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Impact of Livestock Grazing Pressure and Above-Ground Vegetational Changes on Yield of Caterpillar Mushroom (*Ophiocordyceps sinensis*)

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Abstract: The perceptible decline in the yield of caterpillar mushroom or Yartsa Gunbu [*Ophiocordyceps sinensis* (Berk.) Sung, Sung, Hywel-Jones & Spatafora], has taken place, primarily because of over-exploitation, and resultant habitat degradation. Does livestock grazing worsen the problem? This aspect vis-a-vis salient changes in the above-ground vegetation profile with increasing magnitude of grazing pressure remains the prime objective of the present study. Three sites- Janthri, Balmiya top, and Rukhiyan, were selected based on increasing order of magnitude of livestock grazing pressure, with the site- Janthri being treated as 'Control site', since it exhibited no grazing pressure. Care was taken, that all other parameters- slope aspects, altitudinal range, anthropogenic pressure, duration of grazing, etc, were relatively similar across the selected sites, with the only variable being the livestock grazing pressure. With 13 out of 21 palatable species and 3 out of 15 unpalatable species recorded as host plant species of the obligate host of Yartsa Gunbu, i.e., *Thitarodes balmiya* The perceptible changes in palatable plant species being replaced by non-palatable species with grazing intensity, is a cause of concern for the future viability of the host *Thitarodes balmiya*larva; as is so succinctly observed by the declining number of *Thitarodes* larval population size with grazing intensity, in the present study.

***Keywords*:** Livestock grazing pressure, Non-palatable, Palatable species, *Thitarodes balmiya,* Yartsa Gunbu

Ophiocordyceps sinensis (Berk.) is known to infect around 60 species of lepidopteran larva, distributed across the Himalaya, and the adjoining Tibet Autonomous Region (Sung et al 2007, Wang and Yao 2011), primarily *Thitarodes* (order Lepidoptera, family Hepialidae). Yartsa Gunbu represents a mummified larva, filled and coated with mycelia of *Ophiocordyceps sinensis*, with slender, brown, club-shaped stroma, usually emerging out just above the eyes of the larva (Plate 1), and reaching a length of 8-15 cm (Negi et al 2015). *O.ps sinensis* contains a broad range of bioactive compounds, considered both nutritional as well as with proven pharmacological benefits (Holliday et al 2004). The exorbitant increase in the international price between US$ 13,000 and US$ 20,000 per kilogram depending upon the quality of the harvested lot of Yartsa Gunbu has resulted in its over-exploitation, and the resultant falling yield. Among the principal causal factors- over-exploitation (Negi et al 2016), habitat degradation (Cannon et al 2009, Negi et al 2016) and climate change (Yan et al 2017, Hopping et al 2018) are highlighted for this decline in yield. The livestock grazing pressure result in changes in the above-ground plant community characteristics or diversity (Tarhouni et al 2015, Álvarez-Martínez et al 2016). The impact of grazing pressure on vegetation phenology is defined by herbivore density (Austrheim et al 2008), productivity of the grassland (Eskelinen et al 2012) evolutionary history of grazing phenomenon (Milchunas et al 1988) and the time aspect (Olofsson 2006, Maurset 2015). The present is being carried out in *in situ* conditions, with each of the three study sites known for exploitation of Yartsa Gunbu differing in the magnitude of grazing pressure.

MATERIAL AND METHODS

Study area and grazing pressure: The present study was undertaken in three alpine meadow sites situated in the Munsiari Tehsil, District Pithoragarh, Uttarakhand, Western Himalaya, and are known habitat sites of Yartsa Gunbu or caterpillar mushroom. The altitudinal range, on average, of the three selected sites, lies approximately between 3800 and 3900m amsl, and are situated between N=30°088′46″ and E= 80°17.935′ (Fig. 1). All three sites differ in the magnitude of grazing pressure, with Janthri, experiencing no grazing pressure (on account of the presence of the poisonous species of *Aconitum lethale*) and thus were treated as the 'control site'. Balmiya top, experiencing relatively lesser grazing pressure than the Rukhiyan study site, principally on account of the relative area- larger than that of the latter (Table 1). All the study sites are separated apart, on an average of 2.5 km. The study was carried out from June till August end. The ambient temperature recorded was between 7-8°C, while the average humidity was around 50 percent that varied between a minimum of 26 percent increasing to 83 percent.

A preliminary survey of the three sites reflected a similar vegetation profile, with the average height of each site, not varying much- Balmiya Top (3822m), Rukhiyan (3792m), and Janthri (3899m), and similar slope aspect, with minor variation in Janthri. Due care was taken that the study within each broad study site is confined to sites with similar slope aspects. The livestock population size, their duration of stay, was procured from the local shepherds, frequenting the two sites- Balmiya top and Rukhiyan, over the last 10 years. Since the same number of livestock move from one site to the other, the grazing intensity could be calculated based on the duration of stay of the livestock population in each site, and the relative size of the alpine meadows. Lastly, the anthropogenic pressure, i.e., the number of harvesters, too was ascertained, which in all three sites, were more or less the same. Thus, **g**razing pressure was calculated as the number of livestock (AU- animal unit) divided by the area of the study site (Sharma et al 2021). The animal unit (AU) equivalent was calculated disjointedly for the sheep/goat (predominantly) and horse and then multiplied by their numbers (Table 1).

Phytosociology-palatable versus non-palatable species: Within each sub-quadrate (1m x 1m), phytosociology was carried out as per Misra (1968). Growth forms of plant species were studied as per Raunkiaer (1934). Palatability and non-palatability of the plant species were ascertained, through close observation (presence of the bite marks of the livestock), and through information gathered from the *Anwals* (local shepherds). All plant species were photographed and cross-referenced with the standard texts for identification (Polunin and Stainton 1984, Stainton 1988). The nomenclature of Uniyal et al (2007) was followed, which again was cross-checked with www.plantlist.org for accepted nomenclature and author citation.

Host insect-*Thitarodes balmiya* larval population size: Within each sub-quadrate measuring 1m x 1m, 3 pits measuring 1 x 1 x 1 foot (0.028 m^3) were dug and the larvae were hand sorted, across each soil profile- 0-10, 10-20, and

Plate 1. Yartsa Gunbu (caterpillar mushroom)

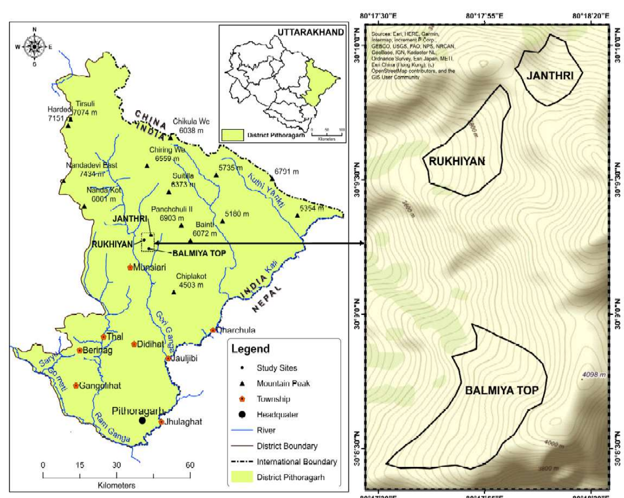

Fig. 1. Study sites- Janthri, designated as control site with no grazing pressure; Balmiya and Rukhiyan, both experiencing grazing pressure, with relatively more in case of Rukhiyan, primarily on account of the relatively smaller area than in case of Balmiya top

Table 1. Grazing pressure in the two study sites

Study site	Class of animal	Number (A)	AUE* value (B)	Total AU (A x B)	Grazing pressure (AU/Area)
Balmiya top	Sheep	2010	0.3	603	12.53
	Horse	20	1.25	25	0.52
Total					13.05
Rukhiyan	Sheep	1680	0.3	504	26.52

* AUE- Animal Unit Equivalent. The site Janthri experiencing no grazing pressure, hence not included in the table

20-30 cm depth. *T. balmiya* larva were selectively collected based on the diagnostic features, principally, the subdorsal SD1 and SD2 setae possessing a mat of microtrichia around the base of the setae (Grehan and Gargiulo 2021).

Statistical analysis: All data are represented as an average value, with statistical analyses being carried out using IBM SPSS software (version 23).

RESULTS AND DISCUSSION

Grazing pressure: The Rukhiyan study site exhibits a relatively higher grazing pressure than the adjoining Balmiya top, simply on account of its relatively lesser area, even when the livestock population size in Balmiya top exceeds that of Rukhiyan (Table 1).

Phytosociology-palatable versus non-palatable species: Altogether 36 species (33 genera, 19 families) were encountered during the study (Table 2). This number is significantly more than Devkota (2009) and Sigdel et al (2017), reporting 15 species and 10 families, and 33 species and 16 families, respectively, being associated with the caterpillar fungus. Apart from Hypericaceae, Balsaminaceae, Boraginaceae, and Liliaceae, the rest of the associated families encountered in the present study relates to those reported by several authors (Wu 1997, Zang and Kinjo 1998, Chen et al 2000, Devkota 2009, Lei et al 2011, He et al 2017, Sigdel et al 2017, Zhong et al 2014, Wang et al 2020) (Table 2). The families- Balsaminaceae and Boraginaceae, are represented by non-palatable species. Out of the 36 species, 21 species were recorded as palatable and 15 as unpalatable (Figure 2, Table 2). The number of unpalatable species shows an increase with the increase in grazing pressure (Table 2).

The dominance (calculated in terms of the abundance, density, and frequency) of the palatable species decreases with grazing pressure. In Janthri, the first 9 species in terms of relative IVI (sum of relative frequency, relative density, and relative basal cover), are all palatable. This number, declines to 8 in Balmiya site, while Rukhiyan site, the most intensely grazed site is marked out by *Megacarpaea polyandra* Benth, a non-palatable species, occupying the top second spot in IVI (Table 2). Change in vegetation profile with increase in grazing pressure becomes more conspicuous when one compares the cumulative IVI of the palatable species versus unpalatable species in each of the study sites. The cumulative IVI of palatable species exhibit a decline with an increase in grazing pressure, being 2.459, 2.311, and 2.108 for Janthri, Balmiya top, and Rukhiyan, respectively. The values for the non-palatable species exhibit an increase, to 0.488, 0.681, and 0.878 across the gradient of increased grazing pressure (Fig. 3, Table 2). Further, when one compares the two sites experiencing the grazing pressure, the average figure for abundance for all the palatable species combined, exhibit a perceptible decline- Balmiya top (22.84 m^2) and Rukhiyan (16.14 m^2), while non-palatable species exhibit a marked increase in abundance with increased grazing pressure, with values 5.5, 5.92, and 8.26 m^2 for Janthri, Balmiya Top, and Rukhiyan, respectively (Table 2).

The overall number of palatable species remains more or less constant throughout the three sites- 19-21 in Janthri, Balmiya top, and Rukhiyan, respectively, while the number of unpalatable species shows a marked increase with the increasing grazing pressure (Table 2). The increase in species richness 29, 33, and 36 in Janthri, Balmiya Top, and Rukhiyan, respectively, is primarily due to the increase in the number of non-palatable species, i.e., *Aquilegia pubiflora* Wallich ex Royle, *Megacarpaea polyandra* Benth., *Rumex nepalensis* Spreng., *Impatiens glandulifera* Royle, and *Hackelia uncinata* (Royle ex Benth.) Fisch., all non-palatable species (Table 2). In contrast to palatable species, the non-palatable species are predominated by short or tall forbs (93 percent, Fig. 4, Table 2).

Host insect-*Thitarodes balmiya* larval population size: A greater number of larvae were collected in the upper two soil profiles (0-10 and 10-20 cms). Larva population size exhibits

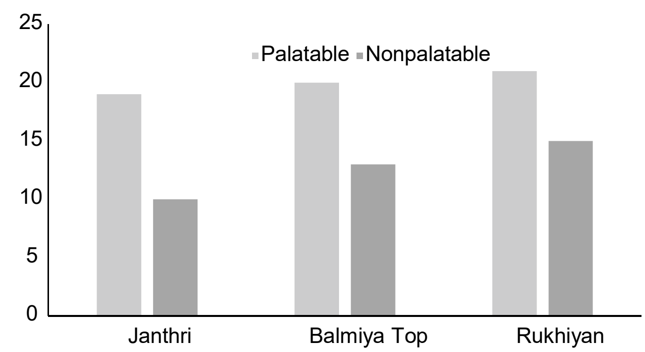

Fig. 2. Extent of the palatable versus non-palatable

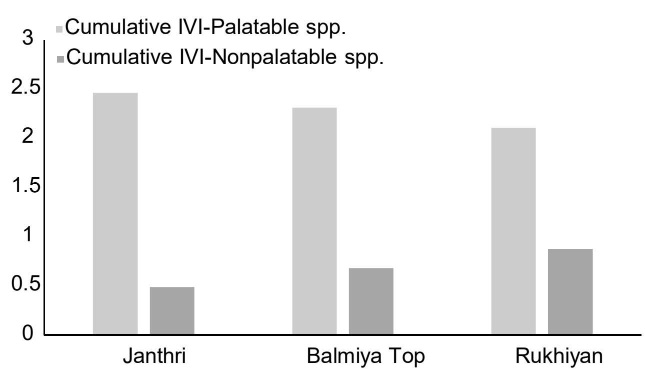

Fig. 3. Cumulative IVI of palatable species versus non-palatable species

Table 2. Comparative statement of the diversity, palatability, life and growth forms, abundance, and IVI of the species encountered in the study sites differing in the magnitude of grazing pressure

Name of species	Family	Palatability	Study sites			Life form	Growth form	Abundance (m^{2-})			IVI		
			1	2	3			1	2	3	1	2	3
Cortia depressa (D. Don) C. Norman	Apiaceae	PA	+	+	+	Th	SF	48.11	42.03	31.87	0.321	0.193	0.145
Selinum candollei Edgew.	Apiaceae	PA	+	+	+	Th	TF	2.9	2.83	2.41	0.066	0.040	0.048
Carex setosa Boott	Cyperaceae	PA	+	+	+	He	Gr	18.73	9.65	13.19	0.075	0.070	0.061
Polystichum stimulans (Kunze ex Mett.) Bedds	Dryopteridaceae	PA	+	+	+	Ge	TF	4.28	3.22	3.14	0.366	0.286	0.142
Euphorbia stracheyi Boiss.	Euphorbiaceae	PA	+	+	+	He	CF	5.8	17.5	2.8	0.020	0.057	0.020
Hypericum monanthemum Hook.f. & Thomson ex Dyer	Hypericaceae	PA	+	+	+	Ch	SF	7.02	6.0	14.27	0.078	0.043	0.054
Lloydia longiscapa Hook.	Liliaceae	PA	+	+	+	Th	G	9.69	10.75	9.58	0.038	0.027	0.048
Corydalis cashmeriana Royle	Papaveraceae	PA	+	+	+	He	SF	1.9	3.27	3.52	0.015	0.033	0.037
Poa annua L.	Poaceae	PA	+	+	+	He	G	14.96	192.75	15.39	0.173	0.176	0.154
Polygala sp.	Polygalaceae	PA	-	-	+	He	SF	-	-	52.16	-	-	0.038
Persicaria wallichii Greuter and Burdet.	Polygonaceae	PA	+	+	+	Th	TF	3.51	3.77	6.72	0.063	0.059	0.177
Primula denticulata Sm.	Primulaceae	PA	+	+	+	Th	SF	3.0	2.5	1.66	0.179	0.141	0.088
Anemone obtusiloba D. Don	Ranunculaceae	PA	+	+	+	Th	SF	5.02	7.7	5.43	0.136	0.132	0.082
Anemone tetrasepala Royle	Ranunculaceae	PA	+	+	+	Th	SF	3.43	3.56	3.94	0.106	0.094	0.093
Caltha palustris L.	Ranunculaceae	PA	+	+	+	Ge	TF	7.05	4.64	9.05	0.158	0.156	0.126
Oxygraphis polypetala (Raf.) Hook.f. & Thomson	Ranunculaceae	PA	+	+	+	He	SF	57.07	97.52	102.42	0.367	0.441	0.496
Ranunculus hirtellus Royle	Ranunculaceae	PA	-	+	+	Ch	SF	-	5.76	13.4	-	0.044	0.067
Aruncus diocus (Walter) Fernald	Rosaceae	PA	+	+	+	Ch	SF	3.7	4.9	3.66	0.024	0.029	0.011
Geum elatum Wallich ex Hook.f	Rosaceae	PA	+	+	+	Ge	SF	7.63	7.93	9.13	0.152	0.147	0.106
Potentilla atrosanguinea G. Lodd. ex D. Don	Rosaceae	PA	+	+	+	He	SF	11.7	14.88	3.37	0.073	0.059	0.020
Potentilla lineata Trevir	Rosaceae	PA	+	+	+	Ge	CF	28.16	15.72	31.76	0.049	0.084	0.095
Average value of all palatable combined								12.82	22.84	16.14	0.13	0.11	0.10
Seseli roylei (Lindl.) Pimenov & Kljuykov	Apiaceae	NP	+	+	+	Th	SF	1.94	2.16	4.31	0.079	0.091	0.072
Anaphalis triplinervis (Sims) Sims ex C.B. Clarke	Asteraceae	NP	+	+	+	He	SF	6.2	4.37	3.12	0.010	0.022	0.015
Ligularia amplexicaulis DC.	Asteraceae	NP	+	+	+	He	CF	5.16	3.94	4.94	0.077	0.106	0.051
Impatiens glandulifera Royle	Balsaminaceae	NP	-	+	+	Th	TF	-	6.0	19.11	-	0.069	0.119
Hackelia uncinata (Benth.) C.E.C. Fisch.	Boraginaceae	NP	-	+	+	He	SF	-	7.4	6.66	-	0.028	0.036

Cont...

Table 2. Comparative statement of the diversity, palatability, life and growth forms, abundance, and IVI of the species encountered in the study sites differing in the magnitude of grazing pressure

Name of species	Family	Palatability	Study sites			Life form	Growth form	Abundance (m^{2-})			IVI		
			1	2	3			1	2	3	1	2	3
Megacarpaea polyandra Benth. ex Madden	Brassicaceae	NP	-	-	+	Ge	TF	-	-	6.55	-	-	0.345
Nardostachys grandiflora DC.	Caprifoliaceae	NP	+	+	+	Ge	SF	16.94	2.16	9.42	0.062	0.013	0.023
Clintonia udensis Trautv. & C.A. Mey	Liliaceae	NP	+	+	+	He	SF	3.04	4.18	5.83	0.047	0.068	0.020
Nomocharis sp.	Liliaceae	NP	+	+	+	Ge	SF	10.6	24.4	17.6	0.041	0.066	0.019
Epilobium sp.	Onagraceae	NP	+	+	+	He	SF	2.16	4.54	7.13	0.009	0.024	0.051
Bistorta affinis (D. Don) Greene	Polygonaceae	NP	+	+	+	He	SF	3.73	7.48	9.83	0.028	0.075	0.016
Rumex nepalensis Spreng.	Polygonaceae	NP	-	+	+	He	TF	-	6.1	21.88	-	0.044	0.044
Aconitum balfourii Stapf	Ranunculaceae	NP	+	+	+	Ge	TF	2.96	2.2	3.0	0.083	0.026	0.016
Aquilegia nivalis (Baker) Falc. ex B.D. Jacks	Ranunculaceae	NP	-	-	+	Ch	SF	-	-	1.83	-	-	0.014
Aquilegia pubiflora Wall. ex Royle	Ranunculaceae	NP	+	+	+	Ge	SF	2.57	2.0	2.75	0.052	0.049	0.037
Average value of all non-palatable combined								5.5	5.92	8.26	0.048	0.052	0.058

Study sites: 1- Janthri, 2-Balmiya Top, 3- Rukhiyan
*NP- Nonpalatable, PA- palatable (the palatable and nonpalatable species were differentiated based on personal observations (e.g., signs of herbivory- bite marks, as well as physical observation) and ascertaining the observed facts with the local shepherds, the *anwals,* and the harvesters). Those species, e.g., *Rumex nepalensis* Spreng., which is grazed upon by the livestock, when all other palatable species are unavailable, has been categorized as unpalatable.
Plant species were separated into different life forms following Raunkiaer (1934) classification. Ph =Phanerophytes; Ch = Chamaephytes; He = Hemicryptophytes; Ge = Geophytes, Th = Therophytes; G= grass; CF= Cushion forb; SF= short forb; TF= tall forb; Gr= graminoid. + =present; - = absent

a marked decline when both Balmiya Top and Rukhiyan sites (experiencing grazing pressure) are compared with Janthri (experiencing no grazing pressure) (Fig. 5). Also, the data shows significant differences in all sites and across the soil depth except in between Balmiya Top and Rukhiyan.

Future viability of Yartsa Gunbu: The dominance of shrubs with poor forage quality, in general, is considered indicative of the degraded pasture (Roques et al 2001), as is also depicted in the present study, where the number of the forbs- both short and tall forbs, greatly outnumber the number of the graminoids as also their relative dominance being

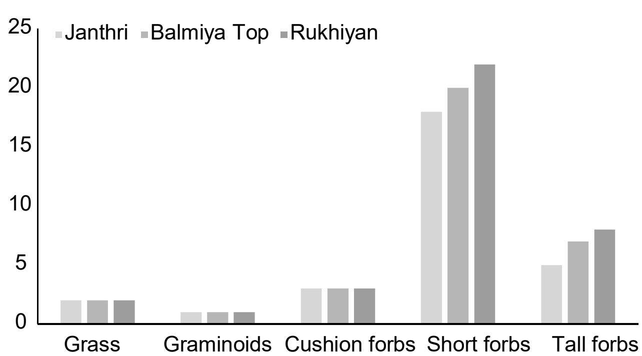

Fig. 4. Growth form types encountered in the three study sites (differing in grazing pressure), represented mostly by forbs- short forbs (< 30 cm) and tall forbs (> 30 cm)

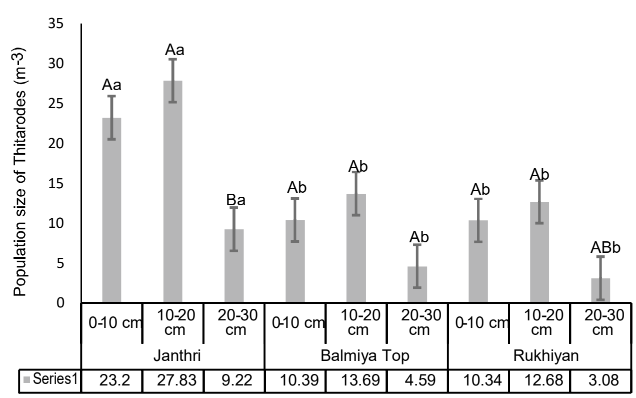

Fig. 5. Comparison of *Thitarodes balmiya* larva population size with standard deviation in three study sites across the soil depth- 0-10, 10-20, and 20-30 cm. The Upper-case letters indicate significant differences in *T. balmiya* larval population among three different soil layers within the same study site; whereas lower case letters indicate significant differences in soil layers across the three different study sites, differing in the order of increasing grazing pressure

proportional to the increasing grazing pressure (Fig. 4). It's obvious that the change in the vegetation characteristic- tall or even short forbs replacing the graminoids or grasses, will impinge upon the spore dispersal and thus the infective pathway, and thus the abundance of Yartsa Gunbu. This fact has been aptly emphasized by Cannon et al (2009). The host insect (*T. balmiya*) in turn depends on the host plant species, upon whose roots it feeds upon during its larval stages, any increase in the abundance of the non-host plant species vis-à-vis increase in richness of non-palatable species, majority of which are non-host species, will effectually result in a decline in the population size of the obligate host-*T. balmiya*. The perceptible decline in the population size of the host *T. balmiya* larva was, with the increase in grazing pressure (Fig. 5).

CONCLUSIONS

The grazing pressure impinges upon the habitat ecology, principally in terms of the resultant changes in the above-ground vegetation profile vis-à-vis palatable species being replaced by non-palatable. Since most of the palatable species are also the hosts of *T. balmiya* larva (13 spp. as against just 3 non-palatable species), it would not be impertinent to predict that the yield of Yartsa Gunbu is only going to decline further. However, studies of similar nature need to be undertaken in multiple different sites experiencing the different intensity of grazing pressure, to derive conclusively the impact of livestock grazing upon the yield of Yartsa Gunbu. There is a need to not just monitor the anthropogenic pressure, but also the livestock population size, and their duration of stay in one habitat site. This does not imply that the meadows or the habitat sites be altogether excluded from grazing, since grazing exclusion will impinge upon the very livelihood of local practitioners, but may result in an irreversible change in vegetation profile. Monitoring of livestock primarily means restricting the duration of stay in the site for long.

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