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Article

Monitoring of Trophic State of Urban Lake Using Insect Biotic Index

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Abstract: The objective of the study is to reveal the seasonal variations and diversity of aquatic entomofauna of freshwater lake with relation to the trophic state. The study was conducted in two phases (before and after restoration) of lake to determine the diversity of aquatic insects during 2005-06 and 2016-17. The aquatic insect's diversity of lake during 2005-06 belonging to 6 orders vizHemiptera, Coleoptera, Diptera Ephemeroptera, Trichoptera and Odonata. Whereas in 2016-17, 7 orders were recorded in which order Plecoptera is observed. The percentage of aquatic fauna of lake was contributed by Diptera (30%), Coleoptera (26%), Hemiptera (19%), Odonata (13%), Trichoptera (9%) and Ephemeroptera (3%) in 2005-06, whereas after restoration of lake, the maximum insect population was contributed by Plecoptera (22%) followed by Ephemeroptera (21%) Coleoptera (20%), Hemiptera (13%), Diptera (11%), Trichoptera (9%) and Odonata (4%) respectively. The trophic state index values of reveals that the lake was under eutrophic condition and exhibited low diversity of entomofauna, while 2016-17 the insects diversity has been increased due to restoration of lake. The family biotic index values were recorded high during 2005-06 (7.32) and low values noticed during 2016-17 (2. 48).

Keywords: Lake Restoration, Aquatic entomofauna, family diversity index.

1. Introduction

Aquatic habitats are known to support an extraordinary array of species and our knowledge of the ecology of aquatic invertebrates has been reviewed and enhanced by recent syntheses [1,2]. Invertebrates play significant roles as nutrient recyclers, primary and secondary consumers, food for wildlife, and indicators of ecosystem function [3,4]. Biomonitoring is the use of biological variables to survey the environment [5] and aquatic insects are the most widely used organisms in freshwater biomonitoring of anthropogenic impact. Because of the high monetaryinvestment in freshwater management, decisions are often based on biomonitoring results, and a critical and comparative review of different approaches is required.An indicator may be used for biomonitoring at many levels of organization from organism's level to ecosystem level.

Insects are the dominant class among macro-invertebrates. The diversity of insects can only be described as amazing. Current estimates of known species of insects are well over 1 million, of which about 8,600 species of insects are associated with freshwater environments during some part of their lives [6]. Aquatic insects are playing a key role in the flow of organic resources and energy all the way through most of the aquatic food-webs [7]. Aquatic insects are sensitive indicators of environmental changes in streams because they express long-term changes in water and habitat quality rather than instantaneous conditions [8-10] and exhibit a great breadth of genetic diversity and species richness, maintenance of which is essential for the survival of any type of aquatic ecosystem [11]. As compared to the vertebrate fauna, the invertebrate species diversity in most parts of the world, particularly the tropical regions, is poorly described. The lack of information is caused by a various factors, such as the great diversity of invertebrates, their numerical abundance has contributed to their neglect, and in addition to this, their small size and difficult to identify. In spite of the scarcity of studies on the aquatic invertebrate fauna, many of the aquatic invertebrates are being lost as their habitat deteriorates some without ever been discovered and made known as species [12]. A considerable work on the aquatic macro-invertebrate has been done by several aquatic biologists [13-15]. Some of the studies have also been made in the different parts of the Indian subcontinent [16-20].

However, no effort has been made so far to study the insect fauna, particularly aquatic insects diversity in the north east Karnataka state, therefore, a maiden attempt has been made to explain aquatic entomofauna diversity with relation to trophic status of Sharanabasaveshwara Lake, Gulbarga District, Karnataka State, India.

2. Materials and Methods

Gulbarga township situated in the northern part of Karnataka state, which falls under Latitude 17° 19' 47.03"N and Longitude 76° 50' 3.46"E (Fig 1) and it is 454 m above MSL. Sharanabasaveshwara lake situated in the heart of the city having an area of 700 ha. This urban lake was fed with city drainage system and later it is restored (de-siltation) by State Government of Karnataka during 2005-2007.

Figure 1: Satellite map of Gulbarga city and showing Sharanabasaveshwara Lake.

Monthly samplings for analyzing the hydrological attributes and biotic components of macro-invertebrates were conducted for two annual cycles (October 2005 to September 2006 and October 2016 to September 2017. Physical parameters like, temperature and transparency were measured at the time of sampling and transparency as measured using Sechhi disk (SD). Other parameters such as total phosphorus (TP) and chlorophyll a (Chl a) concentrations were delivered immediately to the laboratory and determined according to standard methods [20] and trophic index [21]

Trophic State Index (TSI) calculation:

Calculating the TSI (Trophic State Index)

a. TSI (Trophic State Index) for Chlorophyll a (CA)

TSI = 9.81 In Chlorophyll a (μg/l-1) + 30.6

b. TSI (Trophic State Index) for Secchi Depth (SD)

TSI = 60-14.41 In Secchi Depth (meters)

c. TSI (Trophic State Index) for Total Phosphorous (TP)

TSI = 14.42 In Total Phosphorous (μg/l) + 4.15

In = Natural logarithm

Where TSI is Carlson Trophic State Index and In is natural logarithm.

Carlson's TSI = [TSI (TP) + TSI (CA) + TSI (SD)]/3

(TP and chl-a in micrograms per liter (ug/L) and SD transparency in meters).

Aquatic insects

Aquatic insects were sampled with a Surber sampler (0.5 mm mesh net) and by hand picking, detaching the stones and pebbles from an area of 1.0 m^2. Additional samples were obtained with a hand net (mesh size 1 mm) in a variety of microhabitats for qualitative purposes. Collected samples were examined under a dissection or stereo zoom microscope (10 X and above) and identified using standard taxonomic literature [22, 28]

Modified Family Biotic Index [29]

Tolerance values range from 0 to 10 for families and increase as water quality decreases. The index was developed by Hilsenhoff [30] to summarize the various tolerances of the benthic arthropod community with a single value. The Modified Family Biotic Index (FBI) was developed to detect organic pollution and is based on the original species-level index (BI) of Hilsenhoff. Tolerance values for each family were developed by weighting species according to their relative abundance in the State of Wisconsin.

The formula for calculating the Family Biotic Index is:

$$FBI = \sum \frac{x_i \ t_i}{n}$$

Where

x_i = number of individuals within a taxon

t_i = tolerance value of a taxon

n = total number of organisms in the sample (100)

3. **Results** and Discussion

Trophic State Index

Determining the trophic state in lakes is essential for the purpose of evaluating and managing the water quality. Generally, nutrients concentration (tota1 phosphorus; TP or total nitrogen; TN), chlorophyll a concentration and transparency have been provided as useful factors to decide the trophic level. A number of researchers have indicated the trophic state using above mentioned parameters [21,31]. The ranges in photosynthetic rate have been suggested for determining the trophic state [32] with photosynthetic carbon assimilation, which has been known as high values in the high nutrient conditions[33,34].

The obtained values of different variables are presented in Table 1 and the index value of each parameter is depicted in Table 2 respectively.

Table 1: Trophic State Index of Sharanabasaveshwara Lake.

Year / season	S.D	CHL	TP	TSI (SD)	TSI(CHL)	TSI (TP)	Average TSI
2005-06							
NEM	1.1	79.2	215	58	73	81	71
Summer	0.8	83.8	198	63	74	80	72
SWM	0.7	67.9	233	65	71	82	73
2016-17							
NEM	2.9	6.5	11	44	48	38	43
Summer	2.4	8.3	12	47	51	39	46
SWM	2.1	4.1	33	49	37	54	46

Table 2: CARLSON'S TROPHIC STATE INDEX (TSI)

TSI <30	Classic Oligotrophy; Clear water, oxygen through the year in the hypolimnion, salmonid fisheries in deep lakes.
TSI 30-40	Deeper lakes still exhibit classical oligotraphy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
TS 40-50	Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
TS 50-60	Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnion during the summer, macrophyte problems evident, warm-water fisheries only.
TSI 60-70	Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.
TSI 70-80	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

A range between 40-50 is usually associated with the mesotrophic (moderate productive); index values greater than 50 are associated with eutrophy (highly productive); values less than 40 are associated Oligotrohic status (low productive).

Based on the Trophic Status Index results, before restoration (2005-06) the Sharanabasaveshwara Lake shown TSI values between 70-80, whereas after restoration of the lake, TSI values varied between 40-50. Before restoration the water transparency (S.D) of Sharanabasaveshwara Lake was between 1.1 m (max) to 0.7 m (min), while after restoration (2016-17) the S.D was 2.9 m to 2.1m respectively. The high values of chlorophyll-a was recorded in summer and low values were noticed in southwest monsoon season in both the periods. The phosphorus content was high in northeast monsoon season and low amount was observed in summer. By the calculating the Trophic State Index of 2005-06, the Sharanabasaveshwara lake was attributed to eutrophic where water is less clear, algal bloom is high and light limited productivity and after restoration, the Trophic State Index values indicate Sharanabasaveshwara lake water was clear and productive. It supported for high diversity and density of biotic component of lake.

Aquatic insects

The aquatic insects population before restoration (2005-06) belonging to 6 orders vizHemiptera, Coleoptera, Diptera, Ephemeroptera, Tricoptera and Odonata. Whereas after the restoration (2016-17) the total 7 orders aquatic insects were recorded of which order Plecoptera is observed. The Biotic Index values and its seasonal variations are presented in Table 3, 4 and 5 respectively.

Aquatic insect biomonitoring has a long tradition that developed from a few initial approaches and expanded to a large number of different methods used in various countries or regions of the world. In addition, diversification of methods was related to (*a*) the type of information that different methods provide for various types of human disturbances;(*b*) variation of priorities among freshwater ecologists; (*c*) the spatial and temporal complexity of freshwater systems, which required the adaptation of existing methods to different areas; and (*d)* differences in the required precision for types of impact assessment. Finally, developments in aquatic insect biomonitoring were often fostered by new regulatory laws and mandates (e.g., Indian water act 1974, Environment Protection Act 1986 and U.S. Clean Water Act, the Canadian Protection Act, or the European Water Framework Directive).

The rationale to use aquatic insects, as indicators of pollution or self-purification potential was based on their capacity to reveal a source of pollution even if this source does not discharge pollutants, a feat impossible by chemical analysis alone [34]. Thus, aquatic invertebrates served as indicators of pollution for the management of lakes [27].

In present study, before restoration (2005-06) six families were identified and after restoration (2016-17) seven families were identified. Among the aquatic insects, order Diptera was dominant group in 2005-06, whereas after restoration Plecoptera, Hemiptera, Coleptera groups were dominate.

Table 3 : Family biotic index (FBI) for aquatic insects of Sharanabasaveshwara lake (2005-06)

Order	Family	Number of organisms	Tolerance value	Ct X Tolerence value
Hemiptera	Belostomatidae	89	10	890
	Corixidae	72	9	648
	Naucordiae	45	5	225
	Nepidae	32	8	256
	Vallidae	71	6	426
Coleoptera				
	Scirtidae	121	7	847
	Dryopidae	134	6	804
	Hydrophilidae	104	7	728
Diptera				
	Tipulidae	135	3	405
	Chironomidae	206	10	2060
	Culicidae	325	8	2600
Ephemeroptera				
	Neoephemeridae	16	6	96
	Siphlonuridae	14	7	98
Trichoptera				
	Hydroptilidae	42	8	336
	Leptoceridae	26	4	104
	Molannidae	21	6	126
Odonata				
	Aeshnidae	60	8	480
	Coenagrionidae	25	7	175
	Libellulidae	13	9	117
	Calopterygidae	17	4	68
Total		**1568**		**11489**

$$\text{Family Biotic Index} = \frac{\sum \text{Abundance} \times \text{Tolerance value}}{\text{Total abundance}} = \mathbf{7.32}$$

Table 4: Family biotic index (FBI) for aquatic insects of Sharanabasaveshwara lake (2016-17)

Order	Family	Number of organisms (A)	Tolerance Value (B)	(A X B)
Hemiptera	Belostomatidae	26	10	260
	Corixidae	18	9	162
	Gelastocoridae	43	2	86
	Gerridae	18	0	0
	Mesovellidae	26	0	0
	Naucoridae	37	5	185
	Nepidae	10	8	80
	Vallidae	30	6	180
Coleoptera	Psephenidae	38	0	0
	Elmidae	54	0	0
	Noteridae	29	0	
	Curculionidae	42	1	42
Diptera	Tipulidae	22	3	66
	Culicidae	41	8	328
Ephemeroptera	Heptageniidae	40	2	80
	Baetidae	25	4	100
	Leptophlebiidae	49	2	98
	Neoephemeridae	16	6	96
	Ephemeridae	4	2	8
	Siphlonuridae	14	7	98
Plecoptera	Pteronarcyidae	42	0	0
	Nemouridae	22	2	2
	Leuctridae	31	0	1
	Chloroperlidae	26	0	0
	Perlidae	18	1	18
	Perlodidae	7	2	14
	Capniidae	1	3	3
Trichoptera	Hydroptilidae	18	8	144
	Leptoceridae	10	4	40
	Glassosomatidea	35	0	0
	lepidostomatidae	29	0	0

Odonata	Aeshnidae	8	8	64
	Coenagrionidae	12	7	84
	Libellulidae	7	9	63
	Calopterygidae	9	4	36
	Corduliidae	46	0	0
	Gomphidae	36	0	0
TOTAL		**939**		**2338**

$$\text{Family Biotic Index} = \frac{\sum \text{Abundance} \times \text{Tolerance value}}{\text{Total abundance}} = \mathbf{2.48}$$

Table 5: Seasonal variations in aquatic insect population of Sharanabasaveshwara lake

	Before restoration (2005-06)			**After restoration(2016-17)**		
	NEM	**SUMMER**	**SWM**	**NEM**	**SUMMER**	**SWM**
Hemiptera	148	72	89	32	106	105
Coleoptera	124	156	79	83	54	25
Diptera	216	334	116	12	35	16
Ephemeroptera	09	15	6	68	28	52
Plecoptera	00	00	00	33	83	24
Trichoptera	51	19	43	30	52	16
Odonata	13	60	42	36	55	28

The Biotic Index (BI) values (Table 3 and 4) of before restoration (7.2) clearly explain, that the lake was eutrophication state and eutrophication of lake does not support to the high diversity, dominated by pollution tolerated species. After restoration Biotic Index values of lake was 2.7, indicate the lake is oligotrophic condition, which supports to the high diversity and provide the good environment for many species. [21]

Hemiptera

In thepresented study, before restoration (2005-06) the group was represented by 5 families VizBelostomatidae, Corixidae, Naucoridae, Nepidae, Vallidae, whereas after restoration (2016-17) the group was represented by 8 families viz., Belostomatidae, Corixidae, Gelastocoridae, Gerridae, Mesovellidae, Naucoridae, Nepidae, Vallidae. After the restoration the composition of Hemiptera group increased by 3 families, which have low tolerant values (Table 3 and 4). Present findings clearly explain eutrophication state of aquatic ecosystem support to the low diversity and dominated by few genera.

The maximum Hemipterans was observed during northeast monsoon season and summer seasons, while low values recorded in southwest monsoon season of both the years. Dissolved oxygen and temperature play key role in Hemiptera growth and reproduction [35]. Present study results are agreeable with earlier reports.

Statistically the Hemiptera group showed a significant correlation with Ammonical Nitrogen ($P < 0.01$), Phosphorus (<0.01), Coleoptera ($P<0.05$), Diptera ($P<0.01$) respectively.

Coleoptera

Coleoptera group respresented by 3 families during 2005-06 (before restoration), Viz., represented by Scirtidae, Dryopidae, Hydrophilidae. After restoration (2016-17) the group was represented by 4 families Viz., Psephenidae, Elmidae, Noteridae, Curculionidae.

Before restoration the Coleoptera families have high tolerance values and these families were completely disappeared in 2016-17 (after restoration), whereas after restoration the Coleoptera group have low tolerance values. Psephenidae, Elmidae, Noteridae, Curculionidae have tolerance values is 0.

In the present study the maximum Coleoptera population was occurred in during northeast monsoon season, and summer season. While low density was noticed in southwest monsoon season. The present finding, though very confined, correlates with the previous studies [36,37]

The increased temperature accelerate the emergence of aquatic insects [38]. Macrophytic vegetation also plays a major role in their emergence. Before restoration the lake was covered by vegetation, which provides a microhabitat for all Coleopterans. themacrophytic abundance is major factor in the occurrence of Coleoptera species and vegetation coverage most be of decisive importance with respect to the number of aquatic insects and these insects were present in high number even on decomposed litter. In the present study the Coleopteran group was more in their number during 2005-06 compare d to after restoration. This may be due to low amount of decomposed matter in lake. After the restoration the lake was in oligotrophic state and less amount of nutrients which intern effect the aquatic vegetation.

In the present study the Coleoptera group showed a significant positive correlation with phosphate ($p<0.05$) Hemiptera ($P<0.05$) and Odonata ($P<0.01$) respectively.

Diptera

The Diptera, or true flies, are represented by forms which may be found in all types of stream habitats from the cleanest situation to the most polluted water. Because aquatic Diptera are to be found in many different ecological niches in both clean and polluted water and many species are highly selective in their choice of habitat, they constitute one of the most important groups of indicator organisms.

In the present study, the Diptera group before restoration represented by 3 familesViz, Tipulidae, Chironomidae, Culicidae, whereas after the restoration the Tipulidae family was completely disappeared from lake. During 2005-06 (before restoration) the Diptera contributed 30% of the total insects, while during 2016-17 (after restoration) the group contributed 11% of the total insect population.

Among the aquatic insects the Diptera group was more abundant in polluted water. They live under certain conditions, such as at low dissolved oxygen and Chironomidae family used as pollution indicator [13]

The maximum abundance of Diptera group was recorded during northeast monsoon and summer season of 2005-06 (before restoration). The high temperature is more important factor for these species. This due to their capability to adjust with low level of dissolved oxygen. While the availability and amount of food and oxygen were the most important factors determining the distribution of the majority of species of Diptera in all aquatic ecosystems [19]. After the restoration the Diptera population was completely reduced. This may be due to less availability of food, low amount of decomposed matter [6, 38,39].

In the present investigation, statistically the Diptera group showed a significant positive correlation to phosphorus ($P<0.05$), temperature ($P<0.01$), Hemiptera (P0.05) respectively.

Ephemeroptera

Ephemeroptera constitute on integral part of aquatic environment in their larval as well nymphal stages. These nymphs are immense utility as bioindicators of pollution besides their use as fish food. May flies larvae are one of the most important groups of insects that spend the major part of their lives as nymphs in the water. The absence or presence of a particular species in a body of water can often yield, much information about the quality and environmental characteristics of water.

During the study period the Ephemeroptera group was represented by 2 families Viz., Neoephemeridae, Siphlonuridae (before restoration), whereas after restoration the group was represented by 6 families. The diversity index values were very high after the restoration of lake, compare to values of diversity index of before restoration period (Table 3). the high density of Ephemeroptera during 2016-17, indicted that pollution free ecosystem, while low abundance during 2005-06 (before restoration) indicate that, the eutrophication status and changes in chemical environment leads to the decrease in density and diversity of Ephemeroptera. The high diversity values for Ephemeroptera in oligotrophic water bodies during northeast monsoon, summer seasons and the low abundance in south west monsoon season may be due to turbidity of lake [19].

In the present study, the Ephemeroptera group showed a correlation with Chloride ($P < 0.05$), Total Hardness ($P < 0.05$), Turbidity ($P < 0.01$) respectively.

Plecoptera

Thegroup Plecoptera group restricted to only clean water due to high sensitivity to pollution. In the present study, before restoration the Plecoptera group was completely absent.

After the restoration (2016-17) the Plecoptera group was represented by 7 families Viz., Pteronarcyidae, Nemouridae, Leuctridae, Chloroperlidae, Perlidae, Perlodidae, Capniidae**.** The Trichoptera population was high in summer season, while low density was observed in southwest monsoon season (27 individuals/quadrate). The absence of this group during 2005-06 (before restoration) stated that high degree of sensitivity to pollution.

Every species is restricted in its distribution to a certain temperature range may be influence on Plecoptera community [41,42]. In the present study the influence of temperature on abundance of Plecoptera was noticed and the maximum density was observed in summer season than other seasons. in the oligotrophic lakes are dominated by less pollution tolerant species with high degree of diversity compare to the polluted or eutrophicated lakes[43]. In the present study Plecoptera group results are correlate with earlier reports.

In the present investigation, this group statistically correlated with Nitrate ($P < 0.01$) temperature ($P < 0.05$), primary productivity ($P < 0.01$) respectively.

Trichoptera

Trichoptera is the largest group of insect in which every member is truly aquatic. Trichoptera are close relatives of butterflies and moths and like Lepidoptera, they have the ability to spin silk. This adaptation is largely responsible for the success of this group. Trichoptera are important in aquatic ecosystems because they process organic material and are an important food sources for fish.

In the present study the Trichoptera group represented by 3 families during 2005-06 (before restoration), 4 families during 2016-17 (after restoration).

Trichoptera community has dominated group in lake and reservoirs, which are minor component of the aquatic fauna, they served as link food chain. Trichoptera group occurred in all type of habitats this group has capacity to adopt in any environment like eutrophicated lakes to oligotrophic condition [17]. During the 2005-06 the group was represented by Hydroptilidae, Leptoceridae, Molannidae, whereas after restoration (2016-17) the group was represented by Hydroptilidae, LeptoceridaeGlossosomatidae, Lepidostomatidae. This group contributed with 9% to the total population of insects. Among the families of this group Glossosomatidae and Lepidostomatidae have 0 tolerant values, where as high pollution tolerant values exhibited by Hydrophilidae (8), Leptoceridae (4) and Molannidae (6).

The Tricoptera group dominated in winter and summer seasons. In the present study the maximum abundance of Trichoptera group was observed northeast monsoon season, while low population was recorded in southwest monsoon season [36, 44].

Statistically the Trichoptera group showed a significant positive correlation with Ammonical Nitrogen ($P < 0.01$), Phosphorus ($P < 0.05$), Temperature ($P < 0.05$), Diptera ($P < 0.05$) Coleoptera ($P < 0.01$) respectively.

Odonata

The Odonatagroup includes dragonflies (Anisoptera) and damselflies (Zygoptera) . In the adult Anisoptera the hind wing are slightly larger and both pairs of wings are held in horizontal position. In Zygoptera imagoes both the wings are equal in size but are folded backwards on the abdomen or kept in vertical position. These graceful insects are commonly found darting and dancing actively on surface of lakes, reservoir and ponds soon after rainy season.

The order Odonata represented by 4 families in 2005-06 (before restoration) viz., Aeshnidae, Coenagrionidae, Libellulidae, Calopterygidae, where as 6 families were identified during 2016-17 (after restoration) viz., Aeshnidae, Coenagrionidae, Libellulidae, Calopterygidae, Corduliidae,Gomphidae.

During study period the Odonata contributed 4% in 2005-06 (before restoration), 13% in 2016-17 (after restoration) to total insect population. Among the Odonata group Aeshnidae was the dominant group in 2005-06, where asCorduliidae,Gomphidae dominant families after restoration. Before restoration the population of Odonata population was reduced due to heavy organic pollution, while after the restoration the lake has no organic pollution, which helps in increase the population of Odonata group and oligotrophic lakes support the good environment of aquatic insects specially Odonata group [45]

In the present investigation, this group statistically correlated with Nitrate (P < 0.01) temperature (P < 0.01), primary productivity (P < 0.05) respectively

Conclusion

The present study results reveals that, the Sharanabasaveshwara Lake was in eutrophic condition during the 2005-06 and supported less aquatic insect diversity and after restoration (2016-17) results indicate that the aquatic entomofauna diversity has been increased and the family biotic index is the best tool for testing trophic state of lake ecosystem. Keeping in view the simple trophic structure of lake and management is essential for its proper eco-functioning and sustainability. Anthropogenic activities should be regulated in lake with awareness progrommes with the active public participation. Freshwater must be recognized as the blood of society [37], despite the extensive discussion and evolution of human needs for water of reasonable quality, it is essential to know how aquatic ecosystems function to manage them successfully. Management of stream must be determined in consideration of its significance for conservation on the basis of which management priorities and objectives need to be clearly defined.

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