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RESEARCH

No evidence of negative effects of aerial 1080 operations on red deer (*Cervus elaphus*) encounters and sightings in South Westland forests

Jason Malham[1], Graeme P. Elliott[1] and Susan Walker[2]*

[1]Department of Conservation, Private Bag 5, Nelson 7042, New Zealand
[2]Landcare Research, Private Bag 1930, Dunedin 9054, New Zealand
*Author for correspondence (Email: walkers@landcareresearch.co.nz)

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Abstract: Recreational hunters are concerned that aerial 1080 operations in New Zealand's forests may adversely affect deer hunting, but data are rarely gathered in a way that enables such effects to be assessed. Between 2011 and 2015, we recorded two relevant indicators of the recreational hunting experience – number of red deer (*Cervus elaphus*) encounters, and number of individual red deer seen – in 865 person days of quarterly surveys across seven blocks of native forest in South Westland, New Zealand. Four blocks were treated with aerial 1080 before and during the study, and three were untreated. Generalised linear mixed effects models provide no evidence that aerial 1080 treatments reduced numbers of red deer encounters or numbers of individual red deer seen over time. There were no overall trends in numbers of deer encounters and deer seen per person day in either treated or untreated blocks over the study period, and average numbers of deer encounters and deer seen in treated and untreated blocks were similar. Models fitted to data from the 1080-treated forest blocks alone showed that numbers of deer encounters and numbers of deer seen per person day were highest in the period immediately following an aerial 1080 operation and declined over the following 2–3 years. This pattern is likely to result from a change in deer behaviour rather than in deer numbers, and its cause is unknown.

Keywords: aerial pest management, deer behaviour change, native forest, recreational hunting

Introduction

Sodium fluoroacetate (1080) is incorporated into cereal baits and used on the New Zealand mainland to kill stoats, rats and possums to protect indigenous fauna and flora, and to reduce bovine tuberculosis (Wright 2011; Green & Rohan 2012). Aerial 1080 operations used to treat large areas can also kill wild deer (Family Cervidae), which are regarded both as conservation and agricultural pests, and as a recreational and commercial resource (Nugent et al. 2001; Nugent & Fraser 2005). Recreational hunters frequently express concerns that aerial 1080 operations will harm deer and deer hunting in New Zealand forests (Green & Rohan 2012) and are prominent in opposition to its use (Nugent & Yockney 2004; Hansford 2016).

Surprisingly few studies provide information on how recreational hunting of red deer is affected by contemporary 1080 operations. Most published studies that have assessed rates of deer kill by aerial 1080 (e.g. Nugent et al. 2001) pre-date the practices used in modern operations. Operational practices have changed greatly over the last two decades (Brown et al. 2015) in ways that are likely to alter rates of by-kill of non-target species (Veltman & Westbrooke 2011), including deer. For example, cereal (not carrot) baits, pre-feeding (or pre-baiting), and small pellet sizes (e.g. 6 grams vs 12 grams) are now routinely used in forests, sowing rates have been reduced (Wright 2011), and the timing of conservation-focussed operations has become more sophisticated and targeted (Elliott & Kemp 2016).

The number or proportion of total population of deer killed in an aerial 1080 operation may not indicate how deer hunting will be affected, and few datasets have been collected in ways that allow the effects of 1080 operations on deer hunting to be robustly assessed. Here we analyse one such dataset, which records the number of encounters with red deer (*Cervus elaphus*) and the number of individual red deer seen, quarterly over 4 years in 1080-treated and untreated native podocarp-broadleaf and podocarp-broadleaf-beech forests in South Westland. We test the hypothesis that aerial 1080 operations reduce numbers of deer encounters and numbers of deer seen, and discuss the implications of our results.

Methods

Study area and blocks

Encounters with red deer (*Cervus elaphus* – hereafter deer) were recorded quarterly in February, May, August and November (hereafter months) from November 2011 to August 2015 in seven blocks of rainforest in South Westland, New Zealand. The seven forest blocks range in size from 5500 to 23 000 hectares (median 17 000 hectares), are 96–100% covered in forest, span elevation ranges between 35 and 800 metres, and

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lie between latitudes of 43° 36' and 43° 47' (Table 1). The rainforest canopies are dominated by mixtures of podocarp, broadleaved (rata-kamahi) and silver beech (*Lophozonia menziesii*) trees in different proportions.

Five of the blocks (Monro, Pearson, Topsy, Mistake, and Yankee Dan; Fig. 1) were chosen for a bird acoustic monitoring research programme and had similar ranges of elevations and forest types, all of which include a large component of silver beech. The Kini block was also included in the acoustic monitoring programme and is at a similar elevation to the other acoustic study blocks, but has no beech component. The smaller Waituna block was included in the study because it was visited regularly for an associated bird study (GP Elliott unpubl. data); its forests also have a large component of silver beech.

Treatments were assigned randomly to the blocks. Two of the seven forest blocks (Monro and Pearson) were treated with aerial 1080 three times: twice before the period in which deer were recorded (in June 2009 and October 2011) and once during it (in November 2014) (Table 1). Two forest blocks (Mistake and Topsy) were treated with aerial 1080 once before the deer recording period (in December 2010) and once during it (November 2013). The remaining three blocks (Yankee Dan, Kini and Waituna) were not treated with 1080 either before or during the study. All treatment operations occurred during fine-weather windows, and used cereal RS5 baits with a cinnamon lure and no deer repellent. Application of 12 g baits (toxin loading 1.5 g kg^{-1}, applied at 2 kg ha^{-1}) occurred within the 3 weeks following a single pre-feeding operation (6 g baits at 1 kg ha^{-1}).

There will have been some variation among the blocks in their intrinsic suitability for hunting, and in hunting pressure. Unfortunately, we have no empirical estimates of hunting

Table 1. Elevation range and area of the seven forest blocks, total sampling effort (in person-days), and dates (day, month and year) of aerial 1080 operations.

Block	Elevation (m)	Area (ha)	Effort	Month and year of 1080 operation
Kini	15–580	15 000	129	Untreated
Yankee Dan	20–760	17 000	125	Untreated
Pearson	15–540	17 000	141	2 June 2009, 27 October 2011, 7 November 2014
Waituna	95–700	5500	26	Untreated
Monro	15–840	16 000	144	2 June 2009, 27 October 2011, 7 November 2014
Topsy	20–800	19 000	148	1 December 2010, 22 November 2013
Mistake	20–550	23 000	152	1 December 2010, 22 November 2013

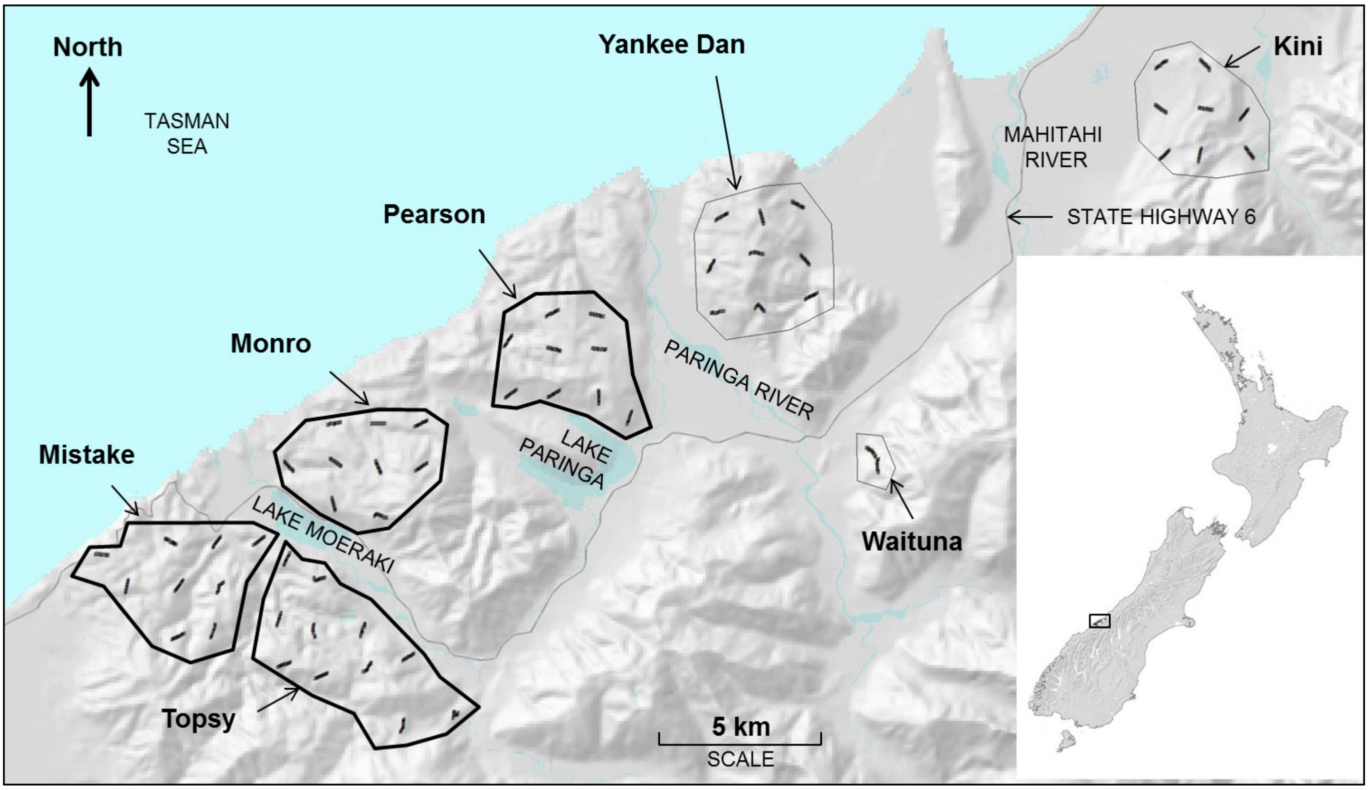

Figure 1. Map of the South Westland study area, showing the approximate boundaries of the seven forest blocks (indicated by labelled arrows). Blocks treated with aerial 1080 before or during our study are outlined in bold. The short black lines within each block indicate the positions of rat tracking tunnels lines which were visited while deer encounters and sightings were recorded.

pressure in the blocks, and these data would have been difficult to collect. Six of the blocks were freely accessible to private recreational hunters on foot through public land, and one (the untreated Kini block) was not. The authors' personal observations are that ease of access to recreational hunters on foot is reasonably similar among the six freely accessible blocks, considering topography and natural access routes such as roads, lakes, and river valleys. Most of the recreational hunting occurs on the river flats that are nearer to the state highway and the remote forested parts of the six blocks are rarely visited by recreational hunters. All blocks are subject to commercial helicopter deer recovery operations. However, the amount of non-forested land that can be successfully hunted by helicopters (primarily the river flats, and a few treefall gaps) is limited (<4%), with the remainder too thickly forested for helicopters to see deer, and only the smallest Waituna block adjoins any non-forest habitat above treeline.

Data and analyses

Deer were recorded in all blocks quarterly from November 2011 to August 2015. In each quarterly survey of each forest block, a record was kept of (1) the number of encounters with live deer, and (2) the number of individual deer seen within that survey period. A single encounter with live deer was recorded when one or more deer were either seen or heard, and the total number of individual live deer seen was recorded whenever one or more individual deer was sighted. Both of these variables are likely to be relevant indicators of the hunting experience, and are likely to have been affected by factors associated with both abundance and detectability, such as the suitability of the habitat for deer, the detectability of deer in different forest types, and behavioural or numerical responses of deer to hunting pressure or disturbance.

All records were made by experienced wildlife field technicians (see Acknowledgements) while they traversed the blocks on foot to monitor a network of rat tracking tunnels and service acoustic recording devices. Most observations were made while moving steadily on a circuit between rodent tracking tunnels, often in thick bush, while carrying tracking tunnel sampling equipment. Therefore, observers were likely to be making more noise than a hunter might. Observations began when they entered the bush and continued all day until they left the bush, and continued while observers were stationary at tracking stations and during breaks. Encounters and sightings were not recorded if they were sufficiently close together in space or time that the observer judged that the same deer individual or group was involved.

Records were also kept of the total number of person days in the field in each survey as an index of exposure to deer encounters (hereafter effort) and of the season of survey (represented by 1 of 4 months: February, May, August or November). The raw numbers of encounters and of deer seen per person day in each quarterly survey are plotted in Figure 2, along with the dates of aerial 1080 operations. We

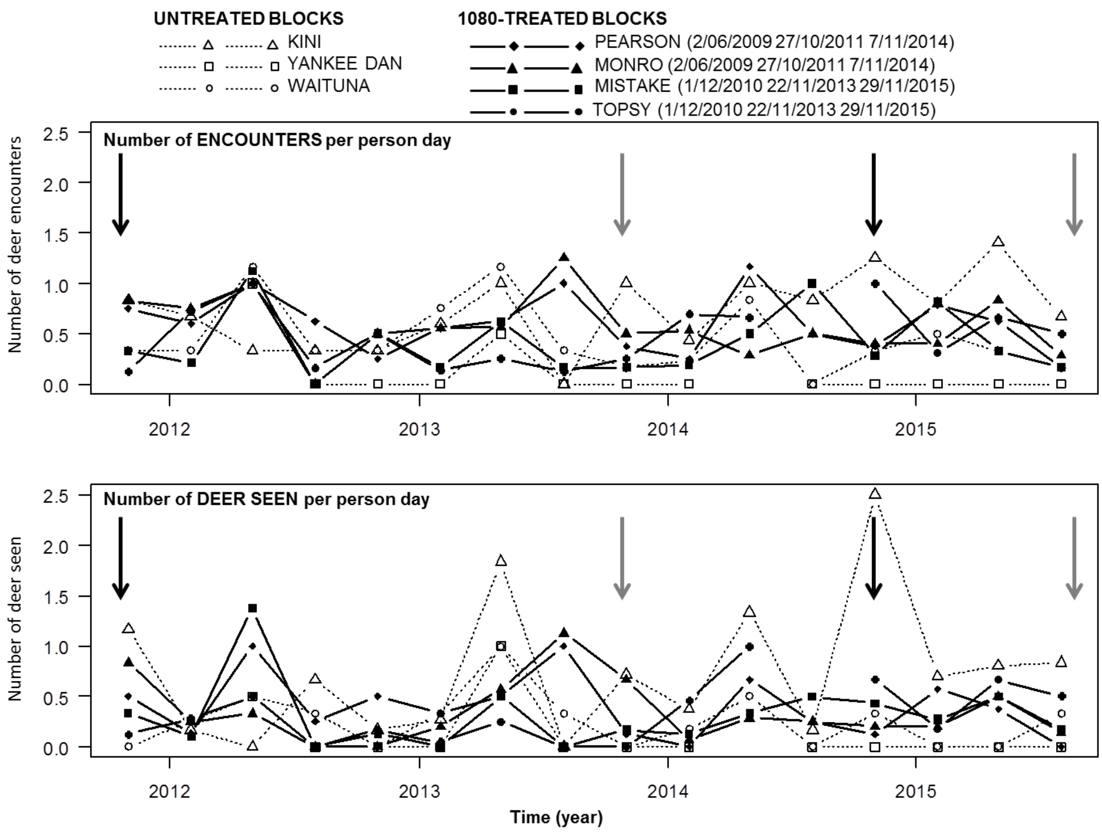

Figure 2. Raw data showing numbers of encounters with live deer, and numbers of individual live deer seen per person day, in quarterly surveys from November 2011 to August 2015 in seven forest blocks in South Westland. Dashed lines and open symbols show data from untreated blocks, and solid lines show data from blocks treated with aerial 1080. Observations were made in four sampling months (February, May, August and November, respectively) in each sampling year. Dates of aerial 1080 operations (including those preceding deer recording) are provided in the legend; arrows show dates of 1080 operations immediately before, within, and immediately after the study period (black arrows = operations in the Pearson and Monro blocks, grey arrows = operations in the Mistake and Topsy blocks).

fitted generalised linear mixed effects models (GLMMs) to determine how numbers of encounters with live deer and of individual deer were related to effort (person days), and how the two response variables were related to one another. Each model assumed a Poisson error distribution in the response variable, used a log link function, and included month (as a four-level factor) as a fixed effect, and sampling block as a random effect. After checking for over-dispersion (i.e. variance larger than the mean, which violates statistical assumptions), we also included an observation-level factor (unique to the quarterly survey × block combination) as a random effect in each model.

Models of overall trends

We fitted GLMMs of numbers of live deer encounters and deer seen to compare 4-year trends between untreated blocks and those treated with 1080. Fixed effects in these models were:

- the variable 'treated', coded as a factor (1 indicating that the block had been treated with 1080 and 0 indicating an untreated control block)
- the variable 'time since study commenced' (number of weeks after the start of deer recording in November 2011, scaled by dividing by the standard deviation and mean-centred for analysis)
- the two-way interaction between the 'treated' and 'time since study commenced' variables
- the month (modelled as a four-level factor variable)
- an offset term, which was the natural log of the number of person days in each survey (our proxy for sampling effort).

A significant interaction between treatment and time since study commenced would indicate that trends in numbers of deer encounters or deer seen differed between 1080-treated and untreated blocks. A decrease in the number of deer encounters or deer seen in treated blocks would be consistent with 1080 poison operations compromising the recreational hunting of red deer, either through reducing deer populations or by directly or indirectly altering their behaviour.

Month was included as a fixed effect because numbers of deer encountered and seen were expected to vary seasonally. We included the forest block as a random effect to account for non-independence of data collected in the same location at different times, and because we were not concerned with identifying differences among individual blocks.

Models of short-term effects of 1080

We then used a similar approach to test for a short-term effect of 1080 in addition to an overall trend in the four 1080-treated blocks alone. We fitted GLMMs to numbers of live deer encounters and deer seen, with four fixed effects: time since the most recent aerial 1080 operation (number of weeks, scaled by dividing by the standard deviation and mean-centred for analysis); time since study commenced; month; and an offset term (the latter three defined as in the models of overall trends).

In these models, positive effects of time since the last 1080 operation would be consistent with 1080 operations temporarily reducing numbers of deer encounters and deer seen. To account for the non-independence of data collected at the same time as well as at the same location, we included random effects for sampling period (a factor representing the unique combination of year and month) and for forest block in each model.

When fitting the 'overall trend' and 'short-term effects of 1080' models we assumed Poisson error distributions in the response variables, and used log-link functions. We included observation-level factors as random effects in each model to remove over-dispersion. We also calculated and plotted the autocorrelation functions of the mean model residuals at each quarterly time step. We found no evidence that there was temporal autocorrelation remaining unaccounted for in any model, and therefore did not include autocorrelation terms.

The upper and lower bounds of the 95% highest posterior density interval (HPDI) of parameter estimates were calculated to assess the statistical significance of fixed effects, and we calculated and plotted the fitted values and HPDI of each fixed effect at the average levels of all other parameters. We used functions in the libraries lmer (version 1.1-13; Bates et al. 2015), effects (version 3.1-2; Fox 2003), arm (version 1.9-3; Gelman & Su 2016), coda (version 0.19-1; Plummer et al. 2006) for the statistical software R (version 3.4.0; R Core Team 2017) for these analyses.

Results

Summary statistics

Across the eight blocks, there were 442 deer encounters (one or more deer was heard 228 times and one or more seen 214 times) in 865 person days, and 288 individual deer were seen. On average, there were 0.51 encounters and 0.33 individual deer seen per person day (medians 0.37 and 0.25, respectively) across all of the surveys from November 2011 and August 2015.

Plots of the raw data show that numbers of deer encounters and of deer seen in surveys were positively related to effort (i.e. person days; Fig. 3a,b) although the relationship between number of deer seen and effort was relatively weak (Fig. 3b). This pattern may reflect a few influential sightings of relatively large groups of deer that were not predictably related to effort. There was a positive relationship between the number of encounters with deer and the number of individual deer seen in a quarterly survey (Fig. 3c).

Models of overall trend

The interaction between 1080-treatment and trend with time was not significant in either model of overall trend, indicating that trends in numbers of deer encounters and deer seen across the 4 years did not differ between 1080-treated and untreated blocks. Parameter estimates for the 'time since study commenced: treated interaction' in Table 2a were not significantly different from zero, so that slopes of fitted effects on time since study commenced (Fig. 4a,b) did not differ significantly between treated and untreated blocks. Over the duration of the study, fitted estimates of the number of deer encountered per person day fell slightly in both treated and untreated blocks (from 0.36 [95% highest posterior density interval (HPDI) 0.22–0.60] to 0.35 [0.21, 0.58] and from 0.41 [0.30–0.59] to 0.37 [0.60–0.53] respectively), while fitted estimates of the number of deer seen rose gradually (from 0.21 [0.11– 0.41] to 0.26 [0.14–0.50] and from 0.22 [0.14–0.36] to 0.23 [0.14–0.38] respectively) (Fig. 4a,b). None of these temporal trends were significant, and the result is not consistent with management regimes of 1080 poison reducing either numbers of deer encounters or numbers of deer seen.

Across the whole study period, numbers of deer encountered and seen were similar in blocks treated with 1080 to those in the untreated blocks ($z = 0.37$, $P = 0.69$ and $z = 0.64$, $P = 0.52$ respectively for the 'treated' parameters

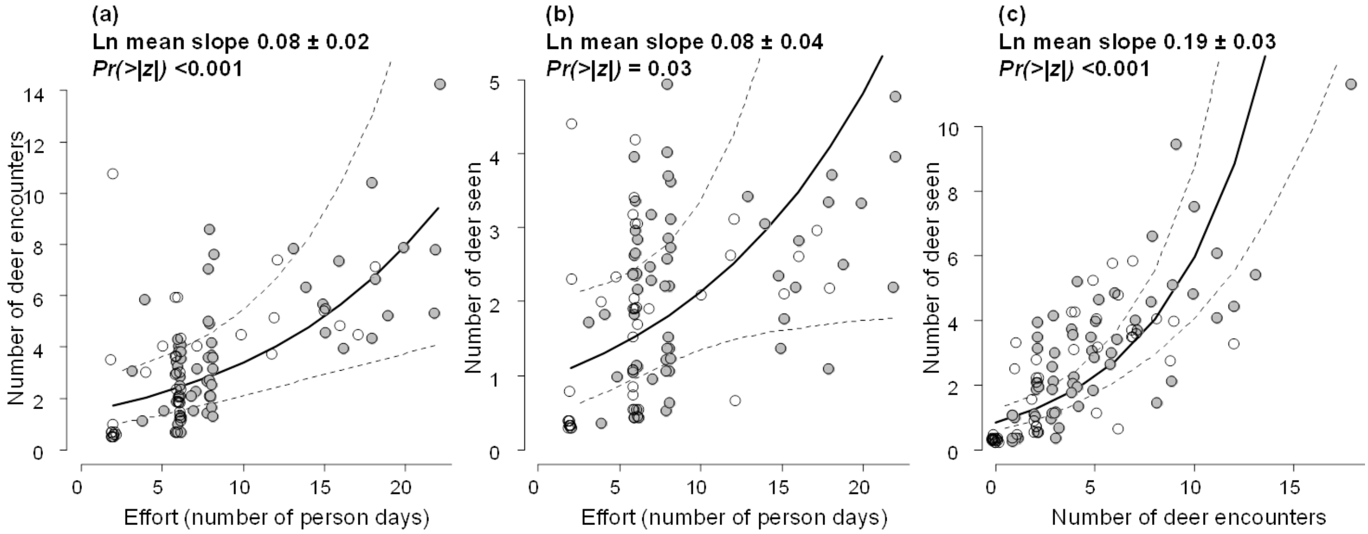

Figure 3. Raw data showing relationships of numbers of deer encounters (a) and deer seen (b) to survey effort expressed in person days, and the relationship between numbers of deer encountered and seen in surveys (c). Each subplot shows fitted effects as solid lines and 95% confidence intervals as dashed lines. Annotations show the average slopes (on the log scale of the model link function) and *Pr(>|z|)* (how likely that a slope as or more extreme than that observed would have occurred under the null hypothesis of no effect) from generalised linear mixed models. Points show fitted effects plus residuals for each observation (which aggregates the records made by all observers in one block in one quarterly sampling period): filled symbols indicate observation from blocks treated with 1080, and open symbols are observations from untreated blocks. To reveal overlapping points, we offset each point by up to 0.2 units in random horizontal and vertical dimensions prior to plotting.

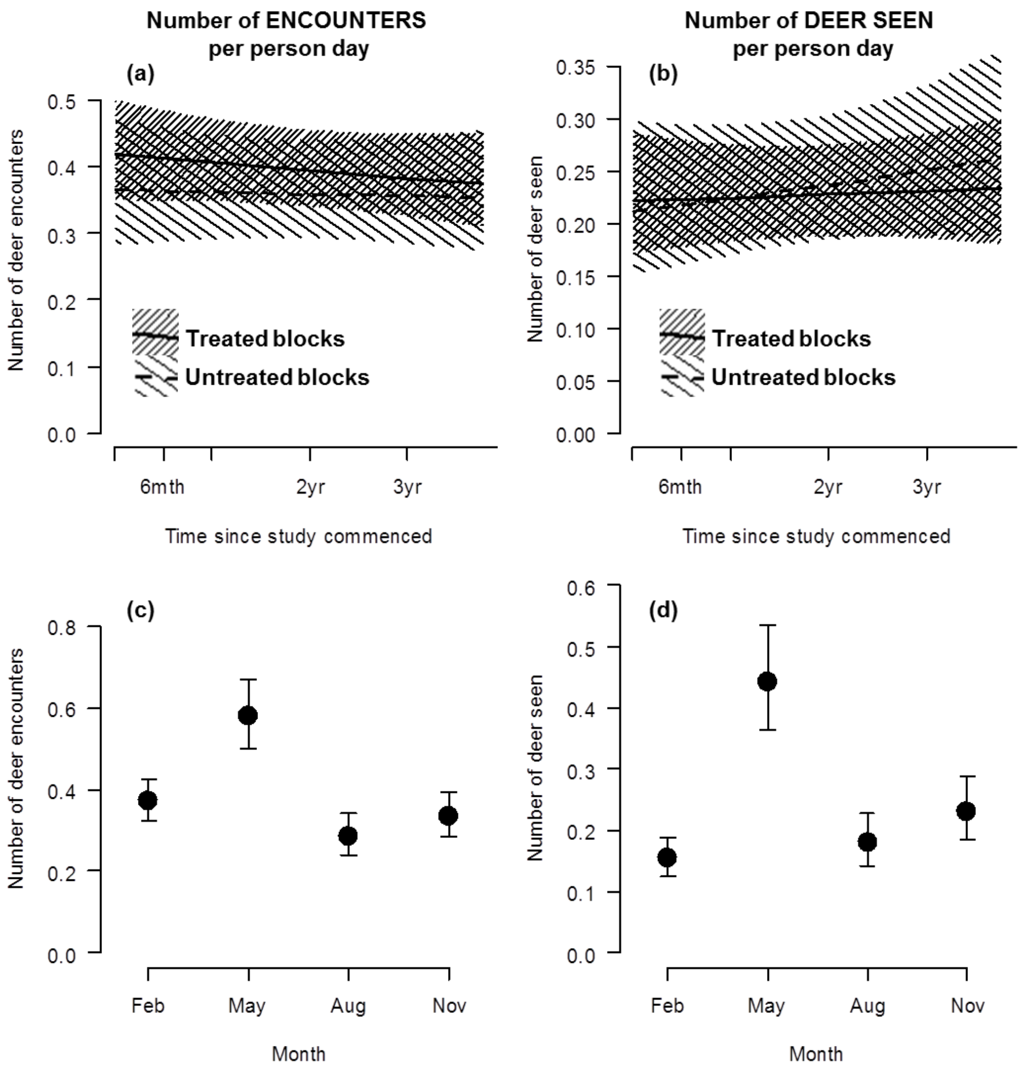

Figure 4. Models of overall trends: effects of time since study commenced and sampling month on number of encounters with live deer (left column) and number of live deer seen (right column) per person day from generalised linear mixed models. Hatched areas (a,b) and error bars (c,d) show ± one standard error.

Table 2. Parameter estimates (shown on the log scale) from two sets of generalised linear models of numbers of deer encountered and seen: model set (a) of overall trend in treated and untreated blocks, and model set (b) of short-term effects of time since 1080 operation in treated blocks only. Note that time since 1080 and time since study were scaled (by dividing by the standard deviation) and centred before model fitting: effects on the back-transformed (real) time scale are shown in Figures 4 and 5. Sampling months May, August and November were contrasted with February (modelled as factor variables). Estimate = the mean parameter estimate, lower/upper = 95% higher posterior density estimate (HPDI) bounds of the estimate (used as confidence intervals), std. error = standard error of the estimate, z value = estimate divided by the standard error, Pr(>|z|) = how likely it is that an estimate as or more extreme than that observed would have occurred under the null hypothesis of no effect (*= P < 0.05, ** = P < 0.01).

a) Models of overall trend	**Estimate**	**Lower**	**Upper**	**Std. error**	**z value**	**Pr(>|z|)**
Number of encounters model						
Intercept	−0.82	−1.07	−0.55	0.14	−5.78	<0.001***
Time since study commenced	−0.02	−0.15	0.09	0.06	−0.37	0.711
Treated	0.10	−0.31	0.57	0.24	0.40	0.691
Time since study commenced: treated interaction	−0.02	−0.22	0.22	0.11	−0.21	0.831
May	0.45	0.20	0.72	0.14	3.31	0.001**
August	−0.26	−0.58	0.08	0.17	−1.54	0.124
November	−0.10	−0.40	0.21	0.16	−0.64	0.521
Number of deer seen model						
Intercept	−1.70	−2.09	−1.30	0.21	−8.24	<0.001**
Time since study commenced	0.04	−0.12	0.21	0.09	0.46	0.644
Treated	−0.04	−0.67	0.52	0.30	−0.12	0.905
Time since study commenced: treated interaction	−0.05	−0.37	0.30	0.17	−0.28	0.776
May	1.06	0.68	1.51	0.22	4.91	<0.001***
August	0.16	−0.32	0.65	0.25	0.66	0.512
November	0.41	−0.04	0.87	0.24	1.73	0.084
(b) Models of short-term effects of 1080	**Estimate**	**Lower**	**Upper**	**Std. error**	**z value**	**Pr(>|z|)**
Number of encounters model						
Intercept	−0.85	−1.09	−0.64	0.12	−7.03	<0.001***
Time since 1080	−0.17	−0.32	−0.02	0.08	−2.11	0.035
Time since study commenced	−0.04	−0.17	0.10	0.07	−0.67	0.506
May	0.45	0.09	0.75	0.17	2.60	0.009**
August	0.03	−0.38	0.46	0.21	0.16	0.871
November	−0.11	−0.47	0.30	0.20	−0.58	0.564
Number of deer seen model						
Intercept	−1.81	−2.15	−1.46	0.19	−9.53	<0.001***
Time since 1080	−0.27	−0.46	−0.07	0.11	−2.54	0.011*
Time since study commenced	−0.01	−0.17	0.21	0.09	−0.08	0.935
May	1.17	0.73	1.69	0.24	4.80	0.000***
August	0.50	−0.10	1.07	0.30	1.69	0.091
November	0.40	−0.10	0.97	0.28	1.44	0.151

in Table 2a). However, numbers of encounters and sightings were significantly affected by time of year across both treated and untreated blocks. Numbers of encounters with deer were higher in the May quarterly sampling period (95% HPDI of estimates fitted in the model were 0.43–0.77 encounters per person day) than in February (0.28–0.48), August (0.20–0.40) or November (0.24–0.46; Fig. 4c). Higher numbers of individual deer were seen in May (0.30–0.64 individual deer seen per person day) than in February (0.10–0.22), August (0.11–0.29) or November (0.15–0.39; Fig. 4d).

After accounting for treatment and season effects, our models indicated that there were no significant overall trends with time in either numbers of deer encountered or numbers of deer seen across the seven blocks (Fig. 4a,b). On the log-scale of the model link function, the mean slope of the 'time since study commenced' parameter was −0.02 (95% HPDI −0.15, 0.09) in the model of number of encounters, and 0.04 (−0.12, 0.21) in the model of number of individuals seen (Table 2a).

Short-term effects of 1080 in treated blocks

Within the treated blocks alone, our models showed that there were significantly more encounters and deer seen soon after a 1080 operation than later (Fig. 5a,b). Parameter estimates for time since 1080 were negative and significant at P < 0.05 in both models. The mean slope on time since 1080 (on the log-scale of the model link function) was −0.17 (95% HPDI −0.32, −0.02); z = −2.11 and P = 0.035) in the model of number of deer encounters, and −0.27 (−0.46, −0.07; z = −2.54 and P = 0.011) in the model of number of deer seen (Table 2b). Effects fitted in both models show that declines in numbers of encounters and individual deer seen were more-or-less linear over the 3 years after an operation. The number of encounters with deer per person day fell from 0.64 (95% HPDI 0.49–0.85) to 0.36 (0.25–0.51), and the number of individual deer seen per person day fell from 0.44 (0.31–0.62) to 0.17 (0.11–0.28; Fig. 5a,b).

After accounting for this variation associated with timing of 1080 operations, there was no significant residual overall trend

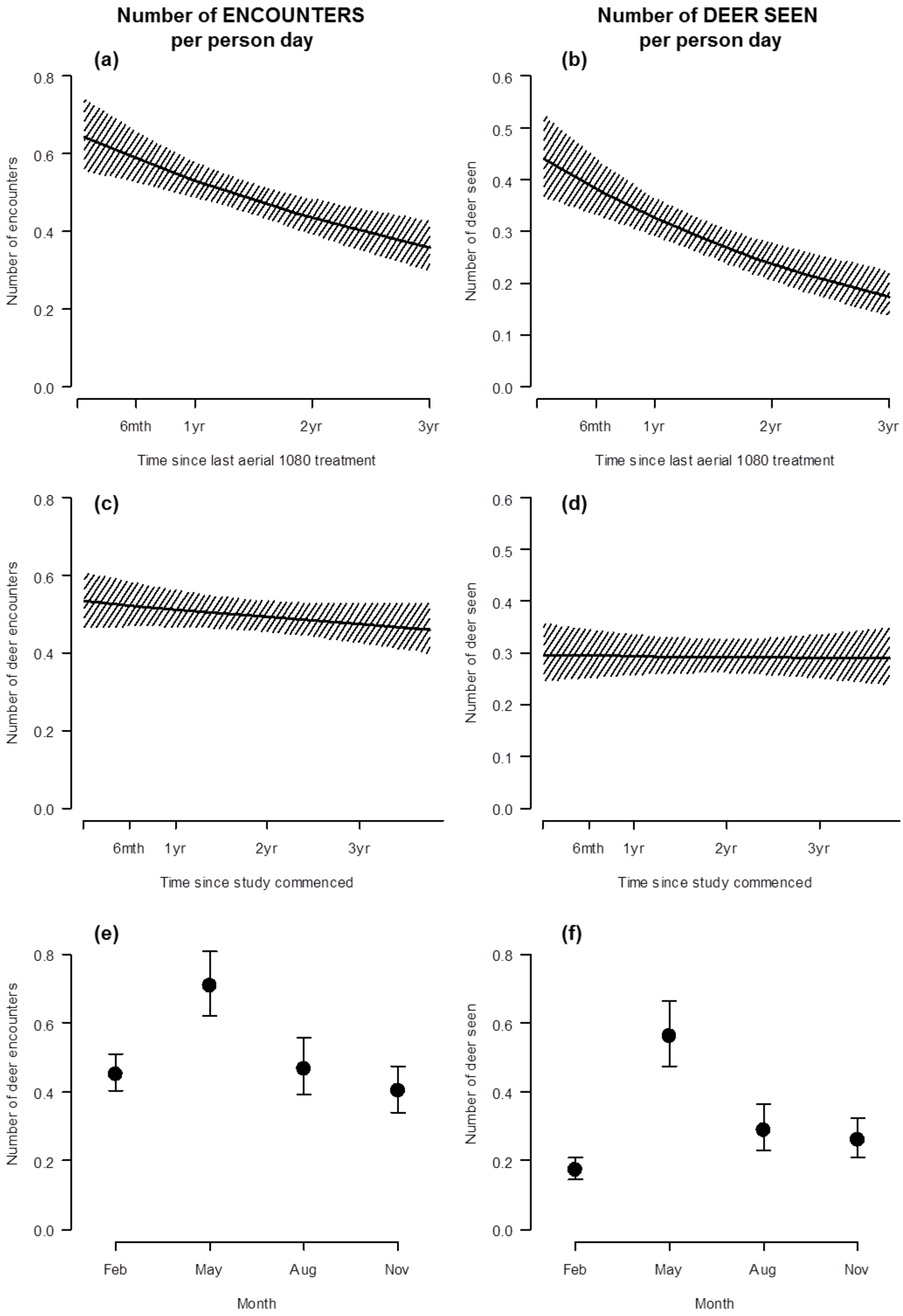

Figure 5. Models of short term effects of 1080: fitted effects of time since most recent aerial 1080 operation (a,b), time since study commenced (c,d), and sampling month (e,f) on number of encounters with live deer (left column) and number of live deer seen (right column) per person day from generalised linear mixed models. Hatched areas (a–d) and error bars (e,f) show ± one standard error of the fitted effects.

with time in either numbers of deer encountered or numbers of deer seen across 1080-treated blocks (Fig. 5c,d). The mean slope of the 'time since study commenced' parameter on the log scale of the model link function was −0.04 (−0.17, 0.10; $z = -0.67$, $P = 0.506$) in the model of number of encounters, and −0.01 (−0.17, 0.21; $z = -0.08$, $P = 0.935$) in the model of number of deer seen (Table 2b). The models showed significantly higher numbers of deer encounters and individual deer seen in May than in any other month in the treated blocks alone (Fig. 5e,f), similar to the pattern across all blocks (Fig. 4c,d).

Discussion

Our results from the rainforests of South Westland do not support assertions that modern aerial 1080 operations compromise deer hunting (Green & Rohan 2012; Hansford 2016). First, trends in deer encounters and deer seen in quarterly surveys between November 2011 and August 2015 did not differ between forest blocks that were repeatedly treated with aerial 1080 and those that remained untreated, and average numbers of deer encounters and deer seen remained similar in untreated and treated blocks across the 4-year study. Second, we found no evidence of even short-term negative effects of aerial 1080 operations on numbers of deer encounters and deer seen. We did not attempt to assess the numbers of deer killed by aerial 1080 operations, nor did we directly measure any change in deer populations in our study. However, our results show that 1080 operations did not have negative effects on two hunting-relevant variables – numbers of deer encounters and numbers of deer seen – and suggest that there may be other factors that have more important effects on these variables.

There is likely to have been some variation among the blocks in intrinsic suitability for hunting, and in hunting pressure (as noted in our Methods). Could the overall similarity in trends that we found between treated and untreated blocks in numbers of deer encounters and deer sighted be a result of preferential hunting of untreated blocks and avoidance of treated blocks by hunters? Higher hunting pressure in untreated blocks might lead to numerical or behavioural changes in deer that reduced the numbers of encounters and deer seen. If, at the same time, treated blocks were avoided by hunters, deer might be able to recover rapidly from reduced numbers following a 1080 operation, and/or might exhibit less wary behaviour, leading to more encounters and sightings.

We do not consider that this explanation for our results is credible. In the authors' experience, more recreational hunting occurs in the treated blocks than the untreated blocks in our study area. In part this is because public access to the Kini block for recreational hunting is restricted by a private landowner (our data show there were more encounters and deer seen in this block than any other; Fig. 2). We also consider it unlikely that the untreated Yankee Dan block is hunted more intensively than treated blocks because it is relatively remote from highway and river access routes, has the highest proportion of infertile (strongly-leached) soils, and appears to naturally hold few deer (Fig. 2).

It is possible that temporary cessations of commercial helicopter hunting reduced overall hunting pressure on and around the treated blocks. Commercial helicopter recovery for the venison trade is prohibited within an exclusion zone and over an exclusion period following aerial application of 1080 (several months; Environmental Protection Agency 2008). However, because little land in any block is accessible to helicopter hunting, we expect that any effect would have been minor.

In forest blocks treated with aerial 1080, we found strong evidence that more deer were encountered and more deer were seen shortly (0–12 months) after an operation, and that encounters and sightings reduced over the following 2 to 3 years until the next aerial 1080 operation. This result is the opposite of that which would be expected if aerial 1080 operations reduced numbers of deer encounters and deer seen. Our models account for the effect of calendar month, and so we can rule out this effect being a consequence of the coincidence of 1080 operation timing and a tendency for deer to be more frequently encountered in the spring.

The result is also intriguing because it is difficult to explain, on the basis of red deer demography, why populations would immediately grow in response to aerial 1080 operations and then decline again. Therefore, we suggest the effect is more likely to be a consequence of a change in deer behaviour than a change in deer numbers. The response of deer is also opposite to the short-term behavioural response to 1080 operations observed in possums (*Trichosurus vulpecula*), which become less (rather than more) conspicuous for a period of weeks. Numbers of possums detected with waxtags and traps decreased immediately and then increased steadily for a number of weeks immediately after 1080 operation in South Westland (GP Elliott and L Hines, unpubl. data).

We offer two hypotheses for the drivers of deer behavioural change in response to aerial 1080 operations that are amenable to further investigation. The first is that aerial 1080 directly affects deer behaviour in ways that make encounters and sightings by humans more likely. For example, if 1080 operations have lethal or sub-lethal effects that disrupt the social organisation of the population, animals in a process of social reorganisation following an operation might exhibit less wary behaviours resulting in the higher numbers of encounters and sightings by humans that we recorded. Further detailed investigation of deer responses to 1080 operations would be needed to test this hypothesis.

An alternative hypothesis is that the behavioural response of deer could be caused indirectly by temporal changes in the intensity or type of recreational or commercial hunting pressure (Nugent & Sweetapple 1989) that is associated with 1080 operations. For example, deer might become less wary and/or more detectible if fewer recreational hunters visit treated blocks immediately following treatment (e.g. because dogs are at risk if they eat possum carcasses, or hunters expect deer to be less numerous). Temporary cessations of commercial helicopter hunting following 1080 operations might also contribute to this effect. We have heard anecdotal reports of commercial aerial hunting operations in South Westland that concentrate on blocks immediately before a 1080 operation (G Gamble, pers. comm.), and this behaviour could potentially lead to decreases in numbers of deer encounters and deer seen prior to 1080 operations.

We consider that changing hunting pressure is unlikely to be a sufficient explanation for the greater numbers of deer encounters and deer seen following 1080 operations in our study areas, however. As we have noted, most recreational hunting in the forest blocks we studied takes place along narrow strips of accessible river flats, and our observations suggest that recreational hunters make little or no use of the more remote areas of forest outside the April roar period. Second, as noted above, it is only limited areas of these blocks that are accessible to helicopter hunting at any time. Therefore, we consider that any indirect effect of changing hunting pressure on deer behaviour will have been minor.

Conclusion

The data collected in this study provide an uncommon opportunity to assess whether and how modern aerial 1080 operations affect numbers of deer encountered and seen, which should be relevant indicators of effects on recreational hunting. Our results do not support the hypothesis that 1080 operations reduce numbers of deer encounters or deer seen, either over time or temporarily. They should alleviate concerns among recreational hunters that repeated modern aerial 1080 operations necessarily compromise recreational hunting of red deer – at least in the beech-podocarp forests of South Westland we studied. The effects of aerial operations on hunting may vary with forest type and productivity, and with management (e.g. operation timing or frequency). Understanding this variation would require a similar measurement approach under different environmental and management regimes.

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