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Research Paper

DIET COMPOSITION AND FEEDING HABITS OF NAUJAN WHITE GOBY *Glossogobius aureus* Akihito & Meguro, 1975 IN NAUJAN LAKE, PHILIPPINES

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ARTICLE HIGLIGHTS

- The Naujan White Goby (*Glossogobius aureus*) is an economically important commodity, valued locally for dried fish, making it vulnerable to overexploitation.
- Domestication efforts attempt to lessen fishing pressure while conserving wild populations; however, the feeding ecology of this native fish in Naujan Lake is still unknown.
- Understanding *Glossogobius aureus*' diet composition and feeding habits from its natural habitat is critical for establishing its culture.
- *Glossogobius aureus* is a benthic carnivore that feeds primarily on shrimp, followed by fish and other prey items.

Article Information

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ABSTRACT

Naujan White Goby (*Glossogobius aureus*), commonly processed as dried fish, is a local delicacy in Oriental Mindoro, Philippines. However, the product's growing popularity and rising demand have raised concerns about the overexploitation of this economically valuable species. While efforts to domesticate *G. aureus* have been initiated as a conservation measure, information on its feeding ecology in Naujan Lake National Park is lacking. This study investigated the diet composition, feeding habits, feeding intensity, and seasonal and site-based variations in the diet of *G. aureus* in Naujan Lake by monthly sampling from February 2020 to January 2021. A total of 1,938 *G. aureus* comprising 1,094 males and 844 females were collected, ranging from 75 mm to 280 mm in total length. *Glossogobius aureus* is a benthic carnivore. Shrimp forms the bulk of its diet, followed by fish and other prey. Occasional opportunistic feeding was observed in June to August when the usual prey were scarce. Pairwise comparison showed a significantly high percentage occurrence of shrimp observed during the dry months (January to March) and rainy months (September to November) compared to the lowest ingestion recorded in June and July ($P < 0.05$). The dietary patterns varied significantly across the six sampling sites and seasonal periods. Feeding intensity was the highest before spawning and declined during the spawning period. Males exhibited greater feeding activity compared to females. The findings offer valuable insights into the feeding patterns of *G. aureus*, which could help optimize dietary strategies for its successful culture in captivity.

Keywords: feeding ecology, foraging behavior, freshwater fish, Gobiidae, gut content analysis.

INTRODUCTION

The foraging strategy and fish diet are crucial factors in understanding the trophic interactions among fish in a given community (Manko 2016). The dietary composition is influenced by various factors, including diel cycles (Carman *et al.* 2006), fish sizes (Dinh *et al.* 2017), habitats (Dinh *et al.* 2020), and seasons (Brush *et al.* 2012). Gut content analysis, a standard method in fish ecology, provides critical insights into dietary preferences, offering valuable information for fisheries management and conservation (Chipps & Garvey 2007; Kamler & Pope 2001; Pikitch *et al.* 2004). Additionally, understanding feeding patterns may aid in optimizing feeding protocols for aquaculture fish species (Fabay *et al.* 2021; Ribeiro *et al.* 2022).

Naujan Lake National Park (NLNP), located on the northeast portion of Mindoro Island, is the 5th largest lake in the Philippines. This protected area is home to various economically important fishery resources. Lit *et al.* (2011) listed twenty-nine (29) fish species in the lake. Sixteen (16) of which are native species, including the three *Glossogobius* spp.: *Glossogobius celebius*, *Glossogobius. giuris*, and *Glossogobius aureus*.

Naujan White Goby (NWG) *Glossogobius aureus* (Akihito & Meguro 1975) is among the most commercially important and dominant species. This amphidromous fish could inhabit fresh, brackish, and seawater environments during different stages of its life cycle. Dinh *et al.* (2021) reported a significant decline in the length at maturity (L_m) of this goby species in the brackish water, suggesting that freshwater is a more favorable habitat than seawater. *Glossogobius aureus* spends its larval stage drifting in a marine environment before migrating to freshwater habitats to mature and reproduce (Abdulmalik-Labe *et al.* 2023).

In Naujan Lake, the commercial value of *G. aureus*, driven by local demand for dried fish, rendered it particularly at risk of overexploitation. Interest in domesticating the species has been initiated to potentially reduce fishing efforts and preserve the remaining population in the wild. However, information regarding its feeding ecology in Naujan Lake is scarce. Understanding the dietary ecology of NWG is a fundamental prerequisite for facilitating the culture of this native species. So far, published studies have primarily focused on flathead goby (*G. giuris)* feeding and dietary patterns in other lakes across the Philippines. Common diet components include fish, shrimp, insects, and zooplankton (Bejer 2015; Lagbas *et al.* 2017; Marquez 1960; Uy *et al.* 2019). This study aimed to: 1) determine the diet composition of *G. aureus* in Naujan Lake; 2) assess seasonal and site-based variations in feeding habits; and 3) analyze feeding intensity in relation to reproductive patterns.

MATERIALS AND METHODS

Sampling Site

Six known fishing grounds for Naujan White Goby (NWG) were chosen as sampling sites for the study. These sites are located around Naujan Lake and are within the four municipalities surrounding the lake. Butas (Site 1) in Barangay Bayani, is located on the northern part of the lake, at the river outlet where Butas River drains towards Tablas Strait. Site 2 was directly at the mouth of Borbocolon River, where water drained into the lake. Together with Malayas (Site 4) and Pasi (Site 5), these sites were positioned on the lake's western side. Site 3 was in Barangay Tigbao on the eastern coast of the lake, along with Site 6 (Tagbakin). All sites were associated with river mouths except Site 1, which was an outlet. Sites 1 and 3 are within the municipality of Naujan, while Sites 2 and 4 are within the Municipality of Victoria. Site 5 is under the jurisdiction of the Municipality of Socorro, while Site 6 is within the Municipality of Pola (Fig. 1). Only Site 1 had a salinity of 3 - 5 ppt. The climate in all sites was Type III, with no pronounced wet or dry season and maximum rainfall from June to September. The warmest month was May, the wettest was December, the coldest was February, and the driest was April. The average annual temperature ranged from 28 °C to 32 °C (Weather & Climate n.d.).

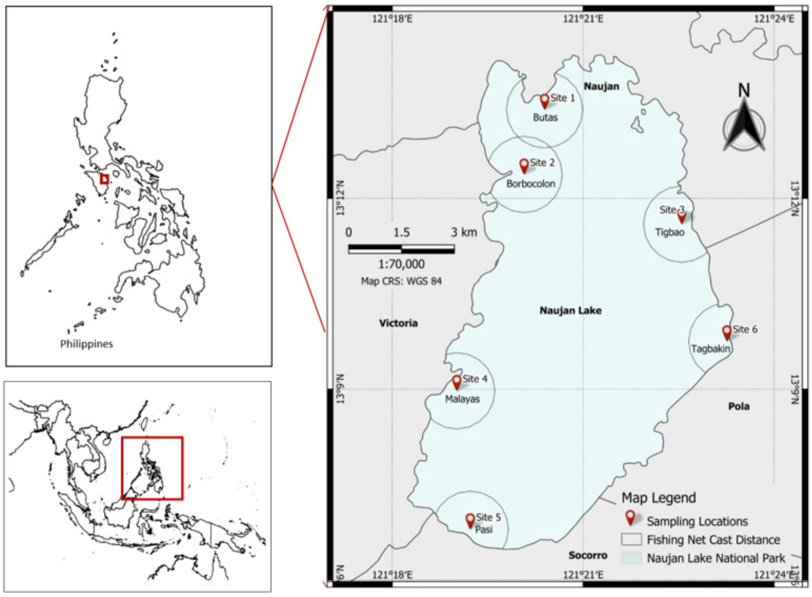

Figure 1 Maps of Southeast Asia (lower left), the Philippines (upper left) and Naujan Lake (right) showing the six sampling sites

Fish Collection

Fish sampling was done experimentally on all sites using a 1,000-m gill net number 14 with a mesh size of approximately 1.5 cm. The gill nets were used to capture a minimum of 50 adult fish and set for 8 hours to standardize fishing efforts in all sampling sites. Samples were collected 2 or 3 days before a full moon every month from February 2020 to January 2021. Collected samples were stored in an iced-styrofoam box and transported to the Fisheries Biology Laboratory of the Institute of Fisheries, Mindoro State University Bongabong Campus for further examination. The fish were identified morphologically based on the arrangement of pit organs and sensory papillae (Akihito & Meguro 1975; Abdulmalik-Labe *et al.* 2022).

Gut Content Analysis

The gut content analysis was conducted using the methods described by Dinh *et al.* (2022). In the laboratory, sex, body weight (BW, g), and total length (TL, mm) of individual adult fish were determined. The whole gut was removed from each fish, weighed (gut-weight, g), and measured (gut length, mm). Gut contents were taken by dissecting the stomach and examined under an LB 220 compound microscope. The stomach was categorized as containing food (non-empty) or without food (empty).

The wet weight of the prey item was recorded to the nearest 0.01 g using an analytical balance and classified based on the following prey types: shrimp, fish, phytoplankton, zooplankton, mollusks, insect larvae, and other food items. Prey identification involved analyzing both partially and fully digested remains. Partially digested prey items are characterized by degraded soft tissues and varying degrees of fragmentation, while fully digested prey items have unrecognizable structure and the gut appears homogenous.

For the identification of prey items, presence of hard structures was used, specifically head fragments, otoliths, teeth, vertebrae, carapaces, shells (exoskeleton) and legs. For shrimp, a single individual is equivalent to 1 carapace, 5 pairs of walking legs, and 1 abdominal region. Separately, vertebrae, head pieces, and otoliths were identified among the fish remains. To estimate the individuals for both fish and shrimp, the most commonly occurring remains were identified. Miscellaneous food items, such as prey bones, plant detritus, sand, mud, and other unidentifiable gut materials were not included as they constitute only smaller proportions of the diet.

The following indices were determined from 1,646 *G. aureus* with stomach contents to characterize its dietary patterns and food preferences:

1. Frequency of Occurrence: to depict seasonal changes in diet composition, computed following Hynes (1950):

$$\%O = 100\ ni/n$$

where:

ni = the number of fish containing prey *i*
n = the number of fish whose stomachs contain food regardless of the amount

2. Index of Relative Importance (IRI): to assess the dietary importance of various prey items consumed by the Naujan White Goby, calculated following Hyslop (1980):

$$IRI = \%O\ (\sum (\%V + \%N))$$

where:
%O = the percentage of frequency of occurrence of each food item
%V = the percentage by volume of the food item
%N = the percentage by number of food item

Feeding Intensity and Feeding Habits

The seasonal variation in the feeding activity of NWG was assessed by determining the Gastrosomatic Index (GaSI). The GaSI values were obtained by dividing the gut weight by fish weight, then multiply by 100 (Biswas 1993). Relative Gut Length (RGL) was also measured to determine the feeding habits of NWG by calculating the ratio of gut length with the total length of the fish. A Relative Gut Length (RGL) of < 1 indicates a carnivorous diet, 1 < RGL < 3 and RGL > 3 signifies omnivorous and herbivorous diets, respectively (Borlongan *et al.* 2002; Ward-Campbell *et al.* 2005).

Statistical Analysis

Alternative Kruskal-Wallis Test was performed to assess the seasonal and site differences in the feeding intensity of NWG at $P < 0.05$. The test was used since the normality and homoscedasticity assumptions were unmet. Pairwise comparisons were performed following significant results to highlight specific differences among groups.

Significant values have been adjusted by the Bonferroni correction for multiple tests. Differences in feeding intensity between male and female NWG were evaluated using a t-test. Data analyses were performed using SPSS software v26 at P < 0.05 significance level.

RESULTS AND DISCUSSION

Diet Composition of *G. aureus*

A total of 1,938 NWG *(G. aureus*) (1,094 male and 844 female), ranging from 75 mm (3.33 g) to 280 mm (148 g), were collected from February 2020 to January 2021. Site 6 (Tagbakin) had the highest number of fish samples collected, followed by Site 3 (Tigbao). Site 1 (Butas), Site 2 (Borbocolon), Site 4 (Malayas), and Site 5 (Pasi) had sample counts of 292, 307, 260, and 216, respectively.

The *G. aureus* has been seen foraging on a variety of food throughout the year. The five prey items were shrimp, fish, phytoplankton, zooplankton, and insect larvae. Shrimp constituted the bulk of the food consumed (40.52%), while mollusks showed the lowest occurrence frequency (0.26%). Fish and phytoplankton were observed to have relatively high occurrence in the gut. The remaining food items, such as zooplankton, insect larvae, and mollusks, were the rarely consumed diets. The Index of Relative Importance (IRI) also indicated that shrimp is the primary food item NWG consumes (Table 1). Fish comprised the next essential prey item, followed by phytoplankton.

The rest of the food items were occasionally consumed. Similar findings were reported for *G. aureus* in the Mekong Delta, where shrimp, particularly *Acetes* spp., were identified as the primary food source; additionally, diets were entirely of animal origin, consisting predominantly of zoobenthos (Phan *et al.* 2023). Differences in the diets within the same fish species have also been observed in *G. giuris* captured from distinct water bodies. In the Philippines, adult *G. giuris* in Lake Mainit predominantly consumes fish, followed by shrimp (Uy *et al.* 2019).

In contrast, those in Lake Taal primarily feed on crustacean eggs, with shrimp absent from the diet (Bejer 2015). These dietary differences may be influenced by food availability, environmental conditions, and habitat-specific resources (Heng *et al.* 2018). Therefore, discriminating the diet composition of *G. aureus* from its natural habitat is necessary to have a basis for its nutritional requirements when cultured under captive conditions.

Seasonal Variation in the Diet

The seasonal fluctuation in the diet composition of *G. aureus* in Naujan Lake was clearly shown in Figure 2. Pairwise comparison showed a significantly high percentage occurrence of shrimp observed during the dry months (January to April) and rainy months (September to November) compared to the lowest ingestion recorded in June and July (P < 0.05).

Teleost fish was the most preferred food during the onset of the cool season in December and the end of the hot, dry season in May. Seasonal variations in the diet components were also found in *G. giuris* but were not observed in *G. sparsipapillus* (Dinh *et al.* 2024; Tran *et al.* 2021). This pattern may reflect seasonal variations in shrimp availability, environmental conditions, or changes in the feeding activity of the fish. The decline in shrimp consumption during June and July may coincide with shifts in prey abundance or other ecological factors influencing prey-predator dynamics (Heng *et al.* 2018).

Phytoplankton was the preferred diet, recorded only in June, July, and August. *Glossogobius aureus* may have exhibited seasonal opportunism in feeding during this period, which occasionally consumes readily available and abundant phytoplankton without being classified as omnivorous. Beaudoin *et al.* (1999) reported opportunistic feeding of carnivorous North pike when the usual prey is scarce. In Naujan Lake, shrimp were recorded in a minimal proportion of the NWG diet from June to August, which may likely lead to occasional opportunistic feeding behavior. The high occurrence of phytoplankton in the gut samples of adult NWG collected during the rainy months might be triggered by an increase in the concentration of nutrients carried to the lake by runoff, particularly in Butas and Tagbakin. Additionally, the consumption of phytoplankton may indicate a trophic transfer of plant material within the food chain, as the fish could ingest small amounts of phytoplankton found in the stomachs of its prey (Horn & Ferry-Graham 2006).

Table 1 Index of Relative Importance (IRI) of various dietary components of NWG *G. aureus*

Food items	%Ni	%Vi	%Oi	(%Ni + %Vi) x %Oi	IRI	Rank
Fish	21.97	36.21	23.44	1,363.74	23.77	2
Shrimp	34.64	44.60	40.52	3,210.80	55.96	1
Mollusc	0.14	0.00	0.26	0.04	0.00	6
Zooplankton	6.75	5.55	5.60	68.88	1.20	4
Phytoplankton	31.88	9.22	25.61	1,052.57	18.35	3
Insect larvae	4.61	4.42	4.58	41.36	0.72	5

Notes: %Ni = percentage by number of food item; %Vi = percentage by volume of the food item; %Oi = percentage of frequency of occurrence of each food item; (%Ni + %Vi) x %Oi = sum of the percentage by number and volume, multiplied by the percentage of frequency of occurrence of each food item); IRI = Index of Relative Importance.

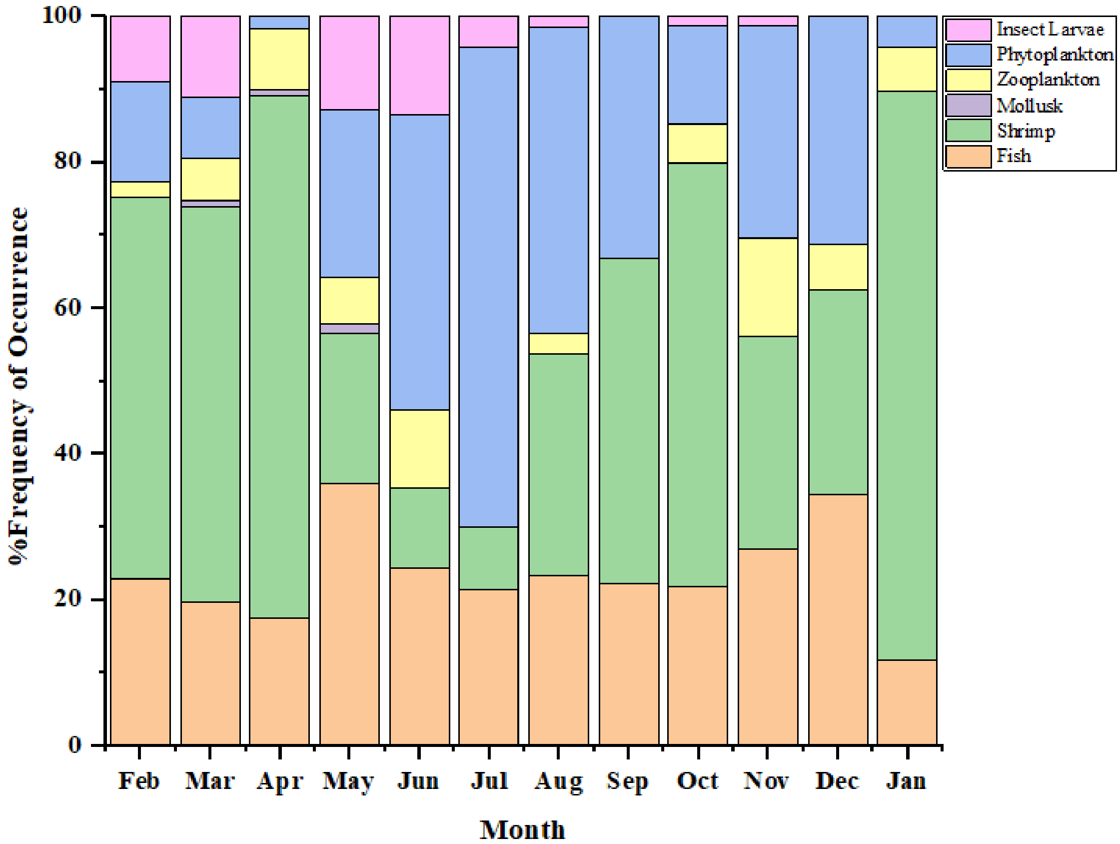

Figure 2 Frequency of occurrence (%O) of food items consumed by *Glossogobius aureus* (n = 1,646) in Naujan Lake from February 2020 to January 2021

Site-Based Variation in Diet Composition

Shrimp dominated the diet composition of NWG across the six sampling sites; however, a significant variation in the proportion of other dietary items was recorded (Fig. 3). Dietary components of samples from Site 6 (Tagbakin) significantly varied with that of Sites 3, 4, and 5, respectively ($P < 0.05$). Site 1 (Butas) had significantly lower proportions of fish in the diet than Site 3 (Tigbao) and Site 4 (Malayas). However, Site 4 (Malayas) samples exhibited a more diverse diet with the occurrence of all the six food items identified in the gut.

The findings may be attributed to the diversity and availability of food sources across the sampling sites. Additionally, competition for food, manifested in diet overlaps, was observed among fish species (Das *et al.* 2018; Matern *et al.* 2021). Insect larvae were absent from the diets of fish sampled at Site 1 (Butas) and Site 2 (Borbocolon) but were present in varying proportions at the other sampling sites. The limited occurrence of insect larvae in deep waters may explain their absence in the stomachs of the samples from Sites 1 and 2, which are both deep sites. Meanwhile, mollusks were observed only in Site 4 (Malayas). Their distribution may be influenced by substrate type, water depth, and hydrochemical parameters (Bespalaya *et al.* 2021).

Phytoplankton abundance in the stomach of *G. aureus* was relatively high in Site 1 (Butas), Site 2 (Borbocolon), and Site 6 (Tagbakin), but relatively lower occurrence in Site 4 (Malayas). All sites are associated with rivers with varying flows. Among the rivers, Malayas (Site 2) has the biggest flow. Phytoplankton growth is always associated with nutrient inputs from runoff but also results from complex dynamics of water flow, light penetration, and temperature (Lu *et al.* 2023). The presence of phytoplankton in the stomach of all samples, irrespective of sites, indicates they are part of the regular diet of the species. Specifically, the consumption of benthic forms, as gobies are benthic feeders.

Feeding Intensity and Food Habits

With a preference for shrimp and fish and the ability to exploit various prey types, NWG is potentially classified as a carnivorous generalist feeder. It showed a highly carnivorous diet correlated with the computed relative gut length of 0.631. Because meat is easier to digest, carnivorous fishes often have short, more or less straight intestines (Shukla 2009). The burrowing goby *Parapocryptes serperaster* also showed a similar trophic strategy (Dinh *et al.* 2017), differing from the specialist feeding behavior of goby *Economidichthys pygmaeus* (Gkenas *et al.* 2012). Moreover, the presence of sand, mud, and detritus in the diet of *G. aureus* collectively indicates benthic feeding, a characteristic commonly observed in the Gobiidae family (Macinnis & Corkum 2000; Parkinson & Booth 2011).

From 1,938 gut samples, 1,646 (85%) contained food and 292 (15%) were empty. This percentage of empty stomachs is lower relative to the 65.36% reported for *G. sparsipapillus* (Tran *et al.* 2021a). Variations in the rate of empty stomachs may be linked to differences in spawning events or reproductive cycles. The food intensity of *G. aureus* was observed based on the gastrosomatic index (GaSI) and gut food volume taken monthly. Sanchez-Escalona *et al.* (in press) identified March, June, and December as the peak spawning months for male *G. aureus* and June and November for females. The highest percentage of empty stomach of NWG was recorded in March in males and June in females, coinciding with the spawning season of *G. aureus* in Naujan Lake. The lowest percentage of empty stomachs of NWG was observed from November to January for both sexes. There was no significant variation (t-test, $P = 0.60$) in the mean GaSI values in both sexes; however, males generally feed more actively than females. The mean GaSI estimates showed that females forage intensively in March, April, and October, while in males, a high feeding activity was observed in April, September, and November (Fig. 4). The GaSI values were observed to be high before spawning months and decreased during spawning season in both sexes.

A similar result was observed in the feeding intensity of *G. guiris* in Bangladesh, which showed maximum feeding during the off-breeding season while minimum during the spawning period (Hossain *et al.* 2016). The findings may suggest possible biological or behavioral differences that are not strongly linked to the GaSI values. Halting food intake during most of the spawning period is likely associated with previous build-up and stored energy reserves from high feeding intensity during pre-spawning periods. The suppression of feeding activity may also have been due to less space in the body cavity for food (Hoar *et al.* 1983). However, as males do not bulge as much as females, the male's body cavity was likely able to provide more space for food than the female's

(Maklad *et al.* 2016). Male NWG grazed more actively than females during the breeding season. In naked goby (*Gobiosoma bosc),* males forage less intensively during the breeding season (D'Aguillo *et al.* 2014). Males of the species are in charge of egg guarding and territory defense, reducing their opportunity for foraging activity and lowering their feeding intensity. Differences in feeding intensity between sexes of a species, thus, may be the reproductive status (Rideout 1999) and the member's investment in parental care (D'Anguillo *et al.* 2012).

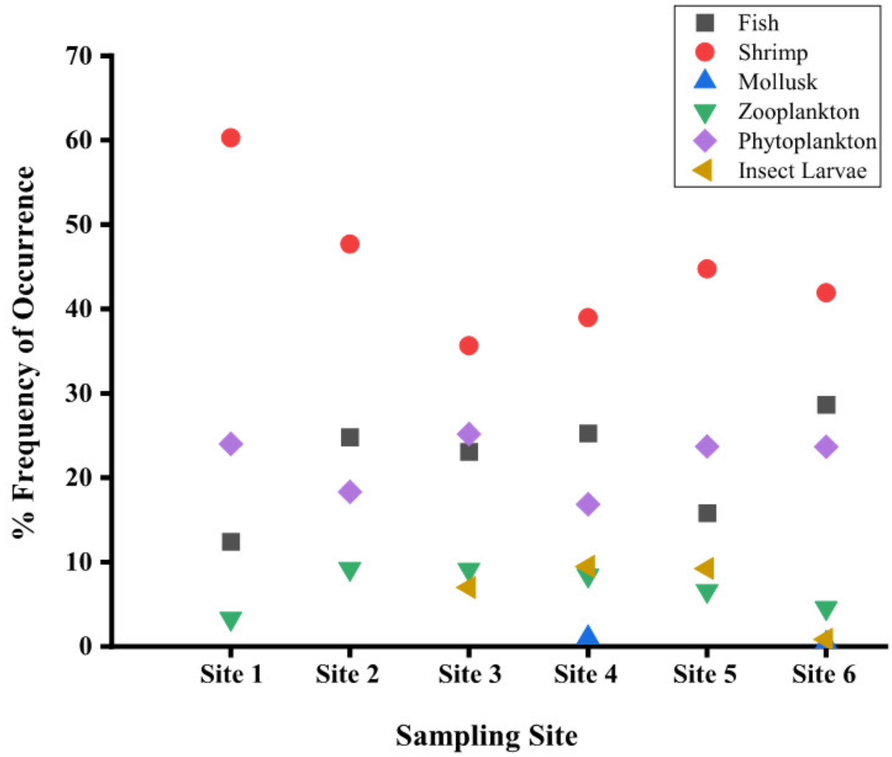

Figure 3 Frequency of Occurrence (%O) of food items consumed by *Glossogobius aureus* across the six sampling sites in Naujan Lake

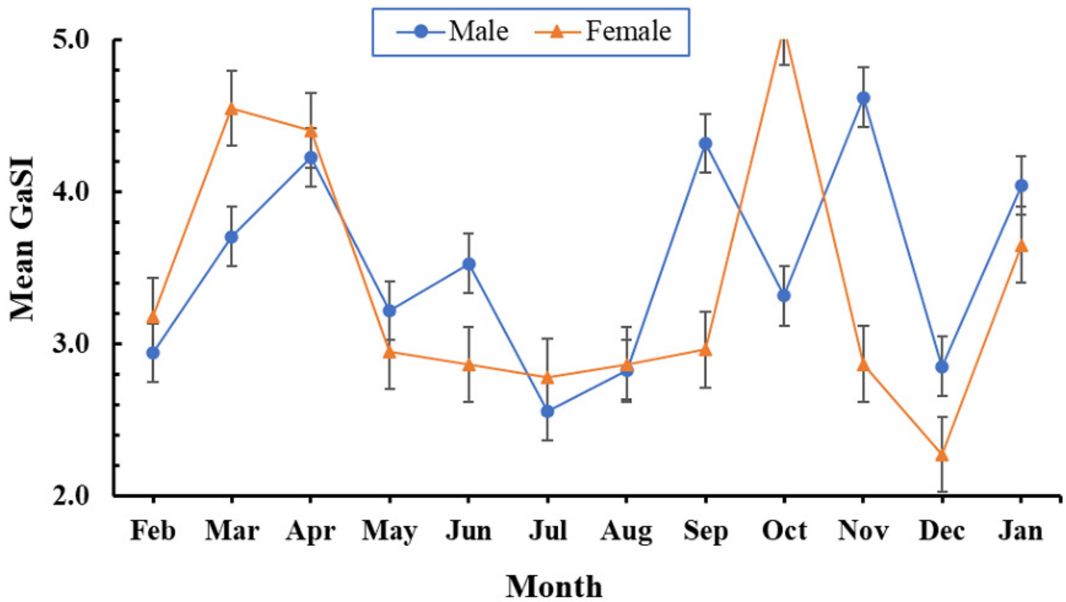

Figure 4 Gastrosomatic Index (GaSI) of male and female *Glossogobius aureus* from Naujan Lake

CONCLUSION

The gut content analysis revealed that Naujan White Goby (*Glossogobius aureus)* is a carnivorous fish, with shrimp and fish being the most important prey items in the diet. Due to its ability to utilize a variety of prey types, *G. aureus* is considered a generalist feeder, with occasional opportunistic feeding behavior on benthic organisms like insect larvae and plankton. The mean GaSI estimates showed that males and females had low feeding activity during peak spawning months of NWG in Naujan Lake.

This study provides baseline information for future fish nutrition research for NWG, which could optimize dietary strategies for the aquaculture production of this native species. Further research is needed to examine gut contents of other life stages, such as larvae and juveniles, to determine dietary ontogeny. The use of fatty acid analysis, molecular approaches, and isotope analysis may also be explored to have a deeper understanding of the trophic relationships and interactions within food webs, including the identification of dietary components. This study is the first to assess the food and feeding habits of *G. aureus* in Naujan Lake. The findings will contribute to a deeper understanding of the species' ecological role and provide a foundation for sustainable aquaculture and conservation initiatives.

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