salinity at the mouth to less than 10 psu during the flood season so that it is not comparable to the salinity levels of the rest of the Gulf. The region's climate is desert with high humidity: and northwest or north winds during most times of the year (Muttashar et al., 2024; Sale et al., 2011). Map (1) shows a map of the study area, within the coordinates (29°50'46.806"N 48°40'17.465"E; 29°5140.536"N 48°2929.544"E).



Map (1): Study specimens collection sectors.

Collecting fish specimens: Fish specimens were collected from January-December 2022. In the form of monthly sea, trips on a fishing boat 25 meters long and eight meters wide, with 250 horsepower, its fishing speed is 2-3 knots/sec, and it is equipped with bottom trawl nets 25 m long and 2.5 m high. The mesh openings in the wings are 2.5 cm, and the mesh bag is 1.5 cm. The length of the tow rope is between 100 and 150 m. The duration of pulling the net into the water while fishing is three hours, and the sea journey takes seven-nine days. The fish specimens were preserved with ice and placed in refrigerated boxes to preserve the specimens before conducting studies on them when arriving at the laboratory. Four environmental factors were measured in the field: water temperature (°C), water salinity (psu), pH, and dissolved oxygen (mg/L) using a German made multi parameter portable meter Multiline ® Multi 3630 IDS.

Laboratory work: Fish were classified based on Carpenter *et al*. (1997), and verified by Fricke and Eschmeyer (2023). Commercial and non-commercial species were identified based on species released at the fish-landing site in the Al-Faw area. Fish specimens were measured by weight (kg) and length (cm). The numbers and weights of individuals for each species were recorded monthly.

Statistical analysis: The statistical program SPSS, a package of statistical programs, was used for quantitative and descriptive statistical analysis (SPSS Statistics Version 23.0). To analyze the correlation coefficient between environmental factors and the rest of the factors included in the study, an analysis of variance table was used to show statistically significant differences between the parameters' averages. Quantitative data analysis was used using (XLSTAT 2023), which is a package of a complete set of statistical programs to analyze the data, from which the following programs were chosen: Principal Component Analysis (PCA), PCA with Supplementary Variables, Agglomerative Hierarchical Clustering (AHC), and autocorrelation.

RESULTS

Environmental factors: Diagram (1) shows the statistics of environmental factors measured during the study period. It shows the highest and lowest values for each factor and the average, median, first, and third quartiles of water temperature data, salinity, dissolved oxygen, and pH in Iraqi marine waters. The lowest temperature values in January were 15°C, while the highest values were recorded in August at 34°C and an average of 26°C. Significant differences were found among the year's seasons for water temperatures (p-values< 0.01, F = 11.78).

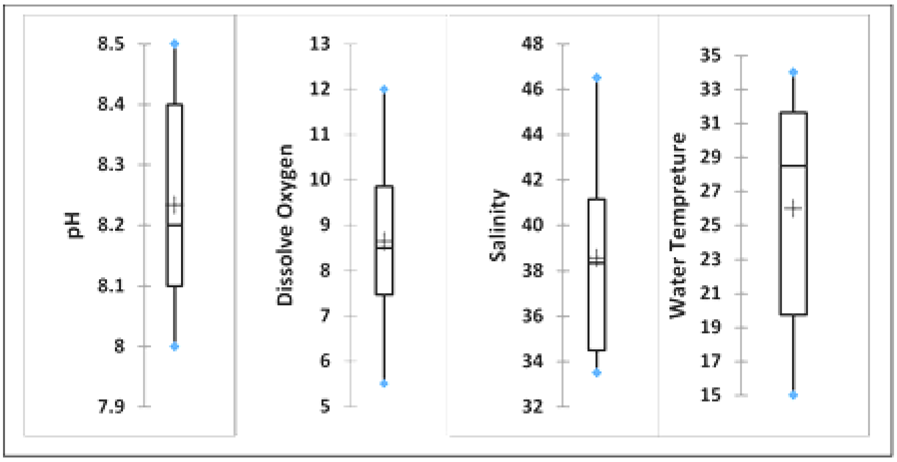


Diagram (1): Summary of environmental factor values.

The lowest values of salinity in March were 33.5 g/L, while the highest values in August were 46.5 psu, with an average of 38.6 psu. A positive correlation was found between salinity and water temperature ($r = 0.76$, $p < 0.004$, $R^2 = 0.57$). The analysis of the variance table revealed that there was a significant difference between the seasonal results for salinity (p-values< 0.003, F = 11.78); the lowest dissolved oxygen in August was 5.5 mg/L, while the highest values were recorded in January at 12 mg/L, at an average of 8.65 (mg/L). Dissolved oxygen was inversely correlated with water temperatures and salinity ($r = -0.833$, p-values< 0.001, $R^2 = 0.694$; $r = -0.623$, p-values < 0.030, $R^2 = 0.388$ respectively) . Significant differences existed between the year's seasons during the study (p-values< 0.005, F = 9.648).

The results indicated no significant differences between the average pH values for the seasons of the study year (p-values< 0.637, F = 0.593). The minimum and maximum pH values ranged between 8 and 8.5 during April, May, February, and June respectively, at an average of 8.23. Diagram (2) shows the principal component analysis of the measured environmental factors (PCA).

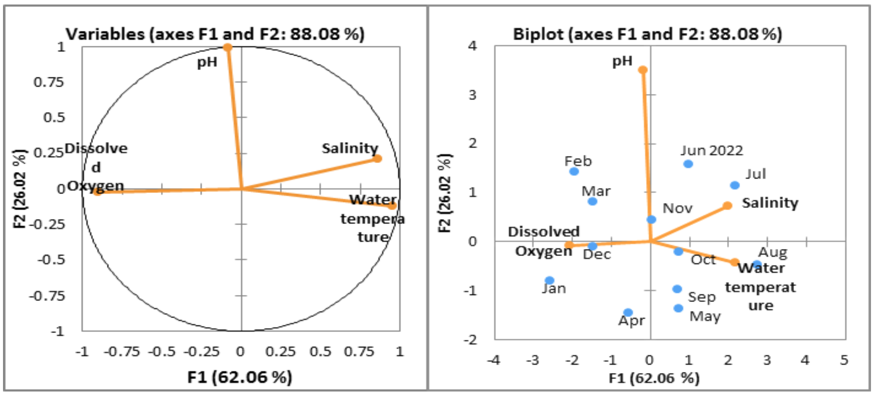


Diagram (2): Principal components analysis of environmental factors.

Table (1) includes a summary of the analysis results, showing the eigenvectors and eigenvalues, the percentage of influence of all environmental characteristics under study, and the correlation between environmental characteristics and F-factors.

Table (1) Principal components analysis results.

Environmental factors	F1		F2	
	a	*b*	*a*	*b*
Water temperature	0.96	36.93	-0.12	1.44
Salinity	0.86	30.00	0.21	4.17
pH	-0.08	0.27	0.99	94.35
Dissolved Oxygen	-0.90	32.81	-0.02	0.04
Eigenvalue	2.48		1.04	
Variability %	62.06		26.02	
Cumulative %	62.06		88.08	
(a)= Correlations between variables and factors (F)				
(b)= Percentage contribution of variables				
(F)= The axis that passes through most of the data points of the factors involved in the statistical analysis.				

Diagram (3) shows the cluster analysis of the similarity percentage between the measured environmental factors. It is noted that the similarity between water temperatures and salinity is 78%, and the percentage of similarity between dissolved oxygen and pH was meagre and reached 2%. The cluster analysis separated three groups: the first was between water temperature and salinity; the second included dissolved oxygen only; and the third was for the pH factor only, as shown in Diagram (3).

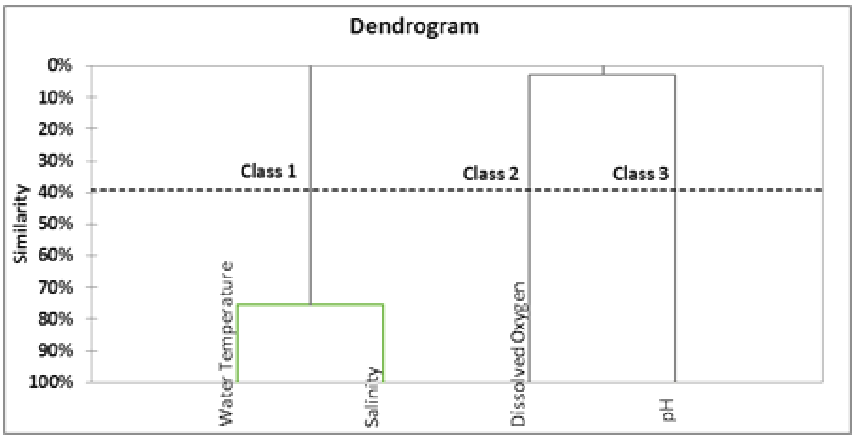


Diagram (3): Cluster analysis of the percentage of similarity between environmental factors during the study.

Fish community structure:

(1) Changes in the structure of commercial and non-commercial fish:

A- Numerical structure: Diagram (4) shows the monthly number of individuals for commercial and non-commercial fish structures. The total number of individuals of commercial species reached 5967, equivalent to 76.14% of the total number of fish caught (7,836 individuals). The lowest numbers were recorded in August and reached 115 individuals, while the highest numbers reached 1075 individuals in May, with a monthly average of 497.25 individuals.

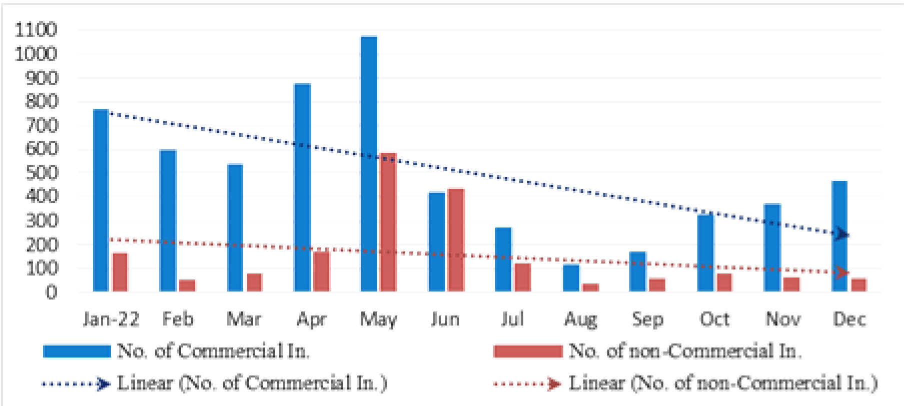


Diagram (4): Monthly numbers of individuals for the composition of commercial and non- commercial fish.

The number of individuals of non-commercial species constituted 1869 individuals, representing 23.86% of the total number of individuals caught annually; the lowest numbers caught were 32 individuals in August, while the highest numbers recorded in May were 582 individuals, with a monthly average of 155.75 individuals. The statistical analysis results showed an inverse correlation between the numbers of individuals of commercial species, water temperatures, and salinity (r = -0.500, p-values = 0.098, R^2 = 0.250; r = -0.573, p-values = 0.051, R^2 = 0.328, respectively). The results showed significant seasonal differences between the numbers of individuals of commercial species (Sig. = 0.019, F =6.046). It is observed from Diagram (4) that the values of the numbers of individuals of commercial and non-commercial species converge and decrease during June and the rest of the hot months, with the direction of the forecast line steepening steeply for commercial species and less steeply for non-commercial species.

Diagram (5) shows a supplementary variable analysis that shows the nature of the correlation between the number of individuals of commercial and non-commercial species and environmental factors, the loadings and weights of each factor, and the directions of their influence within the study environment. It is observed that the numbers of individuals of commercial species respond inversely to temperatures and salinity, and the opposite responses of non-commercial species to temperature and salinity.

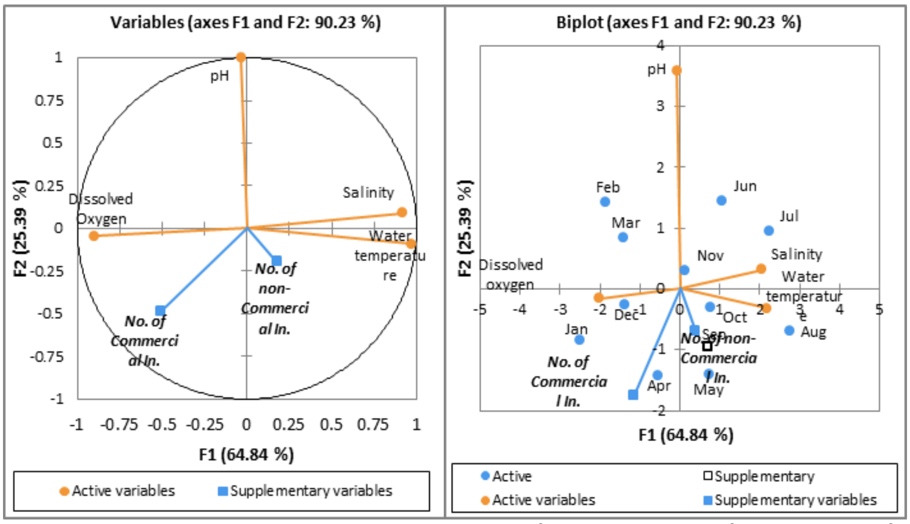


Diagram (5): Supplementary variable analysis for the number of individuals of commercial and non-commercial species.

b- Weight structure: Diagram (6) shows the weights of commercial and non-commercial species. Data on commercial species, whose total weights reached 665.481 kg, representing 86.69% of the total catch, show that the highest catch values were in February at 108.427 kg. The lowest in August was 9.545kg, with an average monthly weight of 55.456 kg, while the total weight of non-commercial species reached 102.139 kg, equivalent to 13.31% of the total weight, the lowest weight was 1.236 kg in November, and the highest was 19.481 kg in June, with a monthly average of 8.511 kg**.**

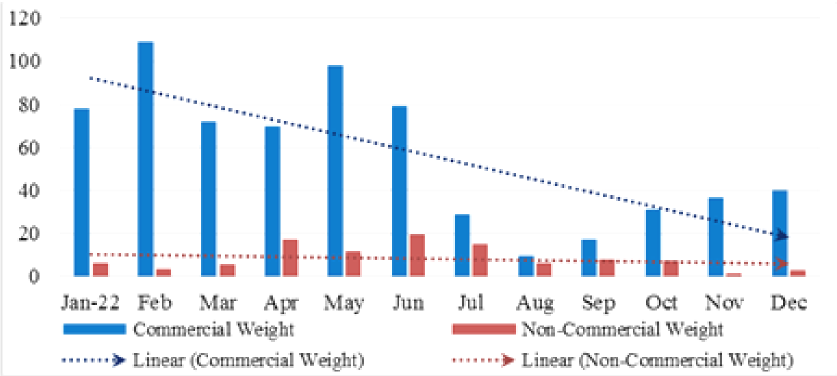


Diagram (6) Weights of commercial and non-commercial species caught during the study.

The statistical analysis results show an inverse correlation between commercial fish weights, water temperatures, and salinity (r=-0.633, p-values= 0.027, R^2=0.401; r=-0.606, p-values= 0.037, R^2=0.367, respectively). The results also showed significant seasonal differences between the weight values of commercial species (Sig. = 0.001, F = 19.073).

It is noted from Diagram (6) that the linear prediction trend is strongly sloped for the weights of commercial species, with a slight slope for the weights of non-commercial species. Diagram (7) shows the supplementary variables analysis of the effect of environmental factors on the weights of commercial and non-commercial species. It shows the inverse responses to the effects of temperature and salinity on the weights of commercial species. In contrast, these factors' positive effects on non-commercial species' weights are similar to the results of the number of fish individuals.

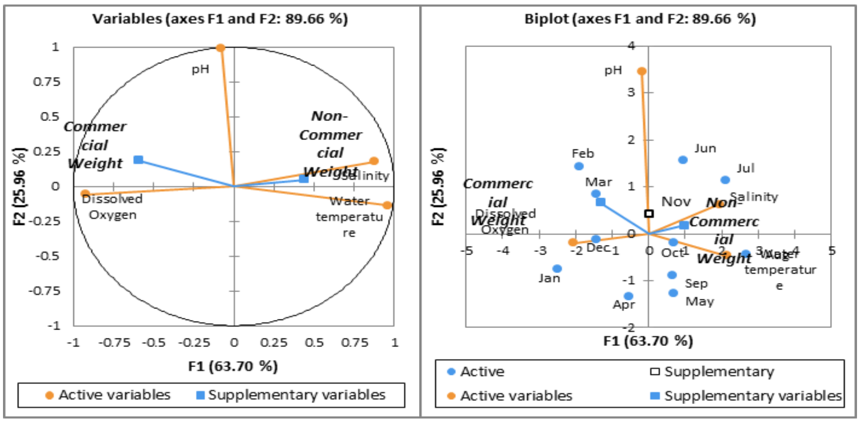


Diagram (7): Supplementary variable analysis of the effect of environmental factors on the weights of commercial and non-commercial species.

c- Diversity structure: Diagram (8) shows the number of commercial and non-commercial species and the total number of fish caught. The number of commercial species reached 101, while the number of non-commercial species reached 58, making 159 species. The lowest commercial fish were collected in August (19 species), and the highest number of species were 52 in March, with a monthly average of 40 species. While the lowest non-commercial species reached 10 in August and the highest number of species recorded in June (33 species), with a monthly average of 22 species. The percentage of commercial species represented 63.5% of the total number caught, while the percentage of non-commercial species reached 36.5% (Diag., 9).

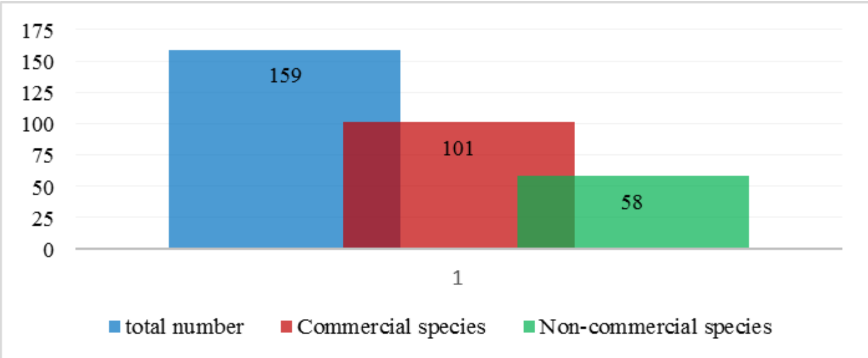


Diagram (8): Number of total, commercial, and non-commercial species.

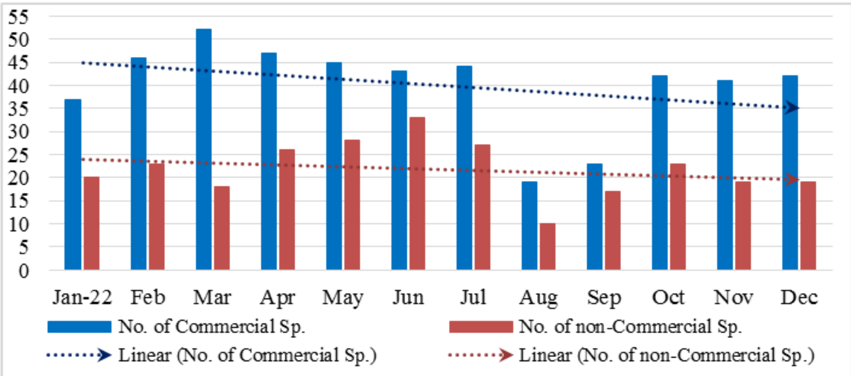


Diagram (9): monthly variation of commercial and non-commercial fish diversity during the study period.

Commercial species were inversely correlated with water temperatures and salinity (r=-0.484, p-values= 0.111, R^2=0.234; r=-0.398, p-values= 0.200, R^2=0.158 respectively); analysis of variance shows that there are significant differences between the summer, winter, and spring seasons (Sig. = 0.033, F =2.999). Diagram (10) shows a supplementary variable analysis of the effect of environmental factors on the diversity of commercial and non-commercial species. It shows the inverse correlation of commercial species with water temperature and salinity and the positive correlation of non-commercial species with water temperature and salinity.

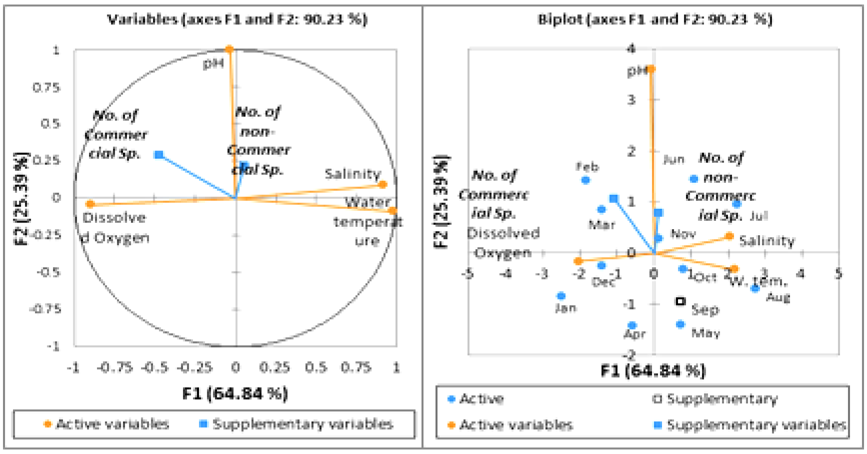


Diagram (10): Supplementary variables analysis of the impact of environmental factors on diversity of commercial and non-commercial species.

After conducting a correlation analysis between the numbers of individuals of the 101 commercial species, it was found that 63.5% were inversely correlated with water temperature. Commercial fish species (highly consumed food fish), such as the Sparidae, the Lethrinidae, the Psettodidae, the Paralichthyidae, Soleidae and most members of the Epinephelidae, occupied this inverse relationship and the extent of their vulnerability to high summer temperatures. The correlation analysis showed that 68% of commercial species were also inversely correlated with salinity in the summer.

d- Autocorrelation: Autocorrelation is distinguished from Pearson correlation in that Pearson correlation gives the final value for the nature of the correlation between factors. In contrast, autocorrelation analysis gives continuous values for the nature of the correlation over a specific time series. Therefore, Diagram (11) gives some relationship between a rising water temperature and salinity with the number of individuals of both commercial and non-commercial fish species that may give a clearer picture of the environmental situation. Diagram (11) shows the autocorrelation between the number of individuals and commercial species with water temperature and salinity. The diagram shows the effect of changes in water temperature and salinity on the path of biodiversity in the study area and consequently, the decrease in diversity and the number of individuals in the summer starting in July.

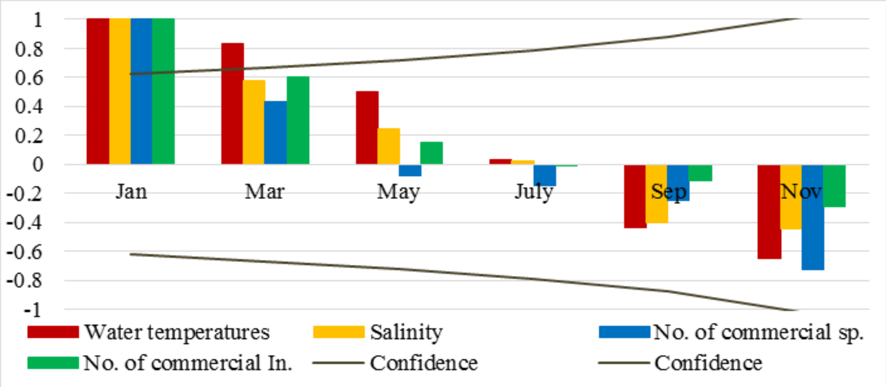


Diagram (11): Autocorrelation between the number of individuals, commercial species and some environmental factors.

DISCUSSION

Fisheries managers have long confirmed the importance of measuring environmental factors associated with fishing, but it has taken a long time to acknowledge the consequences of ignoring these considerations. Environmental factors are often not included in fisheries and management models, but they are likely to impact fish stocks significantly. Predation, competition, ecosystem changes, and habitat change have changed community dynamics, stock abundance, and composition (Link, 2002)**.**

It was observed that temperature increased significantly in the summer of sample collection, especially in July and August, when average water temperatures reached 26◦C in 2022. When making a comparison between the average temperatures of this study with previous studies, it is noticed that it has increased over the years. For example, Mohamed and Ali (1993) stated that the average water temperature during 1989–1990 reached 22.9°C, while that of Mohamed *et al*. (1998) recorded 23°C between 1995 and 1996. Ali *et al*. (2000b) showed that the average temperature of our regional waters for 1997–1998 was 25°C, which was one centigrade lower than the average temperature of the current study. Mohamed *et al*. (2001) recorded the same temperature average 25°C for 1998–1999. Mohamed and Ali (1992) mentioned in their study during 1989–1990 that the maximum temperature is recorded in July, while in the present study, the highest temperature is recorded in August. This confirms the prolonged period of high temperatures during the summer months. At the same time, the average water temperature that recorded by Mohamed and Resen (2010) reached 24.4°C during 2007–2008. The current results show that climate change has a role in the emergence of marine heat waves in our territorial waters during the summer and their peak in August. These waves, repeated over the past few years, hurt marine organisms, the most important of which are fish**.**

The results of the present study showed that the average salinity reached 38.6 psu, while Ali *et al*. (1998) stated that the ranges of salinity were between 27 and 38 psu for the period between 1990 and 1994. Mohamed *et al*. (2002) indicated the ranges of salinity during 1998–

1999 between 12.8 and 36.6 psu in April and July, respectively, while the peak salinity in the current study was 45.1-46.5 psu during July and August (See Table 2).

The salinity values in Mohamed *et al*. (2008a) were 22.5 and 41.2 psu during March and August, respectively, between 1999 and 2000. It was noted in a recent study that total and commercial catch amounts were positively correlated with water temperature and salinity. In contrast, in this study, they were inversely correlated to these factors. The salinity was also measured in Ali *et al*. (2000b), with a minimum of 20.4 psu in April and May and a maximum of 38 psu during the summer. Mohamed *et al*. (2005) showed that the salinity reached 25 psu during the spring and 40 psu during the summer. Mohamed and Mutlak (2006) stated that the lowest reached 22.5 psu in March, and the highest of salinity was recorded in August (41.2 psu), while the ranges of our study reached 33.5-46.5 psu in the same months of the previous study (See Diagram 1).

The current results indicated that the structure of the commercial fish community in Iraqi territorial waters northwest of the Arabian Gulf differs from that of historical data; in fact the numerical, weight, and abundance of diversity are inversely correlated to water temperatures and salinity, and there are significant differences between the seasons of the study year. Diagrams (4, 6, 8) show the decline in fish diversity during the summer months, and supplementary variable analysis shows these relationships in Diagrams (5, 7, 9).

Multivariate (multidimensional) statistical analyses are essential tools to illustrate statistical results in the form of a statistical graph (correlation circle). Supplementary variables are displayed on the correlation chart and do not affect the explanation ratio for any dimensions because they are not considered in PCA calculations. Supplementary variables are not used to calculate the coordinates of the active variables (factors) but help interpret the results, according to Faith and Norris (1989).

Our study data were similar to Al-Shamary and Younis (2022) in the period of a decrease in total and commercial catches during their study in 2018–2019 in July, August, and September. Qasim (2021) also showed the same effect of the summer season on fish catch quantities in 2017. If we go back to previous years, a radical difference appears in the extent of the abundance, distribution, and diversity of fish during the summer. Mohamed *et al*. (2002) during 1998–1999 found highest catches were recorded during July of 1998–1999. Moreover, Mohamed *et al*. (2005) showed that temperature and salinity directly affected by *Saurida tumbil*, commercial fishing, and total catch during 1999-2000. Mohamed *et al*., (2008a) evaluated Sultan Ibrahim stock (*Upeneus sulphureus*) and showed a positive correlation between temperature and salinity with the catch quantities per unit of effort, and temperature were more affected than the other factors. The monthly fluctuations of catch per unit effort in Mohamed *et al*. (2008b) ranged from 14.8 kg/hour in January to 39.2 kg/hour in August, indicating the high catch during the summer. Ali *et al*. (2000a) dealt with the state of Iraqi fisheries in Khor Al-Amaya for the period from 1997 to 1998; the study proved that there was a noticeable seasonal change in fisheries, as the most significant fishing effort was recorded in May to August, while the lowest average was during the winter months of December to

February. Mohamed and Mutlak (2006) showed that the highest catch averages for three species of goatfish were in the summer and fall seasons. Mohamed (1993) studied the fish structure from 1989 to 1990, it was noted that there were apparent seasonal changes in the total catch averages, ranging between 60.9 kg/hour during February and 772.9 kg/hour during August. The previous studies above prove a change in the course of fishing from summer to winter-spring, as in our study and the two studies that preceded the current study.

This indicates that the biological responses of fish to rising water temperatures have changed since that period, or perhaps in the very recent years (Qasim, 2021; Al-Shamary and Younis, 2022). The results of previous studies, when compared to recent studies, can be considered strong evidence of a change in the shifting of fisheries and the impact of temperatures on them due to the climate changes in our region. Specifically, marine heat waves can affect the change in the behavior of fish and perhaps other marine organisms in their distribution.

Fredston *et al*. (2023) explained that marine heatwaves constantly lead to community reorganization and collapse of fish biomass and have catastrophic consequences for ecosystems and fisheries, with severe declines in biomass sometimes occurring after the progress of marine heatwaves. Smith *et al*. (2023) explained that marine heatwaves are discrete periods of hot water and are becoming more frequent and widespread stressors on marine ecosystems, affecting the health of those systems globally. Cheng *et al*. (2017) showed that the warming trends were represented by an increase in warm days and nights and a decrease in cold nights and days. With maximum night-time temperatures rising at more than twice the average of their corresponding maximum daytime temperatures, the intensity and frequency of hot days increase, and minimum temperature indicators increase.

In this context, we understand the impact of the rapid decline in the number of species, the number of individuals, and weight abundance in August 2022. This is due to marine heat waves that continued during the summer, affecting the composition of fish populations in the northwestern Arabian Gulf. The critical question is: What are the measures and strategies for fish adaptation during marine heat waves? Intuitively, they will look for more suitable places; one of the conservation scenarios is their descent to deeper areas less affected by rising temperatures (vertical migration). However, this scenario does not work due to the shallow depths of most our territorial waters, which means that they are affected by rising temperatures in the same way as surface waters. The second scenario is its departure to distant areas (horizontal migration) within the more bottomless open sea; Sale *et al*. (2011) explained that the average depth of the waters of the Arabian Gulf is 34 m and that the maximum depth reaches 94 m. There are other reasons. Some fish species are tolerant of environmental stress. However, they will follow their prey that already left their appropriate environment, which may be difficult to obtain during those conditions, and there may be a break in the food chains of many species of organisms.

Our results show that commercial fish species, numbers, and weights were inversely correlated with water temperatures and salinity. In contrast, the correlation was positive for non-commercial species with water temperature and salinity. It appears that non-commercial species are classified as tolerant to a certain extent to these conditions. Perhaps their abundance and presence may collapse when temperatures or salinity are higher than recorded during the study. The same applies to commercial species during heat waves in the summer.

It is observed from Diagram (10) that there was an autocorrelation between the number of individuals, species of commercial fish, and some environmental factors; the direction of the influence of factors on the number of individuals and species seemed to be in a positive direction until May, and then things continued to change in different directions until they reached the opposite direction in November. Here, the interaction of living organisms with their ecosystem appears which would affect the abundance, distribution, and spread of aquatic organisms within their tolerance range for those conditions or the zonation of their original environments and according to the limits of their tolerance for changes that occur in the environment.

Table (2): Comparison of some ecological factors in historical and current studies.

References	Water temperature values (°C)	Salinity concentration values (psu)
Mohamed and Ali (1993)	22.9°C	-
Ali *et al*. (1998)	-	27 - 38
Mohamed *et al*. (1998)	23°C	-
Ali *et al*. (2000b)	25°C	20.4 - 38
Mohamed *et al*. (2001)	25°C	-
Mohamed *et al*. (2002)	-	12.8 - 36.6
Mohamed *et al*. (2005)	-	25 - 40
Mohamed and Mutlak (2006)	-	22.5 – 41.2
Mohamed *et al*. (2008a)	-	22.5 - 41.2
Mohamed and Resen (2010)	24.4°C	-
The current study	26°C	33.5 - 46.5

CONCLUSIONS

The results of multivariate statistical analyses confirmed that Iraqi territorial waters were affected by marine heat waves during the summer because of climate change. Fish biodiversity decreased during the summer, and marine fish composition decreased under the influence of these waves. As a result, marine fisheries have declined under these conditions. Most commercial species were sensitive to high temperatures and salinity, and a few species tolerated those conditions. Likewise, fish moved away from their biospheres through horizontal migrations towards deeper, lower-temperature waters. There have been changes in fishing seasons and the number of species from summer and fall, as we witnessed in previous decades, to winter and spring because of climate changes, as the winter season has become warmer.

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CONFLICT OF INTEREST STATMENT

The authors have no conflicts of interest to declare. Also, all ethical guidelines related to Fish and care issued by national and international organizations was implemented in this paper.

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تأثير موجات الحر البحرية وأنماطها الزمنية على وفرة وتنوع الثروة السمكية قبالة المياه البحرية العراقية

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الخلاصة

استخدمت بيانات الدراسة لتحليل تأثير موجات الحر البحرية نتيجة التغيرات المناخية على أنماط وفرة وانتشار مصايد الأسماك البحرية العراقية في شمال غرب الخليج العربي، بلغ معدل درجات حرارة المياه وتراكيز الملوحة 26°م، 38.6 غم/لتر على التوالي، وهي اعلى من المعدلات المقاسة خلال العقود السابقة، وبلغ معدل الأوكسجين الذائب 8.65 ملغم/لتر والأس الهيدروجيني 8.23. أوضح تحليل المكونات الرئيسية (PCA) أن عاملي الحرارة والملوحة قد شكلا 66.93 % من نسبة تأثير العوامل المدروسة، بينما بلغت نسبة الأوكسجين المذاب 32.81 % والأس الهيدروجيني 0.27%. بينت النتائج انخفاض التركيبة الوزنية والعددية والنوعية خلال فصل الصيف عكس نتائج دراسات العقود السابقة، وأوضح تحليل المتغيرات التكميلي ارتباط الوفرة النوعية والعددية والوزنية لمصايد الأسماك البحرية التجارية عكسيا مع درجات حرارة المياه وتراكيز الملوحة، كشف تحليل الارتباط التلقائي التغيرات الزمنية في تأثير درجات الحرارة والملوحة على انحدار تواجد الأسماك خلال فصل الصيف. ومن المهم للغاية إحراز تقدم كبير في فهم موجات الحرارة البحرية والمخاطر التي تشكلها على النظم البيئية البحرية للتنبؤ بكيفية تأثر هذه الأنظمة والسلع والخدمات التي تقدمها.