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Salinization Impact on Degradation of Biodiversity Intactness Index at East Hammar Marsh -Basrah- Iraq

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ABSTRACT

Biodiversity intactness index (BII) was applied to monitor the deuteriation of diversity status of East Hammar marsh (EHM). Proposed bench mark list of 30 fish species existed in EHM after inundation in 2003 was initiated. Number of fish species recorded by previous authors varied between 22 to 44. In total, 35 non-native out of 52 total fish species recorded in EHM represent 67.1% of fish assemblage. Values of Shannon and wiener biodiversity index fluctuated between 1.89 & 2.9 and were positively related to an increase in salinity of EHM. As result of the increased salinity in EHM, a rise was detected in migratory marine species and an absence of freshwater native ones. Salinity fluctuation plays a major role in altering the composition of fish assemblage in EHM.The highest BII value observed at EHM was 103.57, and the lowest score was 52.07. The highest salinity value recorded was 16.1psu in EHM in August 2018. Salinity fluctuations in EHM play a major role in increasing or decreasing BII values through migration or immigration of marine fish species to or from the marsh to the Shatt al-Arab estuary. Consequently, an opposite relationship existed between BII values and marsh salinity. The fluctuation of freshwater discharge from the Shatt al-Arab River plays a major role in salinity changes in EHM. An indirect relation exists between the BII of EHM and discharge of the Shatt al-Arab River. Non-native species tend to increase diversity value accompanied with an increase in the number of marine species. Negative relation existed between BII values and non-native species ratio in EHM. Establishing baseline BII data for fish assemblages in EHM is a vital step to create an intact reference mark.

INTRODUCTION

Wetlands are among the most threatened aquatic ecosystems, closely linked to human activity, industrial and agricultural beside global freshwater shortage **(Ortega *et al.*, 2004)**.

Construction of several irrigation dams on the Tigris and Euphrates rivers in Turkey, Syria, Iran and Iraq, resulted in a considerable reduction in freshwater influx qualitatively and quantitatively to the southern Iraqi marshes. Now, East Hammer marsh (denoted by EHM) gets a considerable amount of water from the Shatt al-Arab River,

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with an additional replenishment from groundwater seepage **(Hussain & Taher, 2007; Al-Nagar, *et al.*, 2020)**.

The biodiversity intactness index (BII) is an indicator of the status of biological diversity within a given geographical area or any define area with a biota reference assemblage. It is even possible to estimate the value of BII for the past and future **(Biggs *et al*., 2004)**. BII could also be defined as an estimated percentage of the original number of species and their abundance that remain in any given area.

Biodiversity losses have increased in southern Iraqi marshes due to shortage in freshwater supply from the sources in Turkey and Iran, habitat destruction by oil exploration and production, planned desiccation by Saddam regime and global climate change. In general **Dudgeon *et al*. (2006)** and **Hui *et al*. (2008)** pointed out that these factors led to the loss of biodiversity in rivers and wetlands.

Maintaining biodiversity is essential as its degradation lead to less stable ecosystems **(Naeem *et al*., 1995; stachowicz *et al*., 1999)**. The educed function and stability of EHM lead to a decline or damage in ecosystem services, affecting the welfare of inhabitants of the Arab marsh.

Allen *et al.* (2003) emphasized the importance of benchmark reference conditions when measuring and reporting BII for comparison and indexing. Establishing these benchmarks is crucial for baseline referencing in BII evaluations. BII also is considered an important tool for enhancing and improving applicable environmental laws and regulations. Moreover, it contributes to enhancing environmental awareness and knowledge among individuals and institutions. It is worthnoting that the BII is an indicator of the overall state of biodiversity in a given area.

Original fish assemblage of EHM was extensively altered during the last 20 years through the introduction of a huge number of exotic species, the increased migration of marine fish species mainly from Shatt al-Arab estuary and the Arabian Gulf in addition to the uncontrolled release of numerous ornamental species. **CIMI (2006)** concluded that the introduction of exotic species and the increased occurrence of marine fish resulted in compositional changes in the assemblages.

Freshwater fish assemblage in East Hammar marsh is facing conservation crisis. Recent studies **(Al-Najjar *et al*., 2019, Abdalhsan *et al*., 2020; Abdullah *et al*., 2022)** indicated that more than 60% of native freshwater species are on the brink of extinction. A major threat is posed by the introduction of exotic and ornamental species, along with the increased migration of marine species from the Arabian Gulf via the Shatt al-Arab, which has invaded the East Hammar Marsh.

At the time being, the original biodiversity of East Hammar Marsh is threatened by the increased salinity and the migration of marine fish species from the Shatt al-Arab estuary and the Arabian Gulf.

The aim of the present study was to detect the degree of loss in biodiversity intactness of EHM and to estimate the loss in the original biodiversity of the fish assemblage at EHM through the implementation of BII formula **(Lamp *et al*., 2009)**.

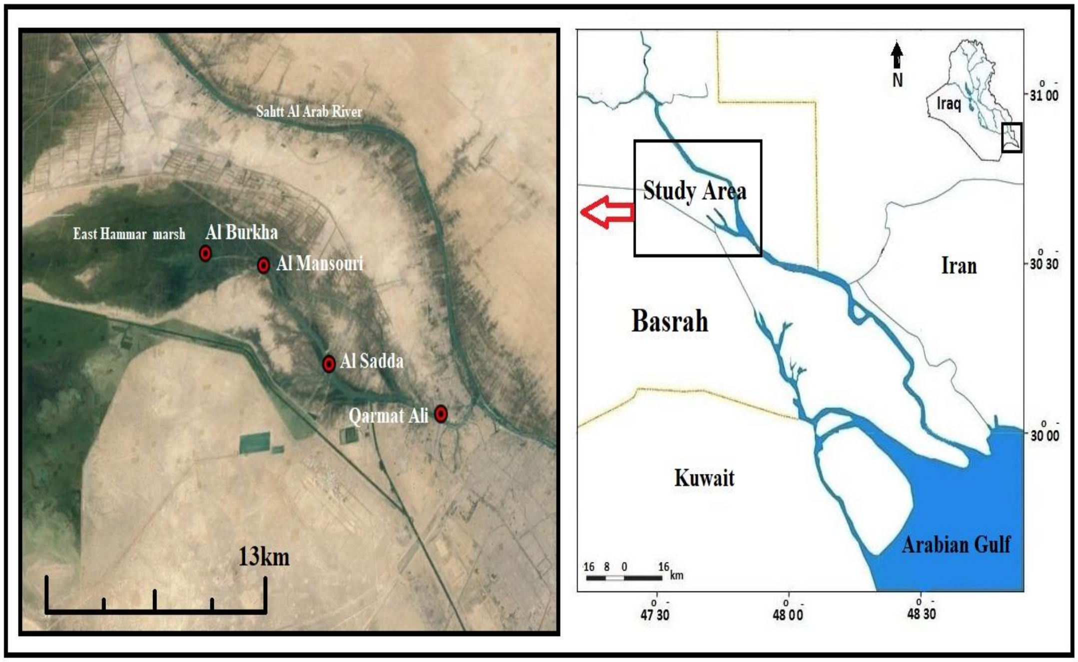
MATERIALS AND METHODS

1- Geographical setup

The East Hammar Marsh (EHM) is one of the largest wetlands in southern Iraq, with significant economic and social importance. Located on the outskirts of the large Rumaila oil fields, EHM supports a large water buffalo herd for dairy production, important anadromous fish and shrimp fisheries, and several Arab Marsh settlements. It spans approximately 123 to 130km in length, 26 to 35km in width, and covers an area of 82,968 hectares **(Bachmann *et al*., 2017)**.

Previously, the area of Hammar Marsh varied with water influxes from snow melt in spring and rising water levels in the Tigris, Euphrates, and the Shatt al-Arab rivers. However, it is now considered nearly closed and relies mainly on the semi-diurnal tides of the Shatt al-Arab River (Map 1).

The marsh was subjected to deliberate desiccation during the 90s of the last century. After inundation in 2003, the marsh exhibited the return of its flora and fauna with different percentage **(Richardson & Hussain, 2006)**. The marsh was affected by semidiurnal tide from the Arabian Gulf via Shatt al-Arab River. Its weather is characterized by a dry short winter and long hot summer extending from 8-9 months. Marsh water is well oxygenated, with alkaline pH and grey mud-silt sediments.



Map.1. East Hammer marsh located at the north, North West of Basrah province. Four major stations in marsh from East to West, Qarmat Ali, Al Sadda, Al Mansouri and Al Burkha. The Shatt al-Arab River is located to the east and the Arabian Gulf to the south.

2-Sampling stations

Most previous data were collected from specific sampling stations representing various biotopes in EHM. In general, four stations were commonly used for sampling fish assemblages: Al-Sadda, Al-Mansouri, and Al-Burkha, located in the main body of the marsh, and Qarmatj Ali, situated at the outlet channel connecting the entire marsh with the Shatt al-Arab River (Map 1). Their coordinates were determined using a GPS device.

1- Qarmat Ali station : A deep channel marsh connecting the main body of East Hammar marsh with the Shatt al- Arab River with water depth fluctuating between 7-8 meters and length of 10.5km, width of 280 meters, with co-ordinates of 30º 34'30.93'N and 47º 44' 38.87''E.

2- Al Sadda station: Actual inlet zone to the marsh with water depth fluctuating during semidiurnal tidal cycle, with co-ordinates of 30º 36' 49.16''N and 47º 40' 13.65''E.

3- Al Mansouri station: Wide channel marsh with water depth fluctuating during the tidal cycle, with co-ordinates 30º 40' 28.08''N and 47º 37' 42.79''E.

4- Al Burkha station: Wide shallow openness marsh with water depth fluctuating 0.5-2.0m during tidal cycle, with co-ordinates 30º 41'18.97''N and 47º 35' 11.93''E (Map 1).

3-Fish assemblage data used for computing BII

Due to the accumulation of significant data on the composition and biodiversity of fish assemblages in EHM, previous studies have focused on the nature of fish assemblage composition, and the occurrence and abundance of both native and non-native species. Biodiversity indices were recalculated using these data to evaluate the degree of degradation in the BII. Various authors used these biodiversity data to calculate the BII for EHM, assessing the marsh's health and intactness.

4- Ratio of native and non-native species to total fish species

The ratio of native to non-native fish species relative to the total number of fish species was calculated. This involved counting the number of native species (N) occurring in the samples and the number of non-native species, which includes marine, exotic, and invasive species (Nn). The ratios of native and non-native species to the total number of species (T) were calculated as follows:

Ratio of the number of native species (N) / total number of species (T) =

N / T x100

Ratio of the number of nonnative species (NN) / total number of species (T) =

NN /T x100

5- Biological intactness index (BII)

BII = [(R-O\R) +1].100, (**Lamp *et al*., 2009)**

BII= biological intactness index.

R= previous reference of diversity record.

O= observed diversity record.

To standardize the calculation of diversity, previous data were recalculated using the past program version 4.03.

6- Bench mark list of fish species

As a step to implement the biological BII according to **Lamp *et al*. (2009)**, a benchmark list was created by combining occurrence and abundance data from the studies of **Hussain *et al.* (2009)** and **Mohamed *et al.* (2013)**. In the former study, data were provided for fish species collected from the main body of the marsh (i.e., Al-Sadda, Al-Mansouri, Al-Burkha stations), while the latter focused on species from the lower reaches of the marsh at Qarmat Ali station. The benchmark list includes 30 species: 13 native, 11 marine, five exotic, and one invader. The mean number of individuals for each species was separately counted to calculate the benchmark diversity value.

RESULTS

1-Total number of species

After inundation of southern marshes in 2003 and formation of EHM, several fish survey were conducted during the period from 2006 to 2022. In general, 52 fish species were recorded, consisting of 24 marine, 17 freshwater native, ten exotic and one freshwater invader. 35 species were non-native representing 67.1% of total fish species existing in EHM (Table 1).

The bulk of the recorded species formed 46.1% mostly migratory species from the Shatt al-Arab estuary and the Arabian Gulf. This was followed by 17 species of native freshwater species, forming 30.6% endemic to the Tigris and Euphrates rivers. Additionally, exotic species consisted of 10 species, making up 10.2% of those introduced to Iraqi inland waters. One freshwater invader species from Iran was recorded in EHM.

Table 1. The occurrence and abundance of fish species collected from EHM during the sampling period from 2009 to 2022.The total number of fish species collected were 52 species distributed as follows: Marine species (M)=24, Native species (N)=17, Exotic species (E) =10 and Invader species (I) = 1

No	Species	Originl	Hussain *et al.*, (2009)	Mutlak, (2012)	Mohamed *et al.*, (2013)	Ahmed Et al., (2017)	Al-Najjar *et al.*, (2019)	Abdalhsan *et al.*,(2020)	Abdullah *et al.*, (2022)
1	*Garra rufa*	N	0	2	0	0	0	0	-
2	*Carasobarbus luteus*	N	267	3435	98	3	0	8	+
3	*Alburnus mossulensis*	N	631	16734	105	21	1012	9	+
4	*Mesopotamichthys sharpeyi*	N	24	16	0	0	0	0	
5	*Leuciscus vorax*	N	288	5751	81	0	2684	0	+
6	*Mystus pelusius*	N	0	18	3	0	2	0	+
7	*Planiliza abu*	N	5807	23131	1932	238	457	250	+
8	*Silurus triostegus*	N	123	719	55	0	255	12	+
9	*Acanthobrama marmid*	N	1747	14941	142	13	847	0	+
10	*Cyprinion macrostomus*	N	74	0	0	0	0	0	_
11	*Aphanius mento*	N	50	93	55	0	456	0	_
12	*Arabibarbus grypus*	N	8	25	0	0	0	0	_
13	*Mastacembelus Mastacembelus*	N	8	2	3	0	0	0	+

14	*Luciobarbus Kersin*	N	0	11	0	0	0	0	_
15	*Luciobarbus xanthopterus*	N	3	38	1	0	0	0	_
16	*Aphanius dispar*	N	64	2982	92	2	0	3	+
17	*Cyprinion kais*	N	0	15	0	0	0	0	_
18	*Tenualosa ilisha*	M	1627	9533	26	90	2173	12	+
19	*Thryssa whiteheadi*	M	613	17424	0	252	5276	1672	+
20	*Photopectoralis bindus*	M	0	57	0	7	0	0	+
21	*Sillago sihama*	M	0	103	0	3	116	32	+
22	*Planiliza klunzingeri*	M	3	3041	281	24	1688	0	+
23	*Acanthopagrus arabicus*	M	1	0	62	19	2151	0	+
24	*Boleophthalmus dussumieri*	M	0	99	0	0	11	127	+
25	*Platycephalus indicus*	M	0	0	0	0	0	2	
26	*Pseudosynanceia melanostigma*	M	0	0	0	0	0	8	
27	*Sparidentex hasta*	M	0	131	0	0	75	0	
28	*Brachirus orientalis*	M	1	45	0	0	211	5	
29	*Scatophagus argus*	M	1	1	3	0	89	0	
30	*Nematalosa nasus*	M	27	205	0	0	227	61	+
31	*Bathygobius fuscus*	M	0	439	2	35	16	237	+
32	*Netuma bilineata*	M	0	75	0	0	0	0	
33	*Planiliza subviridis*	M	264	4470	29	26	2473	23	+
34	*Johnius belangerii*	M	0	3	0	0	93	0	
35	*Sardinella albella*	M	0	2	0	0	112	0	
36	*Ilisha compressa*	M	0	180	0	0	237	0	
37	*Thryssa. hamiltonii*	M	0	13822	61	147	2801	0	+
38	*Planiliza carinata*	M	0	1	0	0	28	0	
39	*Netuma bilineata*	M	0	0	0	0	32	0	
40	*Cynoglossus arel*	M	0	0	0	0	55	0	
41	*Hyporhamphus limbatus*	M	1	2293	0	5	255	0	+
42	*Ctenopharyngodon idella*	M	1	3	0	0	0	0	
43	*Cyprinus carpio*	E	463	142	11	0	50	2	+
44	*Heteropneustes fossilis*	E	110	8	6	0	0	0	+
45	*Coptodon zillii*	E	0	0	0	190	4299	1119	+
46	*Oreochromis aureus*	E	0	0	0	159	1505	1026	+
47	*Carassius auratus*	E	3822	20331	1041	166	2983	634	+

48	*Poecilia latipinna*	E	100	9768	0	151	2684	4388	+
49	*Poecilia sphenops*	E	0	0	344	0	0	9	
50	*Oreochromis niloticus*	E	0	0	0	5	3300	1165	+
51	*Gambusia holbrooki*	E	1	185	242	31	0	623	+
52	*Hemiculter leucisculus*	I	0	1106	51	36	0	0	+

2-Benchmark list

In order to implement BII formula of **Lamp *et al.* (2009)**, a benchmark list of occurrence and abundance of fish species was introduced. Proposed bench mark list of fish species existed in EHM after inundation in 2003. It was composed of 30 species including 13 native, 11 marine, five exotic and one freshwater invader (Table 2).

Table 2. Benchmark list of occurrence and abundance of fishes existing in EHM after inundation in 2003 arranged according to their origin

No.	Bench mark species list	Origin	Average abundance
1	*P.abu.*	Native	3870
2	*A.marmid*	Native	945
3	*A. mossulensis*	Native	368
4	*L. vorax*	Native	185
5	*C. luteus*	Native	183
6	*S. triostigus*	Native	89
7	*A. dispar*	Native	78
8	*A. mento*	Native	53
9	*M. sharpeyi*	Native	12
10	*M. Mastacembelus*	Native	6
11	*A.grypus*	Native	4
12	*L. xanthopterus*	Native	2
13	*M. pelusius*	Native	2
14	*T. ilisha*	Non-Native (M)	827
15	*T. whitheadii*	Non-Native (M)	307
16	*P.subviridis*	Non-Native (M)	147
17	*A. arabicus*	Non-Native (M)	32
18	*T. hamiltonii*	Non-Native (M)	31
19	*N. nasus*	Non-Native (M)	14

20	*S. argus*	Non-Native (M)	2
21	*P. klunzingeri*	Non-Native (M)	2
22	*H. limbatus*	Non-Native (M)	1
23	*B. fiscus*	Non-Native (M)	1
24	*B. orientalis*	Non-Native (M)	1
25	*C. auratus*	Non-Native (E)	2432
26	*C. carpio*	Non-Native (E)	237
27	*G. holbrooki*	Non-Native (E)	122
28	*H. fossilis*	Non-Native (E)	58
29	*P. latipinna*	Non-Native (E)	50
30	*H. leucisculus*	Non-Native (I)	26

3- Biodiversity values and number of species in EHM

Values of biodiversity index was implemented from published studies on fish assemblage in EHM, which was executed during the period from 2009 to 2022, covering the entire marsh. The number of species recorded by previous authors ranged between 22 to 44, as recorded by **Mutlak (2012)** and **Ahmed (2017)**, respectively. The highest biodiversity values was 2.9 as recorded by **Abdalhsan *et al*. (2020)**. Additionally, the lowest was 1.89, as mentioned by **Hussain *et al*. (2009)**. The lowest evenness value was 0.24, which was registered by **Hussain *et al*. (2009)**, moreover the highest eveness value recorded was 0.81 **(Abdullah *et al*, 2022)**. The average diversity results was equal to 2.42, indicating an appreciable number of dominate species. On the other hand, evenness average value (0.43) showed unbalanced distribution of the number of individuals of the existing species, especially the rare ones (Table 3).

Table 3. Values of biodiversity indices and the number of fish species recorded in previous studies in EHM including the Shannon-Wiener diversity index (H') from **Shannon and Weaver (1949)** and the evenness index (J) from **Pielou (1968)**

NO	Source	Number of species	Diversity (H˜)	Evenness (J)
1	Hussain *et al*. (2009)	31	1.89	0.24
2	Mutlak (2012)	44	2.53	0.29
3	Mohamed *et al*. (2013)	25	2.1	0.31
4	Ahmed (2017)	22	2.49	0.52
4	Al-Najjar *et al*. (2019)	35	2.79	0.46
5	Abdalhsan *et al*. (2020)	23	2.9	0.4
6	Abdullah *et al*. (2022)	32	2.29	0.81
7	Bench mark list	30	1.96	0.23

4- Biodiversity values and salinity fluctuation

The values of the Shannon-Wiener diversity index appear to be positively related to increases in the salinity of EHM. Rising salinity has facilitated the movement of marine species from the Shatt al-Arab estuary and the Arabian Gulf to EHM, leading to a noticeable increase in the number of migratory marine species, especially following the salt wedge's advancement from the Gulf after 2018/2019. This increase in salinity has consequently resulted in higher biodiversity and a greater number of species, as demonstrated by **Al-Najjar *et al.* (2019)** and **Abdalhsan *et al.* (2020)** (Fig. 1).

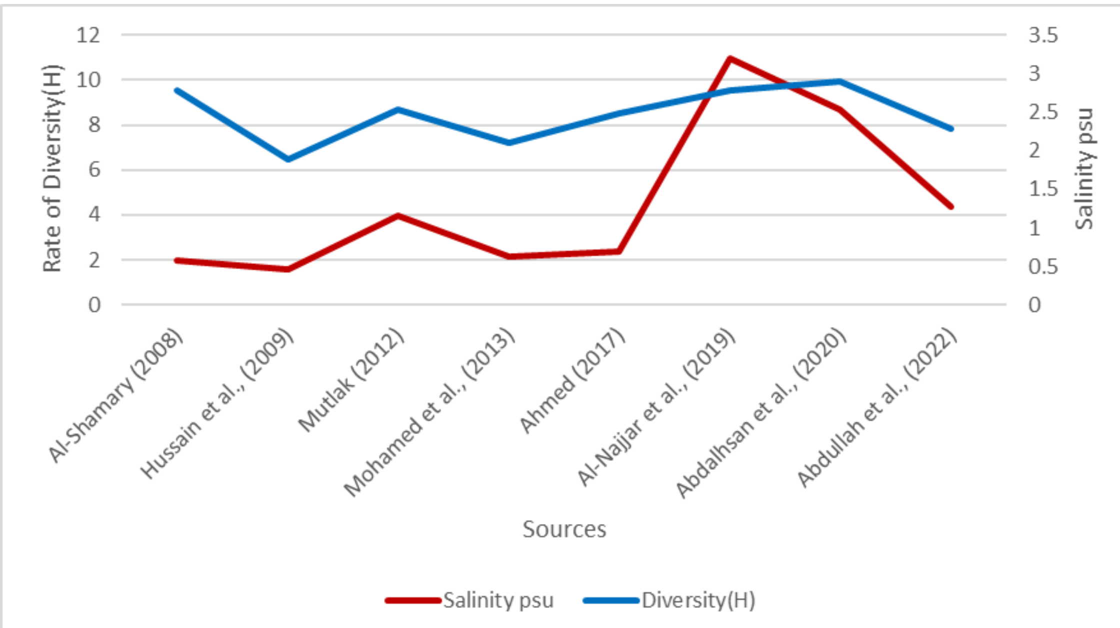


Fig. 1. The positive relationship between Shannon and Wiener biodiversity index (H˜) and salinity psu in EHM during the period from 2009 to 2022

5- BII values at EHM

Values of BII were calculated from previous studies listed in Table (4), according to formula of **Lamp *et al*. (2009)**. The highest value recorded was 103.57 and the lowest score was 52.07, as recorded by **Hussain *et al*. (2009** and **Abdalhsan *et al*. (2020)**, respectively. The mean score of nine studies on BII in EHM was 74.93. The time span of sampling for nine previous studies extended from 2006 to 2021, covering a total of 15 years, with an average of 44.96 samples per year.

Table 4. BII calculated values form previous studies in EHM during the period from 2009 to 2022. Recalculated of diversity values were done by implementing past program (4.03) for the previous biodiversity data.

No	Source	Original diversity value (H˜)	Recalculated diversity value	BII value
1	Al-Shamary (2008)	2.78	_	58.16
2	Hussain *et al*. (2009)	1.69	1.89	103.57
3	Mutlak (2012)	2.58	2.53	70.91
4	Mohamed *et al*. (2013)	3.32	2.1	92.85
5	Radi (2014)	2.29	_	83.16
6	Ahmed (2017)	1.75	2.49	72.95
7	Al-Najjar *et al*. (2019)	2.24	2.79	57.65
8	Abdalhsan *et al*. (2020)	1.45	2.9	52.04
9	Abdullah *et al*. (2022)	2.29	_	83.16
10	Benchmark list	-	1.96	_

6- BII values and salinity

Opposite relationship tends to exist between BII and salinity values as demonstrated in Fig (2). Lower salinities in EHM tend to increase BII values, while higher salinities, especially those exceeding 8psu, tend to decrease BII values by increasing the occurrence and abundance of migratory marine fish species.

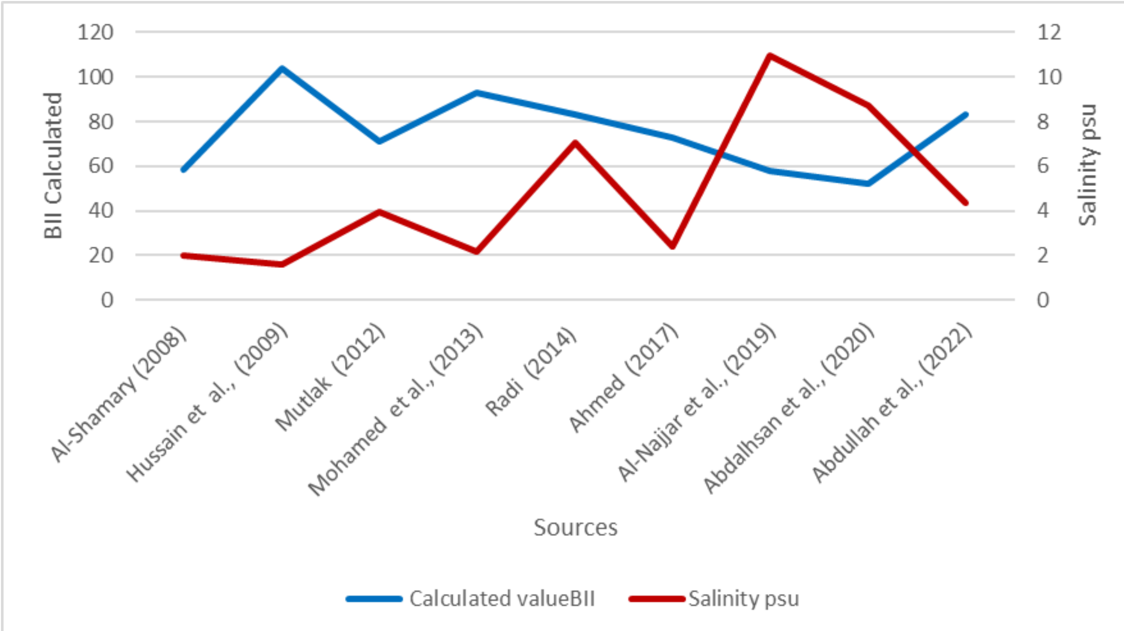


Fig. 2. The relation between measured salinity psu and values of BII at EHM during the period 2009 to 2022

7-BII values verses ratio of native and marine fish species

An inverse relationship was observed between BII and the ratio of marine fish species to the total number of species. BII values tend to decrease as the ratio of marine species to the total number of species increases **(Al-Najjar *et al.*, 2019; Abdalhsan *et al.*, 2020)**. Conversely, a decrease in the ratio of marine species leads to an increase in BII values **(Abdullah *et al.*, 2022)** (Fig. 3).

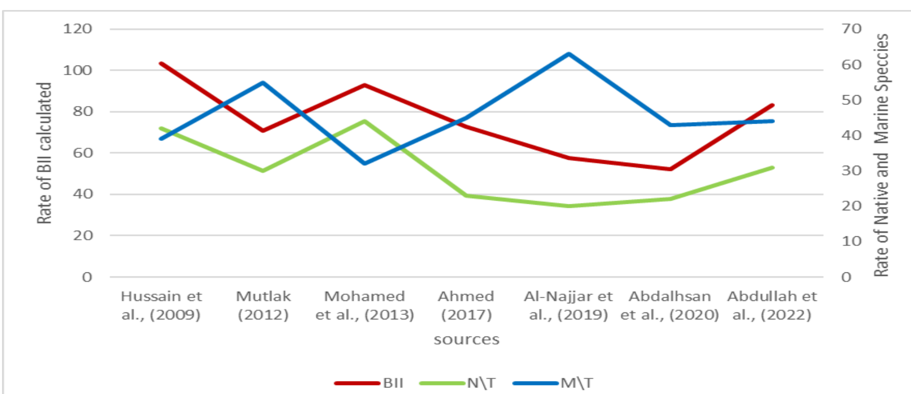


Fig. 3. The relationship between ratio of native and marine species to the total fish species and values of BII calculated from previous studies in EHM during period from 2009 to 2022. N/T= Ratio of native species to the total number of species. M/T= Ratio of marine species to the total number of species.

8- BII values and ratio of native; non-native species ratio

A relationship seems to exist between BII, ratio of native and non-native fish species to total species. BII values increase with a decrease in the ratio of non-native species **(Al-Najjar *et al.*, 2019; Abdalhsan *et al.*, 2020)** and decrease as the ratio of non-native species increases **(Hussain *et al.*, 2009; Mohamed *et al.*, 2013; Ahmed *et al.*, 2017)**, as shown in Fig. (4).

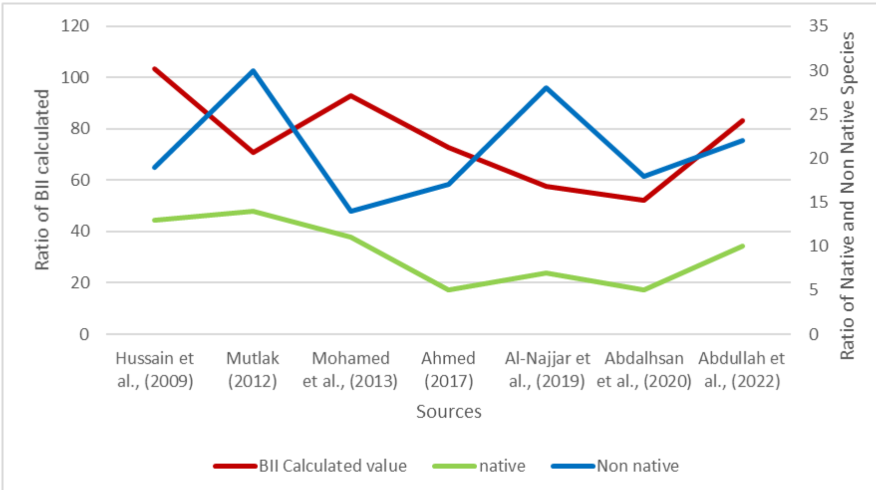


Fig. 4. The relationship between BII, native and non- native fish species ratio to the total number of species in EHM during 2009 to 2022

9-Relationship between BII and annual discharge of the Shatt al-Arab River

Positive relationship existed between BII and the annual Shatt al- Arab discharge. The increase in BII values of EHM coincides with the increase in the discharge of the Shatt al-Arab River, as witnessed in 2009, 2013 and 2022. In general, there has been a pronounced decrease in the discharge of the Shatt al-Arab, which now does not exceed 50 cubic meters per second due to the limited supply from the Tigris and Euphrates rivers (Iraqi MO Water Resources, unpublished data, 2023).

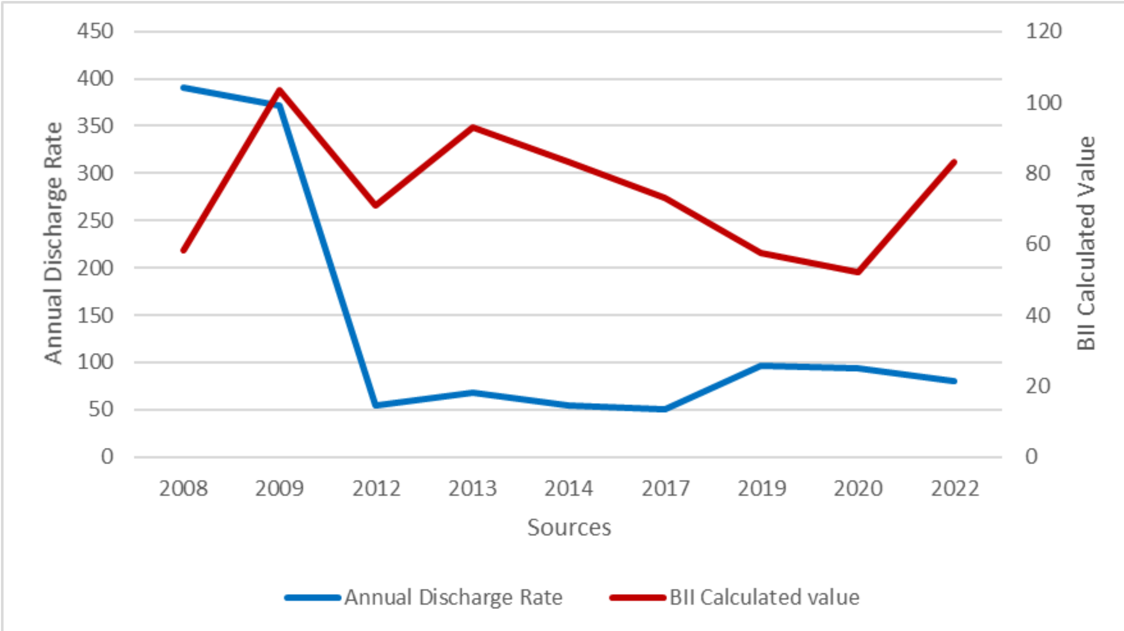


Fig. 5. The relationship between annual discharge rate m^3/ sec of the Shatt al-Arab River and BII calculated value in EHM during 2008 to 2022

DISCUSSION

Typically, BII values are used to monitor biodiversity degradation in natural systems. In this study, BII values were used to assess the biodiversity status of EHM. The aim was to convey the diversity status of the marsh to decision-makers, helping them understand the current situation and take necessary actions. We hypothesized an empirical list of fish species occurrences and abundances in the marsh after inundation in 2003 to create a benchmark list.

Three key issues in applying the BII formula by **Lamp *et al.* (2009)** to previous studies of fish assemblage diversity in EHM are: 1) establishing a benchmark list of fish species after the inundation in 2003, 2) the focus of most previous studies on fish stock assessment **(Mutlak, 2012)**, national park creation **(Radi, 2014)**, or water quality indices rather than fish diversity, and 3) the lack of data on species abundance in several studies **(Al-Shamary, 2008; Radi, 2014; Abdullah *et al.*, 2022)**, which hampers the calculation of diversity, BII, and the ratio of native to non-native species. Establishing bench mark list for computing BII is crucial step, since the marsh was deliberately desiccated during the nineties by Saddam regime **(Allen *et al.*, 2003)**. The benchmark list is a crucial step for facilitating the calculation of changes in BII for EHM. Deviations in previously calculated BII data from the reference benchmark ranged from a low of 52.4 to a high of 103.57, as reported by **Al-Shamary *et al.* (2008)** and **Hussain *et al.* (2009)**, respectively. Generally, 33.3% of previous studies scored less than 60%, indicating an alarming status of BII and a significant loss in biodiversity values. Establishing baseline BII data in EHM is essential for creating a reliable reference mark for fish assemblages.

Temporal changes in species assemblages over 14 years showed an increase in non-native species and a decrease in native ones. The results suggest that fish assemblages at different stations in EHM have become increasingly dissimilar over time due to the growing occurrence and abundance of marine species. **Magurran (2004)** indicated that the non-native invasive species tend to increase standard diversity indices, which is a negative sign for native biodiversity intactness.

The reduction in freshwater input to East Hammar Marsh has shifted the environment from previously oligohaline to more mesohaline/estuarine **(Hussain & Taher, 2007; Habeeb *et al.*, 2023)**, making it more favorable for marine/estuarine species to invade. Salinity fluctuations in EHM, driven by changes in freshwater influx from the Shatt al-Arab River, reflect these environmental changes. There is no direct correlation between freshwater supply from the Shatt al-Arab River and BII values, primarily due to the significant decrease in discharge, limited freshwater inflow through the Qarmat Ali channel (Map 1), and time lag differences between the semidiurnal tides of the two water bodies **(Al Tememi *et al.*, 2015)**.

Salinity plays a major role in influencing BII values in EHM. The reduction in freshwater supply has transformed the environment from oligohaline to estuarine, encouraging marine fish species to invade. While this invasion increases the total number of species and biodiversity score, it simultaneously decreases BII values. The higher ratio of marine species and non-native species reduces BII values. The shift from oligohaline to estuarine conditions has led to BII degradation through the promotion of marine species migration. The decrease in salinity in 2020/2021, as noted by **Abdullah *et al.* (2022)**, resulted in a marginal increase in BII values. Generally, salinity values above 8psu in EHM reduce BII values, despite increasing the biodiversity score. **Nielsen *et al.* (2007)** noted that the consequences of salinization are severe and often involve significant changes in the hydrology and aquatic ecology of a water body.

Habeeb *et al.* (2023) documented the impact of an advanced salt wedge from the Arabian Gulf on salinity levels in EHM, with recorded salinities of 10.3psu in July and 16.1psu in August 2018. This sharp increase in salinity led to the invasion of marine fish species and the disappearance of native freshwater species. The fragile ecology of EHM rapidly shifted from an oligohaline to an estuarine environment, jeopardizing vital resources and endangering the culturally unique Arab marsh livelihoods. **Kuiper *et al.* (2014)** noted that alterations in natural water regimes are a major threat to biodiversity in rivers and wetlands.

Comparing the ratio of native to non-native species in fish assemblages over time revealed fundamental changes in the occurrence and abundance of native species, with an increase in exotic and marine species. There was a significant reduction in the presence of native freshwater fish species and an increase in non-native fishes. **Nielsen *et al.* (2007)** concluded that an increase in non-native species is associated with decreased biodiversity intactness. Non-native species compromise ecosystem integrity while also increasing biodiversity scores. According to **Lamp *et al.* (2009)**, a low BII score indicates severe biodiversity degradation and environmental constraints on native species. This study found a degradation in native species and the disappearance of several common freshwater species, consistent with the idea that non-native species increase is a sign of ecosystem degradation and loss of biodiversity intactness **(Arriaga *et al*., 2004; Hooper *et al*., 2005)**.

In conclusion, the primary cause of BII degradation in EHM is the increased salinity resulting from reduced freshwater input from the Tigris and Euphrates rivers to the Shatt al-Arab and EHM. Managing salinity levels is crucial for maintaining fish biodiversity and ecological integrity in EHM. **Mausbach and Dzialowski (2019)** highlighted that salinization is a global issue threatening freshwater ecosystems. This study observed temporal alterations in fish assemblages from 2009 to 2022 associated with salinity fluctuations in EHM. Effective biodiversity monitoring programs are necessary to track salinity fluctuations, freshwater influx, and deviations in diversity and BII from reference status in EHM.

CONCLUSION

We concluded that the BII of the East Hammar Marsh is damaged and needs sufficient fresh water quantities to be released and efficient ecological laws to be implemented in order to improve the BII of EHM.

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