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Tools for co-existence: Fladry corrals efficiently repel wild wolves (*Canis lupus*) from experimental baiting sites

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Abstract

Context. Mitigating wolf–livestock conflict is crucial for both wolf (Canis lupus) conservation and livestock farming. Wolf attacks at livestock gathering areas often result in surplus killing, severe economic losses and emotional distress for the farmers, and financial claims from compensation funds. They may also trigger retaliatory killing of wolves. One method for reducing attacks on gathered livestock is the fladry fence, a primary repellent based on wolf neophobia. Fladry, used mainly in North America, remains largely untested in southern Europe.

Aims. To test the effectiveness of fladry corrals at excluding wild wolves from experimental feeding sites and discuss their potential for protecting livestock in human-dominated landscapes.

Methods. We tested the repelling efficiency of fladry corrals at six stations baited with livestock remains close to the homesites of three wild-wolf packs in central-northern Greece. Using infrared cameras, we recorded approaching and feeding rates of wolves, brown bears and wild boars attracted to the baits, before and during fladry use.

Key results. The feeding rate of all wolf packs reduced to zero during fladry use. Effective repelling lasted from 23 to 157 days and ended with the removal of fladry. Wolf approaches also reduced by 75%. Modelling of wolf-approach levels showed fladry effect to be stronger when using a less attractive bait and weaker as pre-baiting duration or wolves' pre-exposure time to fladry increased. Fladry also significantly reduced the overall feeding rates of wild boars, whereas repellence of brown bears was poor.

Key conclusions. Fladry can be a cost-effective tool to exclude wolves from small-sized corrals, for weeks or months. It may also be useful for repelling wild boar. We recommend further testing with live-prey at the regional scale with standardized protocols.

Implications. Fladry installation at farms should take into account livestock attractiveness and wolf habituation. Fladry efficiency and deterrence duration can be improved when it is combined with other livestock protection methods. Wolf habituation to fladry can be reduced by deploying it primarily in high-risk depredation areas. Moreover, deployment soon after an attack could prevent wolves from associating specific farms with being sources of prey.

Additional keywords: brown bear, Greece, livestock, mitigation, predation, surplus killing, wild boar, wolf.

Introduction

Across most of its range the grey wolf (*Canis lupus*) feeds mainly on large and medium-sized wild ungulates (Newsome *et al.* 2016); a pattern observed both in long established and in recovering wolf populations (Nowak *et al.* 2011; Wagner *et al.* 2012). In southern Europe wolves can seasonally or regionally depend on anthropogenic food sources such as livestock, carrion, and garbage (e.g.; Torres *et al.* 2015; Lahneza and López-Bao. 2015; Petridou *et al*. 2019) and can cause considerable damage to livestock (Gazzola *et al.* 2008; Iliopoulos *et al.* 2009; Pimenta *et al*. 2017).

The need to develop non-lethal, economically affordable, socially acceptable, and effective methods to reduce livestock depredation by wolves has been attracting increasing scientific and public attention in recent years (Krofel *et al.* 2011; Chapron *et al.* 2014; Miller 2015; Treves *et al.* 2016; Bergstrom 2017). In Europe, most wolf attacks – as an absolute number of incidents – involve livestock grazing in pastures, with only 2.3-18% concerning penned livestock at night (Ciucci and Boitani 1998; Gazzola *et al.* 2008; Iliopoulos *et al.* 2009). However, attacks at livestock pens can result in the killing or wounding of many times more animals than those occurring in pastures (Ciucci and Boitani 1998; Gazzola et al. 2008; Iliopoulos et al. 2009). Such surplus killings reinforce negative attitudes towards wolves within rural communities, and have a disproportionate financial cost on insurance-fee based compensation systems (Gazzola *et al.* 2008). This is the type of livestock damage that we focus on in this study.

Permanent fencing, electric or not, has been used successfully to protect gathered livestock (Miller *et al.* 2016; Stone *et al.* 2016, Van Eeden *et al.* 2017). Its effectiveness can be further increased when combined with other depredation prevention methods such as the use of livestock guarding dogs (Giannakopoulos *et al.* 2017; Eklund *et al*. 2017).

However, using carnivore-proof fencing may be impractical in mountainous and steep terrain or when livestock need to stay temporarily close to grazing grounds. For instance, in Greece, transhumance pastoralists herd their sheep at higher altitude in the summer, away from their permanent winter pens (Hadjigeorgiou 2011).

To address such limitations, an alternative, mobile type of fencing is required. The 'fladry-fence' (hereafter fladry) has been used traditionally in Eastern Europe for centuries to funnel wolves towards a kill zone during wolf hunts, or more recently for live-capturing wolves for scientific purposes (Okarma and Jedrzejewksi 1997). It consists of red or other light-colored flags hung at regular intervals along a thin rope which is strung alone or along an existing fence to form a fluttering visual barrier. Currently, fladry use for protecting gathered livestock is mainly limited to North America (e.g. Primm *et al.* 2017; Stone *et al.* 2016; 2017) and some parts of Europe (Reinhardt *et al.* 2012).

Having evidence of effectiveness is recognized as a prerequisite for advocating the use of livestock loss prevention methods (Van Eeden et al. 2018), but challenges in evaluating them under field conditions has led to many methods being used based only on limited field testing (Shivik 2006; Treves *et al.* 2016). A review by Eklund *et al.* (2017) of interventions to reduce carnivore-livestock conflict concluded that while there is evidence fladry affects wolf movement, the sample size of related studies remains small.

Fladry is a primary repellent with its effectiveness based on carnivore neophobia (Harris and Knowlton 2001); wolves generally respond to novel stimuli by expressing suspicion, fear, confusion, hesitation and ultimately avoidance (Musiani and Visalberghi 2001; Musiani *et al.* 2003; Shivik *et al.* 2003; Lance 2009; Lance *et al.* 2010). As such, time is an important factor for fladry effectiveness as wolves tend to habituate to its presence after the initial novelty fades (Musiani *et al.* 2003; Shivik *et al.* 2003). The duration of fladry effectiveness has been tested on captive wolves and ranged from 30 minutes to 28 hours (Musiani and Visalberghi 2001; Musiani *et al.* 2003; Lance *et al.* 2010). Under field conditions at baiting stations or farms, fladry reduced wild wolf incursions for approximately two months (Musiani *et al.* 2003; Davidson-Nelson and Gehring 2010). Shivik *et al.* (2003) found overall deer carcass consumption by scavengers not to differ significantly before and after fladry use, but the study did not specify the effect fladry had on consumption by wolves. Eklund *et al.* (2017) pointed out the need for studies that a) disentangle the carnivore deterring effect of human-presence from that of the fladry (e.g. Musiani *et al.*

2003) and b) are long enough to properly evaluate the duration of fladry deterrence.

So far fladry's effectiveness in deterring wolves has only been tested in North America. Since wolf packs in southern Europe have adapted over generations to prey or scavenge on livestock in human-dominated landscapes, it is important to test the method thoroughly in the region. Tests should be done under realistic field conditions prior to advocating fladry use by local pastoralists, who are typically skeptical of novel methods they perceive to be 'foreign' and 'naïve' of local realities.

This study was carried out at the core of the Greek wolf population, an area in which wolves have been continuously present for millennia. We tested on wild wolf packs the hypothesis that neophobia induced by fladry can modify wolf behavior to not scavenge on a typical anthropogenic food source – livestock remains. Specifically, using experimental baiting stations within known wolf pack territories, we examined: a) the approach and feeding rates of wolves at bait sites before and during fladry use, and b) the effect of elapsed time since fladry use on its deterrence effect on wolves. We also opportunistically examined the response of brown bears (*Ursus arctos*) and wild boars (*Sus scrofa*) to fladry – two species which can also cause conflict with human rural activities (Amici *et al.* 2012; Ballari and Barios-Garcia 2014; Bautista *et al.* 2017; Lombardini *et al.* 2017). Finally, we discuss fladry's potential to reduce carnivore attacks on livestock in Greece, and propose ways of improving future studies examining fladry effectiveness.

Materials and methods

Study area, selection of baiting locations and monitoring of large mammal responses

We studied the response of wild wolf packs to baiting stations before and during fladry use from March to November 2015. Winter months were excluded due to access issues, to avoid disturbance from hunting (i.e. hunting dog consumption of baits), and to reduce the risk of equipment theft.

We considered as potential experimental baiting stations areas close to five homesites of four different wild wolf packs well known to us (Iliopoulos *et al.*

2014), where wolf presence was expected to be high throughout the study period. Prior to starting the study, the territorial presence of the wolf packs was verified for two months with automated camera, snow tracking and sign-track surveys. Ultimately, we selected three homesites of different packs separated by >20 km. We defined one to three baiting stations per pack (n=6), which were >1000 m apart (range = 1.1 – 4.8 km, within the same wolf territory), to account for seasonal shifts in a pack's movements within its territory. At any given time, only one bating station was operated per pack area, and C2 was only used during the pre-treatment phase (Table 1). Wolf pack homesite area A and baiting station A1, were located in Hasia Mountains, Central Greece, at 900 m.a.s.l., in a highly forested area with oak (*Quercus sp.*) interspersed with cedar (*Juniperus oxycedrus*) scrublands and wheat fields. Average free ranging sheep-goat and cattle density in area A, is 71 head/100 km^2 and 6.1 head/100 km^2 respectively (Hellenic National Statistic Service 2009). Wolf pack A consisted of four animals, a marking wolf pair and two sub-adult individuals. Wolf pack area B and baiting stations B1 and B2 were located at Vourinos Mountains in Central Macedonia at 1300 m.a.s.l, with black pine forests *Pinus nigra* mixed with *Carpinus orientalis* and *Ostrya carpinifolia* thermophilus deciduous stands. Average free ranging sheep-goat and cattle density in area B, is 109 head/100 km^2 and 1.3 head/100 km^2 respectively (HNSS 2009). Wolf pack B consisted of at least five animals at the onset of the experiment, a reproductive wolf pair and 3 subordinate individuals. This pack reproduced successfully during the experimental period as we photo-trapped wolf pups at the baiting sites. Wolf pack area C and baiting stations C1, C2, C3, were located in Hasia Mountains, Central Macedonia, Grevena municipality, at 800 m.a.s.l.. The habitat characteristics were the same as in area A. Average free ranging sheep-goat and cattle density is 98 head/100 km^2 and 2.7 head/100 km^2 respectively (HNSS 2009). Wolf pack C consisted of at least six animals at the onset of the experiment, a reproductive wolf pair and four sub-adult individuals. All baiting stations were >2km from human settlements and seasonal grazing areas, to minimize the risk of site disturbance by livestock, equipment theft by humans and bait consumption by shepherd dogs. All three wolf packs were known to frequent livestock grazing areas to kill sheep, goat and cattle (Iliopoulos *et al.* 2009; Iliopoulos 2010; ELGA 2016). At all sites, brown bears are common and breeding, roe deer (*Capreolus capreolus*) are present at low densities and wild boars are abundant. The baiting stations were >100 m away from roads (incl. dirt/logging roads), in natural forest openings of >1 ha in size. During the pre-treatment phase no fladry was used. The treatment phase involved placing fladry in the form of a circular corral of 8.5 m radius (220 m^2 area / 55 m perimeter) centered around the bait (Fig. 1). The design resembled in size the temporal corral used by transhumance pastoralists to accommodate ~100 sheep/goats in summer pastures.

Fig.1

During spring and early summer, we used as bait fresh goat or sheep carcasses from healthy adult individuals. They were tightly attached to a small tree in the center of the baiting site, to prevent them from being dragged away by wolves or other large mammals. In late summer and autumn, we also alternatively used as bait 50-60 kg of goat or sheep animal parts (viscera, intestines, skin, fat and legs) since the fast decomposition of carcasses necessitated the use of additional sources of baits. Animal remains are known to attract wolves to offal sites in the study area and elsewhere in Greece (Iliopoulos 2010). All baits were provided by the public slaughter house of Grevena municipality. We increased the probability of wolves detecting the bait by dragging animal viscera from the nearest paths and dirt roads all the way to the bait stations. We only visited the stations for rebaiting and spent less than an hour in the area to minimise human disturbance. During these visits we also repaired fladry flagging (coiling, tearing) when necessary and checked the trail cameras.

We baited each station during pre-treatment twice, except in C1 where we baited once (Table 1). We installed fladry at a station only after we confirmed that wolves had approached and fed on the bait. We rebaited the stations in total 18 times during fladry use (mean 3.6 ± 2.3 SD per station, range 1-7, n=5) (Table 1). We used livestock carcasses at stations A1, B1, C1, in five out of 11 pre-treatment and nine out of 18 fladry treatment baitings. The bait used for each station's pre-treatment and fladry treatment phase was the same.

To monitor large mammal activity at each baiting station, we used automatic trail cameras with infrared illumination. One camera (Reconyx RC60) was placed at the access path/road, three (Bushnell HD Trophy Cam) monitored the periphery of each baiting station, and a fifth (Reconyx RC60/HC 600) was mounted on a tree, inside the fladry fence, facing the bait from a distance of seven to ten meters (Fig. 1). We camouflaged the cameras with branches. All camera models used non-visible 900 nm infrared illumination, to not interfere with the experimental process by distracting the wildlife. The cameras were set to be active continuously (24h/day) and to take, when triggered by movement, a burst of three high resolution pictures at one second intervals. We consider it unlikely that a large mammal could approach or trespass the fladry or feed on the bait without being recorded, as all the field-team's movements during re-baiting visits were recorded. We considered an animal as having trespassed the fladry when it was recorded feeding on the bait by the central camera located inside the fladry. To avoid pseudo replication and to account for limited camera trap availability, we run up to two baiting stations at a time and always only one within a wolf pack territory during the fladry treatment phase (Table 1).

Fladry design and deployment

Fladry flagging consisted of 50X10 cm lightweight orange-colored nylon flags, hanging at length, spaced over a 4 mm nylon rope at 50 cm intervals (Musiani *et al.* 2003; Young *et al.* 2015) (Fig. 2).

Fig. 2

To reduce the coiling of flags by wind and thus creation of gaps that could encourage wolves to trespass, the flags were attached to the nylon rope in a way that permitted their free oscillation and rotation as proposed by Young *et al*. (2015). To ensure good tension of the nylon rope (Primm *et al.* 2017), we hung fladry over light-weight, dark-colored laminated posts (length 120 cm) spaced at 2.5-3 m intervals and inserted at least 20 cm into the ground. The rope was attached to the posts with tie wraps (cable ties) at 75-80 cm from the ground, so that the clearance of the lower edge of the flags to the ground to be <30 cm. The fladry cost per meter was estimated at 1.67 € (1.85 $), including materials used and the labor to cut the flags. The cost does not include our personal labor to assemble and attach flags at the rope, which required approximately two working days for a 50 m fladry fence.

Sampling unit for wolf responses at baiting sites

To buffer for individual wolf responses, we divided the whole experiment in 47 equal duration 'experimental periods' of approx. 11 days each (x=11.1 ± 1.2 SD), based on the average time that wolf packs took to completely consume pre-treatment baits (i.e. stop visiting it; x=10.8 ± 3.8 SD days, n=11) (Table1). Moreover, the average rebaiting time corresponding to each experimental period was 10.2 days (± 7.2 SD). Pooling our data this way permitted better estimation of feeding and approaching variation than day-level analysis, as in the latter case we would have zero-inflated results (Min and Agresti 2005).

Table 1.

To address uncertainty regarding null responses to the baits for reasons other than fladry use (e.g. due to seasonal movements), we excluded from the analysis those experimental periods when the subjects (wolves, bears, wild boar) were absent from the broader baiting station area. Absence was deduced by the lack of fresh field signs during field visits and no camera detections. We adjusted all time variables in our dataset to reflect actual animal exposure to baits and fladry.

Response variables to treatments

Wolf behavioral responses were pooled together per experimental period and baiting station, as individual identification was not possible. Wild boar responses were pooled per social group as defined by Maselli *et al.* (2014). Brown bear responses were at the individual level, as identification was feasible based on size, color and distinctive body features.

We defined as a single '*Approaching event*' of a species any animal movement towards the bait, separated by ≥1 hr from a conspecific's visit. When followed by bait consumption, the incident was also registered as a '*Feeding event*'. All fladry trespasses led to feeding.

We considered three response variables per species: a) Approaching rate (APR) = sum of '*Approaching events*' per experimental period (i.e. ~11 days), b) Feeding rate (FDR) = sum of '*Feeding events*' per experimental period, and c) feeding to approaching ratio (FDR/APR) = ratio of '*Feeding events*' to '*Approaching events*' per experimental period.

For each baiting station and species, we estimated the fladry deterrence duration (hence "fladry survival") until trespass, or until the end of the experiment when no trespasses occurred, in three ways: a) as the days elapsed since fladry installation, b) as the number of days with recorded species presence ("distinct visitation days"), and c) as the cumulative approaching rate. For wolves, "fladry survival" was estimated and expressed per wolf pack. For wild boar it was estimated separately per social groups that trespassed fladry and those that did not. For brown bears it was estimated per individual or family group.

Statistical analysis

To compare the approach rate, feeding rate, and approach/feeding ratio between pre-treatment and fladry treatment for each species, we used the non-parametric Wilcoxon signed rank exact test for related small-sized samples (Whitley and Ball, 2002). We considered baiting stations as our statistical sampling unit (n=6) rather than the number of wolf packs (n=3) because in our study baiting stations serve as analogues of livestock farms within a wolf landscape. Therefore, we believe that pseudo replication – conceptually – is not a serious concern for this test.

To measure the magnitude of fladry's effect, we calculated the effect size (r) according to Field (2005): $r=z/\sqrt{(2n)}$, where z is the z-score normal approximation statistic derived from Wilcoxon signed rank test, and n the sample size. Only for this test we divided approach rate and feeding rate by the duration of each experimental period (i.e. APR/day, FDR/day), to transpose variables to the same scale as the FDR/APR rate and facilitate graphic presentation of results.

To explore the effect of time on wolf approach rate, we calculated a series of variables (e.g. baiting duration, re-baiting interval, and elapsed time since exposure to fladry) and bait type used on fladry efficiency (Table 2), and used generalised linear mixed effect models (GLMM) as they have been developed to handle random effects and repeated measures data (Agresti 2002).

Table 2

We ran GLMM models considering only wolf responses, as we designed our experiments focused on this species. We structured our data according to pack area first, then to baiting station and finally to chronological order. The response variable was counts (sum of wolf approaching events) per experimental period. The use of 'time' as an effect can be used in situations "where patterns over time, or interactions of main effects and time, are of interest" as in our experiment (Robinson et al 2006).

We tested two factors as probable random effects: wolf pack area and baiting station. We selected only approach rate as the GLMM response variable, as feeding rate and FDR/APR ratio equaled zero during fladry use, as no wolves ever trespassed.

We first ran a series of univariate models testing all predictor variables to select only those that performed better than the null model. To avoid multicollinearity effects in multi-variate models, we excluded correlated variables ($r_s>|0.6|$) and models with Variance Inflation Factor (VIF) >2.5 (Zuur *et al.* 2010).

To address data over-dispersion due to zero-inflation, we used a negative binomial distribution with a log-link function (Ver Hoef and Boveng 2007) and considered over-dispersion as non-prominent when deviance and Pearson dispersion ratios were ~1 (McCullagh and Nelder 1989).

We ranked candidate models using Akaike Information Criterion corrected (AICc) for small sample sizes (Burnham and Anderson 2002). We selected the suitable covariance type according to how model fit was improved based on AICc (Barnett *et al*. 2010). We used the Satterthwaite approximation to allow for degrees of freedom to vary across tests, as our samples were small (Li and Redden 2015; IBM 2016). To handle violations of model assumptions, we used robust estimates for the covariance matrix parameters (IBM 2016). All analysis was conducted using SPSS24 (IBM 2016). Since there was no strength of evidence in favor of a single model (i.e. AICc weight >0.9), we estimated the predictor variable's beta coefficients by model averaging as per Symonds and Mussalli (2011) all models with ΔAICc>2 (Burnham and Anderson 2002).

Results

The pre-treatment phase across all bait stations lasted 154 days, and fladry treatment 345 days (Table 3).

Table 3.

Wolf responses

Wolves (minimum n=20) approached and/or fed at all six baiting stations over 85 distinct visitation days during both phases (Table 3). Fladry was set at five baiting stations because in C2 field evidence showed the wolf pack to be absent during the pre-treatment phase. Eventually, fladry was evaluated only at four of those stations as in C1 the wolf pack left the area during the treatment phase.
We did not observe any wolf feeding on the bait while the fladry fence was in place. Wolves approached the fladry corrals at distances >5 m, where they were recorded staring at the fladry flagging and/or marking.
Overall, the median wolf approaching and feeding rates per 11-day period decreased by 75% and 100% respectively after the installation of fladry (Fig. 3). The fladry effect on approach rate was strong (r=0.52), and very strong (r=0.65) and significant on feeding rate (z=1.826, n=4, one-tailed P=0.0625 – p equals to maximum achievable level for the small sample size used at a=0.1).

Fig. 3

Fladry ‘survival’ per station (n=4) was on average: a) 77 experimental days (range = 23-126, SD= 43), b) 8 distinct visitation days (range= 6-9, SD=2) and c) 15 cumulative approach events (range=10-19, SD=5). Since no wolf trespassed the fladry fences before the termination of the experiment, the fladry survival figures can be considered as minimum values. In baiting station A1, the experiment discontinued prematurely after a male brown bear destroyed 8m of the fladry perimeter on the first day of its deployment. Despite that large opening, wolves approached in total 11 times but did not trespass the fladry until its removal 11 days later.

At the level of wolf packs, fladry survival was highest in terms of experimental days elapsed (n=157), visitation days (n=18), and cumulative approaching events (n=38) in wolf pack area B.

At station B1, where the bait was left in place after removing the fladry, feeding to approach ratio increased from 0% during fladry use to 91.7%, which was even higher than the pre-treatment phase (76.6%).

Moreover, at baiting station B2, we recorded direct wolf-bear competition during the pre-treatment phase. A pair of wolves confronted on 20/7/2015 and 9/8/2015 for 1.5 hrs and 5 hrs respectively an adult brown bear which strongly defended access to the bait (animal remains). The wolves managed to feed on the bait on both occasions with the bear present 2-3 meters away (Fig. 4).

Fig. 4

Wild boar responses

We recorded responses of wild boar individuals and social groups (n=34 groups; average group size=5.2, range=2-20). Wild boars appeared and fed at all six baiting stations over 84 distinct visitation days, and approached all five of the fladry fences (Table 3).

Fladry trespasses by wild boars occurred at two (B2, C3) baiting stations. In B2 only a solitary adult male boar entered the fladry corral, while social groups – including a large mixed group and smaller family groups – did not trespass. In C3, the fladry was trespassed twice by several members of a large mixed social group.

Overall, the median approach rate slightly increased, while median feeding rate and feeding/approach ratio decreased by 100% after fladry installation. (Fig. 3). Fladry effect was strong (r=0.58) and significant only for feeding/approach ratio (z=1.826, n=5, one-tailed P=0.063 – p equals to maximum achievable level for the small sample size used at a=0.1).

Fladry 'survival' per station (n=5) and seven social units was on average: a) 61 experimental days (range=7-126, SD=41), b) 5 distinct visitation days (range=0-15, SD=6) and c) 17 cumulative approach events (range=0-82, SD=30).

Brown bear responses

We were able to recognise nine brown bears or family groups which visited over 51 distinct visitation days four of the five baiting stations during the pre-treatment phase and three during the fladry use phase. Of the five bears/family groups that approached the fladry corrals, three fed on the baits.

Overall, median approach rate, feeding rate and feeding/approach ratio decreased by 13%, 35% and 55% respectively during the fladry phase (Fig. 3). Fladry effect was strong (r=0.65) and significant only for feeding/approach ratio (z=1.604, n=3, one-tailed P=0.125 – p equals to maximum achievable level for the small sample size used at a=0.1).

Fladry 'survival' per station (n=3) and five bears/family groups was on average: a) 56 experimental days (range=1-126, SD=47), b) one distinct visitation day (range=0-5, SD=2) and c) two cumulative approach events (range= 0-8, SD=3).

Shepherd dog responses

Although the baiting stations were far from human settlements and farms, we recorded shepherd dogs at the baiting stations (station A1 - 5 dogs/over six distinct days, and station C3 - 7 dogs/over 6 distinct days). In all occasions, the dogs trespassed the fladry fences and fed on baits of all types and age.

Wolf response related to time and bait type

Our data consisted of 36, 11-day experimental periods when wolves were present. Of the 26 candidate GLMM models considered, three met the ΔAICc≤2 criterion and were considered during model averaging (Table 4).

Of the repeated measures and random effect covariance types considered, scaled identity resulted in the best fit in all models, indicating a low temporal dependency amongst experimental periods. Pack area and baiting station, when included as random effects in GLMM, did not improve the fit of the models.

The variables included in the three top models and therefore in the average model were: interaction of fladry use and bait type, overall time elapsed after onset of fladry use (FS), pre-treatment phase duration (PS), and prior exposure of the wolf pack to fladry at another baiting station (PD) (Table 4). Approach rate levels were negatively and significantly related to the duration of fladry deployment (i.e. FS/PD: ratio of fladry use duration to the total experiment duration per pack) with the effect being stronger when animal parts were used as bait instead of carcasses (Table 4).

Table 4.

According to the model averaging predictions, during the pre-treatment phase the approach rate was almost identical regardless of the bait type used. Once fladry was installed, approach rate immediately decreased on average by 63% and then continued to gradually decrease further with fladry-deployment time (FS), (Table 4, Fig. 5). Approach rates – after fladry deployment – were also 68% lower on average, when animal parts were used compared to whole carcasses as bait. For each additional pre-treatment period added (i.e. PS=11 days), approach rate levels increased on average by 15-19% (Table 4, Fig. 5).

Fig. 5

Discussion

Our study presents for the first time experimental evidence of fladry effectiveness in deterring wild wolves for significant period in a typical southern European, human-dominated, wolf habitat. Moreover, following Eklund *et al*.'s (2017) recommendations, our field testing was conducted: a) over an extended period – in fact the longest duration to date for a fladry experiment, and b) using camera traps to reduce human-presence frequency and thus a possible confounding effect on the deterrence value of fladry (Appendix I). Our results also show promising fladry deterrence effectiveness for wild boars and, to a lesser extent, brown bears. Both species are sympatric with wolves across large tracts of southern Europe and are too known to cause conflict with humans.

In terms of fladry effectiveness, our results from wild wolf packs in Greece are in accordance with most fladry studies in North America (Musiani *et al.* 2003; Davidson-Nelson and Gehring 2010; Lance *et al.* 2010). Only Shivik *et al.* (2003) concluded that fladry did not reduce bait consumption, but they could not differentiate consumption by wolves from those of other scavengers. Although our study's wolves forage extensively on free ranging livestock (live and/or carrion) and are constantly exposed to human-related stimuli (e.g. lighting, fences, vehicles), they do not appear to have a reduced neophobic reaction to fladry as captive wolves (Musiani and Visalberghi 2001; Lance *et al.* 2010) and dogs (this study) do. Fladry has not been used in Greece for wolf persecution, so it cannot account for the observed wolf wariness to it. The wariness could in part reflect the species' persisting illegal persecution in Greece, despite nominal protection by the state.

Fladry effect on wolf approach levels

While the observed complete cessation of feeding following fladry use was the ultimate goal, the concurrent 75% reduction in approach rate is also noteworthy. Approaching is linked to overall livestock predation probability (Hebblewhite *et al.* 2005) and habituation to fladry (Mettler and Shivik 2007). Reduced approach rates were also reported by Musiani *et al.* (2003) at baiting stations, where feeding ceased for the study duration (60 days). Lance *et al.* (2010) also reported a fluctuating, but overall declining, approach trend of naïve captive wolf packs at baits protected by electrified fladry.

Our study's decreasing approach rate during fladry use could be due to changes in pack cohesiveness, which is reduced during summer months, or a seasonal variation in pack presence at the baiting stations. Seasonal variations in wolf sociality can affect the foraging behavior of wolves (e.g. Metz et al 2011). Furthermore, the researchers' presence at the baiting stations could have also contributed to the reduced wolf approach rate. Despite the absence of control stations to test for such changes, we remain confident about the strength of the observed fladry effect because we: a) monitored wolf presence throughout the study at the immediate vicinity and removed from the analysis periods when pack presence was not confirmed, b) incorporated in our analysis researcher presence as a variable (see "rebaiting time" in Table 2) and found it no to be informative, c) our study has the lowest researcher visitation frequency compared to similar fladry studies (Appendix 1), and d) observed the same pattern across all wolf packs. Our proposed explanation for the reduced approach rate is that the fladry's deterrence effect (i.e. visual and also acoustic when windy) extended for wolves beyond the range of the fladry-perimeter cameras (Fig. 1).

Our study also shows the importance of properly installing and maintaining the fladry fence. Wolves only touched the fladry – still without trespassing – where a section had been knocked down by a brown bear. The sole wolf trespassing of fladry reported in Davidson-Nelson and Gehring's (2010) study also occurred only after a large fladry opening was accidentally created at a large cattle farm. In previous studies, no wild wolves have trespassed small perimeter fladry fences like ours (Appendix I). Musiani *et al*. (2003) and Lance *et al.* (2010) proposed that fladry could be more practical for protecting small livestock pens than large farms due to problems with flag coiling, which is effort intensive to check for and fix in the latter.

Fladry survival

The average fladry survival in our study (77 days/station) is comparable to reported deterrence durations in Alberta (60 days/station; Musiani *et al.* 2003), Idaho (61 days/farm; Musiani *et al.* 2003) and Michigan (75 days/farm; Davidson-Nelson and Gehring 2010), and twice as large when considered at the pack level (max. 157 days/Appendix I). Our study's values are minima, as the fladry corrals were removed before any wolf trespass occurred.

When considering fladry survival in terms of total wolf approaches per pack area, our study's findings (range 10-38/pack) are similar to Musiani *et al.*'s (2003) results in Alberta (range 16-18/station) and Idaho (6-17/farm). We believe that evaluations of fladry effectiveness should account for the frequency of carnivore presence. For instance, farms close to active wolf homesites may experience lower fladry effectiveness.

Effect of prior exposure and food attractiveness

Our reported higher approach rate levels at fladry stations with preferred baits (i.e. carcasses) and longer pre-treatment periods (Fig. 5) is in line with Musiani *et al.'s* (2003) observations; wolves which had previously preyed on cattle, although they did not trespass fladry, increased their approach rates at those farms during fladry use. Indeed, wolves are known to repeatedly attack farms where they have continuous access to vulnerable livestock (Gazzola *et al.* 2008; Iliopoulos *et al.* 2009; Pimenta *et al.* 2017). Therefore, in practice, fladry survival at farms with frequent prior livestock depredation may be shorter as persisting wolf approaching could lead to quicker habituation.

Our finding that wolves varied their fladry approach rate by bait type (Fig. 5) suggests that reducing livestock "attractiveness" (e.g. by combining fladry with other damage prevention methods) could similarly reduce approach rates and consequently increase fladry survival. Musiani *et al.* (2003) also noted that human presence amplified the effect of fladry.

Another study result, with implementation implications, is that pre-exposure of a wolf pack to fladry reduced its repelling effect at a new baiting station (Table 4). This partially contradicts Shivik *et al.*'s (2003) suggestion to redeploy fladry at new locations to maintain its novelty. Our findings suggest that the initial habituation of wolves to fladry cannot be completely reversed by shifting sites.

Brown bear and wild boar responses

Although our study was focused on wolves, we also undertook a preliminary assessment of fladry effectiveness on other large sympatric mammals. Our low fladry performance with bears is in accordance with Shivik *et al.*'s (2003) report of black bears feeding at their baiting sites. Although fladry did reduce overall brown bear feeding rates when controlling for approach rate (Fig. 3), individual bear behavior played an important role on fladry's effectiveness, as shown in other studies evaluating brown bear damage prevention methods (Skrbinšek and Krofel 2015). Presence of bears should be taken in account when considering fladry use. They could compromise the integrity of the fence, as they did in one of our bait stations, resulting in increased maintenance effort.

To our knowledge, no previous study has reported the effect of fladry on wild boars. Since we observed a significant reduction in wild boar feeding rates after fladry use (Fig. 3), its value as a crop damage prevention measure warrants closer examination.

Limitations and future research

Testing of fladry effectiveness should be ideally undertaken *in situ,* at livestock farms, by comparing losses among control and fladry-protected farms or before and after fladry use at the same farms (Musiani *et al.* 2003; Davidson-Nelson and Gerhing 2010). So, one concern about our study could be whether the baits used elicited appropriately realistic wolf responses. Since wolf scavenging of carcasses and animal parts at offal sites is well documented (Salvador and Abad 1987; Cuesta *et al.* 1991; Ciucci *et al.* 1997; Lagos and Barcena 2015; Tourani *et al.* 2014), we believe our field testing of fladry with carrion – like Musiani *et al.* (2003) and Shivik *et al.* (2003) – captured at least some aspect of wolf behavior. Evidence to that is the incident where wolves fought with a bear for access to the bait (i.e. animal parts) (Fig. 4), and that wolves immediately fed on the bait left at one station after fladry was removed. Nevertheless, we suggest that future studies further test fladry effectiveness using livestock as bait, for similar duration and with control stations.

The low wolf pack sample size of our study is a common limitation of all fladry studies to date attempting to draw conclusions at the population level (range n=1-6, appendix I). Assuming similar resource and logistic limitations in the future, we recommend regional level collaborations with standardized experimental protocols to facilitate pooling of results across studies.

Regarding wild boars, although our study used only carrion as bait and wild boars are mostly herbivorous, animal protein is as an essential dietary component for the species (Ballari and Barrios-García 2014). Therefore, while cautioning against assuming similar fladry effectiveness for crops, we believe our findings to be of interest for those exploring crop raiding prevention solutions.

Implications

Regardless of the need for further field testing, our study clearly shows the value of fladry as a primary deterrent for wolves also in southern Europe's human dominated landscape. We believe that careful planning of fladry deployment is required in order to maximise its survival and effectiveness both at the individual farm and the landscape level. Specifically, when considering fladry for areas where livestock is the primary food source for wolves, its use could divert attacks to nearby unprotected herds (e.g. Musiani *et al.* 2003). To minimize this risk, we recommend that fladry is used either where wild ungulate prey availability is high or as part of a regional strategy involving multiple producers.

Given the effectiveness and practicability of small fladry corrals, we primarily propose their short-term use for protecting transhumance sheep/goat flocks in summer grazing grounds and cattle during calving.

Since fladry was more effective with less attractive baits, we propose combining fladry with other depredation deterrents to similarly reduce the overall attractiveness of livestock as prey. For example, fladry could be combined with livestock guarding dogs (Reinhardt *et al.* 2012) – a very effective livestock depredation prevention tool (Linnell and Lescureux 2015; Eklund *et al.* 2017) – as in our study dogs appeared to be unfazed by fladry.

We also recommend using fladry prior to – or as soon as possible after – an initial wolf attack at a farm, to prevent wolf habituation to livestock depredation. Consequently, fladry use should be prioritized for farms with higher risk of livestock depredation in an area, to delay overall exposure and eventual habituation to fladry by local wolf packs.

Another use for fladry could be to protect livestock carcasses from being scavenged by wolves until a post-mortem examination by veterinarians is possible. This would reduce the risk of attributing the kill to wolves in compensation claims, when the cause of death was not due to wolf depredation, or a farmer losing compensation after predation evidence is destroyed due to extended carcass consumption.

In terms of fladry design, we propose flagging color that contrasts with the background. Also, the flagging should be free to swivel, so as to reduce coiling and to increase fluttering in the wind which may play an important role in repelling wolves (Primm *et al.* 2017).

We do not recommend fladry for protecting livestock or beehives from brown bears as their response was unpredictable and differed among individuals. Instead, we encourage further testing of fladry to protect valuable crops (e.g. vineyards) from wild boar raiding. Moreover, since electric fencing has already been shown to reduce wild boar damages to crops (Geisser and Reyer 2004), we suggest combining fladry with electric fencing (‘turbo fladry’, see Lance et al. 2010) as a wild boar deterrence.

In conclusion, our findings suggest that careful a) planning in selecting farms, b) timing of its use, and c) combination with other preventive methods can increase fladry effectiveness as a tool for preventing livestock depredation by wolves. Using fladry for reducing crop raiding by wild boar is another promising use for fladry that should be further explored.

Conflicts of interest

The authors declare no conflicts of interest.

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901 **Appendix I. Summary of studies evaluating effectiveness of fladry and electrified fladry on wild wolves.**

	Shivik *et al.* 2003	Musiani *et al.* 2003	Musiani *et al.* 2003	Davidson-Nelson and Gehrig 2010	Lance *et al.* 2010	This study
Area	Wisconsin, USA	Alberta-Canada	Alberta Canada and Idaho USA	Michigan USA	Montana USA	Central –northern Greece, Southern Europe
Repellent	Fladry corral, MAG	Fladry corrals	Fladry fence	Fladry fence combined with electrified fencing	Electrified fladry fence	Fladry corrals
Subjects and sample size	Six wild wolf packs, black bears, bald eagles, fishers	Two wild wolf packs	Three wild wolf packs	One pack of wild wolves	Three wild wolf packs	Three wild wolf packs, Wild boar, Brown bears
Experiment type	• Pre-treatment / treatment • Baiting stations • 1 plot per repellent. • 1 control plot without repellent • 30 m. circumference	• Pre-treatment / treatment / post treatment • Baiting stations (n=2) • 10X10 m plots	• Pre-treatment / treatment / post treatment • Farms (n=3) • Comparisons with control farms • Several km of fladry	• Case-control • Fenced-farm trials (n=4 per treatment) • 169ha farm size in average	• Case-control • Cattle farms (n=6, per treatment)	• Pre-treatment / treatment • Baiting stations (n=6) • 60 m. circumference
Season	Spring 2002	Winter 2001, 2002	Winters 2001, 2002 (Alberta), Summer 2002(Idaho)	Summers 2004, 2005	Autumn-Winter 2005	Spring- Summer-Autumn 2015
Attractant	Road-killed deer	Road-killed deer	100-400 cattle	Sheep, cattle	Cattle (40-200)	Livestock carrion
Surveillance methods	• Consumption rates measured at site • Camera traps	• Snow-tracking • Consumption rates measured at site	• Snow-tracking • VHF telemetry	• Wolf signs at scent stations • Farmer reporting	• Track surveys /VHF telemetry assisted • Damage inspection • Farmer reporting	• Camera traps • Bait inspection
Researcher visitation frequency.	2-3 days	3 days	3 days	3-5 days	Bi-weekly	11 days in average

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	Shivik *et al.* 2003	Musiani *et al.* 2003	Musiani *et al.* 2003	Davidson-Nelson and Gehrig 2010	Lance *et al.* 2010	This study
Response metrics	• Proportion of carcasses consumed per day	• Bait consumption rates • Number of approaches and feedings per 60-day period	• Number of approaches and feedings per 60day period (Alberta) • Days for intrusion (Idaho)	Wolf visits inside and outside farms per farm year	• Number of wolf signs or entrances • Cattle killed in and out of fladry fence	• Cumulative approach and feeding events per experimental period/day/baiting station /species • Feeding to approach rates/species
Duration of repellent testing	16-29 days	2 months per pack	2 months per pack (Alberta)- open for Idaho	75 days	90 days	23 to 165 days per pack
Overall duration of study	60 days	180 days per pack	180 days per pack	75 days (per year)	90 days	58 - 227 days per pack
Main effects	• Fladry did not reduced scavenger guild consumption • Most consumption by black bears and bald eagles	• Stopped wolf completely • Approaches decreased in one pack • Approaches stopped post fladry (i.e. after 120 days)	• Stopped completely wolf feeding in both packs/farms • Approaches increased in one farm during treatment • Approaches and feeding reduced in post-treatment for one pack	• Wolf visitation inside fladry protected farms was 2-3 times less • No wolf depredations at both treated or control farms	• Low wolf visitation rate overall • Few days with approaches & entrances in control farms (n=4) • No entrances in treated farms	• Stopped completely feeding in all packs • Wolf approaches decreased by 75% • Wild boar feeding and feeding to approach rate decreased considerably • Brown bear feeding to approach rate decreased. • Not homogenous response amongst wild boar and bears • Pre-treatment duration and pre-exposure increased wolf approaching during fladry use
Effect duration	Not specified for wolves	60 days minimum (termination)	• 60 days minimum (termination) • 61 days in Idaho (trespass)	75 days minimum	90 days	• Minimum 23 to 157 days per pack (termination) • Average 61 days per baiting station for wild boar

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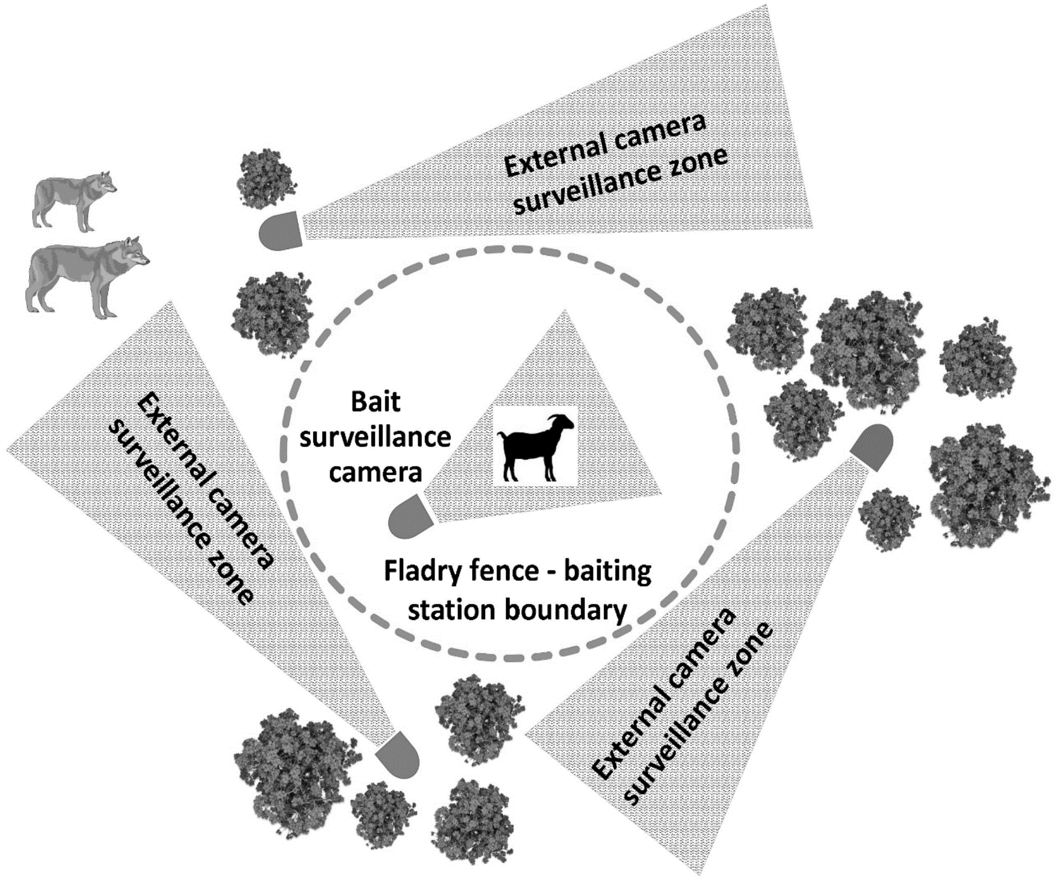

Fig 1. Schematic representation of bait, fladry corral and surveillance camera installations at baiting stations. The setting enabled detection of approaching mammals at a maximum range of 20-30 m.

Fig. 2. Fladry corral installation at baiting station A1.

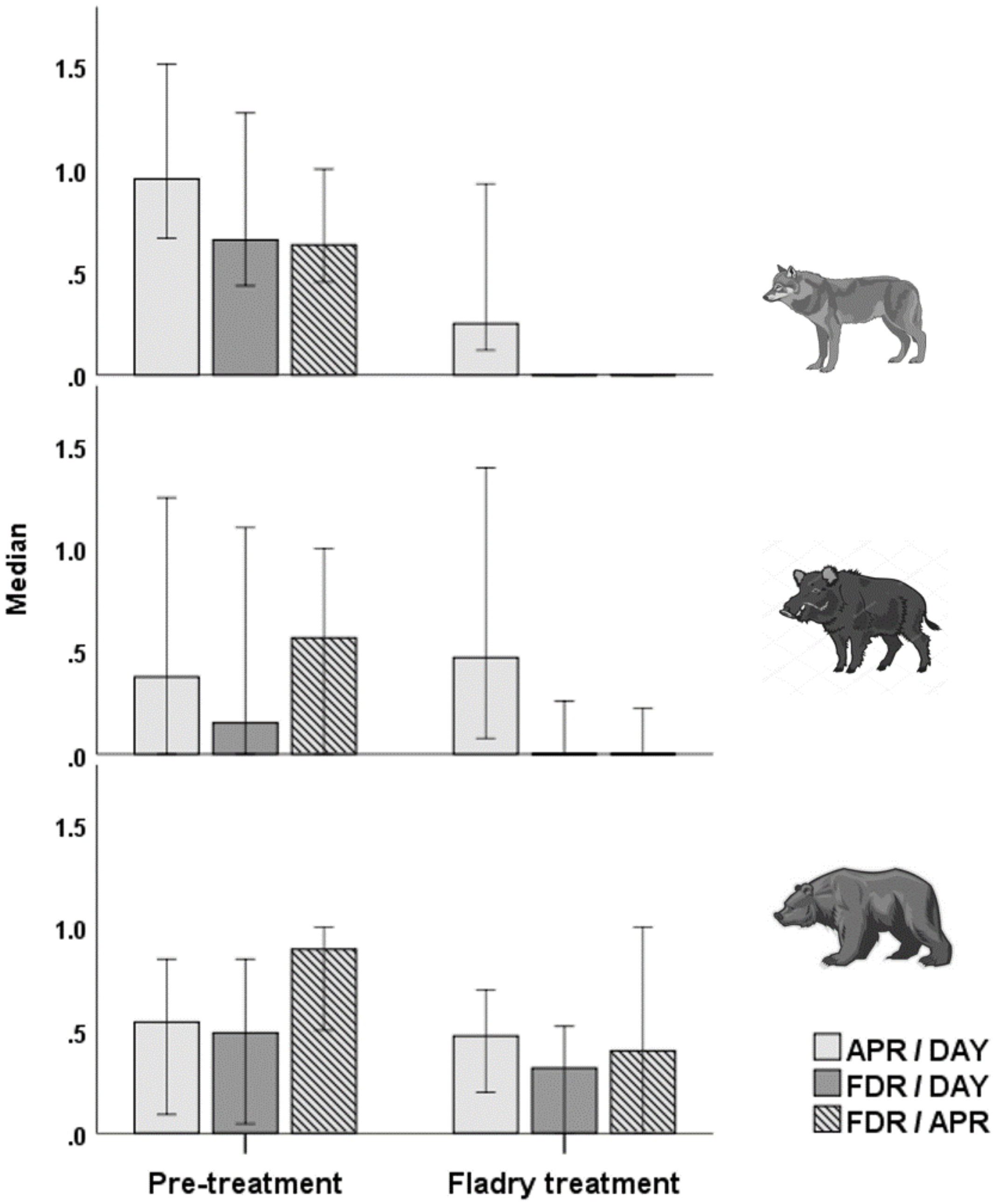

Fig. 3. Overall approaching rate (APR/day), feeding rate (FDR/day) and FDR/APR responses per baiting station, species and treatment. Error bars represent 90% confidence intervals of the median values estimated. Only data from successfully paired-stations (i.e. stations under both pre-treatment and fladry treatment) were used to draw figures.

Fig. 4. Wolves confront at close distance a bait-defending adult bear to feed on animal-part baits during pre-treatment phase at baiting station B2. Wolves managed to feed in several cases when the bear was present, as shown from pictures of the central bait-surveillance camera.

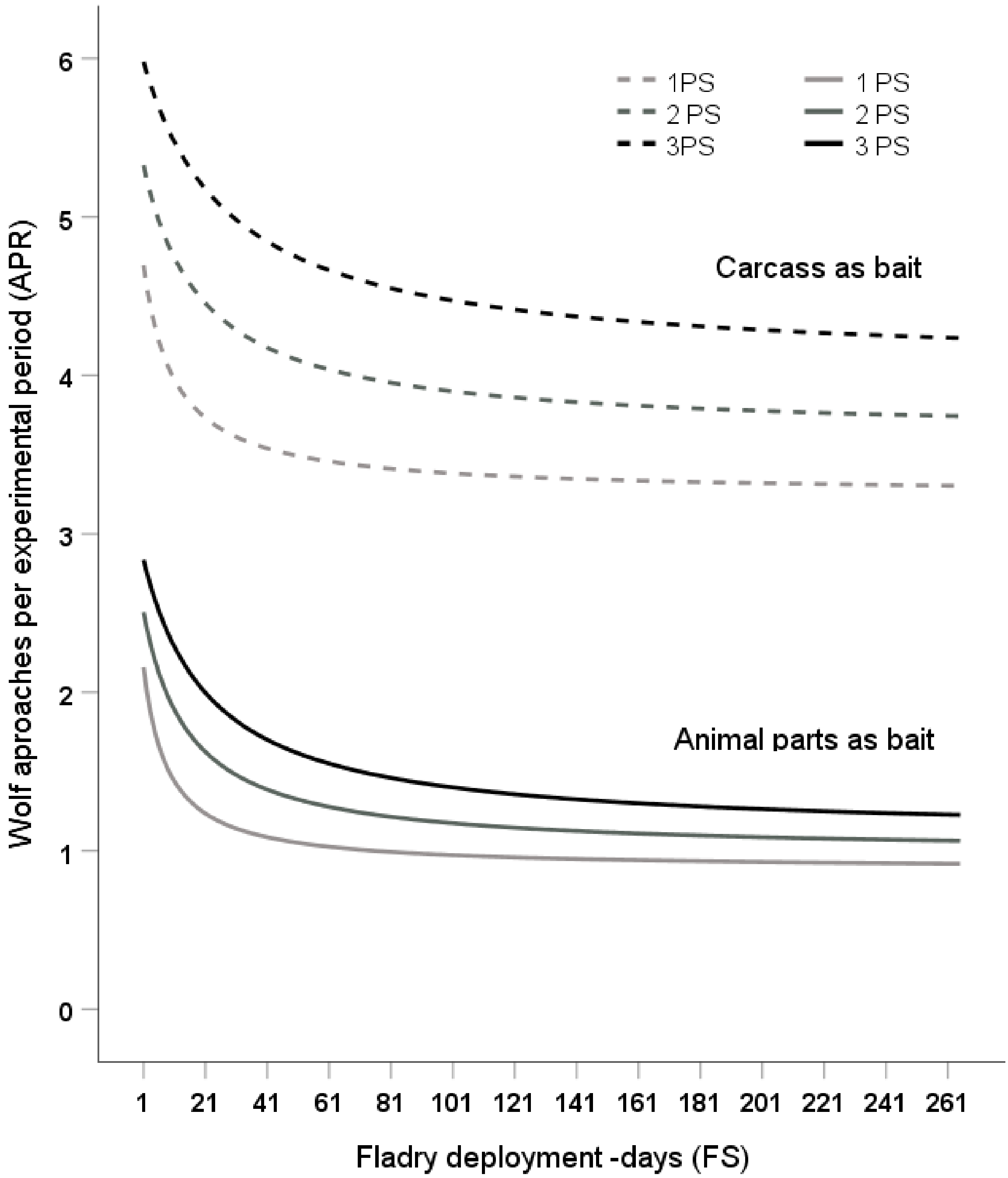

Fig. 5. Predicted wolf approach rates (without any fladry trespasses) in relation to time elapsed after fladry deployment (FS). Levels of approach rates are affected by the number of baitings prior fladry deployment (i.e. pre-treatments, PS, range = 1-3) and type of bait used (whole carcass or animal parts). Maximum duration of fladry use per baiting station was 88 days and per pack area 157 days during actual experiments.

Table 1. Distribution of experimental periods (n=47), re-baitings (n=29) and treatments per pack area, baiting station and season.

Bold characters indicate re-baitings while PR=pre-treatment, FL=fladry treatment. Each period had a duration of 11 days.

	PACK A	PACK B		PACK C		
	Baiting stations					
SEASON	**A1**	**B1**	**B2**	**C1**	**C2**	**C3**
	PR					
	PR					
	PR	***PR***				
	FL	***PR***				
SPRING (March-May)	***FL***	***FL***				
		FL				
		FL		***PR***		
		FL		***FL***		
		FL		FL		
		FL		FL		
					PR	***PR***
					PR	***PR***
					PR	***FL***
SUMMER (June-August)			***PR***			*FL*
			PR			***FL***
			PR			***FL***
			FL			***FL***
			FL			FL
			FL			***FL***
			FL			***FL***
AUTUMN (September-November)			***FL***			FL
			FL			***FL***
			FL			FL
			FL			FL

Table 2. **Predictor variables used in multivariate analysis**.

Cumulative pre-treatment values (PS and PP) for an experimental period and when fladry was already installed was calculated according to the pre-baiting history that was preceded in the respective station or pack area respectively. Those values remain constant for any subsequent fladry experimental period.

	Categorical Variables
Fladry	Binary: Pre-treatment =0, Fladry installed =1
Bait	Carcass or Goat/sheep animal parts of equal weight (~50kg)
	Continuous variables
RA	*Rebaiting time:* Average time passed since last rebaiting in days
PS	*Pre-treatment duration per baiting station:* Cumulative number of days passed in pre-treatment phase
FS	*Fladry duration per baiting station:* Cumulative number of days passed with fladry use
SD	*Experiment duration per baiting station:* Overall days passed since onset of the experiment
PP	*Pre-treatment duration per pack area:* Cumulative number of days passed in pre-treatment phase
FP	*Fladry duration per pack area:* Cumulative number of days passed with fladry use
PD	*Experiment duration per pack area*: Overall days passed since onset of the experiment
FS/PS	Fladry treatment duration to pre-treatment duration ratio per baiting station
FS/PP	Fladry treatment duration per baiting station to pre-treatment duration ratio per pack area
FS/SD	Fladry treatment duration per station to overall days passed since onset of the experiment per baiting station
FS/PD	Fladry treatment duration per station to overall days passed since onset of the experiment per pack area
FP/PP	Fladry treatment duration per pack to pre-treatment duration ratio per pack
FP/PD	Cumulative number of days passed with fladry use per pack area to overall days passed since onset of the experiment per pack area

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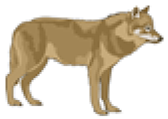
The original definitive paper can be found in the following link:
http://www.publish.csiro.au/WR/WR18146

Table 3. Overall responses of wolves, brown bears and wild boar per pack area and treatment. APR is the sum of all approach events, FDR the sum of feeding events and FDR/APR their respective rate expressed as percentage.

		Pack area A		Pack Area B			Pack Area C	
		Pre-treat	Fladry	Pre-treat	Fladry	Post-fladry	Pre-treat	Fladry
	Rebaitings	2	2	4	8	0	5	8
	Overall duration -days	33	**23**	58	**157**	25	62	**165**
	Response to treatments							
	**Visiting days**	10	6	16	18	7	21	7
	Approaching events	22	13	64	38	12	54	10
	Feeding events	14	0	49	0	11	35	0
	%Feeding / Approach	*63.6%*	*0.0%*	*76.6%*	*0.0%*	*91.7%*	*64.8%*	*0.0%*
	% Feeding reduction		***100.0%***		***100.0%***			***100.0%***
	**Visiting days**	12	6	13	19	2	9	23
	Approaching events	26	12	30	108	2	20	95
	Feeding events	22	0	27	19	2	5	13
	%Feeding / Approach	*84.6%*	*0.0%*	*90.0%*	*17.6%*	*100.0%*	*25.0%*	*13.7%*
	% Feeding reduction		***100.0%***		***82.4%***			***86.3%***
	**Visiting days**	0	5	17	18	2	8	1
	Approaching events	0	7	35	38	2	16	4
	Feeding events	0	7	35	21	2	13	0
	%Feeding / Approach		*100.0%*	*100.0%*	*55.3%*	*100.0%*	*81.3%*	*0.0%*
	% Feeding reduction		***0.0%***		***44.7%***			***100.0%***

Publisher: CSIRO; Journal: Wildlife Research, Article Type: Research Paper- Version: Accepted paper
The original definitive paper can be found in the following link:
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Table 4. Model selection criteria and beta coefficients of top GLMM models (Δi <2) and average models examining effect of fladry treatment to wolf approach levels (APR).

[FS is the elapsed time of fladry use per station, PS the pre-treatment duration per station, and PD the total experiment duration per pack area (all measured in days)].

Top model coefficients

	Intercept (± SE)	**Fladry x Bait (± SE)**			**Bait x FS/PD (± SE)**		**PS (± SE)**	**Model diagnostics**			
		Fladry off & Carcass	Fladry Off & Parts	Fladry use & Carcass	Carcass	Parts		**AICc**	**Δi**	**Wi**	**Max VIF**
1	**0.595** (± 0.219)	**1.778** (± 0.216)	**1.777** (± 0.241)	**0.925** (± 0.518)	-	-	-	103.038	0.00	0.44	1
2	**2.202** (± 0.010)	-	-	-	**- 1.439** (± 0.226)	**- 3.494** (± 0.333)	-	104.136	1.10	0.25	1.013
3	**- 0.667** (± 0.390)	**2.225** (± 0.309)	**2.253** (± 0.116)	**1.172** (± 0.252)	-	-	**0.041** (± 0.013)	104.429	1.39	0.22	1.393

Average model coefficients

Intercept (± SE)	**Fladry x Bait (± SE)**			**Bait x FS/PD (± SE)**		**PS (± SE)**
	Fladry Off & Carcass	Fladry Off & Parts	Fladry use & Carcass	Carcass	Parts	
0.741 (± 0.3)	**1.4** (±0.260)	**1.401** (±0.231)	**0.729** (±0.389)	**- 0.401** (±0.161)	**- 0.975** (±0.315)	**0.01** (±0.007)