İSTANBUL UNIVERSITY PRESS

Aquatic Sciences and Engineering

Aquatic Sciences and Engineering,
ASE 2025 , 40 (3): 153–162

https://doi.org/10.26650/ASE2025.1693187
Submitted: 06.05.2025
Revision Requested: 20.06.2025
Last Revision Received: 04.07.2025
Accepted: 04.07.2025
Published Online 09.07.2025

Research Article

Open Access

Sex-Specific Vulnerability of Fish to Dredging in the Mediterranean Coastal Lagoon (Lake Manzala, Egypt)

Kariman Shalloof [1], Azza El Ganainy [1] & Walid Aly [1]

[1] Fisheries Biology Lab., Fisheries Division, National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt

Abstract Lagoon dredging disrupts aquatic ecosystems and fish populations. A study in Lake Manzala, Egypt, assessed these impacts by analyzing 2616 fish across ten species. Results showed significant variation in the condition factor (K) between sexes, ranging from a low of 0.220 in male European eels (*Anguilla anguilla*) to a high of 1.794 in female redbelly tilapia (*Coptodon zillii*). Sex ratios were predominantly male-biased. The male-to-female ratio was approximately 3:1 in *C. zillii*, *Chelon ramada*, and *Chelon auratus*, and 2:1 in *Dicentrarchus punctatus*, with males also dominating in *Dicentrarchus labrax* and *A. anguilla*. Only three species were female-biased: *Oreochromis niloticus* (1:1.40), *Sarotherodon galilaeus* (1:1.34), and *Clarias gariepinus* (1:3.31). These imbalances suggest dredging may negatively impact female populations, potentially reducing overall fish production. Therefore, incorporating sex ratio data into conservation management for Lake Manzala is crucial. Further research on species' reproductive biology is recommended post-dredging.

Keywords Length weight relationship · Condition factor · Sex ratio · Length frequency

Citation: Shalloof, K., El Ganainy, A. & Aly, W. (2025). Sex-specific vulnerability of fish to dredging in the mediterranean coastal lagoon (Lake Manzala, Egypt). *Aquat Sci Eng*, *40*(3), 153-162. https://doi.org/10.26650/ASE2025.1693187

This work is licensed under Creative Commons Attribution-NonCommercial 4.0 International License.

© 2025. Shalloof, K., El Ganainy, A. & Aly, W.

Corresponding author: Walid Aly walid.soton@gmail.com

INTRODUCTION

Mediterranean lagoons are vital coastal ecosystems, renowned for their rich biodiversity and the critical role they play in driving numerous ecological processes (El Mahrad et al., 2022). Lake Manzala, similar to many other lakes in the northern Egyptian Delta, has unfortunately experienced substantial environmental degradation stemming from both anthropogenic and natural factors (Abd Ellah, 2021). Over recent decades, human activities have profoundly altered the lagoon's ecological balance, resulting in noticeable environmental shifts (Elmorsi et al., 2017). A significant influx of pollutants from various drains flows into Lake Manzala, exacerbating the existing environmental challenges. These pollutants, in conjunction with other encroachments, contribute to a range of significant issues, including diminished fish productivity, alterations in the lagoon's morphology and surface area, deterioration of water quality, and increased eutrophication (Halim & Guerguess, 1978; Hegab et al., 2020).

Despite these considerable challenges, Lake Manzala remains a crucial component of Egypt's fisheries, contributing nearly 14% (59.6 thousand MT) of the nation's total annual fish production (Mostafa et al., 2019). LFRPDA (2021) reported that, total production of fish from Lake Manzala was 82541 MT during 2020. This represents 42 % of the fish production from northern lakes(197973 MT) and 35 % of the total fish production from all Egyptian lakes combined(237758 MT). The lagoon's high fertility, calm waters, and shallow depths establish it as one of Egypt's most economically significant water bodies for fisheries (Shalloof et al., 2022). Recognizing the importance of Lake Manzala, the Egyptian government launched a major initiative focused on the sustainable development of all Egyptian lakes, with the overarching goal of improving water quality for both present and future generations. Since 2017, a concerted national effort has been underway to develop and restore Lake Manzala (Abd Ellah, 2021; Shalloof et al., 2022). One key method employed in lake restoration is dredging, which currently represents the most prevalent approach for maintaining aquatic ecosystems and enhancing their protection and aesthetic value (Hadnagy et al., 2015).

Sex ratio is a fundamental stock characteristic in fisheries management, wielding direct influence over a population's reproductive potential (Jakobsen et al., 2009). This crucial parameter is incorporated into various models employed to assess spawning stock biomass and overall population fecundity (Marshall et al., 2006). Furthermore, environmental factors are recognized as having a substantial impact on sex differentiation in fish (AbouelFadl et al., 2024).

Dredging, an intensive engineering activity frequently undertaken in coastal regions, can exert detrimental effects on fish populations. The suspended sediments generated during dredging operations can negatively affect the survival and abundance of fish eggs and larvae (Yang et al., 2019). Early life stages, such as eggs and larvae, are particularly vulnerable to the fatal impacts of dredging (Wenger et al., 2017). As a result of the habitat alterations caused by dredging, existing species and organisms dependent on the original habitat structure face the risk of local extinction. Sediment removal can lead to elevated turbidity levels and the oxidation-induced mobilization of heavy metals. Therefore, dredging represents a significant re-engineering of a lake and should not be undertaken without a comprehensive understanding of its potential consequences (Gustavson et al., 2008; Abd Ellah, 2022). AbdElghany et al. (2024) concluded that levels of toxic heavy metals in the Manzala Lagoon had increased when comparing recent clean-up and dredging activities to previous investigations conducted on the same lake before dredging operations.

Understanding the drivers and consequences of sex ratio imbalances is crucial for implementing effective conservation strategies (Wearmouth & Sims, 2008). If these imbalances are detrimental to population health, conservation approaches may require adjustments, such as habitat restoration initiatives, captive breeding programs, or regulations designed to protect vulnerable species. Natural and fishing mortality differences between the sexes, along with gear selectivity related to sex-specific behavior and morphology, can contribute to variations in sex composition (Smith, 1956). Any kind of mortality should be seen as a potentially disturbing factor in studies of environmental impacts on sex determination. Sex ratio imbalances can create genotype–phenotype mismatches with impacts on population demography (Geffroy and Wedekind, 2020).

While a multitude of factors can influence sex ratios, this study concentrates specifically on the potential impact of dredging operations, particularly on substrate-spawning fish, which exhibit heightened vulnerability to habitat disturbances.

This study aims to investigate the potential sex-specific impacts of dredging activities on the population structure encompassing size distribution, growth patterns, condition, and sex ratio of key fish species inhabiting Lake Manzala, Egypt. This is in addition to the scarcity of research regarding the reproductive biology of fish in the lake and the sex ratio in particular. Furthermore, this research seeks to contribute essential data for understanding the broader ecological consequences of such anthropogenic disturbances within coastal lagoon ecosystems.

Figure 1.
Location of Lake Manzala (adapted from Abd Ellah, 2022)



MATERIALS AND METHOD

Area of Study

Lake Manzala (Fig. 1), the largest Egyptian lagoon, is situated along the Mediterranean coast on the eastern edge of the Nile Delta. Covering an area of 1071 km², it is considered a major source of fish. Lake Manzala, a shallow brackish lake, connects three governorates: Port Said, Damietta, and Dakahlia (Abd-Elghany et al., 2024; Khedr et al., 2024). Freshwater input into the lake is minimal, primarily occurring through the Enanya Canal, which links the lake to the Damietta branch of the Nile River to the west. A narrow canal (El-Qabuty) connects the lake to the Suez Canal (saline water) to the east. The northern boundary of the lake comprises several outlets connecting it to the Mediterranean Sea, with El-Gamil and the New El-Gamil being the primary outlets contributing to improved water quality within the lagoon (Elshemy, 2016). Furthermore, Lake Manzala receives domestic, industrial, and agricultural waste from numerous drains along its eastern and southern boundaries, including the Hadous, Mataria, Elserw, Faraskour, and Bahr El Baqar drains (Abd-Elghany et al., 2024).

Samples collection and Data analysis

Samples from ten different fish species were collected between 2019 and 2021 from various locations within Lake Manzala using a variety of fishing gear and methods. A total of 2,177 cichlid fish were sampled, encompassing:

- *Oreochromis niloticus:* 454 males, 633 females, 152 unsexed; size range: 4–28 cm total length (TL)
- *Oreochromis aureus:* 318 males, 241 females, 14 unsexed; size range: 5–26 cm TL
- *Coptodon zillii:* 72 males, 25 females, 5 unsexed; size range: 3–16.5 cm TL
- *Sarotherodon galilaeus:* 106 males, 142 females, 15 unsexed; size range: 5–23 cm TL

Additionally, the study included:

- *Clarias gariepinus:* 58 individuals (13 males, 43 females, 2 undetermined); size range: 15.2–59.2 cm TL
- *Chelon ramada:* 197 individuals (131 males, 42 females, 24 unsexed); size range: 11–39 cm TL
- *Chelon auratus:* 38 individuals (27 males, 9 females, 2 undetermined); size range: 11–24 cm TL
- *Dicentrarchus labrax:* 51 individuals (31 males, 18 females, 2 unsexed); size range: 10–55.8 cm TL
- *Dicentrarchus punctatus:* 42 individuals (25 males, 12 females, 5 unsexed); size range: 9–22.5 cm TL
- *Anguilla anguilla:* 53 individuals (25 males, 20 females, 8 unsexed); size range: 39–74.5 cm TL

Total length (TL) was measured to the nearest centimeter, and body weight (W) was recorded to the nearest 0.1 g. Sex determination was performed macroscopically via specimen dissection. Although macroscopic staging is faster and less expensive, there is a greater chance of bias and inaccuracy (Flores et al., 2019). Immature individuals are hard to identify, because juvenile individuals often lack any visible sex-specific features. So, their gonads are underdeveloped and can be easily misidentified or indistinguishable macroscopically.

The length-weight relationship for each fish species was estimated using the following formula (Ricker, 1975):

$W = aL^b$

where:

- W represents the weight of the fish (g) • L represents the total length of the fish (cm)
- a and b are constants.

The allometric coefficient (b) was used to determine the growth type: isometric (b = 3), positive allometric (b > 3), or negative allometric (b < 3) (Morey et al., 2003).

The condition factor (K) was calculated using the following formula (Pauly, 1993): $K = 100W / L^3$ where:

- K represents the condition factor
- L represents the total length (cm)
- W represents the total weight (g)

The overall sex ratio was calculated as the number of males: number of females (Vazzoler, 1996).

A chi-square test (Sokal and Rohlf, 1987) was performed using XLSTAT 2021 software to determine if significant differences existed between observed sex ratios and the expected 1:1 ratio. The chi-square test was also used to assess differences in sex ratios across species.

Expected frequencies were calculated as:

Expected frequency = (Species total * Sex total) / Grand total The chi-square statistic was calculated as:

$\chi^2 = \Sigma$ [(Observed frequency - Expected frequency) ^{2} / Expected frequency] Degrees of freedom were determined using:

Degrees of freedom = (Number of rows - 1) * (Number of columns - 1)

A chi-square distribution table and a significance level of $\alpha = 0.05$ were used to determine the critical value for the given degrees of freedom. The null hypothesis (that there were no significant differences in sex ratios across species) was rejected if the calculated chi-square value exceeded the critical value.

RESULTS AND DISCUSSION

Distribution of lengths of males and females

The size range of the 454 male *O. niloticus* individuals sampled was 5.0 to 26.0 cm with an average length of 15.05 cm, while the length range of the 633 females varied between 6.0 and 28.0 cm with an average length of 16.64 cm. The size ranges (and average lengths) of male *O. aureus*, *C. zillii*, and *S. galilaeus* were 7.7–24.8 cm (15.5 cm); 4.0–16.5 cm (10.42 cm); and 7.5–23.0 cm (15.0 cm), respectively. The corresponding size ranges (and average lengths) for females of these species were 7.7–26.0 cm (15.35 cm); 6.7–16.0 cm (9.88 cm); and 8.3–21.3 cm (14.5 cm), respectively.

The average lengths of males and females, respectively, for the remaining species were: *C. gariepinus* (32.7 cm, 35.2 cm); *C. ramada* (21.0 cm, 22.8 cm); *C. auratus* (16.5 cm, 17.7 cm); *D. labrax* (21.5 cm, 25.8 cm); *D. punctatus* (13.7 cm, 16.2 cm); and *A. anguilla* (50.9 cm, 42.9 cm) (Table 1). Note that females attained larger lengths than males in *O. niloticus*, *O. aureus*, *C. gariepinus*, *C. ramada*, *D. labrax*, and *D. punctatus* (Fig. 2).

Various ecological and life-history characteristics, including aquatic health, selectivity, stock conditions, and breeding seasons, can be inferred from the size distribution of the fish caught (Beyer, 1987). This study demonstrates that females of *O. niloticus*, *O. aureus*, *C. gariepinus*, *C. ramada*, *D. labrax*, and *D. punctatus* grow to larger lengths than their male counterparts. In many fish species, males and females exhibit different growth rates and achieve different sizes. Female fish often grow larger in species where natural selection and environmental factors play a significant role. Conversely, male growth can be more strongly influenced by sexual selection, where traits that enhance male attractiveness to females or

improve their competitive ability for mates are favoured (Zachary & Tobler, 2017).

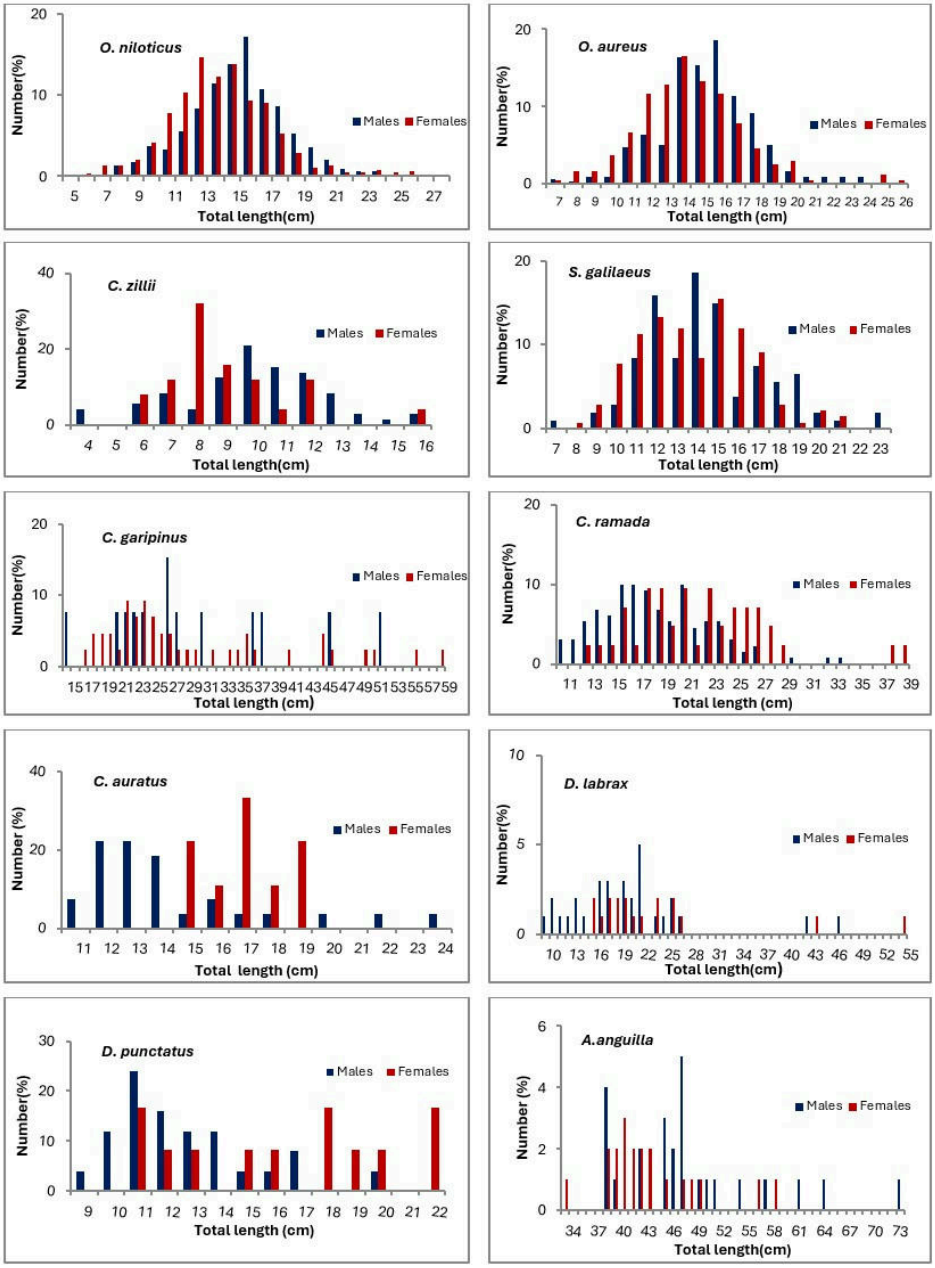
Length- weight relationship and condition factor

The current study estimated parameters a and b of the length-weight relationships and the condition factor (K) for each sex of the various species studied in the Manzala Lagoon (Table 1). R^2 values were greater than 0.94 for all regressions. The b exponent ranged from 2.72 (female *D. punctatus*) to 3.56 (male *A. anguilla*). A tendency towards isometric growth was recorded for males and females of *O. aureus*, females of *O. niloticus*, and males of *D. labrax*. Positive allometric growth was observed for males and females of *C. gariepinus* and *A. anguilla*, females of *C. zillii*, and males of *C. auratus*. The remaining sexes of the different species exhibited negative allometric growth (Table 1).

The condition factors (K) for both sexes of the different species studied in the Manzala Lagoon showed slight variations. K values ranged from 0.220 (male *A. anguilla*) to 1.794 (female *C. zillii*). Both sexes of the studied cichlid species exhibited good condition, with K values ranging from 1.794 (female *C. zillii*) to 1.649 (male *O. aureus*). Females of *O. niloticus*, *O. aureus*, and *S. galilaeus* had slightly higher condition factors than males, while *C. zillii* males had better condition than females. Additionally, males of *C. ramada* and *D. punctatus* displayed slightly higher condition factors than females. Males and females of *C. gariepinus* and *A. anguilla* exhibited similar, but poor, condition factors (less than 1), with values of 0.728 and 0.220, respectively (Table 1).

Figure 2.

Length Frequency Distributions of Fish Species (Males and Females) Studied in Lake Manzala



In the present study, a tendency towards isometric growth was recorded for males and females of *O. aureus*, females of *O. niloticus*, and males of *D. labrax*. Positive allometric growth was observed for males and females of *C. gariepinus* and *A. anguilla*, females of *C. zillii*, and males of *C. auratus*. The remaining sexes of the different species exhibited negative allometric growth. A negative allometric growth pattern (b=2.625) was observed for female *A. anguilla* in Bardawil Lagoon, while males exhibited isometric growth (b=2.997) (Mahmoud et al., 2024). Negative allometry indicates a relatively thinner body, whereas positive allometry indicates that the body becomes relatively broader as it increases in length (Jobling, 2002). Isometric growth signifies that the body increases in all dimensions proportionally. Shalloof et al. (2024) reported that the lowest *K* values for pooled data in the Manzala Lagoon were recorded for *A. anguilla* and *C. gariepinus* (0.21985 and 0.7287, respectively). This may be attributed to the alteration of the environment by dredged materials, significantly impacting food availability. Mean condition factors (K) in Lake Manzala before dredging were higher than recorded in the present study. Bayoumi and Khalil (1988) mentioned that K= 1.96, 1.93, 2.09 and 2.04 for *O. niloticus, O. aureus, S. galilaeus* and *C. zillii,* respectively. The condition factor of *A. anguilla* in Bardawil Lagoon also indicated poor condition, ranging from 0.178 ± 0.002 for females to 0.180 ± 0.002 for males (Mahmoud et

Table 1.
Length-Weight relationships and condition factors (k ± sd) for both sexes of ten fish species in the Manzala lagoon.

Species	Length range (cm)	Average Length (cm)	Sex	a	b	R^2	K± SD
O. niloticus	5-26	15.05	Male	0.0182	2.99	0.97	1.752 ± 0.184
	6-28	16.64	Female	0.0146	3.07	0.98	1.780 ±0.190
O. aureus	7.7- 24.8	15.5	Male	0.0143	3.05	0.96	1.649±0.176
	7.7-26	15.35	Female	0.0153	3.03	0.96	1.686±0.197
C. zillii	4- 16.5	10.42	Male	0.0224	2.90	0.98	1.794±0.250
	6.7- 16	9.88	Female	0.0085	3.33	0.98	1.775±0.185
S. galilaeus	7.5-23	15.0	Male	0.0199	2.94	0.97	1.713±0.174
	8.3- 21.3	14.5	Female	0.0191	2.97	0.97	1.763±0.178
C. gariepinus	15.2- 52.5	32.7	Male	0.0027	3.23	0.99	0.728±0.089
	17- 59.2	35.2	Female	0.0049	3.12	0.99	0.728±0.084
C. ramada	11- 34	21.0	Male	0.0101	2.95	0.97	0.882±0.117
	13- 39	22.8	Female	0.0101	2.95	0.97	0.870±0.098
C. auratus	11- 24	16.5	Male	0.0031	3.35	0.99	0.799±0.081
	15.2- 19.9	17.0	Female	0.0111	2.91	0.95	0.868±0.056
D. labrax	10- 47	21.5	Male	0.0100	3.01	0.99	1.036±0.122
	16- 55.8	25.8	Female	0.0109	2.98	0.99	1.040±0.095
D. punctatus	9- 20	13.7	Male	0.0123	2.92	0.95	1.000±0.135
	11- 22.5	16.2	Female	0.0210	2.72	0.99	0.969±0.104
A. anguilla	39- 74.5	50.9	Male	0.0002	3.56	0.96	0.220±0.033
	39- 59	42.9	Female	0.0010	3.20	0.94	0.221±0.023

Table 2.
Sex ratio variations and expected frequencies of males and females for the investigated ten fish species.

Species	Males	Females	Total	Sex ratio (M:F)	Expected Males	Expected Females
O. niloticus	454	633	1087	1: 1.40	479.61	607.39
O. aureus	318	241	559	1: 0.76	246.43	312.57
C. zillii	72	25	97	1: 0.35	42.79	54.21
S. galilaeus	106	142	248	1: 1.34	110.08	137.92
C. gariepinus	13	43	56	1: 3.31	24.39	30.61
C. ramada	131	42	173	1: 0.32	76.55	96.45
C. auratus	27	9	36	1: 0.33	15.95	20.05
D. labrax	31	18	49	1: 0.58	21.74	27.26
D. punctatus	25	12	37	1: 0.48	16.37	20.63
A. anguilla	25	20	45	1: 0.80	19.95	25.05

al., 2024). Balazik et al. (2020) reported that the migration of anadromous fish to spawning habitats is believed to be seriously threatened or impacted by dredging activities.

Sex ratios of different studied fish species

In the present study, the sex ratio distributions presented in Table 2 reveal that sex ratios were not evenly distributed among the populations of the studied species during the study period. A chi-square test was performed to assess the significance of these deviations. The calculated expected frequencies are shown in Table 2. The calculated chi-square statistic was 114.76, with 9 degrees of freedom. Using a chi-square distribution table with $\alpha = 0.05$ and 9 degrees of freedom, the critical value was approximately 16.92. Since $114.76 > 16.92$, the null hypothesis was rejected. Therefore, the chi-square test revealed a statistically significant difference in sex ratios across the ten species.

In this study, the proportion of males exceeded that of females in most of the studied species. The male proportion was approximately three times that of females in *C. zillii*, *C.*

ramada, and *C. auratus* (M: F ratios of approximately 3:1, or 1:0.35, 1:0.32, and 1:0.33, respectively), while this proportion was approximately double in *D. punctatus* (1:0.48). The proportion of males also surpassed that of females in *D. labrax* (1:0.58) and *A. anguilla* (1:0.80). Females outnumbered males only in *O. niloticus*, *S. galilaeus*, and *C. gariepinus*, constituting proportions of 1:1.40, 1:1.34, and 1:3.31 (male: female), respectively.

The sex ratio is the most significant demographic parameter influencing the structure and sustainability of fish populations (Penman & Piferrer, 2008). Information on the sex ratio is essential for understanding the complex interplay between individuals, their environment, and the overall state of the population (Vicentini & Araújo, 2003). A variety of factors can cause the sex ratio to deviate from the expected 1:1 ratio, either between species or even within the same population at different times. These factors include population adaptation, reproductive behavior, food availability, and environmental conditions (Nikolsky, 1963; Emlen & Oring, 1977; Baroiller & D'Cotta, 2001; Brykov et al., 2008; Vandeputte et al., 2012). Deviations can also arise from differential mortality rates between males and females (Arendt et al., 2014), local competition (Hamilton, 1967), and environmental pollution.

Several factors can contribute to sex ratio imbalances. Temperature, resource availability, and pollution can influence sex determination in some species (Shen & Wang, 2018). Mutations or genetic disorders can also affect sex ratios (Stelkens & Wedekind, 2010). Furthermore, anthropogenic pressures such as overfishing, habitat destruction, and pollution can disrupt natural sex ratios (Heppell et al., 2005; Islam & Tanaka, 2004; Jones & Reynolds, 1997; Rothschild et al., 1994). The observed differences in this study, particularly the increased proportion of males compared to females in most of the studied species, may be due to increased male vulnerability to fishing operations. Additionally, dredging operations can expose fish to elevated levels of suspended dust (clay or sand), potentially hindering their ability to find food, increasing stress levels, and causing gill damage that impairs growth, development, and swimming ability.

The impact of lagoon dredging on fish populations, and specifically their sex ratios, is a complex issue with significant ecological and environmental ramifications. Numerous studies have documented the impact of dredging on the life history parameters of fish species. Bellucci et al. (2002) observed that heavy metals and endocrine-disrupting chemicals can disrupt hormonal balances, affecting sexual differentiation in European sea bass (*Dicentrarchus labrax*) and leading to skewed sex ratios with a higher prevalence of intersex individuals. A study on Indian mullet (*Mugil cephalus*) in the Sundarbans lagoon revealed that pollutants disturbed by dredging had significant effects on sex ratios, favoring the development of females over males. This skewed sex ratio was attributed to elevated levels of bisphenol A (BPA) and other endocrine-disrupting chemicals released during dredging activities (Mukherjee et al., 2015; Bhattacharya et al., 2017). Research by Browne et al. (2013) on coral trout (*Plectropomus leopardus*) demonstrated that dredging-related temperature changes can alter sex ratios, resulting in a higher proportion of males.

A considerable preponderance of males in *O. niloticus*, *O. aureus*, and *C. zillii* was observed by Shalloof (1991) in studies conducted on Lake Manzala. The overall sex ratio (female: male) of *C. zillii* in the Pınarbaşı Spring Creek (Turkey) was reported as 0.7:1 (Innal & Giannetto, 2017). The overall male: female ratio of *Liza ramada* in Bardawil Lagoon was 1:1.28 (El-Aiatt & Shalloof, 2018), while in Lake Timsah, the sex ratio (male: female) was 1:1.7 (El-Halfway et al., 2007). Unequal sex ratios can reduce genetic diversity, increasing population vulnerability to environmental changes and diseases (Stelkens & Wedekind, 2010). Sex ratio imbalances may also lead to changes in mating systems or behaviors (Székely et al., 2014).

Although *C. gariepinus* is a substrate spawner (Bruton, 1979), the proportion of females in the current study was higher than that of males. This may be because the mortality rate of males is higher than that of females, or because the altered depths resulting from dredging are less suitable for male survival. Previous research has demonstrated that various factors, including dredging technique, depth, external controls, and lake characteristics, can influence the impact of dredging (Zhong et al., 2018). Lagler et al. (1977) showed that *C. gariepinus* and eels may avoid nets by burying themselves in soft, muddy bottoms. Conversely, shoals of mullet, typically found in shallow water areas, are fast-moving and timid, making them difficult to encircle with nets unless a deliberate effort is made (Ishak et al., 1988). Within-population variance in family sex ratios can be substantial due to differences in micro-ecological factors affecting eggs or larvae (Wedekind, 2012). Santi et al. (2017) reported that temperature appears to be the primary environmental factor influencing sex differentiation. Consequently, changes in global temperature may negatively impact the fitness of certain populations by altering sex ratios and influencing sex-specific survival through genetic and epigenetic mechanisms (Consuegra & Rodríguez López, 2016). Bruton (1979) also noted the importance of factors such as water level, temperature, clarity, and biological elements like flooded marginal plants,

associated chemical changes, and the availability of suitable spawning areas.

Sex ratio imbalances can have profound consequences for population dynamics. A skewed sex ratio can limit reproductive potential if one sex is considerably more abundant than the other (Lowerre-Barbieri et al., 2011). Therefore, we posit that the noticeable differences in sex ratios observed in most of the studied species may contribute to the general decline in fish populations within the lagoon in recent years. The lower productivity of the lake in 2021 compared to 2020 may be attributed to dredging operations, which could have resulted in female mortality, nest destruction, and egg damage. The Lake Fisheries Resources Development Authority (LFRPDA, 2021) reported that Lake Manzala's fish production decreased by 13.38%, from 82,541 metric tons in 2020 to 71,496 metric tons in 2021. Tilapia production also decreased by 7.55%, from 41,147 metric tons in 2020 to 38,039 metric tons in 2021. Given that cichlids constitute the majority of the fish community in the study area, this decline in tilapia production may be the primary reason for the lake's reduced overall productivity. Furthermore, the noise, turbidity, and water disturbance generated by dredging activities may have negatively impacted female tolerance. The removal of most aquatic plants during lake cleaning operations is another potential factor contributing to the lower production. Stock abundance within a region or productivity zone is often correlated with the density of aquatic vegetation (i.e., stocks increase with increasing vegetation density). This aligns with findings from other African systems dominated by tilapia stocks (Lagler et al., 1977; Toews, 1977).

CONCLUSION

Dredging operations in Lake Manzala have unavoidable impacts on aquatic life, as the removal of bottom substrates disrupts established habitats and essential ecological processes. We hypothesize that the observed male predominance in most studied species, especially substrate-spawners, is linked to female intolerance of the disturbances induced by dredging activities. This sex ratio imbalance likely contributes to the recently observed decline in the lake's overall productivity. It is important to note that conclusions for species with smaller sample sizes are preliminary and have limited dependability. Further investigation into the reproductive biology of these species, particularly their fecundity and population structure, is recommended once dredging activities have ceased. Sex ratio imbalances in this study underscore the need to incorporate sex ratio data into population assessments and conservation management strategies for Lake Manzala.

Acknowledgements This article was produced by the Fisheries Biology Laboratory of the Fisheries Division, National Institute of Oceanography and Fisheries, as part of a larger study entitled "Impact of Dredging Operations on the Biology and Economy of Manzala Lake Fisheries".

Ethics committee approval This study did not involve experiments on living organisms or humans. This study utilized samples obtained from commercial fisheries. No live organisms were involved or maintained for the purpose of this research.

Peer Review Externally peer-reviewed.

Conflict of Interest The authors have no conflict of interest to declare.

Grant Support The authors declared that this study has received no financial support.

Author Details

Kariman Shalloof
[1] Fisheries Biology Lab., Fisheries Division, National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt
0000-0002-3040-8213

Azza El Ganainy
[1] Fisheries Biology Lab., Fisheries Division, National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt
0000-0002-2478-3893

Walid Aly
[1] Fisheries Biology Lab., Fisheries Division, National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt
0000-0002-5961-8214
walid.soton@gmail.com

References

Abd Ellah, R. G. (2021). An extensive nationwide program for developing the Egyptian lakes, Lake Manzala: From an ambiguous to a bright future. *Egyptian Journal of Aquatic Research*, *47*(4), 337–343. https://doi.org/10.1016/j.ejar.2021.11.002

Abd Ellah, R. G. (2022). Using single-beam bathymetric data technique to estimate dredging: A case study in Lake Manzala (Egypt). *Arabian Journal of Geosciences*, *15*, Article 1649. https://doi.org/10.1007/s12517-022-10877-9

Abd-Elghany, S. M., Sayed-Ahmed, M. Z., Rahmo, H. M., Zakaria, A. I., Ahmad, S., Alam, N., Ali, M. S., & Sallam, K. I. (2024). Carcinogenic and non-carcinogenic health risks associated with the consumption of fishes contaminated with heavy metals from Manzala Lake, Egypt. *Marine Pollution Bulletin*, *202*, 116391. https://doi.org/10.1016/j.marpolbul.2024.116391

AbouelFadl, K. Y., AbouDeaf, E. A. A., Mohammed, K. A. S., & Osman, A. G. M. (2024). A comparison of the reproductive patterns of *Oreochromis niloticus* from two distinct locations: Wadi Halfa, Sudan, and Aswan, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, *28*(3), 125–136. https://doi.org/10.21608/ejabf.2024.354894

Arendt, J. D., Reznick, D. N., & López-Sepulcre, A. (2014). Replicated origin of female-biased adult sex ratio in introduced populations of the Trinidadian guppy (*Poecilia reticulata*). *Evolution*, *68*(8), 2343–2356. https://doi.org/10.1111/evo.12445

Balazik, M., Barber, M., Altman, S., Reine, K., Katzenmeyer, A., Bunch, A., Garman, G., & White, S. (2020). Dredging activity and associated sound have negligible effects on adult Atlantic sturgeon migration to spawning habitat in a large coastal river. *PLoS ONE*, *15*(3), e0230029. https://doi.org/10.1371/journal.pone.0230029

Baroiller, J. F., & D'Cotta, H. (2001). Environment and sex determination in farmed fish. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, *130*(4), 399–409. https://doi.org/10.1016/S1532-0456(01)00262-4

Bayoumi, A. R., & Khalil, M. T. (1988). Tilapia fisheries in Lake Manzala, Egypt. *Bulletin of the National Institute of Oceanography and Fisheries*, *14*(3), 87–99.

Bellucci, L. G., Frignani, M., Paolucci, D., & Ravanelli, M. (2002). Distribution of heavy metals in sediments of the Venice Lagoon: The role of the industrial area. *Science of the Total Environment*, *295*(1–3), 35–49. https://doi.org/10.1016/S0048-9697(02)00052-X

Beyer, J. E. (1987). On length-weight relationships. Part I: Computing the mean weights of the fish in a given length class. *Fishbyte*, *5*(1), 11–13. https://hdl.handle.net/20.500.12348/3367

Bhattacharya, M., Debnath, D., & Mandal, R. (2017). Impact of anthropogenic activities on the water quality of the Indian Sundarbans ecosystem. *Journal of Environmental Biology*, *38*(4), 525–529. http://doi.org/10.22438/jeb/38/4/MS-158

Browne, N. K., Smithers, S. G., & Perry, C. T. (2013). Coral reef dredging and ecological resilience: Coral Sea case study. *Marine Pollution Bulletin*, *72*(1), 283–296. https://doi.org/10.1016/j.marpolbul.2012.08.017

Bruton, M. N. (1979). The breeding biology and early development of *Clarias gariepinus* (Pisces: Clariidae) in Lake Sibaya, South Africa, with a review of breeding in species of the subgenus *Clarias* (*Clarias*). *Transactions of the Zoological Society of London*, *35*(1), 1–45. https://doi.org/10.1111/j.1096-3642.1979.tb00051.x

Brykov, V. A., Kukhlevskii, A. D., Shevliakov, E. A., Kinas, N. M., & Zavarina, L. O. (2008). Sex ratio control in pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) populations: The possible causes and mechanisms of changes in the sex ratio. *Russian Journal of Genetics*, 44, 786–792. https://doi.org/10.1134/S1022795408070053

Consuegra, S., & Rodríguez López, C. M. (2016). Epigenetic-induced alterations in sex-ratios in response to climate change: An epigenetic trap? *BioEssays*, *38*(10), 950–958. https://doi.org/10.1002/bies.201600059

El Mahrad, B., Newton, A., & Murray, N. (2022). Coastal lagoons: Important ecosystems. *Frontiers for Young Minds*, *10*, 637578. https://doi.org/10.3389/frym.2022.637578

El-Aiatt, A. A. O., & Shalloof, K. A. S. (2018). Length-weight relationship, condition factor and reproductive biology of the thin-lipped grey mullet, *Liza ramada* (Risso, 1826) in Bardawil Lagoon, North Sinai, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, *22*(5), 461–471. https://doi.org/10.21608/ejabf.2018.23932

El-Halfawy, M. M., Ramadan, A. M., & Mahmoud, W. F. (2007). Reproductive biology and histological studies of the grey mullet, *Liza ramada*, (Risso, 1826) in Lake Timsah, Suez Canal. *Egyptian Journal of Aquatic Research*, *33*(1), 434–454.

Elmorsi, R. R., Hamed, M. A., & Abou-El-Sherbini, K. S. (2017). Physicochemical properties of Manzala Lake, Egypt. *Egyptian Journal of Chemistry*, *60*(4), 519–535. https://doi.org/10.21608/ejchem.2017.1511.1115

Elshemy, M. (2016). Water quality assessment of Lake Manzala, Egypt: A comparative study. *International Journal of Scientific Research in Environmental Sciences*, *4*(6), 196–207. https://doi.org/10.12983/ijsres-2016-p0196-0207

Emlen, S. T., & Oring, L. W. (1977). Ecology, sexual selection, and the evolution of mating systems. *Science*, *197*(4300), 215–223. https://doi.org/10.1126/science.327542

Flores, A., Wiff, R., Ganias, K., & Marshall, T. (2019). Accuracy of gonadosomatic index in maturity classification and estimation of maturity ogive. *Fisheries Research*, *210*, 50–62. https://doi.org/10.1016/j.fishres.2018.10.010

Forsgren, E., Reynolds, J. D., Berglund, A., & Mooi, R. D. (2008). Behavioural ecology of reproduction in fish. In *Handbook of fish biology and fisheries, Volume 1: Fish biology* (pp. 225–247). Blackwell Publishing Ltd. https://doi.org/10.1002/9780470693803.ch10

Fryxell, D. C., Arnett, H. A., Apgar, T. M., Kinnison, M. T., & Palkovacs, E. P. (2015). Sex ratio variation shapes the ecological effects of a globally introduced freshwater fish. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1816), 20151970. https://doi.org/10.1098/rspb.2015.1970

Geffroy, B., & Wedekind, C. (2020). Effects of global warming on sex ratios in fishes. *Journal of Fish Biology*, *97*(3), 598–608. https://doi.org/10.1111/jfb.14429

Gustavson, K. E., Burton, G. A., Jr., Reible, D. D., & Passeport, E. (2008). Evaluating the effectiveness of contaminated-sediment dredging. *Environmental Science & Technology*, *42*(14), 5042–5047. https://doi.org/10.1021/es087185a

Hadnagy, E., Gardner, K. H., Chesner, W. H., & El-Sharnouby, M. (2015). Pilot-scale evaluation of an in situ amendment delivery and mixing device for contaminated sediment remediation applications. *Journal of Soils and Sediments*, *15*, 480–489. https://doi.org/10.1007/s11368-014-1007-0

Halim, Y., & Guergues, S. K. (1978). Eutrophication in a brackish delta lake. In *CIESM IVes Journées d'Etudes sur les Pollutions en Méditerranée, Antalya* (pp. 435–438).

Hamilton, W. D. (1967). Extraordinary sex ratios. *Science*, *156*(3774), 477–488. https://doi.org/10.1126/science.156.3774.477

Hegab, M. H., Ahmed, N. M., Kadry, S. M., ElSayed, R. A., & Goher, M. E. (2020). Impact of heavy metals on the food web in the Mediterranean lagoon, Lake Burullus, Egypt. *Oceanological and Hydrobiological Studies*, *49*(3), 215–229. https://doi.org/10.1515/ohs-2020-0020

Heppell, S. S., Heppell, S. A., Read, A. J., & Crowder, L. B. (2005). Effects of fishing on long-lived marine organisms. In L. B. Crowder (Ed.), *Marine conservation biology: The science of maintaining the sea's biodiversity* (pp. 211–231). Island Press.

Innal, D., & Giannetto, D. (2017). Age structure and length-weight relationship of non-native redbelly tilapia *Coptodon zillii* (Gervais, 1848) (Cichlidae) in the Pınarbaşı Spring Creek (Burdur, Turkey). *Acta Zoologica Bulgarica*, *Suppl. 9*, 111–116. https://hdl.handle.net/20.500.12809/2102

Ishak, M. M., Khalil, M. T., & Toews, D. R. (1988). Fish stock assessment survey in Manzala, Egypt. *Bulletin of the National Institute of Oceanography and Fisheries*, *14*(3), 239–252.

Islam, M. S., & Tanaka, M. (2004). Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: A review and synthesis. *Marine Pollution Bulletin*, *48*(7–8), 624–649. https://doi.org/10.1016/j.marpolbul.2003.12.002

Jakobsen, T., Fogarty, M. J., Megrey, B. A., & Moksness, E. (Eds.). (2009). *Fish reproductive biology: Implications for assessment and management*. Wiley-Blackwell.

Jobling, M. (2002). Environmental factors and rates of development and growth. In P. J. B. Hart & J. D. Reynolds (Eds.), *Handbook of fish biology and fisheries, Volume 1: Fish biology* (pp. 97–122). Blackwell Publishing Ltd.

Jones, J. C., & Reynolds, J. D. (1997). Effects of pollution on reproductive behaviour of fishes. *Reviews in Fish Biology and Fisheries*, *7*, 463–491. https://doi.org/10.1023/A:1018482425027

Khedr, A. I., Ahmed, N. M., Salaah, S. M., Tayel, S. I., Soliman, Y. A., & Goher, M. E. (2024). Assessment of PAH pollution in Mediterranean lakes and health implications for fish and consumers, case study: Manzala Lake, Egypt. *Water Cycle*, *5*, 199–214. https://doi.org/10.1016/j.watcyc.2024.03.003

Lagler, K. F., Kapetsky, J. M., & Stewart, D. J. (1971). *The fisheries of the Kafue River Flats, Zambia, in relation to the Kafue Gorge Dam* (FI:SF/ZAM 11, Technical Report 1). Food and Agriculture Organization of the United Nations.

LFRPDA. (2021). *Fisheries statistics yearbook*. Lakes and Fish Resources Protection and Development Agency.

Lowerre-Barbieri, S. K., Ganias, K., Saborido-Rey, F., Murua, H., & Hunter, J. R. (2011). Reproductive timing in marine fishes: Variability, temporal scales, and methods. *Marine and Coastal Fisheries*, *3*(1), 71–91. https://doi.org/10.1080/19425120.2011.556938

Mahmoud, A. H., Salem, M., Osman, M. F., & El Ganainy, A. A. (2024). Length-weight relationship and condition of the European eel *Anguilla anguilla* in the Mediterranean coastal Bardawil Lagoon, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, *28*(1), 1627–1637. https://doi.org/10.21608/ejabf.2024.341144

Marshall, C. T., Needle, C. L., Thorsen, A., Kjesbu, O. S., & Yaragina, N. A. (2006). Systematic bias in estimates of reproductive potential of an Atlantic cod (*Gadus morhua*) stock: Implications for stock–recruit theory and

management. *Canadian Journal of Fisheries and Aquatic Sciences*, *63*(5), 980–994. https://doi.org/10.1139/f06-003

Morey, G., Moranta, J., Massutí, E., Grau, A., Linde, M., Oliver, P., & Reñones, O. (2003). Weight-length relationships of littoral to lower slope fishes from the western Mediterranean. *Fisheries Research*, *62*(1), 89–96. https://doi.org/10.1016/S0165-7836(02)00250-3

Mostafa, M. S., Ahmed, M. K., & El-Far, A. A. (2019). An economic study on the axes and constraints for Lake Manzala development. *Egyptian Journal of Aquatic Biology & Fisheries*, *23*(2), 55–64. https://doi.org/10.21608/ejabf.2019.30064

Mukherjee, A., Sarkar, S. K., & Bhattacharya, B. D. (2015). Aquatic pollution in the Indian Sundarbans: Implications for ecosystem and biodiversity. *Environmental Pollution*, *208*, 116–123. https://doi.org/10.1016/j.envpol.2015.09.027

Nikolsky, G. V. (1963). *The ecology of fishes*. Academic Press.

Oppenheimer, J. R. (1970). Mouthbreeding in fishes. *Animal Behaviour*, *18*(3), 493–503. https://doi.org/10.1016/0003-3472(70)90014-9

Pauly, D. (1993). Fishbyte section editorial. *Naga, The ICLARM Quarterly*, *16*(2), 26.

Payne, A. I., & Collinson, R. I. (1983). A comparison of the biological characteristics of *Sarotherodon niloticus* with those of *S. aureus* and other tilapias of the delta and lower Nile. *Aquaculture*, *30*(1–4), 335–351. https://doi.org/10.1016/0044-8486(83)90229-2

Penman, D. J., & Piferrer, F. (2008). Fish gonadogenesis. Part I: Genetic and environmental mechanisms of sex determination. *Reviews in Fisheries Science*, *16*(S1), 16–34. https://doi.org/10.1080/10641260802324695

Ricker, W. E. (1975). *Computation and interpretation of biological statistics of fish populations* (Bulletin 191). Fisheries Research Board of Canada.

Rothschild, B. J., Ault, J. S., Goulletquer, P., & Héral, M. (1994). Decline of the Chesapeake Bay oyster population: A century of habitat destruction and overfishing. *Marine Ecology Progress Series*, *111*, 29–39. https://doi.org/10.3354/meps111029

Santi, S., Rougeot, C., Toguyeni, A., Gennotte, V., Kebe, I., & Melard, C. (2017). Temperature preference and sex differentiation in African catfish, *Clarias gariepinus*. *Journal of Experimental Zoology Part A: Ecological and Integrative Physiology*, *327*(1), 28–37. https://doi.org/10.1002/jez.2057

Shalloof, K. A. S. (1991). *Biological studies on Tilapia species in the middle region of Manzala Lake* [M.Sc. Thesis, El-Mansoura University].

Shalloof, K., Aly, W., El-Far, A., Fetouh, M., El-Ganiny, A., & Amin, A. (2022). Distribution of fish species infested by *Livoneca redmanii* (Isopoda, Cymothoidae) in Lake Manzala, Egypt during dredging operations. *Egyptian Journal of Aquatic Biology & Fisheries*, *26*(6), 803–811. https://doi.org/10.21608/ejabf.2022.277838

Shalloof, K., Fetouh, M., El-Far, A., Aly, W., & El-Betar, T. A. (2024). The length-weight relationship and condition factors of twelve fish species, with special reference to cichlid species from the Mediterranean Manzala Lagoon, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, *28*(1), 1221–1237. https://doi.org/10.21608/ejabf.2024.339679

Shen, Z. G., & Wang, H. P. (2018). Environmental sex determination and sex differentiation in teleosts—How sex is established. In H. P. Wang, F. Piferrer, S. Chen, & Z. G. Shen (Eds.), *Sex control in aquaculture* (pp. 85–115). Wiley-Blackwell. https://doi.org/10.1002/9781119127291.ch4

Smith, S. H. (1956). *Life history of Lake herring of Green Bay, Lake Michigan* (Fishery Bulletin 109). U.S. Fish and Wildlife Service.

Sokal, R. R., & Rohlf, F. J. (1987). *Introduction to biostatistics* (2nd ed.). W. H. Freeman.

Stelkens, R. B., & Wedekind, C. (2010). Environmental sex reversal, Trojan sex genes, and sex ratio adjustment: Conditions and population consequences. *Molecular Ecology*, *19*(4), 627–646. https://doi.org/10.1111/j.1365-294X.2010.04509.x

Székely, T., Weissing, F. J., & Komdeur, J. (2014). Adult sex ratio variation: Implications for breeding system evolution. *Journal of Evolutionary Biology*, *27*(8), 1500–1512. https://doi.org/10.1111/jeb.12444

Toews, D. R. (1977). *The Lake Bangweulu Fishery: Zambia Central Africa* [M.Sc. Thesis, University of Toronto].

Vandeputte, M., Quillet, E., & Chatain, B. (2012). Are sex ratios in wild European sea bass (*Dicentrarchus labrax*) populations biased? *Aquatic Living Resources*, *25*(1), 77–81. https://doi.org/10.1051/alr/2012002

Vazzoler, A. E. A. de M. (1996). *Biologia da reprodução de peixes teleósteos: Teoria e prática*. EDUEM.

Vicentini, R. N., & Araújo, F. G. (2003). Sex ratio and size structure of *Micropogonias furnieri* (Desmarest, 1823) (Perciformes, Sciaenidae) in Sepetiba Bay, Rio de Janeiro, Brazil. *Brazilian Journal of Biology*, *63*(4), 559–566. https://doi.org/10.1590/S1519-69842003000400003

Wearmouth, V. J., & Sims, D. W. (2008). Sexual segregation in marine fish, reptiles, birds and mammals: Behaviour patterns, mechanisms and conservation implications. *Advances in Marine Biology*, *54*, 107–170. https://doi.org/10.1016/S0065-2881(08)00002-9

Wedekind, C. (2012). Managing population sex ratios in conservation practice: How and why? In T. Povilitis (Ed.), *Topics in conservation biology*. IntechOpen. https://doi.org/10.5772/31383

Wenger, A. S., Harvey, E., Wilson, S., Rawson, C., Newman, S. J., Clarke, D., Saunders, B. J., Browne, N., Travers, M. J., Mcilwain, J. L., Erftemeijer, P. L. A., Hobbs, J. P. A., Mcclean, D., Depczynski, M., & Evans, R. D. (2017). A critical analysis of the direct effects of dredging on fish. *Fish and Fisheries*, *18*(5), 967–985. https://doi.org/10.1111/faf.12223

Yang, Z. F., Chen, D., & Xiao, B. P. (2019). Impact assessment of dredging on fish eggs and larvae: A case study in Caotan, South China. *IOP Conference Series: Earth and Environmental Science*, *351*, 012035. https://doi.org/10.1088/1755-1315/351/1/012035

Zachary, W. C., & Tobler, M. (2017). Sex-specific evolution during the diversification of livebearing fishes. *Nature Ecology & Evolution*, *1*, Article 0233. https://doi.org/10.1038/s41559-017-0233-4

Zhong, J. C., Yu, J. H., Zheng, X. L., Chen, F., & Yu, D. (2018). Effects of dredging season on sediment properties and nutrient fluxes across the sediment–water interface in Meiliang Bay of Lake Taihu, China. *Water*, *10*(11), 1606. https://doi.org/10.3390/w10111606