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Plateau pika *Ochotona curzoniae* poisoning campaign reduces carnivore abundance in southern Qinghai, China

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Abstract. The plateau pika (*Ochotona curzoniae*), a small burrowing lagomorph that occupies the high alpine grasslands of the Qinghai-Tibetan Plateau (QTP), has been subject to a massive eradication campaign in China since the late 1950's under the assumption that it promotes grassland degradation. However, mounting evidence suggests that pikas are a keystone species that provide critical ecological services in the alpine meadow ecosystem. Since the implementation of pika control programs, few studies have investigated the potential impacts of pika poisoning on native carnivore species. In 2007 we investigated the impact of pika poisoning on carnivores in southern Qinghai Province, China. Our results show a decrease in the abundance of carnivores from areas where pikas had been poisoned compared with non-poisoned sites, suggesting that the eradication of pikas at regional scales may alter or disrupt ecological communities on the QTP.

Key words: *Ochotona curzoniae*, plateau pika, poisoning, Qinghai-Tibetan Plateau, terrestrial carnivores.

The plateau pika (*Ochotona curzoniae*) is a non-hibernating lagomorph that occupies a family burrow system territory structure at relatively high densities on open alpine meadows on the Qinghai-Tibetan Plateau (QTP), China. Starting in 1958 the Chinese government launched a massive poisoning campaign aimed to control or eradicate populations of plateau pikas across the QTP (Smith et al. 1990; Fan et al. 1999; Smith and Foggin 1999; Smith et al. 2006). This large scale and ongoing poisoning campaign has been justified by the assumption that pikas are grassland pests, and the species has been framed as a major causative factor of grassland degradation (Liu et al. 1980; Xia 1984; Fan et al. 1999; Harris 2010; Delibes-Mateos et al. 2011). However, arguments supporting the pest status of pikas have been made without careful examination of the ecological roles played by pikas in the alpine grassland ecosystem (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011). Currently, no evidence suggests that the objectives of the pika poisoning program have been achieved (Arthur et al. 2007; Pech et al. 2007; Delibes-Mateos et al. 2011), whereas mounting evidence demonstrates that pikas provide important ecological services to local biodiversity and ecosystem functioning (Smith et al. 1990; Schaller 1998; Smith and Foggin 1999; Lai and Smith 2003; Hogan 2010; Delibes-Mateos et al. 2011; Wilson and Smith 2015).

As an integral part of the high alpine grasslands of the QTP, plateau pikas increase plant species richness (Bagchi et al. 2006; Hogan 2010), control the spread of poisonous herbs (Schaller 1998), regulate soil physiochemical properties (Guo et al. 2012), and ameliorate the potential for flooding during summer monsoon storms (Wilson and Smith 2015). Pika burrows provide important nesting and breeding sites for a variety of small avian species and reptiles (Smith and Foggin 1999; Lai and Smith 2003). In addition, pikas constitute a major food source for nearly all mammalian and avian carnivores that occupy the open grassland-dominated plateau (Smith et al. 1990; Schaller 1998; Smith and Foggin 1999; Lai and Smith 2003). Mammalian predators on the plateau include Chinese mountain cats (*Felis bieti*), Pallas's cats (*Felis manul*), lynx (*Lynx lynx*), wolves (*Canis lupus*), Tibetan foxes (*Vulpes ferrilata*), red foxes (*V. vulpes*), brown bears (*Ursus arctos*), mountain weasels (*Mustela altaica*), and steppe polecats (*M. eversmanii*), all of which depend on pikas as an important prey source (Smith et al. 1990; Schaller 1998; Smith and Foggin 1999; Xu et al. 2006; Ross et al. 2010; Harris et al. 2014). Snow leopards

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(*Uncia uncia*) primarily prey on blue sheep (*Pseudois nayaur*), but have also been known to supplement their diet with pikas (Schaller 1998). Nearly all the raptors that occur on the plateau, including little owls (*Athene noctua*), black-eared kites (*Milvus migrans lineatus*), northern goshawks (*Accipiter gentilis*), upland buzzards (*Buteo hemilasius*), golden eagles (*Aquila chrysaetos*), steppe eagles (*A. nipalensis*), and saker falcons (*Falco cherrug*) also depend on plateau pikas as a primary food source (Schaller 1998; Smith and Foggin 1999; Lai and Smith 2003; Li et al. 2004). Moreover, plateau pikas appear to be the only common diurnal small mammal in many areas of the plateau (Smith et al. 1986; Wang and Smith 1988, 1989; Smith and Wang 1991; Dobson et al. 1998, 2000). Thus, the eradication of pikas at regional scales may impact predators that rely on pikas as a major food source (Smith and Foggin 1999).

Carnivores play important roles in ecological health (Miller et al. 2001) and ecosystem regulation by exerting top-down effects on lower trophic levels (Beschta and Ripple 2009; Prugh et al. 2009; Estes et al. 2011; Ritchie et al. 2012). These important ecological roles by carnivores are characterized by reducing and controlling the number of herbivores through predation (Terborgh 1988; Terborgh et al. 1997, 1999; Valkama et al. 2005), which in turn influences plant communities (Miller et al. 2001). Despite their important ecological roles, carnivores are among the most threatened taxa worldwide due to naturally low population densities, low reproductive rates, and persistent anthropogenic impacts such as poaching and habitat loss or degradation (Ripple et al. 2014).

Poisoning of small mammals that are important prey has led to massive declines and even extirpations of carnivore populations (Miller et al. 1996; Clark 1997), as well as dramatic declines in carnivore populations that feed on remains of contaminated prey (Reading et al. 2005; Ogada et al. 2012). Therefore, quantifying the impact of control programs on non-target animals is critical to understanding potential ecological ramifications, as well as to inform environmental managers and policy makers of the consequences of these control measures (Buckmaster et al. 2014). Furthermore, the relationship between potential impacts on carnivores resulting from the poisoning of pikas has not been well documented with field investigations. Here we use both a quantitative and qualitative approach to investigate the relationships between the control of plateau pikas and carnivore abundance at two sites, one where pikas had been poisoned and one where they had not, in order to assess the ecological effects of the long-standing pika poisoning program in a poorly studied region of the QTP.

Methods

Study area

The geographic range of the plateau pika coincides with that of the high upland region known as the QTP (Smith and Yan 2008), which covers approximately 2.5 million km^2—an area approximating a quarter of China (Miller 1995).

The study was conducted from September through October 2007 in the region of two pastoral communities in Gyichu (Jiqu in Chinese) Township, Nangchen (Nangqian in Chinese) County, in the southern region of Qinghai Province, China. The poisoned site (Santu community; 32°05'16.90" N, 96°09'01.14" E, 4,200 m a.s.l) and non-poisoned site (Tsashonang community; 32°01'57.10" N, 96°12'33.06" E, 4,050 m a.s.l), are separated by about 50 km of mountainous pasturelands. The two sites are each characterized by open meadow pastureland that is continuous with habitat extending across the plateau in this region. These two study sites were selected based on their overall similarity, with the exception of the primary variable: whether the sites had been poisoned or not.

The two communities were of similar size: 27 households at Santu and 31 households at Tsashonang, each with about 200 inhabitants most of whom reside in a small village (Badingqiuying 2008). The region's dominant economic activity is transhumant pastoralism, and the villages are surrounded by winter pasture. There was no significant difference in population size of total livestock between the two communities (Badingqiuying 2008).

Initial discussions with village residents identified those who were most knowledgeable about the surrounding meadow environment, including its vegetation, wildlife, the trajectory of plateau pika populations, and poisoning history. This subset of village inhabitants included those who herded livestock on the local landscape daily, or senior pastoralists who had a lifetime of experience in livestock management on the surrounding landscape. From each village subset, 30 respondents were chosen at random to participate in quantitative surveys on the vegetation and carnivore populations within their community (Badingqiuying 2008).

Vegetation was sampled on 17 50 × 50 m plots on each site using standard methods for determining plant species richness and dominance. The same grasses, *Kobresia* *pygmaea* and *Carex* spp., were the two most dominant forms at each site, comprising 80–90% of the total vegetation cover (Badingqiuying 2008). Results from quantitative surveys administered to knowledgeable village residents yielded the same two forms as being the most important vegetative species on the landscape and the major forage for livestock and wild herbivores (Badingqiuying 2008). Thus vegetation sampling and responses from the surveys reinforce the overall similarity of the two study sites.

Pika populations

An index of plateau pika population density at each site was determined by counting fresh burrow entrances, a standard metric used for this species (Dobson et al. 1998; Fan et al. 1999). Three 1 ha areas were chosen at each study location randomly, and all active pika burrows were counted. In addition to counting burrows, ten respondents at each village were surveyed to provide their perception of the trajectory of pika populations over time and whether increased pika populations contributed to local rangeland degradation.

Pika control

Whether pika control had occurred in the study area was determined by interviews with local pastoralists at each site as well as representatives from the Nangchen County Bureau of Animal Husbandry (the government sector primarily in charge of grassland affairs including implementation and evaluation of pika control programs). As confirmed by these two sources, pika control programs had never been implemented at the non-poisoned site prior to our fieldwork. Plateau pikas had been poisoned multiple times on the pasture at the poisoned site prior to our study period, with the first control being implemented in the 1970s. The latest control program before the initiation of our research occurred during March and April 2007, and measures for consolidating the efficacy of control were taken the following month confirming the pika eradication objective of 90–95% control; poisoning targeted the full extent of the winter grazing grounds of Santu township (Nangchen Bureau of Animal Husbandry, personal communication).

Occurrence of carnivores

At each site (poisoned and non-poisoned), the relative abundance of carnivores was sampled with standardized walks along fixed transect lines following the methodology of Lai and Smith (2003). Each transect line was approximately 6,000 m in length, extending from a flatter area in the west to the more mountainous eastern end. Three transect lines were established in parallel, each separated by approximately 1,600 m. The three transects were walked simultaneously by three researchers, who walked west to east and then back to the starting point for a total duration of 3 hr. Transect samples were carried out three times a day—at sunrise, mid-day, and dusk. Samples were taken for three consecutive days at each site. Thus, a total of 54 transect walks (up and back) were conducted for a total of 81 hours at each site. Using a non-fixed distance sampling method, all raptors and mammalian carnivores on both sides of the transect line were recorded by species.

Relative abundance of carnivores was further assessed by conducting survey interviews with local pastoralists in autumn 2007. Interviews were designed to obtain information on carnivore abundance in the general area of each respective pastoralist community from the observations of respondents during the summer and autumn of 2007 at each site. The survey interview was based on initial informal interviews with local residents who identified all carnivore species that were present in Santu prior to the poisoning campaign. Thirty respondents were given a checklist of the local carnivores and asked the question: "Rank the frequency of occurrence of carnivores as seen often (O), sometimes seen (S), seldom seen (L), or never seen (N)" based on their own daily observations.

Data analysis

We compared the relative abundance of all observed carnivores between the two sites using a two sample *t*-test after confirming normality and equal variance of the samples. Differences between sites for each species were tested with Chi-square Goodness of Fit tests, using Yate's correction whenever expected frequencies were less than 5. Significance was determined at the 5% level.

In addition to our quantitative analyses, we used a ranking-score-strength method to qualitatively compare responses to each of the assessment criteria from the survey interviews. Strength scores of abundance were obtained by multiplying the number of responses in each category as follows: Often (O) × 3; Sometimes (S) × 2; Seldom (L) × 1; and Never (N) × 0. These scores were then added for each species at each site, and we calculated the difference (Δ) in strength scores between the two sites. We considered differences that ranged from −2–10 to be Weak; differences from 11–20 were considered Moderate; and differences from 21–30 were considered Strong.

Results

Pika population

The average number of active pika burrows was 7/ha at the poisoned site and 487/ha at the non-poisoned site. By comparison, an average of 637 pikas/ha was determined pre-poisoning in 2007 at Santu by the Nangchen County Bureau of Animal Husbandry (personal communication).

All respondents from both villages indicated that the pika population density had increased in recent decades over an earlier background level when pikas were not as abundant; they differed only in their perception of the time-line for these increases. Those from the poisoned site believed that pika populations began to increase at the time of the formation of the commune system in the 1960s, whereas those from the non-poisoned site claimed that increased pika populations were first apparent at the beginning of the 1990s (Badingqiuying 2008).

Field census of carnivores

The overall relative abundance of mammalian and avian carnivores was higher at the non-poisoned site compared with the poisoned site ($t_{18} = 2.791$, $P < 0.01$).

Among 51 mammalian carnivore sightings, 45 were observed at the non-poisoned site, whereas only 6 were seen at the poisoned site (Table 1). Specifically, observations of Tibetan fox, red fox, and mountain weasel were each more frequent at the non-poisoned site than at the poisoned site (Table 1). No Chinese mountain cats, Pallas's cats, lynx, snow leopards, wolves, brown bears, or steppe polecats were observed during the wildlife censuses.

Table 1. Observed sightings of plateau pika predators at a non-poisoned site (Tsashonang) and a poisoned site (Santu) on the Qinghai-Tibetan Plateau during standardized censuses. Chi-square Goodness-of-fit tests were used to evaluate differences between sites for each species; Yate's correction was applied whenever expected frequencies were less than 5.

Species	Non-poisoned Site	Poisoned Site	χ^2	P
Avian species				
Little owl	6	4	0.400	0.5271
Eurasian eagle owl	2	0	*	
Black-eared kite	9	4	1.923	0.1655
Upland buzzard	31	9	12.100	0.0005
Steppe eagle	14	5	4.263	0.0389
Saker falcon	24	9	6.818	0.0090
Raven	10	12	0.182	0.6698
Mammal species				
Tibetan fox	26	4	16.133	0.0001
Red fox	7	0	5.134	0.0233
Mountain weasel	12	2	7.143	0.0075

* Insufficient data to run Chi-square evaluation.

Of 139 raptor sightings, 96 were observed at the non-poisoned site, whereas 43 raptors were sighted at the poisoned site (Table 1). Sightings of upland buzzards, steppe eagles, and saker falcons were each more frequent at the non-poisoned site than at the poisoned site, while the numbers of observed black-eared kites, little owls, Eurasian eagle owls, and ravens were not different between the two sites (Table 1).

Survey interviews of local people

Perceptions of local people, as reflected in our surveys, highlighted that certain species were more likely to be observed at the non-poisoned site than at the poisoned site (Table 2). These observations of local pastoralists concerning the abundance of predatory wildlife mirrored those of our quantitative wildlife censuses.

Moderate-to-Strong differences between the two sites were found in the comparative surveys for four species of mammal: Tibetan fox, red fox, wolf, and mountain weasel. Two relatively rare species, snow leopards and brown bears, were perceived to have a Weak Δ strength score between the sites (Table 2).

Among bird species, Moderate-to-Strong differences between the sites were reported for upland buzzards, steppe eagles, saker falcons, and black-eared kites. No perceived (Weak Δ strength score) difference was found for little owls, Eurasian eagle owls, and ravens (Table 2).

Discussion

Both mammalian and avian carnivore communities on the high alpine grasslands of Qinghai province, China, were found to be impoverished where plateau pikas had been poisoned and their density significantly reduced as reflected by both our standardized census and survey interviews with local pastoralists. As the poisoning had occurred in late spring before the early summer breeding season of plateau pikas (Smith and Wang 1991; Dobson et al. 1998), it is clear that reproduction had not led to a rebound of the poisoned population. Further, as dispersal is restricted in plateau pikas (Dobson et al. 1998), the poisoned region had not been replenished by immigrants from outlying non-poisoned populations. Two large and apparently uncommon species in the region, snow leopards and brown bears, were not perceived as having a

Table 2. Qualitative assessment of carnivore abundance on pika habitat in southern Qinghai Province

Species	Non-poisoned Site				Strength Score	Poisoned Site				Strength Score	Δ Strength Score
	O	S	L	N		O	S	L	N		
Little owl	15	9	6	0	69	12	16	2	0	70	–1
Eurasian eagle owl	9	14	7	0	62	10	13	7	0	63	–2
Black-eared kite	21	7	2	0	79	9	19	2	0	67	12
Upland buzzard	27	3	0	0	87	6	20	4	0	62	25
Steppe eagle	24	6	0	0	84	8	22	0	0	68	16
Saker falcon	29	1	0	0	89	5	22	3	0	62	27
Raven	9	16	5	0	64	9	14	7	0	62	2
Snow leopard	0	5	12	13	22	0	3	19	8	25	–3
Tibetan fox	28	1	1	0	87	4	22	4	0	60	27
Red fox	25	4	1	0	84	14	15	1	0	73	11
Tibetan wolf	18	11	1	0	77	6	20	4	0	62	15
Brown bear	6	19	5	0	61	2	21	7	0	55	6
Mountain weasel	22	8	0	0	82	13	14	3	0	70	12

Local people responded to the question: "Rank the frequency of occurrence of carnivores as seen often (O), sometimes seen (S), seldom seen (L), or never seen (N)." The survey question was administered to 30 people in each of two sites—one with a native population of plateau pikas (*Ochotona curzoniae*) and one where the pikas had been poisoned. Rank-strength scores of abundance were obtained by multiplying the number of responses in each category as follows: O × 3; S × 2; L × 1; and N × 0. Δ = the difference in strength scores between the two sites.

noticeable difference between the poisoned and non-poisoned sites, but this may be because these species are rarely seen.

Possible repeated observations of individuals may have occurred during the field censuses due to the high mobility of both avian and mammalian carnivores and the long duration of observations conducted each day. However, areas and time periods of observation between the two sites were standardized, and both study sites shared similar habitat characteristics, such that our counts reflect a reliable index of abundance between the sites for each species.

Our results on mammals parallel several recent studies that have concentrated on the diets of individual mammalian carnivores on the QTP. Mountain weasels have been reported to prey heavily on plateau pikas across the QTP (Hornskov and Foggin 2007). The Tibetan fox appears to be an obligate predator on plateau pikas (Schaller 1998; Wang et al. 2007; Liu et al. 2010; Harris et al. 2014; but see Tsukada et al. 2014). Harris et al. (2014) determined that 99% of Tibetan fox scats on the QTP contained pika DNA sequences, and Schaller (1998) found that Tibetan fox scats contained 94.1% and 93.5% pikas from two areas in the Chang Tang Reserve on the northern plain of the Tibetan Autonomous Region. On the other hand, red foxes appear to be less reliant on pikas than Tibetan foxes (Tables 1, 2; Schaller 1998).

The dependency of wolves on pikas as prey varies between seasons. Pikas constituted a small percentage of wolf diets (7.1%, 16.9% and 25% from three locations in the Chang Tang Reserve) when alternative sources of prey such as ungulates were abundant (Schaller 1998). However, during winter when ungulates were largely unavailable, 66.8% of wolf scats contained pika remains (Schaller 1998).

Similarly, pikas constitute as much as 59–78% of the diet of brown bears on the QTP (Schaller 1998; Xu et al. 2006). Due to the reliance of bears on pikas, attacks by hungry bears on property (primarily homes of local nomads) have increased in areas where pikas have been eliminated (Worthy and Foggin 2008).

Among birds, our sightings of black-eared kites, upland buzzards, steppe eagles, and saker falcons were approximately three times more frequent at the non-poisoned site than at the poisoned site (Table 1). Our survey of local pastoralists paralleled this finding; the same four raptor species had the highest Δ strength scores among all species reported (Table 2). Saker falcons prominently depend on pikas. Pika remains comprise 90% of the food items in the pellets of saker falcons in the Chang Tang (Schaller 1998). Lai and Smith (2003) found that black-eared kites and upland buzzards were seen 3.6 and 11.2 times more frequently on non-poisoned than on poisoned sites, respectively, although this difference was only significant for the relationship with black-eared kites. These results are supported by the close relationship between sightings of pikas and sightings of upland buzzards throughout Qinghai province (Lai and Smith 2003; Smith et al. 2006). One study, however, found that when abundant, small mammals other than pikas can support a population of upland buzzards (Cui et al. 2008).

Not all raptors examined showed a facultative decline in abundance with pika poisoning. Two of these species were owls, which have the ability to forage at night (although the little owl may be active during the day). Both our sightings of the Eurasian eagle owl occurred on the non-poisoned site, but this sample size was too small from which to draw any conclusions. Local pastoralists perceived no difference in abundance for either owl species between the two sites. The raven similarly showed no difference in relative abundance in either our censuses or in the survey responses by pastoralists between the poisoned and non-poisoned site. This aggressive bird is a generalist and unlikely to have been influenced by the presence or absence of pikas.

Our investigation, coupled with increasing evidence from single-species studies, indicates that the carnivore guild on the QTP is being compromised by the widespread poisoning of plateau pikas. Thus, the reduction in carnivore abundance observed at the pika poisoned site suggests that those carnivores likely either migrated to other areas with greater food availability or starved as a result of the loss of their dominant prey base. These results mirror the loss of the black-footed ferret (*Mustela nigripes*) in North America due to the extensive poisoning of prairie dogs (*Cynomys* spp.), species that share a similar ecological role as the plateau pika (Miller et al. 1996; Clark 1997; Delibes-Mateos et al. 2011). In addition, other carnivore species such as swift foxes (*Vulpes velox*), burrowing owls (*Athene cunicularia*), and ferruginous hawks (*Buteo regalis*) declined dramatically following poisoning of prairie dog colonies (Reading et al. 2005).

Carnivores can also succumb to secondary poisoning following control efforts (Fan et al. 1999; Guo et al. 2009; Buckmaster et al. 2014). Poison agents applied to eliminate pikas include zinc phosphate (fluoroacetate), compound 1080, anticoagulants (diphacinone, gophacide, difenacoum, bromadiolone, brodiafacoum), and botulin type C toxin (Fan et al. 1999; Smith and Foggin 1999; An 2008). Fan et al. (1999) highlighted that zinc phosphate and compound 1080 were determined to be unsafe for non-target species and that their application caused serious social and environmental problems. Several of these rodenticides have been found to be responsible for the decline and deaths of non-target raptors and scavenging vultures around the world whose prey have been targeted with these same poisons (Evans and Ward 1967; Hegdal et al. 1981; McIlroy and Gifford 1991; Shore et al. 1996; Eason et al. 2002; Stone et al. 2003; Laakso et al. 2010; Elmeros et al. 2011; Ogada et al. 2012). Some carnivore losses resulting from poisoning of prairie dogs in North America may have stemmed from secondary poisoning (Reading et al. 2005).

The implementation of China's pika eradication program by policy makers has continued unabated despite observations that the program is counterproductive, thus contributing to further losses of biodiversity and disruption of ecosystem processes (Smith and Foggin 1999; Lai and Smith 2003; Smith et al. 2006; Harris 2008; Delibes-Mateos et al. 2011). Cumulatively, from 1964–1995, an estimated area of 208,000 km^2 was poisoned with zinc phosphate and compound 1080 across the highlands of Qinghai (Fan et al. 1999). By 2006 an area of 357,060 km^2 had been poisoned on the QTP to control small mammals (An 2008). The poisoning program has accelerated in ecologically important regions such as the Sangjiangyuan [three great rivers] National Nature Reserve (SNNR), an area called China's Water Tower for its importance as a watershed (Wilson and Smith 2015). In the SNNR the cumulative area controlled between 2005–2013 (as part of SNNR Project Phase One) covered approximately 78,593 km^2 (China Dialogue 2014). In addition, Chinese newspapers (China Dialogue 2014; Zhang 2014) have reported that eradication of small mammals (primarily pikas) had been conducted across 31,154–45,584 km^2 in the SNNR under the program's Phase Two plan.

The ecological functions that plateau pikas provide are central to the conservation of a large variety of biodiversity on this alpine grassland ecosystem (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011). The Chinese government recognizes the importance of conserving biodiversity and grassland ecosystem functioning of the QTP (Smith and Foggin 1999). However, continuously referring to pikas as a cause of grassland degradation (Liu et al. 1980; Xia 1984; Fan et al. 1999), and persistently poisoning the species across its geographical range, contradicts many stated objectives of the government's conservation policy in the region. The results from our study and other research (Smith and Foggin 1999; Lai and Smith 2003; Hogan 2010; Delibes-Mateos et al. 2011; Harris et al. 2014; Wilson and Smith 2015) demonstrate that eradicating pikas threatens the structure and function of the ecosystem. It also follows that the resulting decrease in carnivore abundance could substantially impair ecosystem processes (Miller et al. 2001). Therefore, the on-going pika poisoning program should be comprehensively evaluated with relationship to its impact on the ecology of the QTP grassland ecosystem.

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