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# Effectiveness of lasers to reduce goose grazing on agricultural grassland

Kevin K. Clausen, Luna K. Marcussen, Niels Knudsen, Thorsten J. S. Balsby and Jesper Madsen

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In recent decades, wild goose populations have grown considerably. Geese forage extensively in agricultural fields leading to frequent conflicts with agricultural stakeholders and calls for effective methods to reduce economic impacts. In this study, we explored the use of handheld lasers to displace grazing barnacle geese *Branta leucopsis* and dark-bellied brent geese *Branta bernicla* from farmland pastures on the Wadden Sea island Mandø in Denmark. We evaluate the efficiency of the laser to displace geese, the resultant impact on goose usage and the derived effect on pasture vegetation height. The laser was effective in displacing geese from pastures, but range and efficiency were affected by time of day, light conditions, distance and flock size. Fields subject to laser treatments experienced seven times lower dropping densities and had a mean vegetation height that was 3.3 cm taller than control fields where geese were not exposed to lasers. While the use of laser reduced goose exploitation of experimental fields, a simple cost-benefit analysis revealed that the personnel-hours needed to find geese and operate the laser carried economic costs outweighing the potential economic benefits. We discuss the potential in displacing geese with lasers, and suggest conditions when the method may be a suitable way to reduce goose damages locally.

Keywords: agricultural conflict, barnacle goose, crop damage, dark-bellied brent goose, laser, management, pasture, scaring, yield loss

During the last few decades, most European goose populations have increased considerably (Fox and Madsen 2017), in response to a combination of improved conservation efforts and a shift in habitat use to energy-rich agricultural foods (Gauthier et al. 2005, Fox and Abraham 2017, Clausen et al. 2018). Growing numbers of geese in the landscape has led to increased foraging pressure on crops and competition with livestock (Olsen et al. 2017, Petkov et al. 2017). In addition, the increase in goose populations have led to concerns for negative effects on air safety, tundra vegetation, human safety and other wildlife (Bradbeer et al. 2017, Buij et al. 2017). As a result, there is increasing demand for managing some rapidly increasing goose populations (Eyrthórsson et al. 2017, Lefebvre et al. 2017, Madsen et al. 2017).

Initiatives to deter geese from vulnerable areas such as crops and airports have involved scaring, hunting and derogation shooting (i.e. culling of otherwise legally protected species). Often, the effects of these initiatives on goose

numbers are difficult to quantify (Madsen et al. 2016, Nolet et al. 2016, Simonsen et al. 2016, Månsson 2017, van der Jeugd and Kwak 2017). Moreover, suitability of these initiatives may not be applicable for some species that either are protected or swiftly habituate to traditional scaring devices. Consequently, there is a growing demand for alternative non-lethal and species-specific methods of displacing geese.

Recent studies demonstrate the potential to displace birds using lasers from areas where they are unwanted. Pilot studies with night-roosting double-crested cormorants *Phalacrocorax auritus* (Glahn et al. 2000) and American crows *Corvus brachyrhynchos* (Gorenzel et al. 2002) showed that both species reacted to lasers and were immediately displaced from the location. However, the temporal effect of the displacement varied considerably between these two studies, and while the cormorants were kept at bay for several days, the crows returned to their roost site later the same evening. Laser light as a mechanism to displace geese has also been tested in airport environments (Cepek et al. 2001), in urban areas (Sherman and Barras 2004, Holevinski et al. 2007) and on captive geese (Blackwell et al. 2002b, Werner and Clark 2010), but the use of laser to deter geese from agricultural areas has hitherto not been scientifically documented. In this study, we investigated the use of lasers to displace geese from farmland pastures, in

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an area with ongoing human–wildlife conflict between farmers and foraging geese. The area is an important breeding site for vulnerable ground-breeding meadow birds, and thus, it is important to identify a management technique that does not disturb breeding birds. Herein, we 1) describe the efficiency of lasers to displace geese, 2) assess the environmental conditions affecting laser performance, 3) evaluate the effect of goose displacement on pasture exploitation and vegetation height and 4) discuss the future applicability of displacing geese from farmland using this method.

## Methods

### Study area and focal species

We conducted this study on the small island of Mandø in the Danish Wadden Sea (55°28N, 8°56E, Fig. 1). Mandø is a 7.6 km<sup>2</sup> island protected from the sea by a dike surrounding

the entire island. It is designated as a Wildlife Reserve and part of the Wadden Sea NATURA 2000 area, and an important breeding area for many meadow birds and stopover site for migrating geese and waders (Laursen and Thorup 2009). In the polders inside the dike, land use is dominated by farming practices with grazed grasslands (sheep and cattle) and a few fields with crop rotation. The island is frequented by tourists for birdwatching, hiking and other activities.

During spring Mandø is an important staging and foraging site for two populations of geese: 1) the Russian/NW Europe-breeding population of barnacle geese *Branta leucopsis* (hereafter barnacle geese), and 2) the Russian-breeding population of dark-bellied brent geese *Branta bernicla bernicla* (hereafter brent geese). The latest estimates of total population size for these two populations are 1 200 000 and 211 000 respectively, with average annual rates of change around 7.8% and 5.6% (Fox and Madsen 2017). Both barnacle geese and grent geese are protected in Denmark (Council Directive 2009/147/EC on the conservation of wild birds).

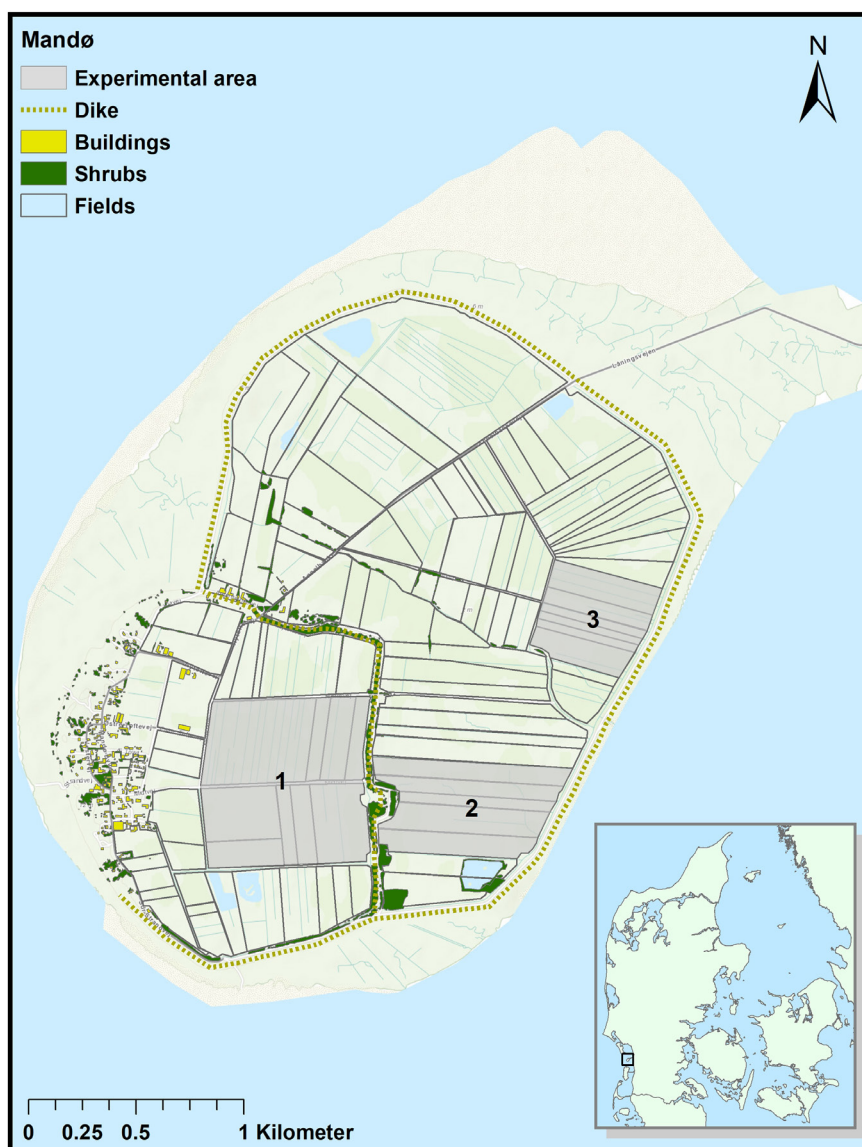


Figure 1. Map of the study area (Mandø; position shown on inserted map of Denmark), indicating experimental areas with displacement and the presence of dikes, buildings and shrubs on the island.

Each day from 10 to 11 a.m. during the study period, we counted foraging flocks of geese and mapped their locations from the dike. A few thousand barnacle geese occur in winter when conditions are mild, but the majority arrive in early spring and stay until the middle of May. Brent geese arrive in March and stay until late May. On the island, both species forage mainly on permanent pastures and rotational clover grass. The heavy exploitation of grasslands in the area affects local farmers' need for fodder, as the pastures are used for either hay harvest or grazing by cattle and sheep.

**The use of laser to displace geese**

We performed laser experiments daily in the period 26 March to 22 May 2018, corresponding to the period with large numbers of spring-staging geese on the island. We applied two handheld lasers (Agrilaser 500), with power <500 mW, wavelength 532 nm (green) and a diameter at aperture of 40–50 mm, which was chosen to represent currently available models sold as bird repelling lasers. Lasers were operated in three experimental areas in the polders of Mandø covering 20 fields (Fig. 1), and all fields outside the experimental areas were considered as control fields with no use of lasers. Two laser operators checked all the experimental fields for geese daily and regularly from sunrise to sunset, from vantage points in the proximity of the experimental areas. When geese were observed inside the experimental fields, operators attempted to displace geese with lasers from nearby dikes using tripods to stabilize both telescope and laser, which enabled accurate aims. The laser beam was aimed and swiped in front of the nearest birds, while care was taken to avoid direct exposure to the geese. This procedure was continued until all individuals had left the experimental field. If not all geese could be displaced from the original location (due to distance or obstructed views), the operator of the laser moved closer and tried again. During each laser treatment, we measured the duration as time passed from turning on the laser until all geese left the field, and collected a set of environmental parameters (Table 1).

Our data did not meet the assumptions of normal distribution and homoscedasticity, but a plot of the distribution of the response variable suggested that Poisson would be appropriate. Therefore, we evaluated the potential effect of influential factors on the performance of the laser using a generalized

linear mixed model with a Poisson distribution and a log link function. The evaluation of Pearson residuals suggested that data were not overdispersed (Littell et al. 2006). ‘Duration’ of the event was treated as the dependent variable, and ‘Day of year’, ‘Time of day’, ‘Cloudiness’, ‘Precipitation’, ‘Temperature’, ‘Flock size’, ‘Distance’ and ‘Species’ as independent variables. ‘Date’ was included as a random effect to account for potential non-independence of experiments completed on the same days. Multicollinearity of independent variables was tested by calculating the variance inflation factors (all <2, Craney and Surles 2002). We tested all independent variables for quadratic effects to check for unimodal patterns, and included interactions between ‘Species’ and all other factors to test for species-specific responses to the other variables. The model was tested using Proc glimmix in SAS 9.4 (SAS Inst.).

**The effect of laser displacement on goose abundance**

We measured field usage by geese by counting goose droppings, which is a widely used and reliable proxy for goose abundance (first described by Owen 1971). Dropping densities can be a good proxy for goose grazing (Patterson et al. 1989, but see Bedard and Gauthier 1986). All field workers were trained prior to field assessments to ensure similar counting procedures across fields. We tested the lifespan of droppings (time passed before they disintegrate and cannot be recognized) by laying out 10 fresh droppings in an area avoided by geese. This revealed that droppings were detectable for more than eight weeks, probably partly because of a very dry spring in 2018. Consequently, we assessed the use of individual fields by geese on Mandø during the study period on the last day of experiments (22 May 2018), by counting the number of goose droppings in five randomly sampled circular plots on each field with an area of 0.54 m<sup>2</sup> (equivalent to the area of applied plastic rings). During winter, prior to the experimental period, very few geese resided on Mandø, and droppings from this period were unlikely to persist until our assessment of usage in late May. The density of droppings in late May was therefore a reliable proxy of field utilization in the period covered by our study.

Field utilization by geese is highly affected by the openness (distance to trees/shrubs) of individual fields (Madsen 1985), and we therefore sought to explain goose usage with a model accounting for both laser experiments and the distance to shrubs. We derived the latter by calculating the distance from the center of each field to the nearest shrub, using the Point Distance tool in ArcMap 10.4 (ESRI 2011). Shrub cover was digitized from an orthophoto from 2017. We evaluated the effect of laser displacement on goose usage (measured by number of droppings) using a generalized linear mixed model with a Poisson distribution and a log link function. We treated ‘Number of droppings’ as the dependent variable, ‘Displacement’ (a binary yes/no variable) and ‘Distance to shrubs’ (in m) as fixed effects, and ‘Field ID’ as random effect to acknowledge the clustered structure of the observations with five sampled plots per field. The evaluation of Pearson residuals suggested that overdispersion did not affect the data (Littell et al. 2006). Geese completely avoided two fields with an initial very high sward (probably due to the lower digestive quality of older vegetation, see Loonen and Bos 2000), and we excluded these fields from the analy-

Table 1. Parameters collected during experiments with lasers to displace geese on Mandø, spring 2018.

Parameter	Description
Date	Date of the displacement event
Time of day	Time of day
Cloudiness	A continuous measure of clouds from full sun (0) to overcast (8)
Precipitation	A binomial yes/no variable for precipitation
Temperature	Temperature (°C)
Flock size	Number of individuals in the flock displaced (thousands)
Distance	Distance from the handheld laser to the displaced flock (km)
Species	The species displaced (barnacle geese og brent geese)
Duration	Time needed to displace all geese in the flock (min)



sis. We also excluded two fields with centroids within 100 m from buildings, as their proximity to settlements probably made the geese avoid these areas. As above, we used Proc glimmix in SAS 9.4 to test the model.

### The effect of laser displacement on sward height

We assessed average vegetation height of fields on the last day of experiments (22 May 2018), by averaging three random sampling measurements of sward height around each of the five dropping plots on each field (corresponding to 15 measurements and five averages per field). We used a light plastic disc (radius 6 cm) placed on a stick with a ruler to measure sward height in homogenous vegetation to the nearest cm. No management occurred on the fields prior to the study period in the year of study, and although sward height might be affected by management actions in previous years, there should be no reason to expect that the randomly selected experimental fields differed from non-experimental fields in this regard. Twenty-five percent of fields on the island was subject to livestock grazing during our study, and we did not sample these fields to avoid confounding effects on vegetation height. We evaluated the effect of displacement on pasture vegetation height using a model with the same explanatory parameters as described above, but for vegetation height, log transformation of the data allowed us to assume normal distribution of residuals. Thus, we applied a linear mixed model with 'Average vegetation height' (in cm) as the dependent variable, 'Displacement' (a binary yes/no variable) and 'Distance to shrubs' (in m) as fixed effects and 'Field ID' as a random effect.

All data sources and statistical code to run the presented analyses are shared in the Supplementary material 'Appendix\_1\_Data sources\_WLB-00560.xlsx' and 'Appendix\_2\_Code\_WLB-00560.docx' accessible on the journal home page: <[www.wildlifebiology.org/appendix/wlb-00560](http://www.wildlifebiology.org/appendix/wlb-00560)>.

### Cost-benefit analysis

The profitability of laser displacement of geese was assessed by a simple cost-benefit analysis, balancing the costs associated with laser displacement (manpower, transportation and investment in a laser) with the monetary gains of preventing crop loss. Costs were based on our own expenses in relation to the laser experiments (assuming standard Danish field worker salaries, mileage allowances and three years depreciation of purchased lasers), while benefits were calculated as the reduced crop loss for local farmers resulting from the displacements. Pasture vegetation height is usually directly proportional to available green biomass (Harmoney et al. 1997), and our estimated difference in sward height between experimental and control areas was therefore used as an expression of the yield gained from laser displacement. Data from the local Wadden Sea area, provided by the agricultural advisory company SEGES, confirmed a linear relationship between yield of green biomass and grass crop height at first cut in our study area (taken mid-May, corresponding to the time of our assessment, Landsforsøg 2018). The relationship indicated a decrease in yield of roughly 530 kg green biomass (wet weight) per hectare per cm grass sward cropped (Landsforsøg 2018), and we used this figure to estimate laser-induced differences in available biomass for local farmers.

## Results

### The use of laser to displace geese

Peak counts of geese on Mandø in spring 2018 totaled ca 15 000 barnacle geese and ca 3000 brent geese, and the total number of goose days during the study period 26 March to 22 May totaled 470 540. We completed a total of 1206 laser trials on Mandø, and generally the laser appeared efficient in displacing geese from the experimental fields: The laser displaced 70% of all flocks within one minute, and 98% within 5 min (range 1–15 min). Displaced flocks generally moved away from the occupied field, but stayed on the island. The total number of laser trials per day varied between 0 and 71, with an average of 22.4 times (SD = 17.4). The number was related to both day length (Pearson's  $r = 0.475$ ,  $p < 0.001$ ) and total number of geese present on the island as assessed by the daily counts (Pearson's  $r = 0.284$ ,  $p = 0.032$ ). The distances from laser operators to flocks of geese for successful displacement events varied between 100 and 1200 m, and light conditions seemed to affect the range. As such, indications of a distinct drop in the ability to displace geese appeared around distances of 800 m in cloudy weather, compared to a similar drop around distances of 400 m in sunny conditions (Fig. 2).

Time needed to displace geese (i.e. duration of laser beaming) was affected by time of day (quadratic term), cloudiness, flock size and distance (Table 2). The effects of time of day and cloudiness indicated that laser performance was affected by light conditions. Hence, displacement was quicker morning and evening compared to mid-day (Fig. 3) and under overcast conditions. Our data also indicated that the time needed to displace geese increased with increasing flock sizes. For instance, an increase in flock size of 1000 birds would require on average 1.6 times longer laser treatment. The effect of flock size was more pronounced for brent geese than for barnacle geese, as indicated by the significant interaction term. Distance had a significant positive effect on duration, indicating that flocks further away were more difficult to displace than flocks close to the laser. As an indication of magnitude, the parameter estimates suggested that an increase of 200 m would result in a 1.7 times increase in time needed to effectively displace geese. Day of year, precipitation and temperature had no significant effect on duration, and while barnacle geese had a tendency to respond faster to the laser beam than brent geese, the main effect of species was not significant either (Table 2).

### The effect of laser displacement on goose abundance

Experimental fields had a significantly smaller number of goose droppings per plot compared to control fields ( $n = 275$  plots, back transformed least square means  $\pm$  SE of  $0.44 \pm 0.24$  and  $3.30 \pm 0.69$  respectively,  $F_{1,218} = 11.6$ ,  $p = 0.008$ ). Number of droppings was positively affected by distance to shrubs ( $F_{1,218} = 14.2$ ,  $p < 0.001$ , estimate = 1.35), and a significant quadratic effect on distance to shrubs ( $F_{1,218} = 6.0$ ,  $p = 0.015$ , estimate =  $-0.11$ ) indicated that the relationship weakened at distances  $> 500$  m, above which further distance to shrubs did not affect goose usage.

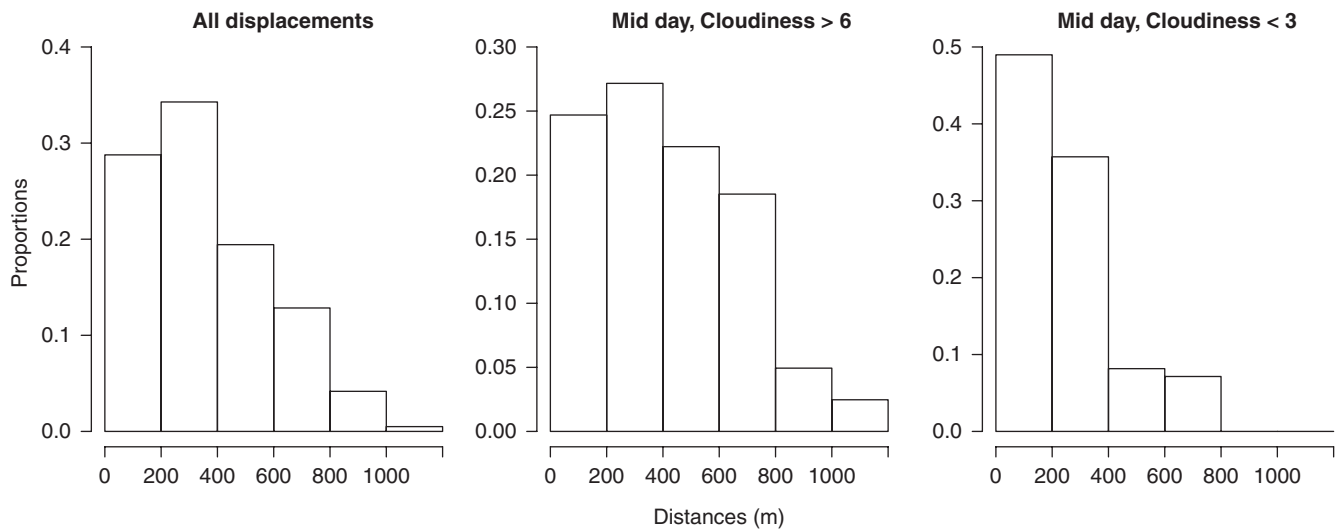


Figure 2. The distribution of distances for all successful displacement events (left) and distribution of successful displacements during mid-day (10 a.m. to 2 p.m.) in cloudy weather (mid) and sunny conditions (right).

### The effect of laser displacement on sward height

Average sward height ( $n=275$ ) differed significantly between fields with and without laser displacement of geese (least square means of 7.1 and 3.8 cm respectively,  $t_{217}=2.65$ ,  $p=0.009$ , asymmetric SEs of  $-1.3/+1.7$  and  $-0.3/+0.4$ ). We also found a significant negative correlation between average numbers of goose droppings and average vegetation height (Spearman's  $\rho=-0.773$ ,  $p<0.001$ ). Vegetation height showed a significant negative relation to distance to shrubs ( $F_{1,217}=13.96$ ,  $p<0.001$ , estimate  $=-0.45$ ), and the quadratic term indicating a reduced effect at higher distances showed marginally significance ( $F_{1,217}=3.54$ ,  $p=0.061$ , estimate  $=0.028$ ).

### Cost-benefit analysis

Total costs of running the laser experiments on Mandø was approximated to €14 440 (Table 3). The laser-induced

difference in sward height between experimental and control fields of 3.3 cm translated into a yield gain of  $\approx 1750$  kg per hectare, corresponding to approximately 288 Scandinavian Feed Units per hectare. The monetary value of this gain (or the cost associated with grazing geese) amounts to approximately €70 per hectare annually in local 2018 prices. The laser experiments covered 111 ha, and the total benefit thus amounted to €7770, indicating a negative balance of €6670 (Table 3).

### Discussion

This study revealed that a handheld laser effectively displaced foraging geese from farmland pastures. When initially unsuccessful, flocks could always be displaced by moving closer and taking another aim. However, due to the large numbers of geese, a lot of movement between fields and transport

Table 2. Output from the generalized linear mixed model describing laser performance in relation to circumstantial parameters at the time of displacement ( $n=1206$ ). Bold p-values indicate significant effects on  $\alpha$ -level 0.05. For species effects, the presented estimates are for barnacle geese relative to brent geese.

Effect	df	F	p-value	Estimate
Intercept				-0.277
Time of day	1,1139	24.68	<b>&lt;0.001</b>	5.219
Time of day <sup>2</sup>	1,1139	23.58	<b>&lt;0.001</b>	-4.703
Cloudiness	1,1139	6.99	<b>0.008</b>	-0.018
Precipitation	1,1139	1.47	0.225	0.194
Temperature	1,1139	0.22	0.639	-0.004
Flock size	1,1139	17.92	<b>&lt;0.001</b>	0.454
Distance	1,1139	8.12	<b>0.004</b>	0.268
Species	1,1139	1.49	0.223	-1.145
Day of year	1,1139	0.26	0.608	-0.006
Time of day $\times$ Species	1,1139	0.00	0.977	0.060
Time of day <sup>2</sup> $\times$ Species	1,1139	0.00	0.980	0.048
Cloudiness $\times$ Species	1,1139	1.24	0.265	-0.019
Precipitation $\times$ Species	1,1139	0.12	0.729	-0.080
Temperature $\times$ Species	1,1139	1.11	0.292	0.015
Flock size $\times$ Species	1,1139	7.77	<b>0.005</b>	-0.360
Distance $\times$ Species	1,1139	0.15	0.698	0.082
Day of year $\times$ Species	1,1139	1.79	0.182	0.008

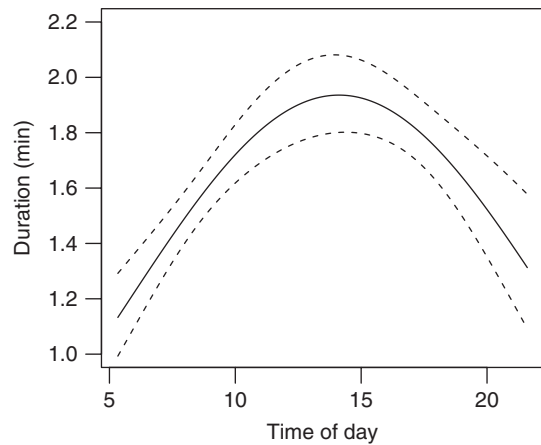


Figure 3. The effect of time of day on the time needed to effectively displace barnacle geese and brent geese on Mandø during spring 2018. Dashed lines indicate the 95% confidence limits.

needs for laser operators, occasional use of the experimental areas could not be fully avoided. Therefore, a varying degree of grazing (albeit at low levels) took place inside the experimental areas. The ability of the laser to displace geese was noticeably influenced by light conditions in the field, which affected both the time needed to displace geese and the range of potential distances at which geese took flight. Thus, displacement of geese was most efficient when the laser beam was a distinct contrast to otherwise dim surroundings.

Species-specific responses to lasers have previously been described for birds in airport environments (Blackwell et al. 2002a), and should probably always be considered. In our study area, barnacle geese appeared to be more susceptible to laser displacement than brent geese, but statistically the tendency was outside the level of significance. We found no indications of increasing tolerance to laser displacement during the study period, as time needed to displace geese did not increase. This may partly be related to the high numbers of geese in the area. Because most birds in a flock react to the behaviour of conspecifics when displaced from a field, the presence of large flocks led to low exposure of the individuals to the laser beam.

While displacement of geese was usually very rapid once flocks were located on the fields, considerable time was needed to continuously oversee the experimental fields and track down newly arrived groups. The effort needed grew with both increasing goose numbers and longer days, and during peak season (late April) the number of laser displacements averaged almost 40 per day. Geese were generally most active in the first two to three hours after sunrise until flocks had settled on appropriate foraging locations, but there was also a smaller activity peak at the end of the day. Total time spent in the field by laser operators to oversee the experimental areas was roughly 10 h a day, and as a result, substantial manpower was needed to manually displace geese on Mandø. The situation on Mandø was probably rather extreme in this regard, given the limited available land on the small Island (relatively few alternatives for geese) and the large number of birds present. Fully automated laser systems exist, using either motion-activation or infrared light to detect moving birds on the fields (Briot 2005, Werner and Clark 2010). However, these systems are less controllable than manually selecting out

Table 3. Cost-benefit analysis of displacing geese with lasers from pastures on Mandø, Denmark, during spring 2018. SFU = Scandinavian Feed Units. One SFU is equal of the nutritive value of 1 kg of dry barley.

	Units	Note
<b>Costs</b>		
Average man-hours per day	10	Rough estimate
Hourly pay (€ per h)	18.7	Standard worker
Days of effort	69	
Total pay (€)	12 903	
Average transport per day (km)	42	Rough estimate
Transport expenses (€ per km)	0.26	
Total transport expenses (€)	753	
Price of laser (three year depreciation, €)	784	Total price:
Total cost (€)	14 440	2351 € ex VAT
<b>Benefits</b>		
Yield gain (SFU per ha)	288	
Area of experimental fields (ha)	111	
Price of organic pasture grass (€, per SFU)	0.243	Local Danish 2018 price
Benefit per ha (€)	70	
Total benefit	7770	
Balance (benefit – cost, €)	–6670	

the intended species and in areas like Mandø, with important bird conservation and recreational interests, these automated methods will have to be both very safe and highly species-specific in order to be considered. In this study, we did not carry out systematic experiments to test the behavioural effect of the laser beam on other species than geese. However, it was observed several times that nearby nesting and territorial meadow birds such as lapwing *Vanellus vanellus*, black-tailed godwit *Limosa limosa* and oystercatcher *Haematopus ostralegus* ignored laser beams directed towards flocks of geese.

Despite occasional goose foraging within the experimental areas, laser displacement had a clear effect on goose exploitation and sward height. Thus, our data demonstrated that goose foraging had a negative impact on crop yield for the affected farmers, either as biomass available for hay harvest or as fodder for grazing livestock in the area. The estimated yield gain due to laser displacement can be regarded as a minimum, because occasional goose foraging occurred inside the experimental areas. In coastal areas like Mandø however, completely avoiding goose grazing might require almost 24-h surveillance, to avoid occasional nocturnal foraging by geese (Lane and Hassall 1996), which would have been very costly. In our study, the economic costs associated with manually operated lasers exceeded the savings from reduced crop damage (Table 3). The negative balance was probably related to 1) failure to completely exclude geese from the experimental areas, 2) distance between the experimental areas, leading to considerable transportation time and 3) very high densities of geese. The analysis does not include the possible indirect benefits of geese on local economy due to the potential attraction of tourists.

The use of lasers is associated with a safety risk for both operators and targeted species, especially with respect to ocular damages of subjects exposed to the laser beam (Glickman

2002, Denton et al. 2007). The potential for human ocular hazards of the applied lasers is defined by the manufacturer's hazard classification of 3B (hazardous for eye exposure; <[www.lasersafetyfacts.com/3B](http://www.lasersafetyfacts.com/3B)>). Ocular hazards from 3B lasers appear to result only from intentional staring at the laser light close to the diffuser (Glahn et al. 2000, Blackwell et al. 2002a), but care should always be taken when applying lasers in the field with risk of exposure to both wildlife and humans. Glahn et al. (2000) reported no ocular damage to cormorants exposed to a laser with the same hazard classification as the one used in our study at distances down to 1 m. Although we did not specifically study the reaction of birds to laser exposure, we observed no apparent effects on the health of geese in terms of abnormal behaviour during the experiments on Mandø.

### Future applicability of displacing geese with laser

Based on the experience gained from our study, lasers can be an effective tool to displace geese from agricultural fields. However, there are a number of considerations to be made before relying on this method. Most notably, the personnel-hours needed to find goose flocks and operate the laser are quite substantial – especially in large areas or areas with many geese. Efforts might be considerably smaller, however, if the focus is limited to one or a few nearby areas that are easily accessible. In addition, the costs associated with the many personnel-hours needed might be tolerable if farmers want to protect more expensive crops than grass.

One solution to reduce human efforts can be to apply automated laser systems, which might be able to operate without problems in purely agricultural areas with limited traffic. However, the startup expenses of these devices are quite large, and their applicability therefore probably limited to situations where the economic losses from birds are quite severe. With a handheld and manually operated laser, individuals or flocks can be targeted, and constant care can be taken to avoid non-target species and people.

Other considerations to be made before relying on lasers to deter geese include distance (beyond 800 m the effect was limited with the laser applied in our study), light conditions (functionality was clearly best in cloudy weather and early or late in the day) and probably the targeted species. Recent studies on the effectiveness of scaring conclude that a combination of techniques as part of an integrated program is the best approach (Baxter and Robinson 2007, Thiérior et al. 2015), and displacement with lasers can be integrated with other scaring techniques in cases where deterring birds is a necessary action. Overall, the use of lasers to displace geese is probably not suitable for all situations where conflicts occur, but may be an effective tool under certain conditions. These include when 1) the effort needed is limited (few displacements and easy access), 2) laser operation can be automated (i.e. in areas of purely agricultural interests), 3) expensive crop types are at risk or 4) risks are high enough to outweigh the necessary efforts (e.g. in airport environments).

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### References

- Baxter, A. T. and Robinson, A. P. 2007. A comparison of scavenging bird deterrence techniques at UK landfill sites. – *Int. J. Pest. Manage.* 53: 347–356.
- Bedard, J. and Gauthier, G. 1986. Assessment of faecal output in geese. – *J. Appl. Ecol.* 23: 77–90.
- Blackwell, B. F. et al. 2002a. Lasers as non-lethal avian repellents: potential applications in the airport environment. – USDA National Wildlife Research Center.
- Blackwell, B. F. et al. 2002b. Lasers as nonlethal avian repellents. – *J. Wildl. Manage.* 66: 250–258.
- Bradbeer, D. R. et al. 2017. Crowded skies: conflicts between expanding goose populations and aviation safety. – *Ambio* 46: 290–300.
- Briot, J. L. 2005. Last experiments with a laser equipment designed for avian dispersal in airport environment. – International Bird Strike Committee, Athens.
- Buij, R. et al. 2017. Balancing ecosystem function, services and disservices resulting from expanding goose populations. – *Ambio* 46: 301–318.
- Ceppek, J. D. et al. 2001. Wildlife Control Methods for Airports (Task 3). Experiment 3: Laser dispersal of Canada geese at Lake Galena, Pennsylvania. – Interim Report submitted to DOT/FAA, William J Hughes Technical Center by USDA/WS/NWRC.
- Clausen, K. K. et al. 2018. Maize stubble as foraging habitat for wintering geese and swans in northern Europe. – *Agric. Ecosyst. Environ.* 259: 72–76.
- Craney, T. A. and Surles, J. G. 2002. Model-dependent variance inflation factor cutoff values. – *Qual. Eng.* 14: 391–403.
- Denton, M. L. et al. 2007. Damage thresholds for cultured retinal pigment epithelial cells exposed to lasers at 532 nm and 458 nm. – *J. Biomed. Opt.* 12: 034030.
- ESRI 2011. ArcGIS Desktop: release 10. – Environmental Systems Research Institute.
- Eythórsson, E. et al. 2017. Goose management schemes to resolve conflicts with agriculture: theory, practice and effects. – *Ambio* 46: 231–240.
- Fox, A. D. and Abraham, K. F. 2017. Why geese benefit from the transition from natural vegetation to agriculture. – *Ambio* 46: 188–197.
- Fox, A. D. and Madsen, J. 2017. Threatened species to super-abundance: the unexpected international implications of successful goose conservation. – *Ambio* 46: 179–187.
- Gauthier, G. et al. 2005. Interactions between land use, habitat use and population increase in greater snow geese: what are the consequences for natural wetlands? – *Global Change Biol.* 11: 856–868.
- Glahn, J. F. et al. 2000. Evaluation of moderate and low-powered lasers for dispersing double-crested cormorants from their night roosts. – *Proc. Eastern Wildl. Damage Manage. Conf.* 9: 34–45.
- Glickman, R. D. 2002. Phototoxicity to the retina: mechanisms of damage. – *Int. J. Toxicol.* 21: 473–490.
- Gorenzel, W. P. et al. 2002. Evaluation of lasers to disperse American crows, *Corvus brachyrhynchos*, from urban night roosts. – *Int. J. Pest. Manage.* 48: 327–331.
- Harmony, K. R. et al. 1997. Determination of pasture biomass using four indirect methods. – *Agron. J.* 89: 665–672.



- Holevinski, R. A. et al. 2007. Hazing of Canada geese is unlikely to reduce nuisance populations in urban and suburban communities. – Hum. Wildl. Confl. 1: 257–264.
- Landsforsøg 2018. SEGES. – <<https://nfts.dlbr.dk/Forms/VisPlan.aspx?PlanID=17296&GUID=4f46cc6a-3bb2-41ba-919a-29d1df5988f8&applLangID=da>>
- Lane, S. J. and Hassall, M. 1996. Nocturnal feeding by dark-bellied brent geese *Branta bernicla bernicla*. – IBIS 138: 291–297.
- Laursen, K. and Thorup, O. 2009. Breeding birds in the Danish Wadden Sea Region 1983–2006, assessment of SPAs. – Dan. Ornitol. Foren. Tidsskr. 103: 77–92.
- Lefebvre, J. et al. 2017. The greater snow goose *Anser caerulescens atlanticus*: managing an overabundant population. – Ambio 46: 262–274.
- Loonen, M. J. J. E. and Bos, D. 2000. Geese in the Wadden Sea: an effect of grazing on habitat preference. – In: Wolff, W. J. et al. (eds), Challenges to the Wadden Sea. Proc. 10th Int Sci Wadden Sea Symp, Groningen. Ministry of Agriculture, Nature Management and Fisheries/Univ. of Groningen.
- Littell, R. C. et al. 2006. SAS for mixed models. – SAS Institute, Cary, NC.
- Madsen, J. 1985. Habitat selection of farmland feeding geese in West Jutland, Denmark – an example of a niche shift. – Ornis Scand. 16: 140–144.
- Madsen, J. et al. 2016. Regulation of the hunting season as a tool for adaptive harvest management – first results for pink-footed geese *Anser brachyrhynchus*. – Wildl. Biol. 22: 204–208.
- Madsen, J. et al. 2017. Implementation of the first adaptive management plan for a European migratory waterbird population: the case of the Svalbard pink-footed goose *Anser brachyrhynchus*. – Ambio 46: 275–289.
- Månsson, J. 2017. Lethal scaring – behavioral and short-term numerical response of greylag goose *Anser anser*. – Crop. Prot. 96: 258–264.
- Nolet, B. A. et al. 2016. Scaring waterfowl as a management tool: how much more do geese forage after disturbance? – J. Appl. Ecol. 53: 1413–1421.
- Olsen, A. K. B. et al. 2017. Yield reductions in agricultural grasslands in Norway after springtime grazing by pink-footed geese. – J. Appl. Ecol. 54: 1836–1846.
- Owen, M. 1971. The selection of feeding site by white-fronted geese in winter. – J. Appl. Ecol. 8: 905–917.
- Patterson, I. J. et al. 1989. Damage to winter cereals by greylag and pink-footed geese in north-east Scotland. – J. Appl. Ecol. 26: 879–895.
- Petkov, N. et al. 2017. The impact of wintering geese on crop yields in Bulgarian Dobrudzha: implications for agri-environment schemes. – Eur. J. Wildl. Res. 63: 66.
- Sherman, D. E. and Barras, A. E. 2004. Efficacy of a laser device for hazing Canada geese from urban areas of northeast Ohio. – Ohio J. Sci. 104: 38–42.
- Simonsen, C. E. et al. 2016. Is it worthwhile scaring geese to alleviate damage to crops? An experimental study. – J. Appl. Ecol. 53: 916–924.
- Thiériot, E. et al. 2015. The efficiency of an integrated program using falconry to deter gulls from landfills. – Animals 5: 214–225.
- van der Jeugd, H. P. and Kwak, A. 2017. Management of a Dutch resident barnacle goose *Branta leucopsis* population: how can results from counts, ringing and hunting bag statistics be reconciled? – Ambio 46: 251–261.
- Werner, S. J. and Clark, L. 2010. Effectiveness of a motion-activated laser hazing system for repelling captive Canada geese. – Wildl. Soc. Bull. 34: 2–7.

Supplementary material (available online as Appendix wlb-00560 at <[www.wildlifebiology.com/appendix/wlb-00560](http://www.wildlifebiology.com/appendix/wlb-00560)>).