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A Review on edible Insects diversity, abundance, and conservation

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Abstract
Insects are the most varied category of creatures, with one million species accounting for 80% of all species on the planet. The practice of eating insects is called entomophagy. Edible insects are consumed and many species serve as good sources of nutrients all over the world. Over 2000 species of insects are consumed around different regions of the world. Coleoptera order consists of the major number of edible insects used as feed in the world followed by Lepidoptera, Hymenoptera, Orthoptera, Hemiptera, Isoptera, Odonata, Diptera, and other orders. These insect species also contain significant amounts of nutrients such as protein, fat, minerals, fiber, ash, amino acids, and others. Despite their potential as alternative human feed, there is still an aversion to the acceptance of insects as food due to a lack of research and study related to this aspect. This paper assesses the diversity and abundance of edible insects around different parts of the world, the nutritive values of these insects, and their conservation. This study is based on recent data available from different sources and literature.

Keywords: Consumption, diversity, edible insects, entomophagy, nutrition

1. Introduction
Insects are a class of living creatures within the arthropods. They have a chitinous exoskeleton, a three-part body (head, thorax, and abdomen), three pairs of jointed legs, compound eyes, and two antennae. Insects are among one of the most diverse groups of animals in the world including more than a million described species and representing more than half of all known living organisms. Insects are important to everyone and are found almost anywhere and on anything.

Insects are the most diverse class of organisms that constitute about 80% of the world's species (Panuwan, 2020) [13]. Orders Coleoptera, Diptera, Hymenoptera, and Lepidoptera dominate the one million species of insects which are divided into 24 orders and more than 2100 of these species are edible (Jongema, 2015) [9].

Entomophagy is practiced in many parts of the world. Temitope *et al*. (2014) [24] have defined Entomophagy as the practice of consuming insects as food (Nutrient source and as condiments). According to them, insects have been a source of human nutrition around Africa, Australia, Asia, and the Americas throughout history. Many insect species such as grasshoppers, caterpillars, beetle grubs (also adults), winged termites, bees, wasps, larvae and pupae of ants, winged ants, cicadas, and different aquatic insects have been used as food by humans. Not only as emergency food to overcome starvation but insects have been included as a normal part of diet according to availability. More than 1400 species of insects are reportedly consumed as food worldwide most of which are harvested from natural forests.

Insects are healthy, high in nutrition, and can be good alternatives to mainstream foods such as chicken, pork, beef, and fish. Many studies have reported the nutritive values of different insects and have mentioned their richness in terms of protein, fat, and minerals like calcium, iron, and zinc. Besides this, the use of insects as feed also serves well for the environment as insects promoted for food emit considerably lesser greenhouse gases (GHGs) and ammonia compared to conventional livestock (Van Huis A, Van Itterbeeck J, Klunder H, 2013) [20].

1.2 Nutritive Value of Insects
Insects have high nutritive value. Insects are rich in proteins, fats, and many vitamins and minerals (Defoliart, 1995) [3].

Gahukar (2020) [6] on their study have reported that edible insects contain carbohydrates (2.7- 49.8 mg/kg, fresh weight), protein (20-76%, dry weight), and fat (2-50%, dry weight). The study also reported the presence of unsaturated (oleic, linoleic, and palmitic most abundant) and saturated fatty acids, 10-30% of essential amino acids in insects which can serve greatly to human nutrition. It was also reported that the energy content in insects may differ in different insects according to their geographical location and they provide about 217-777 kcal/100 g dry weight and mostly coleopteran, lepidopteron and isopteran species provide maximum energy.

Panuwan (2020) [13] reported that insects also contained protein, fiber, essential amino acids (isoleucine, leucine, lysine, methionine, and phenylalanine) suitable for human consumption, and lipids, especially at their larval and nymphal stages. The study also reported that Bamboo worm (*Omphisa fuscidentalis*) in Thailand had 56.89% lipids and provided 778 kcal/100g of energy. Beside these, presence of 60% protein and other nutritive elements such as vitamins and minerals have also been reported (Van Huis, 2016; Yhoung-Aree *et al*., 1997) [21, 23]. The nutritional content of different edible insects is presented in the Table 1, 2 and 3.

Table 1: Protein, Fat, Fiber and Ash content of Different Edible Insects

Food Insects	Common Name	Protein	Fat	Fiber	Ash
Bombyx mori (larva fed artificial diet)	Silkworm	53.8	8.1	6.4	6.4
Bombyx mori (larva fed mulberry leaves	Silkworm	64.7	20.8	-	-
Bombyx mori (larva fed mulberry leaves)	Silkworm	62.7	14.2	-	-
Bombyx mori (pupa)	Silkworm	60.0	37.1	-	10.6
Heliothis zea (larva fed Broad Beans)	Corn earworm	18.2	-	-	-
Heliothis zea (larva fed artificial diet)	Corn earworm	30.2	-	-	-
Spodoptera frugisperda (larva fed artificial diet)	Fall army worm	59.0	20.6	6.8	5.7
Spodoptera frugiperda (lkarva fed fresh plant material)	Fall army worm	59.3	11.7	12.4	11.6
Brachytrupes sp.	Cricket	47.9	21.3	13.5	9.4
Gryllotalpa africana	Mole cricket	53.5	21.9	9.7	9.4
Apis mellifera (adult female)	European honeybee	60.0	10.6	-	17.4
Apis mellifera (adult male)	European honeybee	64.4	10.5	-	17.8
Apis mellifera (larva)	European honeybee	40.5	20.3	1.3	3.4
Apis dorsata	Giant honey bee	41.26	30.84	1.9	3.82
Brachytrupes orientalis	Field cricket	65.74	6.33	8.75	4.53
Odontotermes spp.	Termites	33.67	50.93	6.30	3.01
Oecophylla smaragdina Fb	Weaver ant	55.28	14.99	19.84	2.59
Gryllus bimaculatus	House cricket	75.01	19.29	9.71	5.04
Oryctes rhinoceros	Coconut rhinoceros beetle	65.33	17.73	25.89	3.97
Acheta domesticus	Cricket	64.38	22.80	19.10	5.10
Macrotermes belliscosus	Termite	20.40	28.20	2.70	2.90
Atta mexicana	Ant	66.0	24.02	2.06	3.00

(***Source*:** Williams *et al*., 2016; Rumpold & Schlüter, 2013; Panuwan, 2020; Gahukar, 2020) [22, 16, 13, 6]

Table 2: Mineral Content of Different Edible Insects

Insect	Na	K	Ca	P	Fe	Mg	Zn	Cu	Mn
Bombyx mori	47.5	316.0	15	641	3.1	49.8	3.07	0.36	0.43
Rhynchophorus phoenicis	44.8	2209	208	352	14.7	33.6	26.5	1.6	0.8
Locusta migratoria manillensis (roasted)	55	545	90	424		62	8.4	3.0	1.46
Oecophylla sp.	180	541	48	517	21.8	70	10.1	0.87	9.06
Oecphylla virescens	270	957	79.7	936	109.0	122.1	16.9	2.17	6.30
Musca domestica (pupa)	1350	3030	765	3720	125	26.6	85.8	12.9	26.6

(***Source*:** Williams *et al*., 2016) [22]

Table 3: Amino Acids Content of Different Edible Insects

Food Insect	ILeu	Leu	Lys	Met	Cys	SAA	Phe	Tyr	AAA	Thr	Trp	Val	Arg	His
Caterpillar, *Imbrasia epimethea*	28.6	81.0	74.2	22.4	18.7	41.1	65.0	75.0	140	48.0	16.0	102	66.2	19.7
Caterpillar, *Imbrasia ertli*	36.0	36.7	39.3	15.8	13.4	29.2	17.4	13.2	30.6	40.5	8.1	41.9	-	-
African silkworm larvae Trp *(Anaphe venata)*	21.4	13.12	8.8	-	-	-	21.4	24.9	46.4	3.8	-	17.6	3.20	7.8
Spent silkworm pupae	57	83	75	46	14	60	51	54	105	54	9	56	68	25
Palm weevil larvae, *Rhynchophorus phoenicis*	77.5	58.9	63.9	12.0	10.6	22.6	32.8	13.6	46.4	28.6	5.1	54.9	-	-
Blattalateralis (nymphs)	7.73	12	12.8	3.35	1.44	-	7.67	14.3	-	7.89	1.66	12.3	14	5.49
Brachytrupes sp.	3.1	5.5	4.8	1.9	1	2.9	2.9	3.9	-	2.75	-	4.42	3.7	1.94
House crickets, *Acheta domesticus*	36.4	66.7	51.1	14.6	8.3	-	30.2	44	-	31.1	6.3	48.4	57.3	23.4
Ants, *Atta mexicana*	53	80	49	19	15	34	41	47	88	43	6	64	47	25
Atta Mexicana	53	80	49	34	15	49	88	47	135	43	6	64	47	25
Apis mellifera	41	66	60	25	9	34	70	41	111	44	7	59	64	33

(***Source*:** Williams *et al*., 2016) [22]

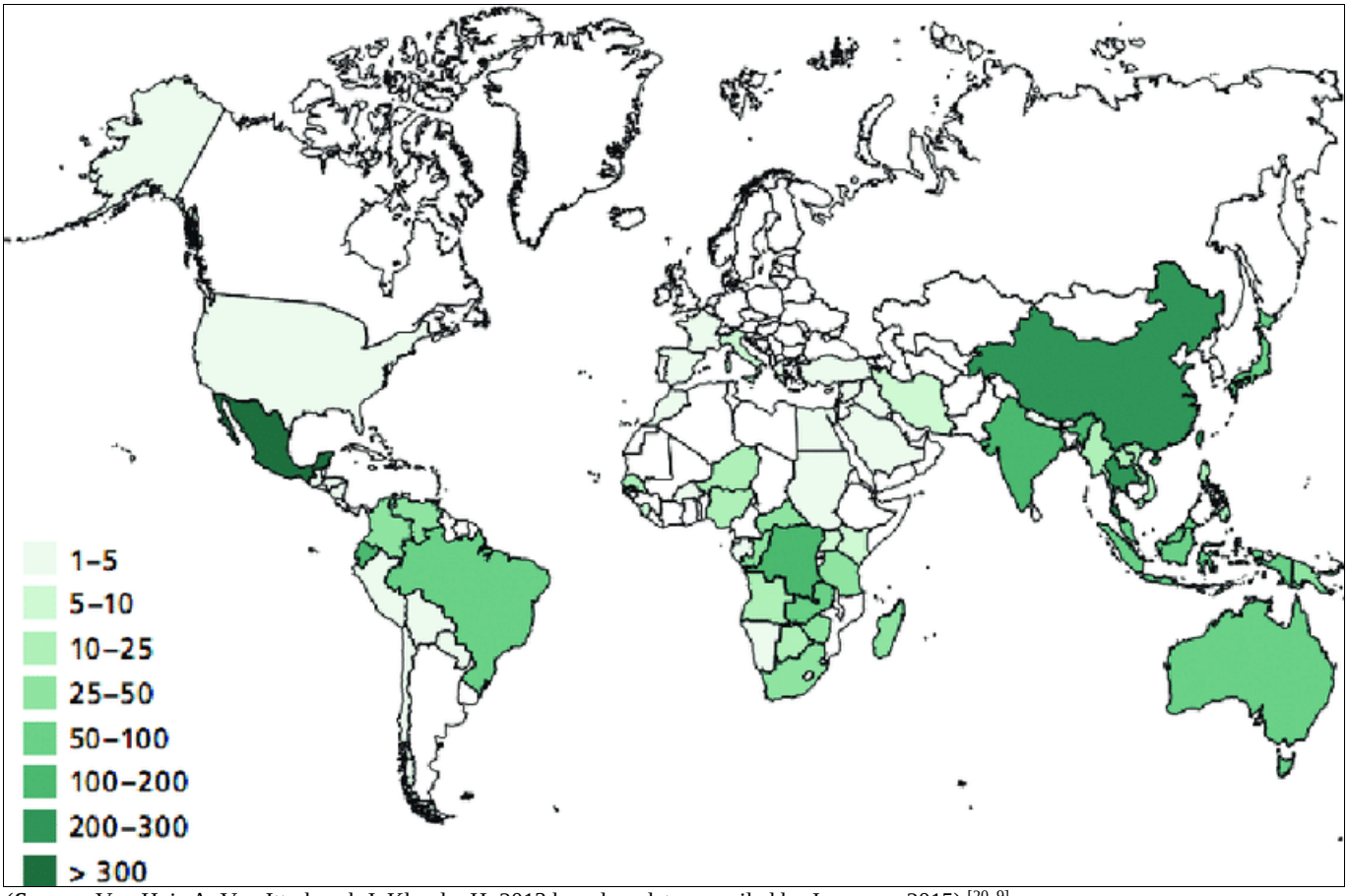
3. Results and Discussion

3.1 Abundance and diversity of Edible insects

3.1.1 Edible insect species identified around the world

More than 1000 species of insects from habitats ranging from arid, rainforests to aquatic habitats are consumed as food worldwide with 20, 30, or more number of species being part of local cuisine in many countries (De Foliart, 1997) [4]. Mitsuhashi (2017) [11] in his book reported about 2141 various edible insects species known to be eaten in around 113-130 countries by people of different ethnic groups (3000-3071), especially in southeast Asia and the Pacific region, Central and South America, and sub-Saharan Africa (Ramos-Elorduy, 2009; Hanboonsong *et al*., 2013) [15, 7]. The number of edible insect species around the world varies from 2000-3000 (Hanboonsong *et al*., 2013; Jongema, 2015; Ramos-Elorduy, 2009) [7, 9, 15], but there may be more number of them as insects consumed by different indigenous communities and ethnic groups are yet not systematically identified.

Defoliart (1995) [3] has also discussed about various edible insects consumed around the world. According to him, many hundreds species of insects are consumed as food by humans, comprising 10 orders at least, more than 90 families and 370 genera. He further mentioned insects of some orders consumed as food which includes insects of order Coleoptera (*Batocera sp.*, larvae *Rhynchophorus sp., and Oryctes rhinoceros*), Hymenoptera (*Apis mellifera*, *Trigona clavipes*, *A. cephalotes*), Isoptera (*M. subhyalinus*, *M. bellicosa*, *M. falciger*), Orthoptera (grasshopper, *Locustana pardalina*), and Lepidoptera (*Gonimbrasia belina*, *mumpa*). He also reported that approximately 100 genera from 17 families in coleoptera, and 80 genera from 20 families of Lepidoptera are consumed as food worldwide



(***Source*:** Van Huis A, Van Itterbeeck J, Klunder H, 2013 based on data compiled by Jongema, 2015) [20, 9]

Fig 1: Recorded number of edible insect species by country

3.1.2. Major group of edible insects

The most consumed insects worldwide are Coleopteran beetles (31%). It is followed by the consumption of insects of Lepidoptera (18%), Hymenoptera (14%), Orthoptera (13%), Hemiptera (10%), Isoptera (3%), Odonata (3%), Diptera (2%) and other orders (5%).

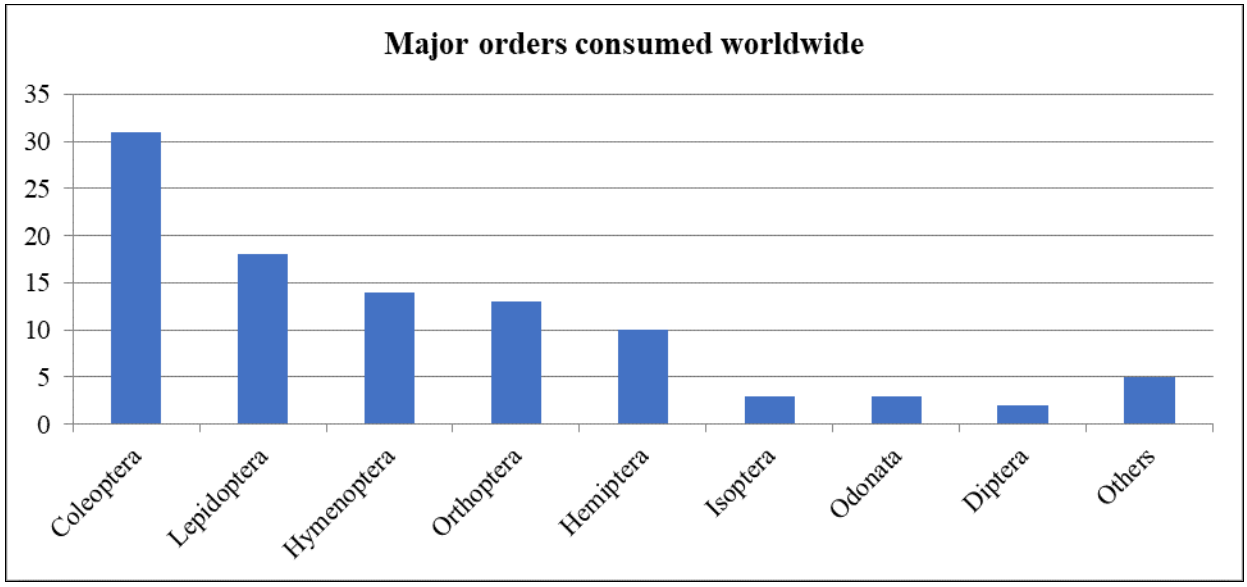


Fig 2: Major orders consumed globally (Source: Jongema, 2015) [9]

3.1.3 Other edible insect diversity

Chakravorty (2014) in her study revealed that about 255 insects species was consumed as food by different tribes in India. Coleopteran insects were the major insects consumed followed by Orthoptera, Hemiptera, Hymenoptera, Odonata, Lepidoptera, Isoptera and Ephimeroptera. Kr (2023) in his study of diversity and abundance of edible orthopteran insects in Assam, India recorded 10 species of orthopteran insects belonging to 4 families and of 10 genera. The most dominant species in the study area was found to be of family Acrididae (5 species- *Chondracris rosea*, *Choroedocus robustus*, *Eupreponotus inflatus*, *Hieroglyphus banian* and *Oxya hyla*), followed by Tettigoniidae (2 species- *Mecopoda elongate*, *Ruspolia baileyi*), Gryllidae (2 species- *Acheta domestica*, *Gryllus bimaculatus*) and Gryllotalpidae (1 species- *Gryllotalpe africana*).

34 different insect species belonging to 6 orders and 16 families were identified as consumed by the people around habitats of Loushi pat basin at Manipur as per the study of Singh & Babu (2021) [17]. The major edible insects were of order Odonata (10 species, all consumed in nymphal stage), Hymenoptera (2 species, larvae consumed), Ephemeroptera (1 species, larvae and adult consumed), Coleoptera (10 species, larvae and adult consumed), Orthoptera (3 species, adult consumed), and Hemiptera (8 species, adult consumed).

A study conducted by Das *et al*. (2019) [2] showed that 16 species of insects of 6 orders and 12 different families were consumed by Koch Rajbongshi community in North salmara sub-division of Bongaigaon district in India. The consumed species belonged to Hymenoptera (Red ant- *Oecophyla smaragdina*, common wasp- *Vespula vulgaris*, Vespa bicolor- *Vespa affinis*, Indian rock bee- *Apis dorsata*, Dwarf honeybee- *Apis florae*, honeybee- *Apis indica*), Orthoptera (Rice field grasshopper- *Heiroglyphus banian*, House cricket- *Acheta domestica*, Mole cricket- *Gryllotalpa africana*, Desert locust- *Schistocera gregaria*, cricket- *Tarbinskiellus portentosus*), Coleoptera (Diving beetle- *Hydrocercus rickesckeri*, white grub- *Leucopholis lepidophora*), Hemiptera (Giant water bug- *Lethocercus indicus*), Isoptera (Termite ant- *Odontotermes obesus*) and Lepidoptera (Eri silkworm- *Philosomia ricini*).

FAO (n.d.) have reported that there are more than 1900 insects which are edible and most of them belong to orders Coleoptera (beetles), Lepidoptera (butterfly and moths), Hymenoptera (bees, wasps and ants), Orthoptera (grasshoppers and crickets), Isoptera (termites), Hemiptera (true bugs), and Homoptera (cicadas). It have also reported about the consumption of 250 species in Africa, 548 species in Mexico, 180 species in china and 160 species in Mekong.

There are 10004 native insect species in Nepal, and 3500 of them are estimated to be of economic importance (Thapa, 1997; MoFSC, 2014) [19, 12]. It has been reported that there are various Nepalese indigenous communities which consume different insect species. Consumption of different species such as aringal (wasps, along with its eggs), phatyangra (grasshoppers), hornet larvae and other different species have been reported (Pokharel, 2019) [14].

Temitope *et al*. (2014) [24]. Have reported 16 commonly edible insects species consumed around Nigeria through field survey. 5 Coleopteran species (*Rhyncophorus phoenics*, *Oryctes boas*, *Oryctes monocerous* Oliver, *Analeptes trifasciata*, *Heteroligus meles* Billberger), 4 Orthopteran species (*Zonocerus variegatus*, *Cytacantharis naeruginosus unicolor*, *Brachytrupes membranaceus* Drury, *Gryllotalpa Africana* P.de.B), 3 Lepidopteron species (*Cirina forda* Westwood, *Bunaea alcinoe* Cram, *Anaphe venata*), 2 Isopteran species (*Macrotermes belliscosus*, *Macrotermes notalensis* Haviland), 1 Hymenopteran species (*Apis mellifera*) and 1 Hemipteran species (*Nezera viridula* L.) were listed. Ojala *et al*. (2022) [25] from their research study reported 88 edible insect species belonging to 30 families and 13 orders around Kakamega tropical rainforest in Kenya.

22 edible insect species of 15 families and 8 orders were reported to present in different habitat in Manas National Park, Assam, India (Hazarika *et al*., 2020) [8]. Maximum number of insects recorded were of Orthoptera (8 species) followed by order Hymenoptera (4 species), Hemiptera (3 species), Lepidoptera (2 species), Blattodea (2 species) and 1 species each from Coleoptera, Odonata and Mantodea. Thangjam *et al*. (2020) [18] have reported on their study that more than 200 edible insect species have been documented from North East Indian region out of which 92 species are found to be consumed in Nagaland, 69 species in Manipur, 67 in Assam, 65 in Arunachal Pradesh, and few in Meghalaya, Mizoram and Tripura.

According to the study of Yhoung-Aree *et al*. (1997) [23],

more than 50 insect species are edible and consumed in Thailand out of which the most consumed species are silkworm pupae, bamboo worms, locusts, beetles, crickets, red ants, and other insects.

3.1.4 Conservation of Edible Insects

Conservation of edible insects is necessary to sustain biodiversity, maintain ecosystem services, and ensuring sustainability. It is important to safeguard edible insect populations. The issues confronting edible insect populations are directly related to their harvesting and are profoundly based in humanity's unsustainable exploitation of the natural environment. Anthropogenic factors like overharvesting, pollution, wildfire, and habitat destruction have resulted in decline in many edible insects population (Van Huis A, Van Itterbeeck J, Klunder H, 2013) [20]. Most of the edible insects are wild harvested. Reduction in pesticide use, development of more efficient harvesting methods, rearing methods (Temitope *et al*., 2014) [24] can play important role in the maintenance of edible insects population and conserving them. Insect farming in controlled areas relieves strain on wild populations and aids to species conservation by offering an alternate source (Ramos-Elorduy, 2009) [15].

4. Conclusion

Over 2000 insect species are consumed by different people all around the world. Insects serve various benefits as human food. They contain good amount of proteins, vitamins, minerals, fats, fibers, ash, amino acids and also have high efficiency in converting their meal into form that can be consumed by humans. Edible insects can be referred as a category of under-utilized food source that have great potential to address global food security. The promotion of insects as food have also positive impact on environment as they produce lower amount of Greenhouse gases (GHGs), ammonia in comparison to other conventional livestocks such as pigs. Having so many benefits in terms of nutrition and environments, edible insects are still a food resources that is used mainly by the populations of rural third world. The importance of these insects is being ignored by food and agriculture researchers and stakeholders. Their consumption is still in rejection in cultures of many developed countries. They are still considered as “food of slaves” or “low prestige food” in some places. Many challenges such as cultural barriers, consumer acceptance of insect as food, and safety concerns which must be addressed properly to integrate insects into mainstream food system.

Very few researches and studies related to abundance, diversity, nutritional composition of edible insects are conducted. Many edible insects are yet not identified due to lack of research and there is also lack of studies about proper rearing and cultivation of edible insects (except some such as Silk worm and honey bee). Therefore more studies and research is required on diversity, abundance, nutrient quality of insects, rearing and cultivation, conservation of edible insect species. The aversion to insects as food should be removed through proper advocacy, research and extension.

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