

Scotland's Rural College

## Cattle responses to a type of virtual fence

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1 **Cattle Responses to a Type of Virtual Fence**

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20 **ABSTRACT**

21

22 Interest in developing more flexible fencing technology to improve pasture and rangeland  
23 management is increasing. The objective of this study was to test the efficacy of a new  
24 virtual fencing product and measure impact on behaviour thus potentially allowing positive  
25 development of virtual fence systems. The Boviguard® (Agrifence, Henderson Products  
26 Ltd., Gloucester, UK) invisible fence is now commercially available, consisting of cow  
27 collars, a battery-based transformer and an induction cable laid on the ground or buried in  
28 the ground. As the Boviguard® collar comes close to the induction cable, a warning sound  
29 is triggered and if the animal continues to move closer, an electrical stimulus is triggered.  
30 We tested this novel system on 10 cows wearing GPS collars to pinpoint location and  
31 activity sensors to gather behavioural data. Two separate exclusion zones were created  
32 consecutively in different areas of a test field, with alternate periods of control, with no  
33 fence activity, and virtual fence activation. The system successfully prevented the animals  
34 from crossing the virtual fence line. No changes in general activity or lying behaviour were  
35 found. There were significant changes in the pattern of use of the rest of the field area  
36 when the fencing system was activated. When only the un-activated cable was left on the  
37 ground in a final control period, the visual cue alone deterred animals from entering the  
38 exclusion area. The trial showed the effectiveness of a collar-based electrical stimuli  
39 system. This approach to virtual fencing could provide solutions for management systems  
40 where moving fences frequently is required, such as for strip grazing; for nature  
41 conservation management of specific areas and habitats and for graziers of land where  
42 physical fences are not preferred or feasible.

43

44 **KEY WORDS**

45

46 animal behaviour, Boviguard, GPS, Invisible Fence, cattle distribution, grazing

47

## INTRODUCTION

48

49

50 Grazing lands cover 32 million km<sup>2</sup>, approximately 25% of the earth's land surface (Reid  
51 et al. 2004) and play a vital role in many agricultural systems. Optimising pasture  
52 management and increasing the output from existing grasslands requires significant  
53 resources in terms of costs and labour. Over the past two centuries, the development of  
54 fencing systems has been a revolution in the management of livestock, as it has allowed  
55 the stockperson to control the location of the animals. It is crucial for successful livestock  
56 management to have the capacity and capability to retain animals within areas and  
57 exclude them from others. However, for extensive systems it is not always feasible or cost  
58 effective to build fences in some areas. In addition, a more flexible approach to grazing  
59 management could lead to improved utilisation of biomass, such as by better exploitation  
60 of seasonal growth, or aid nature conservation and re-establishment of biodiversity  
61 habitats through temporary or permanent exclusion of livestock to certain areas. The  
62 development of virtual fences has been ongoing over recent decades. A very early  
63 approach was the so called 'Invisible Fence', filed as a patent by Peck in 1971 (Peck  
64 1973). The system was originally developed mainly for cats and dogs. Fay et al. (1989)  
65 tested the 'Invisible Fence' system on goats and a similar approach was later tested on  
66 cattle (Monod et al. 2009). Based on that patent, the Boviguard® system (marketed as  
67 registered brand in the UK as Boviguard® Invisible Cattle Fence, Agrifence, Henderson  
68 Products Ltd., Gloucester, UK) was developed as a new commercial system for cattle that  
69 consists of cow collars and a transformer connected to an induction cable that represents  
70 the fence line. The system works through an electromagnetic coupling between the collar  
71 and the induction cable. As the Boviguard® collar comes close to the induction cable, a  
72 warning sound is triggered and if the animal continues to approach the cable, an electric  
73 stimulus is triggered in the collar. Monod et al. (2009) provides a detailed description of  
74 the technological design.

75 The aim of this study was to investigate behavioural responses of animals to the  
76 novel Boviguard® system, specifically, if they respected the exclusion area and if any  
77 strong behavioural changes were detected which might compromise their welfare.  
78 Detailed animal behavioural investigation of this system, using GPS tracking and activity  
79 sensors to monitor cattle responses had not been carried out previously, thus the  
80 resulting information would be novel and critically important to further developments in  
81 virtual fencing.

82

83

## METHODS

84

### 85 **Animals and Location**

86 Ten adult, female, non-lactating cows, in a mixed herd consisting of eight Aberdeen  
87 Angus x Limousin and two Charolais were used in this study. During the period of the trial  
88 (17 October 2011 – 08 November 2011) all cows were maintained in a field consisting of  
89 improved pasture and measuring 7.88 ha. All ten animals were fitted (Fig. 1) with the  
90 Boviguard® collars, separate GPS (Global Positioning System) collars (AgTrex, BlueSky  
91 Telemetry, Aberfeldy, Scotland, UK) and leg-mounted activity sensors (IceTags,  
92 IceRobotics, Edinburgh, Scotland, UK). Cows were maintained in the field for an initial  
93 adaptation stage of seven days before the trial started to acclimatise to the location and  
94 equipment fitted to them. Some visual animal observations were carried out during the  
95 adaptation period in order to confirm the absence of adverse reactions to the fence when  
96 switched on.

97

### 98 **Technology**

99 The Boviguard® system comprised a series of battery powered receivers attached to  
100 leather collars worn by each cow and an induction cable connected to a transformer and  
101 12-volt car battery that provided a low power electromagnetic field. The Boviguard®  
102 collars weighed 1450 gr with the receiver housing having dimensions of 150 x 70 x 90

103 mm. The induction cable was fully sealed, flexible and could be laid on the ground,  
104 suspended or buried. In this case, the colour of the cable was blue. A magnetic field was  
105 emitted by the cable when powered. In this study, the system was tested with the cable  
106 laid on the ground (Fig. 1, inset) forming a boundary around the exclosures (Fig. 2) since  
107 it was important to be able to move the cable during the experiment. The technological  
108 principle of the system was that if a Boviguard® collar came within a certain distance  
109 (depending on the signal strength of the induction cable), the cable's signal would trigger  
110 a warning sound to be emitted from the collar. If the animal continued to approach the  
111 cable, an electrical stimulus would be triggered. The electrodes were integrated into the  
112 collar in the form of braided wiring in contact with the animal. The distances between the  
113 collar and cable required to trigger a warning cue were tested for each collar. All 10  
114 collars showed different triggering distances ranging from 15.2 to 57.2 cm with an  
115 average of 36 cm.

116         In order to accumulate information about the animal responses to the Boviguard®  
117 fence, we deployed GPS collars attached to the neck and activity sensors attached to the  
118 left hind leg of each cow. The GPS collars were switched on between 20 October and 08  
119 November 2011, inclusively. The GPS collars recorded a usable locational reading every  
120 4.5 min. The collars were originally set to log data every 5 min but due to the specific  
121 software the sampling actually took place every 4.5 min. The decision not to log GPS  
122 fixes (recordings of cow locations) more frequently was due to energy restrictions  
123 imposed by the battery power source. The GPS fixes obtained were not differentially  
124 corrected for locational error. The activity sensors operate on integrated accelerometers,  
125 with output including step counts, a motion index and the duration of lying bouts. The  
126 motion index is a parameter that combines the data of the three accelerometers and,  
127 therefore, gives an indication of the degree of movement in three dimensions (no units  
128 available). The detailed algorithm of how the three data streams of the accelerometers  
129 were combined was not available from the manufacturer. Data from cattle using this  
130 equipment and collecting motion index data has been evaluated and reported by Tolkamp

131 et al. (2010). The data were analysed based on 1-min intervals. All cows were fitted with a  
132 GPS collar, however, only nine of the animals were fitted with activity sensors as one  
133 Angus x Limousin cow proved too aggressive when attempting to attach the sensor and  
134 thus was not included in that part of the data collection. In addition, one of the activity  
135 sensors and two GPS collars developed technical problems and discontinued working.

136

### 137 **Experimental Design**

138 The experiment was divided into five sequential periods (Table 1) after the initial  
139 adaptation stage, when the cows became acclimatised to the field and the wearing of the  
140 collars and activity sensors.

141 In the first control period (C1) of three days, cows had full baseline access to the  
142 whole area of the field. This was a period when the cattle could show their natural  
143 behavioural use of the field. This was followed by the next period, the first Treatment  
144 period (T1) when the Invisible Fence induction cable was laid out (as shown in Figure 2)  
145 and the unit was power activated, with the cattle having no previous experience of the  
146 warning or electrical stimuli. Control period 2 (C2) followed with complete removal of the  
147 induction cable to measure any residual effects of the first test period, and to provide a  
148 new baseline period, prior to a new rectangular enclosure of Invisible Fence area being  
149 installed in Treatment period T2. This was a novel area adjacent, but different to, the  
150 enclosure area in T1. This phase was aimed to understand how the cattle behaved in a  
151 second period of full use of the Invisible Fence. The last control period (C3) was a period  
152 with no power, and thus, no warning or electrical stimuli, but with the visible induction  
153 cable remaining laid out. The objective of this period was to identify how cattle responded  
154 to residual visual cues.

155

### 156 **Data Analysis**

157 Eight GPS collars and eight activity sensors recorded full sets of data throughout the trial  
158 with no missing periods or loss of signal from the satellites to the GPS collars. The activity

159 data were analysed with Genstat Version 14 (VSNi 2011), while the GPS locations, used  
160 for cow distribution mappings were analysed within ArcGIS 9.3 (ESRI 2008).

161 GPS location readings of the virtual fence line (location of the induction cable)  
162 were taken and plotted within the GIS (Geographic Information System). Then, a polyline  
163 boundary was hand digitised through the collected GPS locations forming an enclosed  
164 polygon for both treatment enclosures (Fig. 2). Buffer zones at 5 m and 10 m away from  
165 the polyline on the outside and inside of each enclosure were calculated since the GPS  
166 collar fixes (and multiple GPS fixes to position the fence polyline within the GIS) were  
167 both known to have a likely +/-5m margin of locational error. The GPS fixes along with  
168 time stamps for each cow could then be inputted to the GIS, allowing for analysis of  
169 distribution about the field according to time, as well as position relative to the fence line.  
170 To achieve this, the distance of each fix to the nearest edge on the boundary polyline was  
171 calculated out to a maximum distance away from the enclosure boundary of 80 m. The  
172 distance measurements were then exported from the GIS into Microsoft Excel for further  
173 analysis. Considering the large number of GPS fixes obtained, the distribution of distance  
174 measurements for each collar were grouped into 5 m frequency intervals ('bins') within  
175 Microsoft Excel, allowing for graphical plots of the distribution of each cow during the trial  
176 periods to be created (Fig. 3).

177 For analysis purposes, the field was divided into notional north and south section,  
178 creating digitised polygons that would allow for the comparison of cow location and  
179 presence within the two sections (Fig. 2). This notional boundary was not fenced. The  
180 parameter 'section' could then be combined with a day-or-night parameter offering more  
181 detailed behavioural analysis of the cows. The 'day' time period was set as the time  
182 between 7 am and 7 pm and 'night', therefore, was the remaining period of the 24 h clock.  
183 The time points were set according to the analysed activity of the cows (Fig. 4) and were  
184 corresponding with nautical twilight during that time of year.



185           The field was only very slightly undulating and had an easterly aspect. There were  
186 trees and shelter outside the western boundary and a public road along the eastern  
187 boundary and no other cattle were in adjacent fields.

188

### 189 **Statistical Analysis**

190 A Generalized Linear Mixed Model (GLMM) was run with Genstat 14 for the locational  
191 data focussing on the number of fixes in the north and south sections of the field. A  
192 binomial distribution was chosen and the link function 'logit' was set. The model included  
193 the fixed effects: treatment, day\_or\_night and day\_within\_treatment. The collar ID was  
194 included as a random effect. The parameters treatment, day\_or\_night and collar ID were  
195 set as factors, whereas, the parameter day\_within\_treatment was set as a variate.

196           The time the cows were in lying bouts were calculated from the sensor data as  
197 part of the routine output from the activity sensor software package (IceManager 2010,  
198 IceRobotics, Edinburgh, Scotland, UK). However, the presence of a high number of  
199 extremely short lying bouts (too short for a cow to lie down and get up again) were  
200 identified, and dealt with according to the recommendations of Tolkamp et al. (2010); that  
201 is, the inclusion of lying bouts > 4 min only. For the data analysis dealing with the duration  
202 of lying bouts, a GLMM with a normal distribution and the link function 'identity' was  
203 chosen. The response variate was the duration of lying bouts recorded in minutes with the  
204 fixed model, including the parameters: treatment, hour\_of\_day and day\_within\_treatment.  
205 The animal identification code was included in the random model as a random effect.

206           For the analysis of the Motion Index, a Linear Mixed Model was chosen. The  
207 response variate was the log transformed Motion Index with the fixed model, including the  
208 parameters: treatment, hour\_of\_day and date. The animal identification code was  
209 included in the random model as a random effect.

210

211

## 211 **RESULTS**

212

213 The GPS locations in Control period 1 (C1) demonstrated that the cows used the  
214 complete area of the field, including the areas marked as exclusions for the subsequent  
215 treatment periods (Fig. 5 a, Table 2). By contrast, during the two treatment periods (T1  
216 and T2) the number of recorded GPS fixes within the exclusion areas minus the 10 m  
217 inside exclusion area boundary (5 m error of locational cow data plus 5 m error for the  
218 GPS fence recording) decreased dramatically (with only one fix recorded during  
219 Treatment 1 and one fix recorded during Treatment 2; Fig. 5 b). Fewer GPS fixes in total  
220 were recorded during Control period 3 compared to Control period 2 due to only testing  
221 that period for two full days rather than three days. The number of GPS recorded  
222 locations within the exclusion areas (27 and 19 fixes respectively) during Treatments 1  
223 and 2 remained very low compared to the previous control periods (Table 2). The GPS  
224 data further indicated that during Control period 2, the cows used the first exclusion area  
225 59% less (932 fixes; relating to 8.7 h per cow over the Control period 2) than during  
226 Control period 1 (1558 fixes; relating to 14.6 h per cow over the Control period 1), even  
227 though the cable had been removed and the cows were free to re-enter the area. The  
228 exclusion location for Treatment 2 was chosen to cover a nearby area well used by the  
229 cows. During Control period 1, prior to any fence being activated, each cow spent on  
230 average 4.1 hours within the area that would be the exclusion area during T2. In period  
231 C2, when once again there was no activated fence line, the time the cows spent in the  
232 area, that was exclusion during T2, increased to 6.1 hours. This suggested that the cows  
233 continued to avoid the area used as exclusion area in T1 and, therefore, time in the T2  
234 area increased. During the last control period (Control period 3), cows spent only 30% of  
235 their time in Enclosure 1 when compared to the previous Control period 2 (data adjusted  
236 to the different length of those two periods). Figure 6 reveals that the animals continued to  
237 avoid entering the last exclusion area after power to the fence line was switched off.

238 To further analyse the overall behaviour of the cattle within the complete field, the  
239 GPS location fixes for each collar were counted during both day and night, and during the  
240 different experimental periods, separately in the north and south sections of the field.

241 Table 3 shows the numeric locational data. Results suggest that the north section of the  
242 field was less used than south section both during the day and night within Control period  
243 1. This behaviour was reversed during Treatment 1. Overall, the cows spent more time in  
244 the south section of the field during control periods than during treatment periods ( $P <$   
245  $0.001$ ). Cows spent more time ( $P < 0.001$ ) in the north section of the field during the night  
246 than in the south section of the field. In terms of activity patterns, both motion index and  
247 numbers of steps, were different ( $p < 0.001$ ) between days within a treatment period  
248 (day\_within-treatment parameter), but when comparing these same behaviour data for the  
249 greater treatment periods compared with each other, there were no significant  
250 differences.

251 The location data of each cow in relation to the fence line was then analysed to  
252 better understand how the animals reacted to the audio and visual cues presented. The  
253 distribution graph (Fig. 3) shows the frequency of GPS data points for each cow within  
254 each 5 m interval distance away from the nearest part of the fence line during the two  
255 treatment periods. The fence line was represented by the origin on the 'x' axis (at 0 m).  
256 Any distinct frequency peaks in the graphs corresponded to large clusters of GPS data  
257 points recorded at similar distances away from the fence line (e.g. frequently used grazing  
258 areas or periods where groups of cows were possibly resting).

259 During Treatment 1, the majority of cows showed an accumulation of chosen  
260 locations at distances between 20 and 60 m (median = 35 m, standard deviation SD =  
261  $\pm 23.6$ ). During Treatment 2, the pattern appeared to change with a more even distribution  
262 of locations between 0 and 80 m becoming apparent (SD =  $\pm 13.5$ ), except for one cow  
263 (collar 206) which spent considerably more time in the 10 m zone from the fence line.  
264 Overall, there were 42% more GPS observations noted within 80 m of the fence line in  
265 Treatment 1 than in Treatment 2.

266 As mentioned before, the activity data provided three main parameters as output;  
267 the number of physical steps taken, a motion index and the duration of lying bouts. We  
268 found that the motion index was highly correlated with the number of cow steps ( $r = 0.83$ ).

269 The activity sensors showed a clear diurnal pattern for all eight cows (Fig. 4) which would  
270 be expected for the autumn season in Scotland. The 24-hour behaviour pattern usually  
271 shows two peaks during the day (4-5 h before and after noon). This typical pattern was  
272 displayed during the complete experiment for all five experimental periods.

273 Figure 7 shows the average sum of hours during lying bouts per cow per day. The  
274 amount of lying time was unaffected by the different treatments. This indication was  
275 underpinned by the results from the GLMM on lying bout duration. There was no effect of  
276 treatment ( $P = 0.199$ ). However, *hour\_of\_day* showed an effect on behaviour as the  
277 activity behaviour in general is changing considerably during the course of the day ( $P <$   
278  $0.001$ ; Fig. 4). *Day\_within\_treatment* had also an impact on behaviour ( $P < 0.001$ ) due to  
279 activity changes per day. The log transformed Motion Index showed a difference for  
280 treatment, time and day (all  $P < 0.001$ ; Figure 8 original data).

281

282

## DISCUSSION

283

284 This study demonstrates the success of the Boviguard® system as an alternative to a  
285 traditional electric fence. In Treatment 1, only one GPS fix (Collar 219) appeared to occur  
286 inside the enclosure area, after correcting for GPS locational error. The distance  
287 measured for this single data point within the enclosure was 11.86 m from the nearest  
288 fence line. Although the data point might indeed indicate that this cow passed into the  
289 enclosure area for a short period of time, there was no indication from the remainder of  
290 the GPS fixes obtained for collar 219 that this was so. This fix point may have been a  
291 larger GPS error. In addition, no cow was visually observed inside the enclosure during  
292 either of the two treatment periods. We are confident that the few GPS fixes within the  
293 enclosure boundary are compatible with GPS locational error, supported by similar fixes  
294 on the non-field side of the field boundary, including apparent locations on the adjacent  
295 public road.

296 The shift in number and density of GPS fixes around the enclosure areas during Control  
297 periods C2 and C3 clearly suggested that the cows' normal locational behaviour in that  
298 part of the field was affected by the awareness (or memory) of the virtual fence enclosure  
299 positions. During C2, the cows showed increased presence in the area away from  
300 Enclosure 1 and during C3, the cows tended to cluster in areas away from both  
301 enclosures. Our experiment could not test the longevity of this response, but we consider  
302 it would be a short period in the absence of further warning or aversive stimuli, especially  
303 as some cattle quickly moved into the area previously excluded.

304 Overall, the results appear to indicate that once acclimatised to the system, the  
305 cows tended to use the visual cue of the cable lying on the ground rather than the audio  
306 cue; or possibly that the visual cue was a stronger exclusion reinforcement than the  
307 audio. When the cable was removed after the first treatment period, the cows immediately  
308 returned and entered that exclusion area, though as noted above not as much as prior to  
309 the treatment periods. When the cable was not removed after treatment T2, during period  
310 C3 the cows stayed outside the exclusion area while the power was switched off. We  
311 believe the visual presence of the cable led to this effect. In addition, it was noticed that  
312 during the treatment periods, cows spent more time during the night in the north section of  
313 the field, furthest away from the exclusion areas, during the night but were prepared to  
314 spend time in the south part of the field during the day. This suggests that the visual cue  
315 of being able to identify the fence line was most important to them. Limited animal  
316 observations and cross-comparison with the GPS results suggested that some cows  
317 walked along the fence line, reinforcing the view that they were observing the fence line  
318 cable rather than reacting to the audio or electrical cues. Combining the GPS fixes with  
319 the activity data, the animals adapted to the presence of the enclosures yet maintained  
320 their natural activity pattern as demonstrated by the fact that the duration of lying bouts  
321 did not significantly differ between treatment and control periods. The results suggest that  
322 after the initial learning period, the cows responded mainly to the visual cue rather than  
323 the audio warning cue. There was no evidence from the results of any significant impact

324 on animal welfare. Although the increased presence of cows in the north section of the  
325 field at night indicates a possible negative link with the visual cue. It should be noted that  
326 the audio signal of the Boviguard® collar was considered rather quiet. If the audio signal  
327 was louder and the triggering distance longer, it is possible that the cows would have  
328 responded and reacted to the audio signal more strongly, especially in situations when  
329 the cable was less visible - such as during the night. Greater triggering distances would  
330 also improve the option of burying the cable in the ground. The outcome of an experiment  
331 with a buried cable would be uncertain and had nothing to do with the overall  
332 technological approach. It would also be helpful if the triggering distances would be more  
333 similar between the collars in order to be able to optimise the distance, though in this  
334 experiment all collars appeared to be equally effective.

335         There are many different technical approaches patented which fall under the term  
336 'Virtual Fence' (Umstatter 2011). However, to the authors' knowledge, only the 'Invisible  
337 Fence' method patented by Peck, is currently available commercially for livestock (i.e. the  
338 Boviguard® system). The 'next stage' development of a GPS based system is not yet  
339 commercially available. The lack of commercial GPS-based virtual fence technologies is  
340 largely due to the large power requirements for long term use; an energy issue that has  
341 not yet been resolved (Ruiz-Mirazo et al. 2011). Because the induction cable is connected  
342 to a separate power source, the actual Boviguard® collar does not need a large amount  
343 of energy and can be sufficiently powered by 4 AA batteries which can last, according to  
344 the manufacturer, for over one year.

345         Another potential problem with virtual fencing is the use of electrical stimuli as  
346 negative reinforcement. The majority of virtual fence patents include some form of  
347 electrical stimuli (Umstatter 2011). Although some research has looked at other options,  
348 such as using sound as negative reinforcement (Butler et al. 2004; Umstatter et al. 2009,  
349 2011, 2013), or using only positive reinforcement (Lalor 2005, 2009), there is a strong  
350 indication that an electrical stimulus is the most effective form currently available.  
351 However, the debate on whether electrical stimuli are considered acceptable for animal

352 welfare reasons is on-going. This is an important issue in some European nations, such  
353 as Wales where electric shock collars (e.g. for dogs) are banned (Animal Welfare  
354 Regulations 2010) and regulations such as this could potentially influence the future  
355 acceptance of virtual fencing as a viable alternative. Our results indicate that the  
356 Boviguard® collar rarely activates the electrical impulse, and so, could be compared to  
357 traditional electric fences which animals avoid.

358         Some research has been carried out to ascertain the acceptable levels of electric  
359 stimuli use in a virtual fencing environment and their impact on the animals. Tibbs et al.  
360 (1995) investigated the influence of electronic diversion away from riparian areas,  
361 assessing livestock grazing behaviour, nutritional physiology, stress physiology and  
362 performance. The system used ear tags with audio warning cues and electric stimuli.  
363 According to the authors, the animals showed no difference in stress levels or in body  
364 condition score. However, a higher weight gain was detected in the control groups ( $p =$   
365 0.02). They explained this in terms of a higher quality diet because the control animals  
366 were able to access the riparian areas. In addition, Lee et al. (2008) studied the effect of  
367 low energy electric shock on cortisol, beta-endorphin, heart rate and behaviour of cattle.  
368 They found no difference between the stress hormone responses of cattle to three  
369 unpredictable electric shocks and common handling procedures (e.g. being held in a crate  
370 for weighing and restraint in a head bail).

371         In the case of this study, due to the fact that the animals could see the cable on  
372 the ground and possibly associate it with the electrical stimulus, it was not a significantly  
373 different setup to a common electric fence. However, although similar in function, the  
374 Boviguard® system still has the positive aspects of being a 'virtual fence' in terms of not  
375 being a physical and clearly noticeable barrier. This could provide a good alternative  
376 option for when electric fencing is not useable, such as in nature conservation areas. For  
377 example, fencing is not permitted within much of the Exmoor National Park in the UK. A  
378 Boviguard® style approach could offer a cost-effective solution to ensure that managed  
379 grazing is feasible but without the visual side effects of solid or electric fencing being

380 noticeable by the public. Invisible fences, therefore, can be especially useful in  
381 recreational landscapes. However, warning signs for the presence of livestock would be  
382 required in this instance.

383           Costs of current equipment are high, due to low production numbers. At the  
384 moment collars will cost over US \$300 each and charger and cable unit will cost over US  
385 \$500. With small numbers of animals and a relatively small area this could be lower than  
386 the costs of standard post and wire or electric fencing, but still high cost for larger herd  
387 sizes. The relatively short fence length also limits practicality and increases costs in more  
388 extensive grazing locations.

389           Overall, the development of virtual fencing can provide a management tool which  
390 not only can reduce the amount of fencing cost and labour (Umstatter 2011) but also lead  
391 to completely novel management strategies. For instance, with climate change, we need  
392 adaptation strategies resulting in innovative ways to manage our rangelands across the  
393 world (Joyce et al. 2013). Although the Boviguard® system already improves flexibility in  
394 terms of fencing, as no fence posts or stakes are required, future developments using  
395 different technologies could lead to an even greater management flexibility.

396

397

398

## **IMPLICATIONS**

399

400 The experiment presented here has shown that cows can be efficiently prevented from  
401 crossing a 'virtual' fence line using a combination of visual, audio and electrical stimuli as  
402 preventative cues. The installation of an induction cable fence line is much less labour  
403 intensive than erecting an electric fence as no fence posts or stakes need to be installed.  
404 This technology could provide a beneficial solution for farmers needing to move fences on  
405 a frequent basis, such as in strip grazing. Use of virtual fencing for internal subdivision  
406 would allow greater variability in allocation of pasture to meet changing feed requirements  
407 of a herd. This could greatly improve farm efficiency on intensively managed pastures.



408 It can also be a useful tool for farmers, nature conservationists or others who wish to  
409 restrict livestock access to specific areas (for example, to lessen the impact of poaching,  
410 for habitat regeneration or for public access). The study further indicates the potential for  
411 virtual fences to be used as effective barriers where traditional fencing options are not  
412 possible, although it also highlights the apparent effect that visual cues may play on the  
413 behaviour of the animals. The results demonstrate the effectiveness, and the lack of  
414 behavioural changes in parameters measured here, of a collar-based electrical stimuli  
415 system for cattle. Further research is required to analyse how much the cows rely on the  
416 visual warning cue, how a solely audio warning cue based system would fare and a  
417 measure of the number of electrical stimuli given would provide data to answer animal  
418 welfare issues. This study can provide impetus for the continued development of virtual  
419 fencing technologies as a viable alternative and cost-effective option for a wide range of  
420 grazing situations.

421

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423

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426

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500

## FIGURE CAPTIONS

501

502 Figure 1: Cow equipped with GPS (first collar nearer the head), activity sensor (left hind  
503 leg) and Boviguard® collar (second collar). Inset shows induction cable.

504 Figure 2: Experimental field divided into north and south sections using a hand digitised  
505 polygon layer within the GIS. The points indicate GPS fixes of recorded animal locations.  
506 The enclosure areas were located in the south section of the field.

507 Figure 3: Representation of the proximity of all eight cows with GPS data to the virtual  
508 fence line during Treatment 2.

509 Figure 4: Average activity pattern of cows over 24 hour periods for the 5 different  
510 experimental periods. The vertical lines indicate the beginning and end of the nautical  
511 twilight at the midpoint of the experimental period.

512 Figure 5: Locational data during control (no virtual fence) C2 (a) and treatments T1 and  
513 T2 (b). The treatment enclosures can clearly be seen in the second and third picture.

514 Figure 6: Locational data during control C3. The power to the cable is switched off but still  
515 laid on the ground.

516 Figure 7: Average amount of lying time per day and cow during the different treatments (n  
517 = 8 cows).

518 Figure 8: Average Motion Index and step data from IceTags per day (n = 8 cows).

519

520

## TABLES

521

522 Table 1: Experimental design. Cows were wearing the equipment during all five test  
523 periods. Treatments were grazed sequentially without a break. There was an adaptation  
524 phase before the experiment started.

<b>Period</b>	<b>Treatment</b>		<b>Description</b>	<b>No. of measured 24-h-periods</b>
<b>1</b>	Control 1	[C1]	No cable on the ground (7.88 ha)	3
<b>2</b>	Treatment 1	[T1]	Exclusion area no. #1 (approx. 5400 m <sup>2</sup> )	3
<b>3</b>	Control 2	[C2]	No cable on the ground (7.88 ha)	3
<b>4</b>	Treatment 2	[T2]	Exclusion area no. #2 (approx. 7900 m <sup>2</sup> )	3
<b>5</b>	Control 3	[C3]	Exclusion area no. #2; power off but cable left in situ (7.88 ha)	2

525

526

527 Table 2: Frequency of all GPS proximity fixes to the exclusion areas during the  
 528 experiment (counts within band intervals of 5 m).

	<b>Number of GPS fixes</b>
<b>Exclusion area 1 during Control 1</b>	1558
<b>Exclusion area 1 during Control 2</b>	932
<b>Exclusion area 1 during Control 3</b>	184
<b>Treatment 1 (within exclusion area)</b>	27
<b>Treatment 1 (within exclusion area minus the 10 m inside exclusion area boundary)</b>	1
<b>Exclusion area 2 during Control 1</b>	435
<b>Exclusion area 2 during Control 2</b>	653
<b>Exclusion area 2 during Control 3</b>	10
<b>Exclusion area 2 during Control 3 (within exclusion area minus the inside 10 m exclusion area boundary)</b>	0
<b>Treatment 2 (within exclusion area)</b>	19
<b>Treatment 2 (within exclusion area minus the inside 10 m exclusion area boundary)</b>	1

529

530

531 Table 3: GPS locations\* (%) during day (7 am – 7 pm) and night of a 7.88 ha paddock  
 532 divided into notional North and South sections.

	<b>Control</b>	<b>Treatment</b>	<b>Control</b>	<b>Treatment</b>	<b>Control</b>
	<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>3</b>
<b>North – night</b>	21.1	60.3	49.2	80.8	45.3
<b>South – night</b>	78.9	39.7	50.8	19.2	54.7
<b>Total night</b>	100	100	100	100	100
<b>North – day</b>	31.4	60.5	29.7	46.2	26.0
<b>South – day</b>	68.6	39.5	70.3	53.8	74.0
<b>Total day</b>	100	100	100	100	100

533 \* GPS locations were counted for day and night within each Control and Treatment  
 534 period. The counts were then analysed regarding their distribution within the North and  
 535 the South sections and the percentage of counts in each area, respectively, was then  
 536 computed.

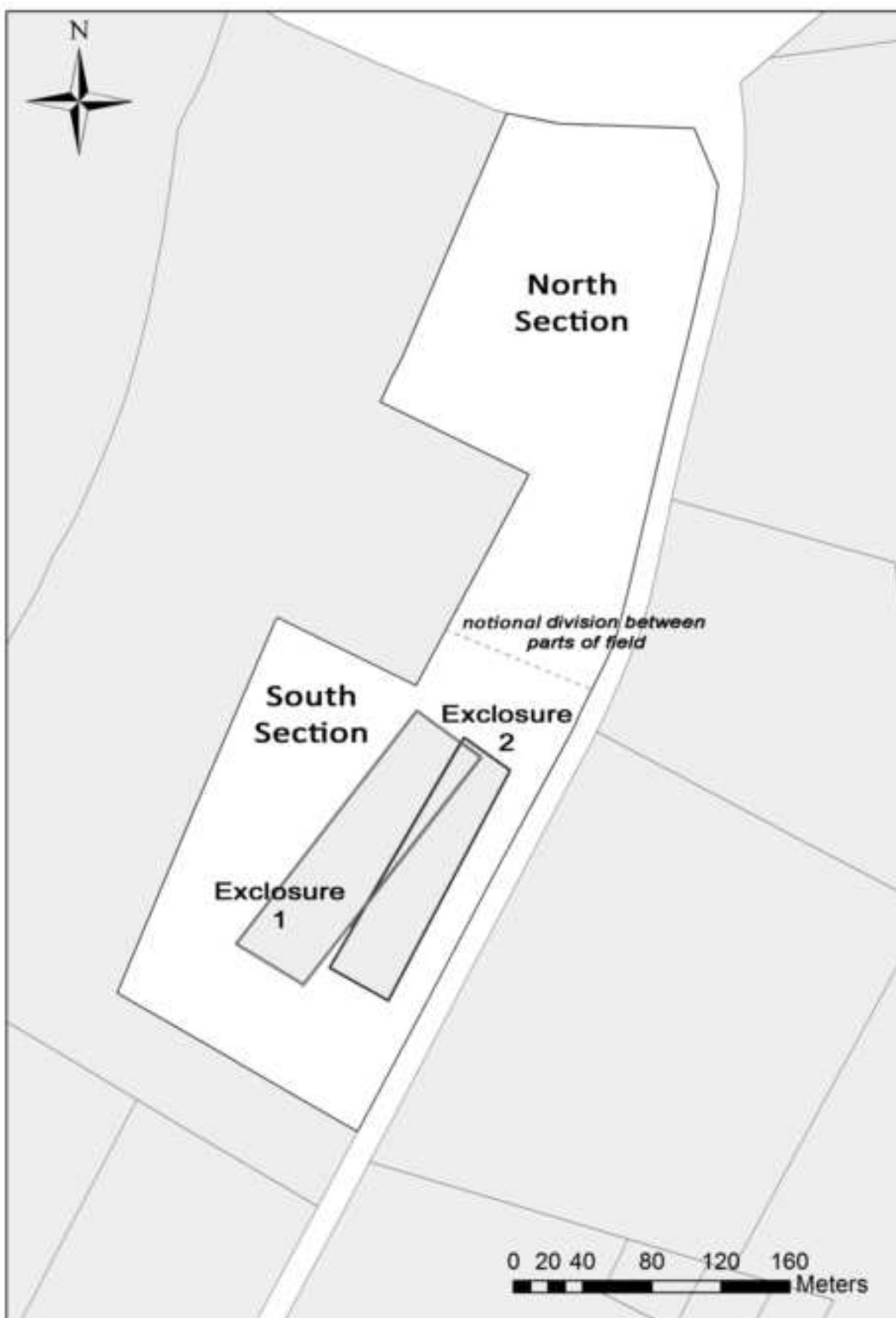
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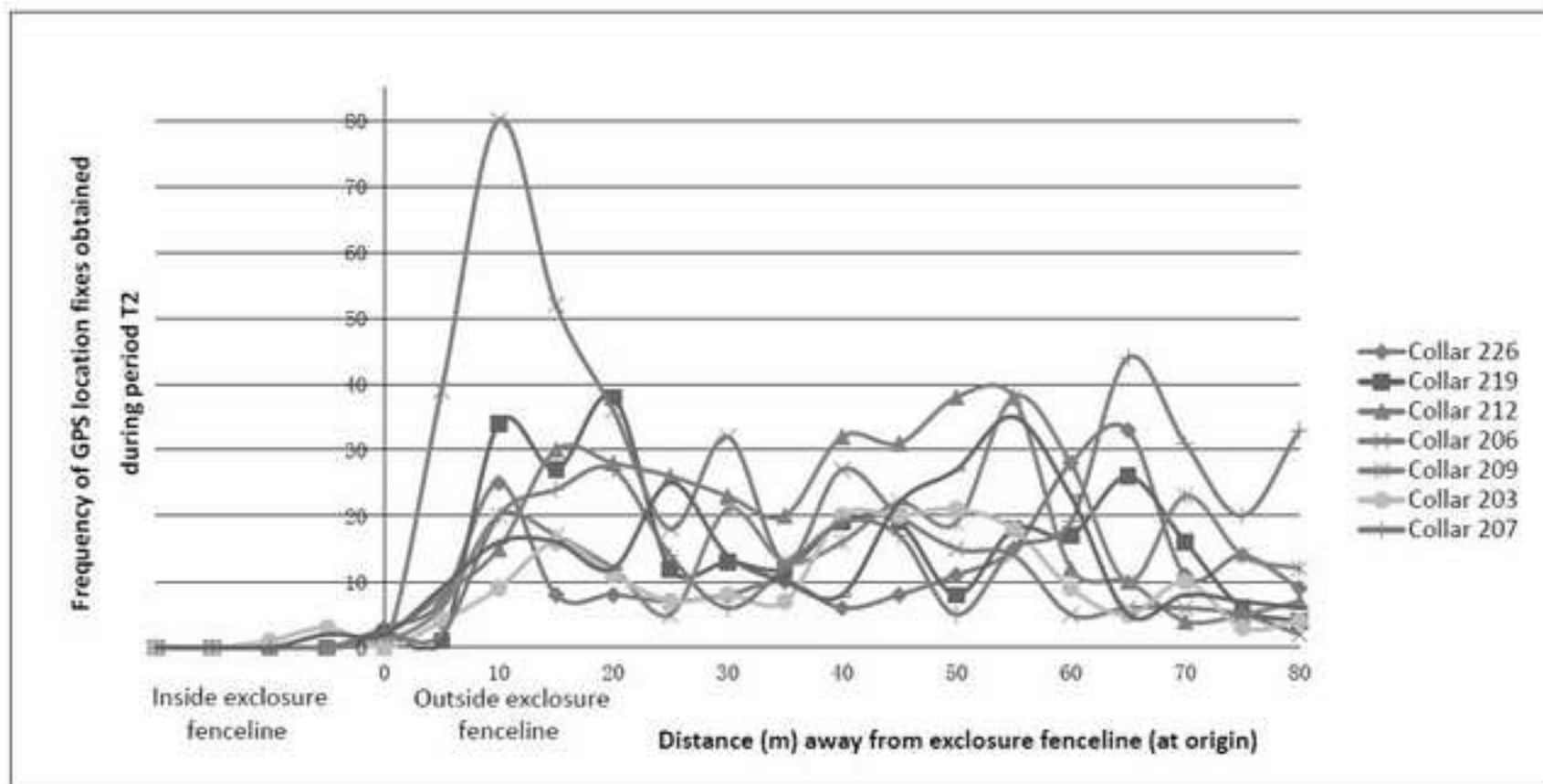
Figure\_1



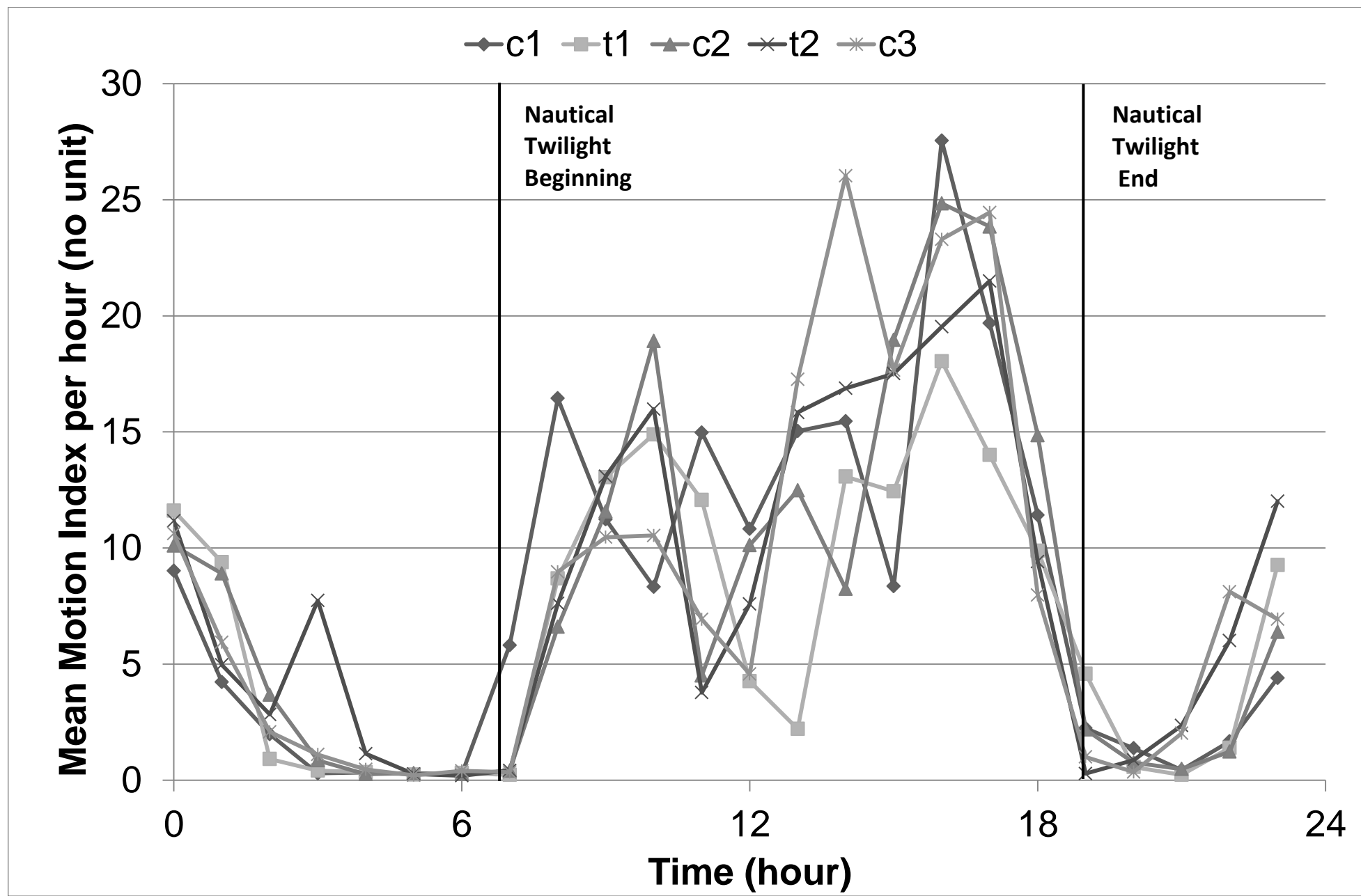
Figure\_2



Figure\_3



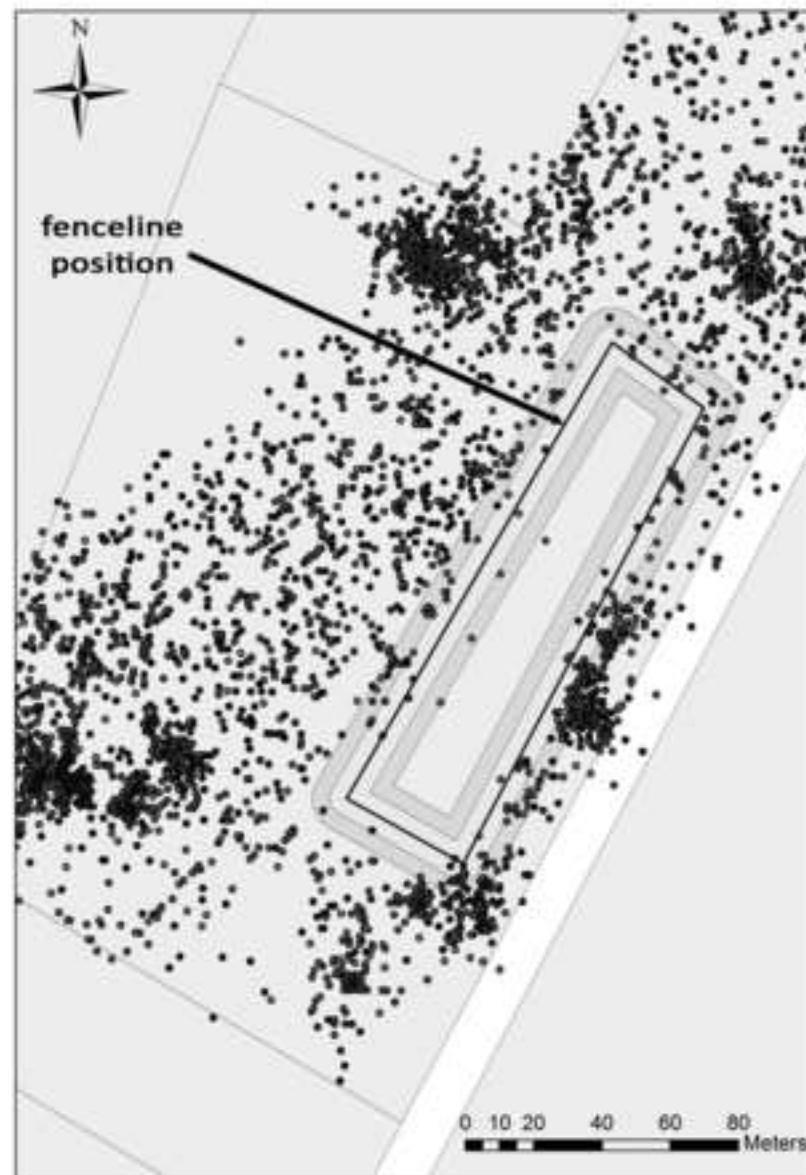
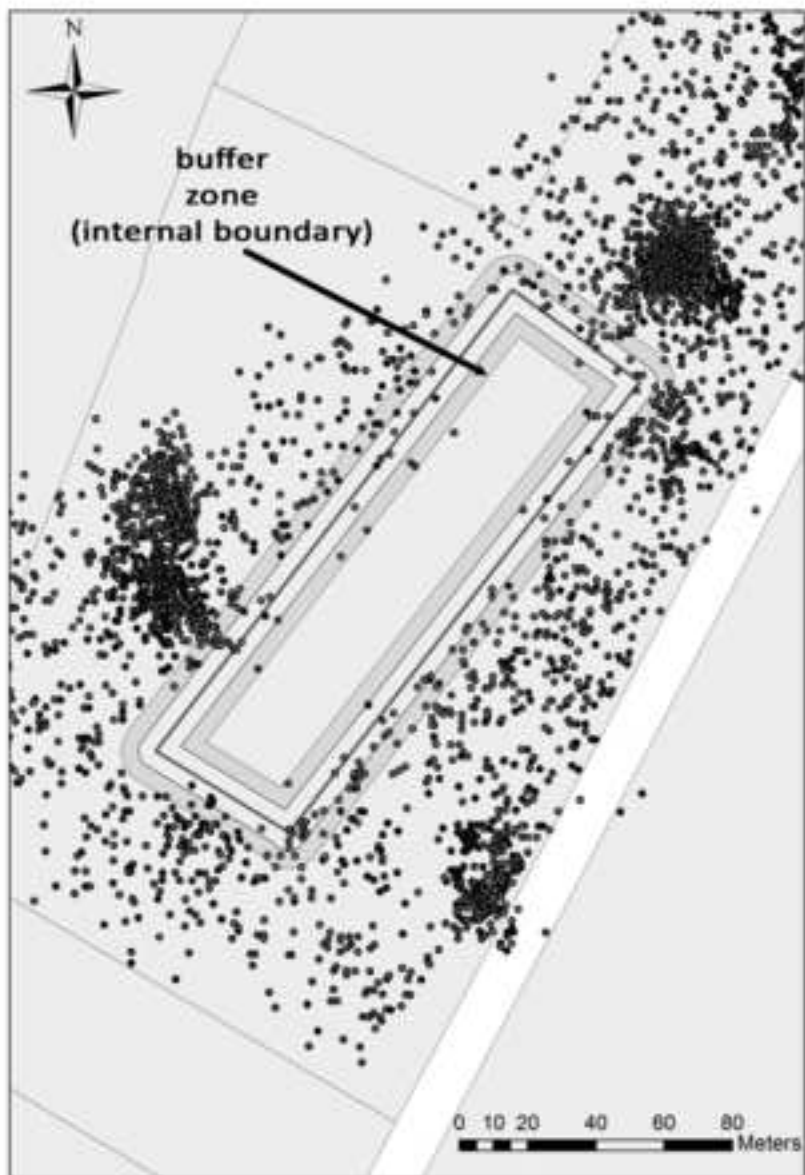
Figure\_4



Figure\_5a



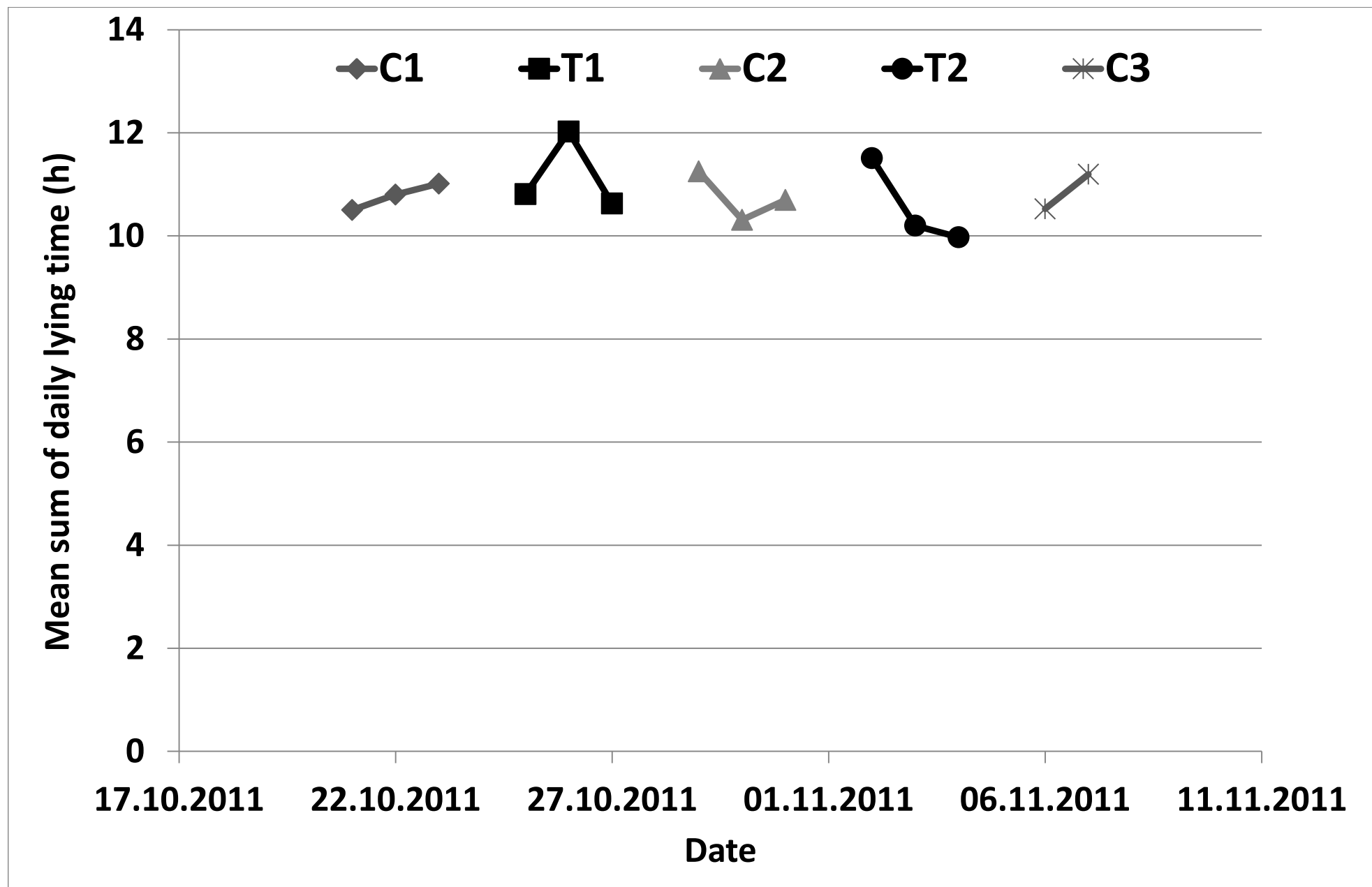
Figure\_5b



Figure\_6



Figure\_7





Figure\_8

