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Gold-standard experiments to deter predators from attacking livestock

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Gold-standard experiments to deter predators from attacking livestock

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Implications

1. The long-held belief that randomized, controlled trials (RCTs) are impossible in wild ecosystems with working livestock is laid to rest.
2. Crossover designs reduce most confounding variables between subjects and strengthen inference beyond the gold-standard of RCTs, yet we describe limitations precisely.
3. Non-lethal methods can be effective in preventing carnivore approaches and attacks on working livestock in fenced pastures or open rangelands. The relationship between approaches and attacks remains uncertain.
4. Lethal methods of predator control have been subjected to less robust study designs that suggest mixed results including increases in livestock losses.

5. Non-lethal methods promise the elusive triple-win for wildlife, domestic animals, and livelihoods.

Short Introduction

We summarize experiences with gold standard, randomized, controlled trials with crossover design to evaluate the effectiveness of non-lethal methods to reduce carnivore attacks on domestic animals in four countries. We synthesize lessons learned in four categories: Experiences with randomized, controlled trials (RCTs), Design recommendations, Effectiveness of non-lethal methods to prevent wild carnivore predation on working livestock, and Conclusions. We place these in a global context with similar trials. We discuss gaps in evidence that should motivate investments in research and precautions among decision-makers at all levels.

Main text

Climate change and extinctions now pose the major threats to life on our planet (Ripple et al., 2017; Chapron et al., 2018; Ceballos et al., 2020). Humans cause many extinctions via persecution or habitat transformation. Among mammals, large carnivores have faced higher than average rates of population extirpation because of direct and indirect competition with people (Woodroffe and Ginsberg, 1998; Chapron et al., 2014; Ripple et al., 2014).

Humans respond to real and perceived threats from carnivores with lethal action and sociopolitical pressure against protecting the last remaining carnivores. Therefore, in recent years, interest groups and individuals focused on preserving carnivore populations and minimizing harm to individual carnivores have prioritized non-lethal methods to prevent conflicts between humans and carnivores. In addition to reducing damage to human property by carnivores, non-lethal methods offer potential benefits to many actors involved, by saving animal lives and benefiting human health, safety, and income. Here we describe lessons learned from gold-standard, randomized, controlled trials (RCTs) with crossover designs, which we have conducted in four countries to protect livestock from wild carnivores of many species.

Experiences with RCTs

Inspired by experiments in the United Kingdom on badgers to evaluate the effect of two interventions on transmission of bovine tuberculosis to cattle (Donnelly et al., 2003) and by Australian experimenters removing red fox (*Vulpes vulpes*) to evaluate the effect on predation of sheep (Greentree et al., 2000), we conducted our first predator-control RCT in Wisconsin, United States (USA) (Shivik et al., 2003). This first effort, which did not involve working domestic animals (defined as commercial or subsistence, not captive colonies), hereafter livestock — but proved the feasibility of robust designs under field conditions, including crossover. Crossover occurs when treatment and control are reversed midway through a study so each subject experiences each condition. In the interim period before our next RCT, other studies proved the utility of randomized experiments to examine the effectiveness of non-lethal methods to influence wild, medium- to large-bodied carnivores preying on livestock (Bromley and Gese, 2001; Davidson-Nelson and Gehring, 2010; Gehring et al., 2010). Also, numerous experiments on American black bears (*Ursus Americanus*) damaging non-mobile property suggested a need for RCTs with predators of livestock. Despite an RCT by Greentree et al. (2000) on fox control in Australia, to date, no further peer-reviewed RCT's have been conducted on lethal control of carnivores. See (Treves et al., 2016) for discussions of other quasi- or apparently experimental work that is not summarized above. Therefore, it remains unclear if insights gained from non-native carnivores preying on sheep in Australia can be generalized to native carnivores elsewhere. Our work builds upon global research on non-lethal methods that used less robust designs, e.g., (Stone et al., 2017).

The second RCT by members of our group focused on large carnivores interacting with working llamas, alpacas, and sheep in Chile's remote Andean altiplano (Figure 1). This study built on Ohrens et al. (2016)'s previous work in the region interviewing domestic animal owners, and used participatory intervention planning methods, citations in (Treves et al., 2009; Ohrens et al., 2019)to recruit landowners for an RCT to evaluate the non-lethal deterrent they chose: Foxlights®, a commercially available random light projector triggered by nightfall (Ohrens et al., 2019). OO published his PhD dissertation as our first RCT with crossover design, aimed at protecting 11 herds of alpacas and llamas from pumas (*Puma concolor*), also known as cougar or mountain lion, using a light deterrent (Figure 2). His study also revealed surprising effects on Andean foxes that we describe below, including an insight from his second experiment not yet published.

Figure 1. Dr. Omar Ohrens at study site, Tarapaca, Chile with alpacas. Credit A. Treves

Figure 2. Foxlight® deployed in Cimitarra, Colombia. Credit: A. Pineda Guerrero

The second peer-reviewed RCT with livestock, aimed to evaluate herders using low-stress livestock handling methods, citations in (Louchouarn and Treves, 2023) — hereafter range riders (Figure 3). Range riders aimed to protect cattle from brown (grizzly) bears, gray wolves (*C. Lupus*), pumas, black bears, and coyotes (*C. latrans*) in the Canadian Rockies of Alberta. This study incidentally shed light on the use of a pseudo-control rather than placebo control. Louchouarn's work also shed the most light of any previous work on the design of range rider interventions (Louchouarn and Treves, 2023). Namely, that a single experienced range rider could deter large carnivores as effectively as several range riders with less experience. Nevertheless, the frequency of range rider visits (dose effect) seemed important to understanding range rider effectiveness.

Figure 3. Range riders in Alberta. Credit. N. Louchouarn

The third RCT as yet not peer-reviewed but published (Fergus, 2020), evaluated the same deterrent lights (Figure 2) as (Ohrens et al., 2019) combined with fladry (a visual deterrent composed of flagging hung at regular intervals from fence lines around a herd, Figure 4) to deter black bears, coyotes, and gray wolves from 5 herds of diverse livestock types in Wisconsin, USA (Fergus, 2020). Another, not-yet peer reviewed but published RCT (led by SJH) used methods as similar as possible to (Fergus, 2020), in hopes of combining datasets; that work is underway (Hermanstorfer, 2023). Hermanstorfer (2023) aimed to protect 5 herds of various livestock from coyotes, pumas, black bears, foxes, and free-ranging cats in Colorado, USA, using the same deterrents (Fergus, 2020) Figures 2, 4.

Figure 4. Fladry hung around a vehicle-killed deer carcass used in our earliest RCT (Shivik et al. 2003). Credit: A. Treves

Pineda-Guerrero's dissertation is the most recent study in our group is not yet peer-reviewed or defended. She aimed to protect 32 herds composed of a variety of livestock from puma and jaguar (*Panthera onca*) predation at two Colombian forested sites, using stationary lights, as evaluated by (Ohrens et al., 2019), and a novel method never tested before: mobile deterrent lights (Figure 5). Her study offers the largest sample size subjected to our RCTs with crossover design (25-32 depending on which effect was tested). Her study also offers insights into the use of true placebo controls versus inactive controls without placebo and an insight into taking farmers' ideas about deterrents and implementing them within an RCT.

Figure 5. Foxlight mounted on the back of a domestic animal, San Luis, Colombia. Credit: A. Pineda Guerrero

Design recommendations

In the following paragraphs, we describe methods we applied and the lessons we learned along the way. Although we were not the first to complete RCTs under such conditions, our crossover designs and strict attention to avoiding sampling, treatment, measurement, and reporting biases (Treves et al., 2019) led to a consistency of methodology that allows a systematic review of lessons learned. We hope, with these insights, we can help other researchers navigate randomized experimental trials with crossover designs in field conditions.

The non-invasive methods used in our RCTs allowed us to obtain an exemption from the Institutional Animal Care and Use Committee at the University of Wisconsin- Madison. Protocols fs 2016-1071-CP005, 2019-0194, and 2021-0923-CP002 protected human subjects.

Recruitment – Our general first step was to recruit owners or managers of livestock as participants. We use one or both individual recruitment interviews or group workshop-style recruitment methods (Treves et al., 2009). All but one RCT (Louchouarn & Treves 2023) involved our team conducting semi-structured interviews before, during, and after implementation so the 'during' interview could measure response to treatment and to control separately. All interviews measure attitudes to carnivores, perceived effectiveness of non-lethal methods, and satisfaction with the participatory experiments.

Sample sizes - Our sample sizes of owners and their herds dropped below our initial designs in four out of the five studies summarized above. Sample sizes declined at various points in the experiment because one owner stopped communicating (OO), one quit in protest and lost our equipment (APG), 2 herds could not be completely protected by fladry (ARF, SJH), the cameras around three herds malfunctioned (APG), and unprotected livestock interfered with two protected herds (APG). The rate of such 'drop outs' ranged from 0-20% and drop-outs may only be partial, providing data for some analyses but not all. Only two owners may have subverted the placebo control condition by turning on deterrent lights, for that reason we conducted a sensitivity analysis excluding those herds to avoid treatment bias (APG). We acknowledge unforeseen circumstances (e.g camera theft or participants turning on the lights when in placebo), can bias the treatment effect. However, we encourage researchers to openly share these experiences and approach data analysis minimizing biases.

Owner's attitudes to the non-lethal methods, carnivores, and coexistence with carnivores have been highly variable. The largest study by APG suggests increased tolerance for carnivores after the experiment and more positive attitudes about non-lethal methods, despite little or no evidence the methods protected their herds. Hermanstorfer (2023) found mixed effects on attitudes with two out of five owners turning more negative to carnivores and three out of five remaining stable. He speculated that landowners may be overall supportive of carnivore coexistence, but express acceptance until they are more comfortable with the researcher, which in turn allows them to be more cautious or intoelrant in the later interviews.

Although relationships with owners take a great deal of care, we have found individual owners easy to work with in general and more willing to engage in experimental studies including placebos, than organizations and agencies express in other public settings. For example, the Department of Agriculture Wildlife Services charged by the US federal government with managing agricultural damages has been explicitly adversarial, e.g., Western watersheds project et al. V USDA Wildlife Services 2018. U.S. District Court for the District of Idaho.

Livestock and herds - we have conducted RCTs on alpacas, cattle, equids, llamas, and smaller stock including poultry. Owners gathered animals in fenced, small pastures or large, unfenced habitats and organized in homogeneous herds or herds of mixed animals that differed from herd to herd. Heterogeneous herds can produce uncertainty about mixed effects of non-lethal interventions. For example, lack of a statistically significant effect of a treatment may result from attraction to one subject herd and deterrence from another subject herd, which might reflect the differential attractiveness or vulnerability of different livestock individuals in each subject herd. Nevertheless, homogeneous herds are not quantitatively identical (Louchouarn and Treves, 2023) and their homogeneity only simplifies the work of statistical inference, they do not undermine the resulting inferences (Ohrens et al., 2019). We recommend larger samples when herd composition is heterogeneous.

Since our first RCT with 47 losses of livestock (Ohrens et al. 2019), losses have been very low (Louchouarn & Treves 2023 1 in the washout period, APG 3 (2 on non-target livestock) - see below, Fergus 2020 and Hermanstorfer 2023 zero), yet we are concluding the last three RCTs show no significant treatment effect (see below).

We follow owner preferences for protecting their herds, while strictly randomizing treatment or control. Owners sometimes select the deterrent methods or even invent a novel deployment. For example, in APG's RCT, owners suggested mounting deterrent lights to the backs of livestock animals. Such deployment proved impossible for some animals (e.g., some cows, note Fergus (2020) also reported difficulties when cattle ate fladry.), but more readily accepted by others (e.g., some equids). Although we found no significant difference in effect of mobile lights versus stationary lights across APG's RCT, we suggest further research on mobile deterrents. Mobile deterrents can potentially overcome constraints imposed by large pastures, forested pastures, or scattered animals across pastures.

Figure 6. Puma photographed by trail camera, Colombia. Credit: A. Pineda Guerrero

Carnivores- we always deploy trail cameras around subject herds and sometimes conduct indirect sign surveys to estimate approaches by carnivores (Louchouarn and Treves, 2023). Our RCTs tried to deter medium- and large-bodied felids and canids, in habitats that also contain bears (North American sites). Ohrens et al. (2019) reported a deterrent effect of lights on pumas but a non-significant tendency to attract Andean foxes. His second still-unpublished study suggests pumas at that site were not deterred by the same lights. Several of us suspect individual differences between carnivores or differences between species of carnivores may have influenced our results. Looking across the literature in our subfield of predator control, we see a major gap in understanding of the relationship between carnivore approaches to humans or domestic animals and the risk of actual attack. Because wild carnivores are elusive (i.e., they are almost always shy of people), they are very hard to detect by eyewitnesses (Chavez and Gese, 2006; Ordiz et al., 2013; Versluijs et al., 2021).. Indirect methods such as telemetry and trail cameras reveal that wild carnivores frequently approach (and leave) proximity to humans or domestic animals without any resulting attack. Our experiments can only infer with confidence about the frequencies of approaches to subject herds. Such approaches are frequent in some areas and less so in others in which we have run RCTs. These observations suggest two general recommendations. First, larger samples and longer studies will be needed where approaches are rare (Mills et al., 2009). Second, claims of rampant carnivore predation on livestock seem dubious in our regions. Individual variation in inclination to approach is likely to be a powerful variable. We hypothesize that an individual carnivore's experience of exposure to deterrents, such as human lights, will modulate that individual's reaction to a deterrent treatment making treatment effects harder to detect when few individual carnivores are exposed to stimuli. Third, a frequent justification is that these non-lethal methods are only implemented on farms with previous attacks. To mitigate such bias from temporal autocorrelations (Murtaugh, 2002; Stewart-Oaten, 2003), our recommendation is to establish a randomized experimental design with treatments and controls when implementing exclusively non-lethal methods on farms that have encountered previous attacks.

Deterrents - we emphasize caution and perpetual scrutiny of deterrent effectiveness using farmer-based monitoring methods. We agree with other authors that individual carnivores may habituate to deterrents and a mix of deterrent tools is safer than a single tool. For example, when two of us tested a nighttime light deterrent and a 24-h fladry deterrent, they split the data on carnivore approaches into daytime and nighttime periods to evaluate differences between single- and double-treatment conditions (Fergus, 2020)(Hermanstorfer 2023). Further work is needed to refine our understanding of multiple deterrents and even single interventions implemented against a backdrop of protective husbandry (Stone et al., 2017)(Louchouarn & Treves 2023). The effect of non-lethal deterrents may depend on acclimatization by target carnivores. OO's Chilean site was very remote with few lights and large distances between human structures, so pumas might have been unfamiliar with lights in that altiplano setting. By contrast, the temperate forest of OO's second site was more densely populated with both humans and pumas. This was our first exposure to contrary and unexpected effects on one carnivore while finding the desired outcomes for another carnivore. Subsequently, Hall & Fleming (Hall and Fleming, 2021) reported elevated risk for piglets during moonlit nights and during an RCT using the same deterrent lights as Ohrens et al. 2019. More complicated yet, APG reported that jaguars initially approached the same deterrent lights at two of her study areas but a second field season revealed jaguars avoided the deterrent lights at one study site. The attraction and deterrence of jaguars was not strongly statistically significant, so she hypothesized that curiosity can lead some individual carnivores to approach deterrents initially; and later deter them for reasons unknown. Taken together, our four RCTs using light deterrents of the Foxlights® brand suggest these lights that randomly flash at night in three colors are unlikely to produce strong deterrent effects on carnivores unless those individuals are unaccustomed to lights. Also, the possibility of attracting two species of foxes and aiding their hunting (Ohrens et al., 2019; Hall and Fleming, 2021) should give users pause.

The issue of initial curiosity or initial deterrence followed by subsequent changes in individual carnivore behavior deserve more study. Louchouarn & Treves (2023) found increased presence of gray wolves during the first phase of the RCT in treatment herds, but not during the second phase, which occurred in the fall when wolves might range more widely. They hypothesized that curiosity by wolves could have attracted them to the new range riders, but this curiosity dissipated as wolves became accustomed to the new humans (Louchouarn & Treves 2023).

Commentators often mistakenly ascribe the inadequacies of short-term effect and counter-productive results to non-lethal methods only, but lethal methods also experience variable durations of effect and counter-productive effects (Santiago-Avila et al., 2018; Khorozyan and Waltert, 2019, 2020). The field would benefit from more acknowledgment that all interventions have variable effects and understanding the causal mechanisms of such variability.

Design – we have had to vary nuances of our standard RCT with crossover, depending on conditions. For example, Louchouarn & Treves (2023) used a pseudo-control because owners refused the true placebo of no range rider present. They were happy to accept an RCT and a pseudo-control in which novice range riders, trained for only a short period, were paired with an experienced range rider. We exploited this situation by maintaining the experienced range rider as the baseline pseudo-control condition and augmenting his work with 1-2 novice range riders for the treatment condition. This granted us new opportunities to test hypotheses about the number of range riders, frequency of their presence around herds, and level of experience as covariates. This RCT allowed us to evaluate the effectiveness of a specific design: range riders practicing low-stress livestock handling, as a non-lethal method to protect cattle (Louchouarn and Treves, 2023). Given only one cow was killed during the wash-out period (between pseudo-control and treatment on the same herd), and given prior to our RCT there had been wolf and grizzly bear attacks on cattle in these same pastures, we feel confident that range riders were protective. We feel even more confidence that a higher frequency of range rider visits is important for deterring grizzly bears. Similarly, in the Colombian study, APG was able to evaluate dose effects measured by the number of light deterrents, two treatment permutations differing by their deployment as mobile or stationary, and two types of control (active placebo control or inactive control). Given her relatively large sample size (n=25-32), APG was able to evaluate multiple conditions while retaining some statistical power.

Effectiveness of non-lethal methods to prevent wild carnivore predation on working livestock

Overall, we repeat the common admonition that any intervention is an experiment and that intervenors would be wise to monitor the effectiveness rigorously. We are confident about two deployments of non-lethal methods to prevent predation on livestock. The first is the deployment of herders using low-stress livestock-handling techniques. The second is the deployment of light deterrents when wild carnivores are not already habituated to human lights with the caveats discussed above. We also have some confidence in fladry from other RCTs and non-RCT studies (Davidson-Nelson and Gehring, 2010; Iliopoulos et al., 2019; Bruns et al., 2020) and references therein. Likewise, work in other countries is producing new insights into potentially effective non-lethal methods with larger sample sizes than have previously been achieved (Khorozyan et al., 2020; Radford et al., 2020). We and the latter continue to follow the advice of Gehring and colleagues to design non-lethal methods so that domestic animal owners can install and maintain them independently. These seem promising trends and offer managers a way to find the triple-win for wild and domestic animals in addition to people.

Conclusions

We recognize that any review and summary of evidence necessarily implies interpretations by the authors, with which other qualified experts may disagree. However, that disagreement must point to evidence as we have done, not simply dismiss or ignore the evidence we have marshaled. We are concerned about a tendency for individuals and organizations conducting applied research and management to ignore inconvenient evidence and dismiss research that strikes at fundamental assumptions about human-wildlife coexistence. Therefore, we encourage open scholarly debate centered on explicit methods, data, and inferences.

We conclude:

1. The long-held belief that randomized, controlled trials (RCTs) are impossible in wild ecosystems with working livestock is laid to rest.

2. Crossover designs reduce most confounding variables between subjects and strengthen inference beyond the gold-standard of RCTs. Yet we describe limitations precisely.

3. Non-lethal methods can be effective in preventing carnivore approaches and attacks on working livestock in fenced pastures or open rangelands. The relationship between approaches and attacks remains uncertain.

4. Lethal methods of predator control have been subjected to less robust research designs that suggest mixed results including increases in livestock losses.

5. Non-lethal methods promise the elusive triple-win for wildlife, domestic animals, and livelihoods.

Bio sketches

Figure 7. A. Treves

Adrian Treves investigates ecology, scientific integrity, public trust principles, and agro-ecosystems where crops and domestic animals overlap carnivore habitat. Founder and Director of the Carnivore Coexistence Lab, and Professor of Environmental Studies at the University of

Wisconsin–Madison, he earned his PhD at Harvard University. Beginning his career as a behavioral ecologist studying predator-prey interactions and infanticide, he pioneered in studies of vigilance before turning to carnivore-human-domestic animal interactions. The members of the Carnivore Coexistence Lab, CCL http://faculty.nelson.wisc.edu/treves/ author peer-reviewed scientific articles and an equal number of other scientific papers, including ground-breaking estimates of the hazard and incidence of wolf-poaching, and modeling risk to predict human-carnivore conflict sites. Current work of the CCL focuses on experimental evidence for the landscape of fear, reintroduction of large carnivores, and responses of wild carnivores to human-associated stimuli.

Figure 8. Abi Fergus

Abi R Fergus completed a master's degree in Environment and Resources through the Nelson Institute at the University of Wisconsin Madison. During graduate school, Abi researched the effectiveness of the deterrents fladry and foxlights at reducing carnivore visits to six livestock farms within the Bad River Tribe's Ma'iingan (Gray Wolf; *Canis lupus*) buffer zone. Abi utilized tracking skills to target camera traps and deterrents where carnivore species and the deer they often follow seemed to be approaching livestock areas on farms. Abi is now certified at the Tracker 3 level in the international CyberTracker evaluation system. Abi has utilized these tracking skills to monitor the wolf packs on the Bad River Reservation as the Tribe's wildlife specialist. Abi has also worked as a contractor for the Lac Courte Oreilles Tribe to train the wildlife biologist in wolf howl surveys, tracking, and camera trapping to study the Reservation wolf packs.

Figure 9. Sam Hermanstorfer

Samuel J. Hermanstorfer was awarded his masters of science at the Nelson Institute for Environmental Studies at the University of Wisconsin—Madison. His research investigated carnivore coexistence in western Colorado through crossover-desig, randomized-controlled trials of non-lethal deterrent devices, and interviews with participating livestock owners.

Professionally, Samuel spent a summer as a coastal bird research intern with The Wetlands Institute (Stone Harbor, NJ), where he studied Fish Crow behavior. He also worked as a zookeeper intern at Brookfield Zoo (Brookfield, IL). Sam currently works as a fishing instructor for the Wisconsin Department of Natural Resources in Milwaukee, WI. In his next role, Sam hopes to focus on conserving Wisconsin species of concern.

Figure 10. Naomi Louchouarn

Naomi Louchouarn, earned her PhD and currently works as a research scientist at the Nelson Institute at the University of Wisconsin-Madison, USA. Naomi received her Bachelor's of Science from McGill University with dual minors in wildlife biology and applied ecology. She then received a Master's of Environmental Science and Management at UC-Santa Barbara's Bren School where she focused on conservation planning. Naomi's PhD research has focused on examining the effectiveness of tools and policies to mitigate human-carnivore conflict in North America. She has also explored and published peer-reviewed papers about what makes high quality carnivore science.

Figure 11. Omar Ohrens

Omar Ohrens is a Chilean agronomist from the Catholic University of Chile. After his professional degree, he worked as an associate researcher at the Fauna Australis Wildlife Laboratory working on several wildlife conservation projects throughout the country. He then completed a master and doctorate degree at the University of Wisconsin-Madison at the Carnivore Coexistence Lab. His graduate research focused on the conservation of carnivores, including pumas, and human-carnivore coexistence in Chile. His research has been funded by the US Fish and Wildlife Service-Wildlife Without Borders conservation program and the National Geographic Society-Conservation Trust. He is currently a Conservation Scientist for the NGO Panthera, Puma program, focusing on puma conservation in Latin America. Specifically, his work focuses on range-wide assessments of pumas across Latin America, puma-human conflict and coexistence and, facilitating and expanding Panthera's puma conservation strategy in Latin America.

Figure 12. Alexandra Pineda Guerrero

Alexandra Pineda Guerrero is a Colombian biologist from Javeriana University. After earning her bachelor's degree, she gained experience by working with the NGO ProCAT Colombia, where she contributed to conservation projects in Colombia and Costa Rica. Alexandra has conducted research projects in collaboration with government environmental agencies, NGOs, and local communities in Colombia. Since 2015, Alexandra has been a member of the Carnivore Coexistence Lab, having joined during her master's at University of Wisconsin-Madison. Currently, she is a PhD candidate. Her doctoral research focuses on the functional and perceived effectiveness of a non-lethal method to prevent puma and jaguar attacks in two areas in Colombia. She is also conducting a longitudinal study assessing changes in attitudes of participants in RCTs. Her research interests include human-carnivore interactions, carnivore ecology, the human dimensions of conflict and applied research to inform decision making.

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