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Evaluation of Well-Being Status of Near-Threatened Gangetic Leaf Fish *Nandus nandus* (Hamilton, 1822) in the Kawadighi *Haor*: Implications to *Haor* Fishery Management in the Northeastern Bangladesh

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Abstract: This study evaluated the status of the well-being of wild *Nandus nandus* in the Kawadighi *Haor* through morphometric and gastrointestinal indices and local people's perceptions. Basic macroscopic morphology of the gastrointestinal tract (GIT), the viscera somatic index (VSI), the hepatosomatic index (HSI), the condition factor (K), length–weight relationships, and gut histology were analyzed from the regular commercial catch. The GIT morphology includes a tube-like esophagus, a tapering stomach, a tubular intestinal region, and a rectum, all of which have clinically normal shapes and conditions. VSI and HSI values fluctuate throughout the year, indicating the periodic variation of food content and availability in the ecosystem. The condition factor (K) was generally stable, with minor deviations in December. The mucosa, submucosa, muscularis, and serosa were identified from the stomach of *N. nandus* and showed normal histological characteristics. There were numerous proliferated villi in the tunica mucosa, but no histopathological abnormalities were found in the gut. These findings suggest that the current population of *N. nandus* in the *Haor* is in a favorable condition. However, local people reported some potential threats that might be a concern for the long-term survival of this species. The results of the present study will be useful for effective and sustainable stock management of the *N. nandus* fishery in the Kawadighi *Haor* and other floodplain ecosystems.

Keywords: *Nandus nandus*; gut histology; Kawadighi *Haor*; morphology; management

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1. Introduction

The *Haor* basin is a naturally occurring complex of a low-lying, unique wetland ecosystem that includes rivers, streams, seasonal floodplains, paddy fields, irrigation canals, freshwater swamps, and hundreds of interconnecting *beels* [1–5]. It is naturally a major hotspot of inland fish diversity, with 154 native fish species covering 12 orders and 35 families, which greatly supports the country's small-scale fisheries as well as providing food security and livelihoods for the local stakeholders in the area [4,6–8]. In the *Haor* ecosystem, the *Nandus nandus* (Hamilton, 1822) is a significant fishery species that is entirely focused on capture and is primarily caught for sale at fish markets alongside other small indigenous fish species [9,10]. Small indigenous species (SIS) of fish are an important source of micronutrients and play a crucial role in ensuring the nutrition security and livelihood of the local *Haor* community [4,11]. *N. nandus* is considered a significant SIS, having a very precious taste and a high market price due to its compact muscle, less intermuscular bone, and excellent morphological features [12,13]. This species can be found throughout the Indian subcontinent and in several Southeast Asian countries, including Bangladesh, Pakistan, India, Cambodia, Laos, Nepal, Myanmar, Bhutan, Vietnam, and Thailand [13–15]. *N. nandus* is considered a predator and exclusively feeds on aquatic insect larvae, small fish, shrimp, and other small creatures [16–18]. This carnivorous, bottom-dwelling species can be found in stagnant water bodies such as lakes, reservoirs, and canals [17] and is known for its ability to camouflage itself in its surroundings [18,19].

The well-being status of a species refers to the overall health and prosperity of the population and encompasses both its physical and psychological well-being [20]. In the context of *N. nandus*, specifically, the well-being status would refer to the physical and ecological conditions of the species in the open water, including the quality of its habitat, the size and health of its population, the availability of food resources, and the prevalence of diseases or other stressors. It can also include factors such as reproduction rate, genetic diversity, and the species' ability to adapt to changing conditions. A species' well-being status is an important indicator of its ability to survive and thrive in its environment, and it can provide insight into the efficacy of conservation and management efforts [21]. The factors that influence the well-being of a species include habitat quality, population parameters, food availability, and disease prevalence. Different biometric indices are essential to explore in relation to fish population growth and aquatic habitat well-being [22]. To determine the well-being status of *N. nandus* in the Kawadighi *Haor*, various parameters, such as morphological, biometrical, and gastrointestinal parameters, habitat quality, and food availability, should be analyzed. It is important to understand the well-being status of the *N. nandus* species in the Kawadighi *Haor* in order to develop effective conservation and management strategies. This includes identifying and addressing any threats to the species and its habitat, as well as promoting sustainable fishing practices in the *Haor* area.

People's perception of fish can influence how they view their management and conservation efforts and can affect their willingness to take action to protect fish populations. The well-being of *N. nandus* in Kawadighi *Haor* was assessed in a study that considered both potential threats to the species and local stakeholders' perceptions of those threats [7]. Previous research has examined factors such as overexploitation, drying *beels*, invasive species, climate change, tourism and leasing programs, and the absence of alternative income opportunities for local fishers [7,23]. Through a survey of 449 stakeholders, including lease holders, fishers, and the general people, it was found that there were both positive and negative perceptions of the impact of aquaculture on fish production, biodiversity, and the overall well-being of native species in the *Haor* ecosystem [7].

The relationship between body metrics is crucial for evaluating an individual's well-being and identifying potential variations among members of the same species living in different habitats [24,25]. In open-water fishery stock assessment (growth, well-being, fitness, etc.) and conservation, the condition factor (K) and length–weight relationships (LWRs) are essential for understanding growth parameters among species [26–28]. Studies on LWRs in open-water fish, particularly in the *Haor* Basin, are still limited in Bangladesh [29]. The condition factor (K) reflects the biological and physical conditions of fish, the suitability of specific water bodies for fish growth, and the size distribution of the studied species [30–32]. The values of this variable are often influenced by the physiological state of fish, specifically their age, lifecycle, spawning, environmental factors, and the food supply in the water body [33,34]. The studies of fish gastrointestinal tracts are thought to be an efficient method for understanding how food is consumed, digested, and absorbed [35–37]. The digestive systems of bony fish exhibit diverse morphological and functional variations due to their diverse positions in the food chain [38,39]. The histology of digestive systems is a useful tool for determining the health status and dietary preferences of aquatic organisms [40–42]. The different layers of the gastrointestinal tract, such as the mucosa, submucosa, muscularis, and serosa, are linked to the feeding habits of the species, the type of food ingested, and the secretion and absorption of mucosubstances [37,38,42,43].

The population of many indigenous fish species in Bangladesh, including *N. nandus*, has decreased [10]. According to the IUCN Bangladesh [44], this species has been listed as a near-threatened fish in Bangladesh and considered of least concern globally [45] for a decade before it was considered vulnerable [46]. The decline of *N. nandus* in open-water bodies such as Kawadighi *Haor* in Bangladesh is likely due to a combination of factors. One possible factor is overfishing, which can reduce the population of the fish and make it more difficult for them to reproduce. Habitat destruction and degradation can also play a role, as the loss of suitable breeding and feeding grounds can make it harder for the fish to survive [9,44]. Pollution, climate change, and invasive species are all significant factors that can harm the population and habitat of fish [7,9,23,46]. Pollution, particularly from agricultural and industrial sources, can contaminate the water and make it difficult for the fish to survive [44]. It is crucial to take immediate action to conserve the *N. nandus* species through various research efforts, such as population studies, conservation biology, and artificial breeding. To effectively conserve this species, it is important to understand its well-being status and conservation biology, as well as take steps to preserve its native habitat. This may include efforts to domesticate the species in order to improve its chances of survival.

To the best of our knowledge, there have been no prior studies published on morphometry (condition factor, length-weight relationship) and gastrointestinal studies (HSI, VSI, gut histology) of *N. nandus* in the *Haor* fishery in Bangladesh, except for limited studies on its histology, morphological and allozyme variation, and biology [47–49]. It is therefore imperative to initiate efforts towards the conservation of this species through further research, management of wild stocks, conservation, and domestication. In light of the foregoing, this study was conducted to determine the well-being status of *N. nandus* from the Kawadighi *Haor* in northeastern Bangladesh using morphometric and gastrointestinal indices, and people's perceptions, with the hope that the findings will aid in gaining deeper insights into the morphometrical, physiological, and functional features of the digestive system, as well as the efficient management of *N. nandus* wild stocks, paving the way for conservation and serving as a source of baseline information for further research work.

2. Materials and Methods

2.1. Study Area

The research was carried out at Kawadighi *Haor*, Rajnagar Upazila (sub-district), in the Moulvibazar district of Sylhet division, Bangladesh. The waterbody is situated between the latitudes 24°26′ and 24°39′ north and the longitudes 91°44′ and 91°58′ east. The map in Figure 1 shows the study area.

2.2. Sample Collection

Fish specimens were randomly collected without regard to sex from the commercial catches of fishers in various *beels* of the Kawadighi *Haor* monthly from January to December 2014. During sampling, most of the fish were either dead or in a moribund state. All collected samples were instantly preserved in an icebox and shipped to the Aquaculture Nutrition and Dietetics Lab, Sylhet Agricultural University, Sylhet, Bangladesh, at the earliest convenience. Prior to sampling, necessary permits were obtained from local authorities, and proper labeling and documentation of the samples were performed in accordance with ethical guidelines for the handling of the fish specimens. Notably, a total of 60 specimens (approximately 4–6 samples per month) of *N. nandus* were collected during the study period.

2.3. Data Collection

To gather information about the perceptions and experiences of the local fishing community, we employed a mixed-methods approach, which included both quantitative and qualitative data collection methods. Quantitative data were collected using a pre-set questionnaire that was administered to a sample of fishers, fish sellers, and local people. The questionnaire specifically targeted local people's perceptions on various anthropogenic and natural threats, such as the drying of *beels*, overexploitation, invasive species, climate change, and sedimentation. The questionnaire included both semi-structured and structured questions, with the aim of gathering information about a range of topics, including the community's perceptions of the local fishing activities, their experiences with fish trading, and any challenges they have faced. We targeted a sample of 300 participants and randomly distributed the questionnaires among them.

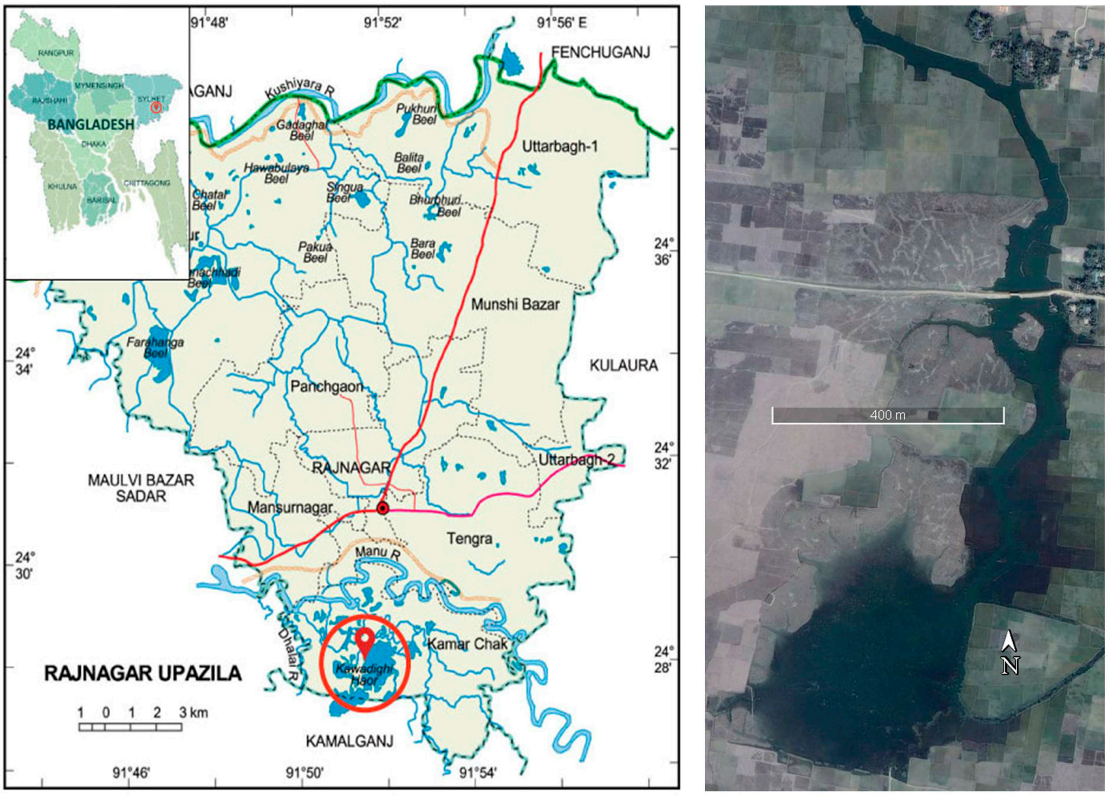

Figure 1. Location of the study area [9].

In addition to the questionnaire, we also conducted focus group discussions with a sample of the community. The focus group discussions were held with a group of 8–10 participants and guided by a moderator who used a set of predetermined questions to elicit the community's perceptions and experiences of the local fishing activities, as well as their opinions on the various anthropogenic and natural threats facing the *N. nandus* fishery. The questions were designed to be open-ended, allowing for more in-depth and qualitative responses. To ensure the accuracy and reliability of the data collected, we also conducted an interview with the fisheries officer of Rajnagar Upazila, who was able to provide valuable insights and cross-check the information provided by the community.

2.4. Measurement of Morphometric and Gastrointestinal Parameters

In the laboratory, the fish were gently cleaned with tap water and dried on tissue paper. Total length (TL) and standard length (SL) were measured using a measuring scale, and body depths (BD) of individual fish were determined with a caliper to the nearest centimeter.

The body weight (BW) of each sample was calculated to the nearest gram using an electronic balance (Ohaus Corp., Pine Brook, NJ, USA). The specimens were dissected with scissors from the ventral side and continued interiorly down the belly of the fish to the head area, following the specific procedures outlined by the Institutional Ethics Committee. The internal organ was exposed after two walls of the body cavity were torn apart. After dissection, the gut length (GL), stomach length (SL), and intestinal length (IL) were measured and recorded. Liver weight (LW) and visceral weight (VW) were measured to the nearest gram. Gut status was visually examined, and a picture was taken with a camera (Canon PC 1737, China). The guts were then preserved for subsequent study in a 50 mL plastic vial (Labtex, China) containing 30 mL of 10% formaldehyde.

Four morphometric characteristics, such as fish weight, total length, standard length, and body depth, were determined by following the procedure of [50]. The parameters were taken to evaluate the gastrointestinal status of the gut by using the following mathematical equations:

$$\text{Hepatosomatic index (HSI)} = \frac{\text{Total weight of the liver}}{\text{Total weight of the fish}} \times 100$$
$$\text{Viscera somatic index (VSI)} = \frac{\text{Total viscera weight}}{\text{Total weight of the fish}} \times 100$$
$$\text{Fulton's condition factor (K)} = \frac{\text{W}}{\text{L3}} \times 100$$

where K = condition factor, W = fish weight (gm), and L = fish length (cm).

2.5. Histology of Gut

The previously preserved sample in neutral buffered formalin was used for histology, and a standard histological protocol was followed [51]. A Zeiss Primo Star microscope was used to investigate tissue sections. A 3–5 micrometer section was prepared in a graded series of alcohol, xylene, and stained with standard hematoxylin and eosin dye. Microscopic observations of the gut were performed according to the procedure mentioned by Delashoub et al. [52].

2.6. Ethical Statement

Methods performed in this research involving fish were in accordance with the ethical standards of the "Sylhet Agricultural University Ethical Committee". The approval number is SAU/Ethical committee/AUP/23/01. Informed consent was obtained from all survey respondents.

2.7. Data Analysis

The statistical analyses were executed in IBM SPSS v27 at $p < 0.05$. Output data from SPSS were used to construct bar and graph diagrams in Excel Tools of Office 365.

3. Results and Discussion

3.1. Morphology of Digestive Tract

The mouth of *N. nandus* is protractile; in the mouth cavity, a sac-like, long structure with a bulging mid-region was found. The internal surface of the mouth cavity was rough, and a high volume was noted due to its predatory food habits.

A tube-like esophagus (Figure 2A) was identified immediately after the pharynx and was the shortest portion of the alimentary tract, being thick and rough, and with several longitudinal edges. The stomach was tapering (Figure 2B), with a nipple-like appearance at the bottom, elongated and tube-like (j-shaped) in structure, and reddish in color. The blood vessels were clearly visible, and they were less elastic compared to the intestine. It swelled the most from May to October.

The intestine of *N. nandus* was tubular and coiled (Figure 2C), starting from the upper part of the stomach and ending in a short rectum. The front and middle segments of the intestine were thick, while the posterior intestine was thin, and the middle sections were more elastic than the front. The color was reddish with a faint greenish tint. *N. nandus* was found to be an extremely predatory fish, swallowing large prey and consuming large amounts of food. During the study, two species of engulfed fish (*Chanda* sp. and *Puntius* sp.) were primarily identified from the posterior part of their intestines (Figure 2D).

Rahman et al. [47] found that the esophagus was the smallest component of the alimentary tract in carnivorous fish and had an uneven inner side connecting to the stomach. The study included *N. nandus* and noted that the esophagus was a small, vasiform shape not identifiable from the outside of the gut. In the case of the long-whiskers catfish (*Mystus gulio*), the esophagus was tiny and connected directly to the stomach [53]. Lagler et al. [54] emphasized the high dispensability of the esophagus.

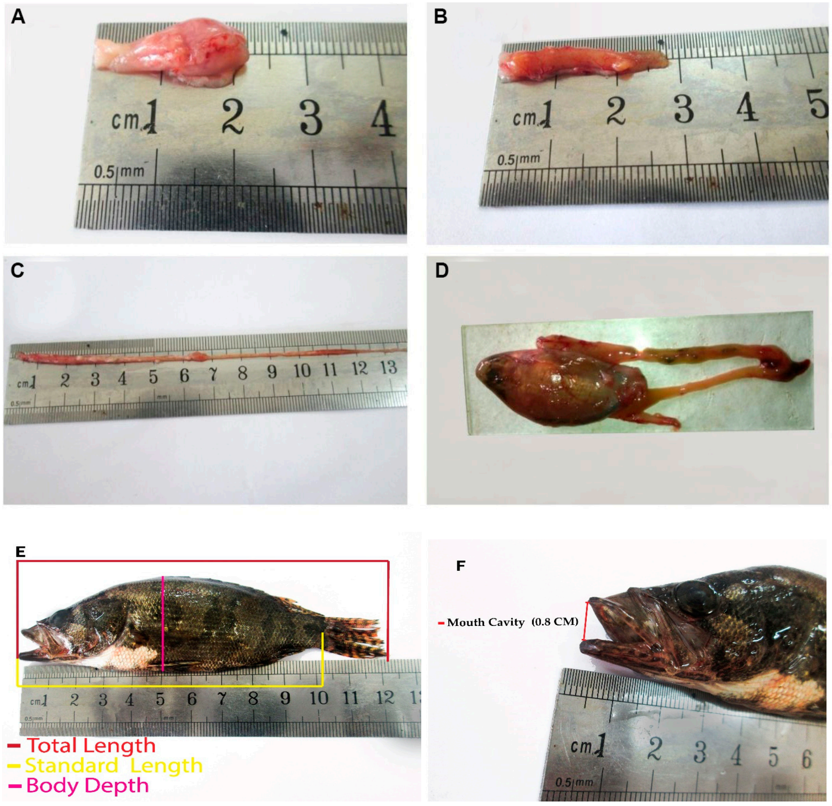

Figure 2. Photographs showing different parts of morphometry and the gastrointestinal tract: (**A**) esophagus, (**B**) tapering stomach, (**C**) tubular intestine, (**D**) engulfed fish in stomach, (**E**) morphometry, and (**F**) mouth cavity.

Rahman et al. [47] found that *Channa punctatus* has a sac-like stomach throughout its abdominal cavity, *Xenentodon cancila* has a tube-shaped, slightly flat-midsection stomach, and *Glossogobius giuris* has a bloated stomach that progressively shrinks in the mid-section. Mookerjee and Das [55] found that the size of a fish's stomach is directly connected to its feeding behavior, specifically the size of the food. They also noted that predatory fish had wide mouths, large stomachs, and small intestinal systems, all of which are consistent with this study's findings.

Rahman et al. [47] studied the digestive tracts of many carnivorous fish, finding that *Anabas testudineus* had intestines arranged in a "U" and "W" shape, connected to the posterior part of the stomach, of moderate elasticity, and of uniform diameter from origin to anus. In the case of *Johnius coitor*, the intestine was tubular, *Channa orientalis* had "S"-shaped intestines, and *Channa punctatus* had intestines extending from the forepart to the anus. Peretti and Andrian [56] found the intestines of carnivorous fish to be narrow, with two folds, and shorter than the body size. Rahman et al. [47] reported differing coiling shapes of fish intestines between species, while Islam [53] found the anterior intestine to have a thick wall and the posterior portion to have a thin one, which was consistent with the findings of the current study.

3.2. Biometrical and Gastrointestinal Parameters

From the biometrical and gastrointestinal parameters, the highest total length (TL) of fish was observed in February (13.94 ± 0.85) and the lowest in January (09.70 ± 0.90) (Table 1). The highest fish weight was recorded in February (50.88 ± 8.65), while the lowest was recorded in January (17.40 ± 03.44) (Table 1). The mean TL, gut length, stomach length, and intestine length of the studied species were 12.94 ± 1.22, 13.74 ± 3.32, 3.16 ± 0.48, and 10.57 ± 3.37 cm, respectively (Table 1). The mean total length was 1.22 times the length of the intestine, and the length of the intestine was 3.34 times the length of the stomach.

Table 1. Biometrical and gastrointestinal parameters of wild *N. nandus* in the Kawadighi *Haor.*

Month	Fish Weight (gm)	Total Length (cm)	Standard Length (cm)	Body Depth (cm)	Liver Weight (gm)	Viscera Weight (gm)	Gut Length (cm)	Stomach Length (cm)	Intestine Length (cm)
Jan	17.40 ± 3.44^{a}	9.70 ± 0.90^{a}	8.10 ± 0.60^{a}	3.32 ± 0.42^{a}	0.30 ± 0.05^{a}	0.79 ± 0.11^{ab}	9.39 ± 0.89^{a}	2.36 ± 0.34^{a}	7.03 ± 0.59^{a}
Feb	50.88 ± 8.65^{c}	13.94 ± 0.85^{c}	11.88 ± 0.76^{cd}	4.04 ± 0.32^{bc}	0.83 ± 0.17^{cd}	1.28 ± 0.42^{cd}	22.05 ± 19.21^{c}	2.62 ± 0.24^{ab}	19.43 ± 19.28^{b}
Mar	44.11 ± 10.00^{c}	13.40 ± 0.73^{c}	11.40 ± 0.65^{cd}	3.90 ± 0.55^{bc}	0.73 ± 0.20^{cd}	1.96 ± 0.36^{e}	12.50 ± 1.07^{ab}	3.02 ± 0.48^{bc}	9.48 ± 0.78^{a}
Apr	46.18 ± 6.28^{c}	13.22 ± 0.38^{c}	11.26 ± 0.34^{cd}	3.96 ± 0.17^{bc}	0.74 ± 0.11^{cd}	1.92 ± 0.23^{e}	12.82 ± 0.43^{ab}	3.24 ± 0.74^{bc}	9.58 ± 0.94^{a}
May	46.22 ± 16.09^{c}	13.54 ± 1.88^{c}	12.10 ± 0.55^{d}	4.36 ± 0.31^{c}	0.74 ± 0.22^{cd}	1.56 ± 0.49^{de}	12.93 ± 1.82^{ab}	2.66 ± 0.21^{ab}	10.27 ± 1.74^{a}
Jun	38.30 ± 8.32^{bc}	12.86 ± 1.29^{c}	11.60 ± 0.23^{cd}	4.24 ± 0.22^{c}	0.88 ± 0.12^{d}	1.83 ± 0.32^{e}	13.42 ± 1.96^{ab}	3.39 ± 0.70^{cd}	10.03 ± 1.31^{a}
Jul	46.86 ± 6.51^{c}	13.80 ± 0.42^{c}	11.84 ± 0.50^{cd}	4.04 ± 0.43^{bc}	0.72 ± 0.13^{cd}	1.09 ± 0.21^{bc}	13.38 ± 0.44^{ab}	2.72 ± 0.40^{ab}	10.66 ± 0.39^{a}
Aug	48.03 ± 9.85^{c}	13.80 ± 1.15^{c}	11.30 ± 1.04^{cd}	4.12 ± 0.62^{bc}	0.67 ± 0.31^{cd}	1.10 ± 0.29^{bc}	13.44 ± 0.98^{ab}	3.98 ± 0.22^{d}	9.46 ± 0.76^{a}
Sep	43.85 ± 13.97^{c}	13.46 ± 1.53^{c}	11.88 ± 1.11^{cd}	4.20 ± 0.46^{c}	0.62 ± 0.18^{bc}	1.83 ± 0.63^{e}	18.36 ± 1.03^{bc}	3.48 ± 0.43^{cd}	14.88 ± 0.62^{ab}
Oct	27.41 ± 12.69^{ab}	11.40 ± 1.52^{b}	9.60 ± 1.08^{b}	3.24 ± 0.43^{a}	0.30 ± 0.17^{a}	0.50 ± 0.19^{a}	11.10 ± 1.54^{ab}	3.42 ± 0.35^{cd}	7.68 ± 1.44^{a}
Nov	38.06 ± 3.67^{bc}	12.94 ± 0.86^{c}	10.96 ± 0.86^{c}	3.94 ± 0.17^{bc}	0.44 ± 0.09^{ab}	1.23 ± 0.07^{bcd}	12.58 ± 0.94^{ab}	3.56 ± 0.62^{cd}	9.02 ± 0.91^{a}
Dec	49.31 ± 2.66^{c}	13.24 ± 0.56^{c}	11.20 ± 0.57^{cd}	3.60 ± 0.29^{ab}	0.75 ± 0.05^{cd}	1.75 ± 0.15^{e}	12.88 ± 0.64^{ab}	3.52 ± 0.40^{cd}	9.36 ± 0.56^{a}

Different superscripts in the same column indicate significant difference at $p < 0.05$.

Rahman et al. [47] reported the TL, SL, and IL of *N. nandus* as 9.63 ± 1.57, 1.98 ± 0.60, and 7.03 ± 1.49 cm, respectively. With a mean of 1.36 cm, the TL was 1.20 to 1.50 times higher than the IL of the studied species. The IL was 2.90 to 3.20 times higher than the fish's SL. From the results, it was observed that this finding is similar to Rahman et al. [47]. Overfishing practices, regardless of size or sex, by using destructive fishing gear in the Kawadighi *Haor* [7], could be one of the major causes of *N. nandus* morphometrical changes observed throughout the year.

3.3. VSI and HSI Parameters

The monthly variation of the VSI of *N. nandus* over the study period is shown in Figure 3. The highest value of VSI was observed in June (4.87 ± 0.73) and the lowest in October (1.86 ± 0.12). VSI increased in January, March, April, June, and September, but significantly decreased in February, May, July, August, and October (Figure 3). Changes in VSI can be influenced by factors such as food and fat content in the stomach, food availability in the ecosystem, and periodic fluctuations in food availability in the surroundings.

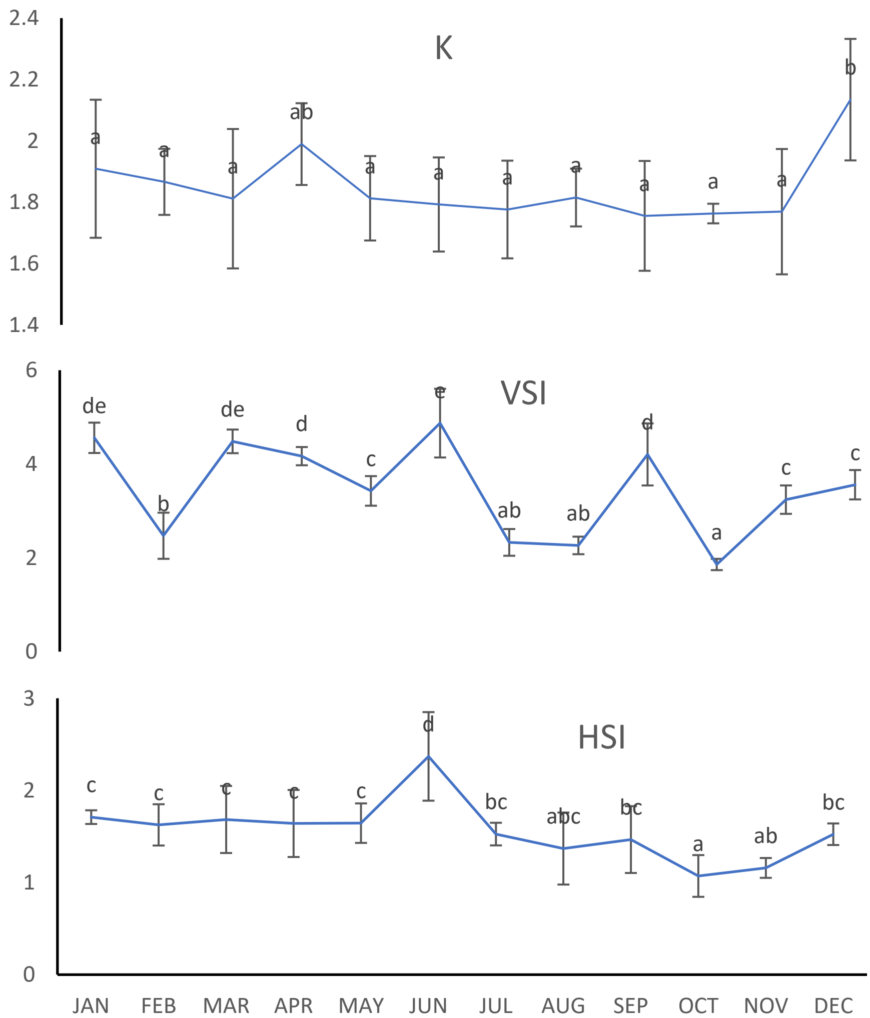

Figure 3. Monthly variation of K, VSI, and HSI (VSI: viscera somatic index, HSI: hepatosomatic index, K: condition factor). Different superscripts indicate significant difference at $p < 0.05$.

To determine energy status and seasonal fat accumulation in the cavity, VSI has been used in several studies [57]. An increase in VSI is associated with an increase in feeding rate and dietary lipids in the food [58–60]. The findings of the current study show fluctuating VSI values, with the highest values recorded in January, March, April, June, and September, which may suggest intraperitoneal fat deposition and the availability of food in the *Haor* ecosystem.

The monthly change of the HSI of *N. nandus* is shown in Figure 3. The highest value of HSI was recorded in June (2.37 ± 0.48) and the lowest in October (1.07 ± 0.23). Figure 3 shows that both VSI and HSI were highest in June and lowest in October. This suggests a positive correlation between the two variables (R^2 = 0.615), which is consistent with the results of Ighwela et al. [61], who found that the extra carbohydrate got stored in the liver as fat and HSI increased with increasing VSI. This result is identical to that recorded by Ahmad et al. [62], who found that VSI and HSI increase with an increase in dietary carbohydrate intake. HSI indicates the amount of energy stored in the fish's body, with fish in poor conditions having smaller livers and less energy stored [63]. Thus, the physical condition and the energy reserve status of fish were high in June (2.49 ± 0.45) in the Kawadighi *Haor*.

During the 12-month study period, no significant difference was found in the condition factor (K), with some exceptions in December. The highest mean value of the condition factor (2.13 ± 0.20) was observed in December and the lowest (1.76 ± 0.03) in October (Figure 3). A high condition factor indicates a favorable environment, while a low one indicates poor quality of the environment [64]. The condition factor also shows the well-being of fish [65]. In the Ganges River ecosystem, a condition factor ranging from 1.258 to 1.336 was considered suitable for the well-being of *N. Nandus* [21]. The results of the current study show stable condition factors, indicating a consistent feeding condition and environmental suitability for *N. nandus* in the Kawadighi *Haor* from January to November.

3.4. Relationship between Dependent and Independent Variables

The results showed a strong positive correlation between fish standard length and body weight (R^2 = 0.78), meaning that as fish length increased, so did their weight. A similar positive relationship was found between total length and body weight (R^2 = 0.93). Additionally, gut length was positively correlated with intestine length, and body depth showed a positive correlation with body weight (R^2 = 0.50) (Figure 4).

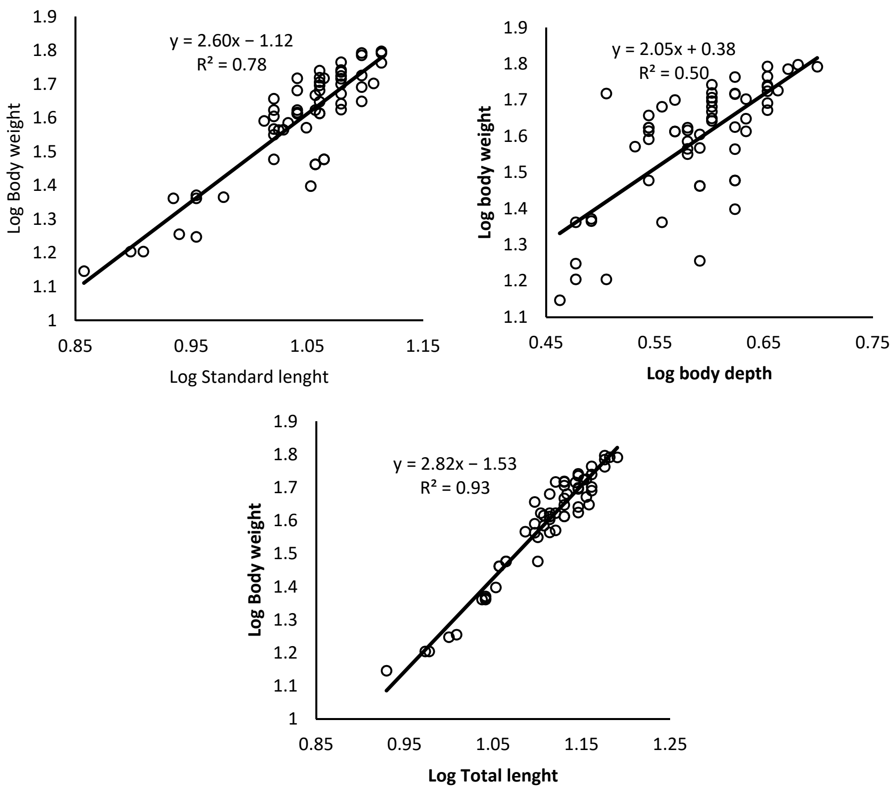

Figure 4. Descriptive statistics and estimated parameters of length–weight and depth–weight relationships.

3.5. Histological Observation of Gut

The histological results showed that the intestinal wall of *N. nandus* consists of the tunica serosa, tunica mucosa, tunica submucosa, and tunica muscularis. The tunica mucosa has numerous folds, known as villi (Figure 5). The tunica mucosa shortens and widens from the anterior to the posterior intestine, and in the posterior intestine, there was significant villous folding and a profusion of goblet cells compared with the anterior. Enterocytes make up the mucosal epithelium, which has a brush border with mucus-secreting goblet cells between them. The tunica mucosa and the submucosa are separated by smooth-muscle fibers. Bighead carp (*Hypophthalmichthys nobilis*) intestines have four layers: the tunica mucosa, tunica submucosa, tunica muscularis, and tunica serosa [52]. This research showed the presence of serosa and villi. Yadav et al. [66] reported the typical appearance of circular muscles, longitudinal muscles, serosa, and villi in the case of the Asian catfish, *Clarias batrachus.* Thus, the current study shows normal histological features, similar to previous findings.

Figure 5. Transverse section photomicrographs of the intestine in *N. Nandus* (V = villi of the intestine, I = inner circular muscle, small arrow = tunica serosa, large arrow = epithelium).

Ghosh and Chakrabarti [67] reported that *O. niloticus* has a cecal stomach composed of the serosa (outermost layer), muscularis, submucosa, and mucosa (innermost layer). The mucosa consists of glandular and superficial epithelium, with the glandular epithelium composed of tubular gastric glands made up of rhombic-shaped cells (Figure 6A,B).

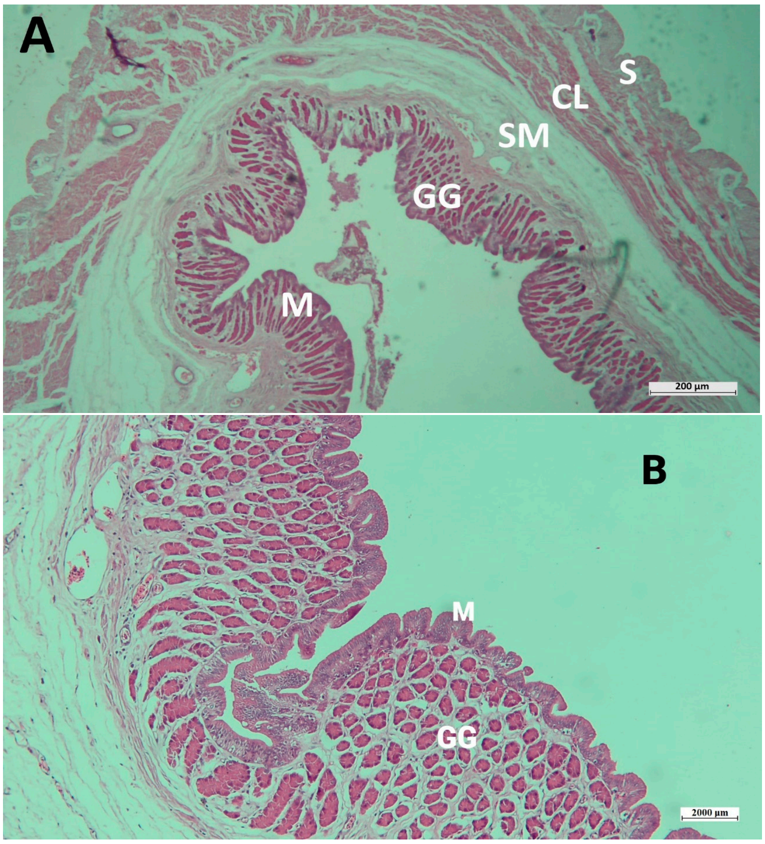

Figure 6. Transverse photomicrographs of a section of the stomach in *N. nandus* (**A**,**B**) where, GG: gastric gland, SM: submucosa, CL: inner circular muscle layer, S: serosa, M: mucosa.

4. People's Perceptions about Threats to *N. nandus*

Despite the abundance of *N. nandus* in the Kawadighi *Haor* [7], there are growing concerns about its long-term viability due to a variety of anthropogenic and natural threats that may reduce its availability and abundance in the *Haor* and surrounding *beels*. Major threats to the *N. nandus* fishery in the studied wetlands were the complete drying of interconnecting *beels* during the winter season (98.67%), followed by overexploitation by using destructive fishing gears (93.33%), the inclusion of invasive species (91.67%), climate change (drought in winter or summer, raising temperatures) (90.33%), and sedimentation (83.33%) (Table 2). Local lease holders dewater their *beels* during the winter and rent them to others, leading to additional dewatering. Similar threats, including dewatering of *beels*, heavy rains, fish exploitation, siltation, use of harmful gear, temperature variations, and nitrogen fertilizer application, were reported in *Haor*-based wetland ecosystems by Aziz et al. [68] and Pandit et al. [3]. Furthermore, limited income-generating options, such as tourism and profit-driven leasing programs, directly or indirectly impact the *N. nandus* fishery.

Table 2. Threats to *N. nandus* in the Kawadighi *Haor.*

Threats to *N. nandus*	**Perceptions % (*n* = 300)**
Complete drying of interconnecting *beels*	98.67
Overexploitation	93.33
Sedimentation	83.33
Climate change (drought in winter or summer, raising temperature)	90.33
Inclusion of invasive ecxotic species	91.67

5. Management Implications and Conservation Approach of *N. nandus*

N. nandus is a very important small indigenous species (SIS), a suitable candidate for aquariums, and has a high market demand [13]. The indices we used in our study, such as VSI, HSI, condition factor, length–weight relationships, and histology, imply that the environment of *N. nandus* was almost constantly fluctuating throughout the year. Therefore, due to several reasons, especially anthropogenic reasons, the population of this SIS is declining in Bangladesh, which can easily be inferred from the poor catch and low availability in the local market, which is creating concerns for the respective conservation biologists [44]. The extent of occurrence and area of occupancy exceed the threshold values of the threatened category. This species is thus considered to be "near threatened". There is no dedicated conservation effort taken to protect this valuable indigenous species. Although, the Bangladesh government and several non-governmental organizations (NGOs) working on conservation strategies have adopted a number of actions that assist the conservation of *N. nandus* and many other fish species living in open-water areas of Bangladesh (Figure 7).

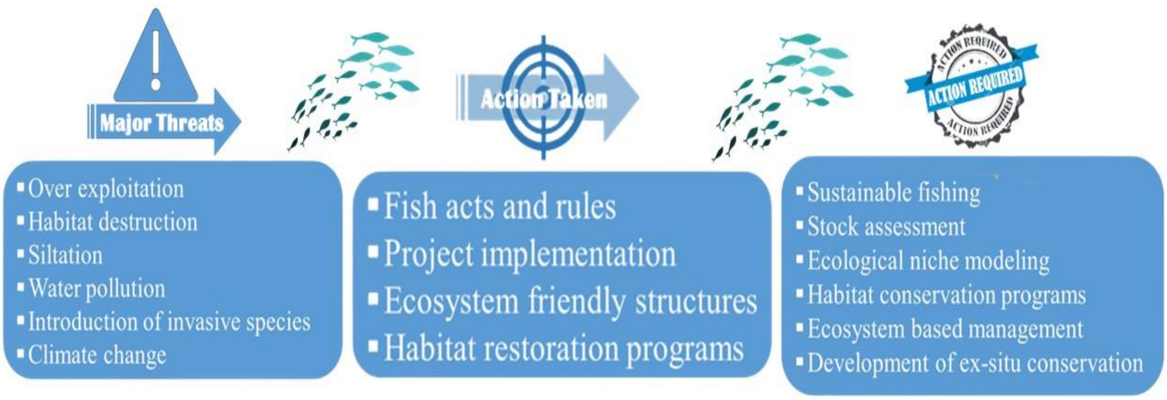

Figure 7. Possible strategies for conservation of *N. nandus* in the *Haor* ecosystem [23,29,47,69].

Several initiatives have been taken to conserve native species, including *N. nandus*, in the *Haor* ecosystem. The implementation of fishing acts and regulations, such as the East Bengal Protection and Conservation of Fish Act (1950), the Protection and Regulations for Conservation of Fish Rules (1985), and the National Fisheries Policy (1998), have scope for the protection and conservation of aquatic organisms. Projects such as the Community-Based Fisheries Management (CBFM) Project and the Management of Aquatic Ecosystems through Community Husbandry (MAECH) Project aim to conserve indigenous species and provide alternative livelihoods for local stakeholders [29]. Sanctuaries and eco-friendly structures, such as fish passes, are effective tools in protecting the natural fish population [5,29,70]. The proper management of the Kasimpur fish pass near the Kawaidighi *Haor* can facilitate the propagation, migration, and sustainable management of native species. The degradation of habitat, such as the complete drying of the interconnecting *beels* of Kawaidighi *Haor*, is a major threat to these species and requires open-water habitat restoration to conserve them [71]. The Bangladeshi government is taking steps to rebuild fish habitats, including re-excavating silted-up waterbodies, spreading water-tolerant vegetation, creating awareness, and inspiring local stakeholders to protect the native species [29].

6. Conclusions

This research provided a comprehensive examination of the well-being of the near-threatened Gangetic leaf fish *Nandus nandus* in the Kawadighi *Haor* of northeastern Bangladesh. By using several morphometry and gastrointestinal indices, as well as incorporating the perceptions of local people, the health and condition of the fish population were assessed. Our findings revealed that the basic macroscopic morphology of the gastrointestinal tract, viscera somatic index, hepatosomatic index, condition factor, length–weight relationships, and gut histology were all within normal ranges for this species. Additionally, there were no significant differences in the condition factor, with some small exceptions in December, and no histopathological abnormalities were found in the gut. These observations suggest that the present population status of *N. nandus* in the *Haor* is in a good condition. However, we also identified some potential threats to the long-term survival of this species, such as fishing pressure and habitat degradation, that should be taken into consideration for effective and sustainable management of the *N. nandus* fishery in the Kawadighi *Haor* ecosystem. Overall, this research highlights the importance of conservation and management of natural wetlands and indigenous fish species for sustainable production and biodiversity. The results of this study provide valuable information for fishery managers, conservationists, and fishery biologists to understand the existing threats and develop an action plan for the conservation and management of this species in the wetlands around the *Haor* ecosystem.

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