Relative abundance of black-tailed deer fawns in Oak Bay, B.C. following application of a single year of immunocontraception

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Executive Summary

Black-tailed deer (*Odocoileus hemionus columbianus*) populations are characterized by a naturally high reproductive output. In the wild, low fawn survival rates are offset by this high reproductive rate, preventing long-term population declines. In the absence of significant natural sources of mortality – predators and starvation – high reproductive rates contribute to large populations in urban environments. Given the high reproductive rate of black-tailed deer, fertility control is a potentially useful tool for managing urban deer populations. In Fall 2019, we administered immunocontraceptive (IC) vaccines to 60 mature female black-tailed deer across the municipality of Oak Bay, British Columbia to test its utility as a non-lethal method of urban deer population control. Thirty-nine remote cameras deployed across the municipality have been monitoring Oak Bay's deer population since 2018. We compared the relative fawn abundance (calculated as the number of fawn images / total number of camera trapping days) for September 2018, 2019, and 2020 to determine if there was a significant reduction in relative fawn abundance following IC treatment. In 2020, we observed a 58% reduction in the total relative fawn abundance the year after IC was administered (61% reduction when averaged across camera sites). The precision and magnitude of difference in average fawn relative abundances shows that this reduction is statistically significant. Average relative abundance of adult deer remained largely consistent across years. Fawn relative abundance is assumed to be correlated with the true abundance of fawns, and therefore can be used to indicate whether reproductive output in the Oak Bay deer population is suppressed following IC. Continued monitoring of the Oak Bay deer population will further reveal whether subsequent applications of IC continue to decrease relative fawn abundance, and whether this decrease in fawn abundance translates into an overall population reduction as fewer fawns are available to mature into adult deer.

Background Information

Black-tailed deer (*Odocoileus hemionus columbianus*) populations are characterized by a high reproductive output[1]. Female black-tailed deer (BTD) may breed as yearlings — generally producing a single fawn — while mature does generally give birth to twins, and occasionally, triplets[2]. The number of fawns produced each year, and the likelihood of their survival, are positively associated with maternal nutritional condition[1]. In the wild, this high reproduction rate compensates for a low fawn survival rate, maintaining generally stable populations[1] at low "carrying capacities": the population size a given habitat can support given available resources and mortality risks.

Given the high reproductive rate of BTD, fertility control may prove useful for managing urban BTD populations. Immunocontraceptive (IC) vaccines are one available tool for fertility control, triggering an animal's immune system to prevent fertilization of the egg[3]. IC vaccines such as the porcine zona pellucida (PZP) vaccine have been applied to various urban deer populations as means of non-lethal deer population control[4,5]. In Fall 2019, the Urban Wildlife Stewardship Society (UWSS), along with the Province of British Columbia (BC) and the Municipality of Oak Bay, implemented the first phase of its IC program.

A 2018 preliminary density estimation for the Oak Bay BTD population suggests 72 – 128 adult deer[6], and observations suggest the higher of these numbers. Herd composition based on camera data for September 2019 and 2020 indicates approximately 3 does for every buck in Oak Bay. Based on these numbers, we treated 60 female BTD with the PZP IC vaccine and a subsequent booster vaccination between September - October, 2019. Treatment of 60 mature (>1.5 year old) female deer in 2019 would be expected to result in at least 63% of the female

BTD population treated with IC, if the adult population remained constant from the 2018 survey to the 2019 treatment.

Application of PZP IC vaccines to wild horses has been shown to suppress pregnancy rates by over 80%[7] and similar rates have been shown for white-tailed deer research, which has almost entirely focussed on the biological responses by animals [8-11]. Only a few singular studies actually research the population responses to IC[4,5,12] and those did not report the number of does treated annually as a proportion of population size. Further, although efficacy of PZP and other IC has been researched in urban white-tailed deer populations [4,13-15], almost nothing is known about urban black-tailed deer. As result we had little guidance around the proportion of the population we should treat with IC to obtain a population response. We reasoned that if we apply a PZP IC-vaccine efficacy of 70 – 90% in BTD and assume 63% of female BTD were treated in 2019, then we would expect to see a 44 – 57% reduction in female BTD pregnancy rates in 2020. However, any changes in mortality or immigration rates in breeding females, or extraneous factors affecting female reproductive rates and fawn survival among our study years, could influence the observed change in relative fawn abundance before and after IC.

We evaluated the effectiveness of the first year of IC on suppressing relative fawn abundance using data collected by wildlife cameras[16] deployed across Oak Bay. Wildlife cameras detect heat-in-motion and triggers a photograph, stored and later analyzed, giving us a record of deer occurrences across space and time. Cameras have been continuously monitoring the Oak Bay deer population since July 2018. Collected images of BTD adults and fawns provide insights into the relative abundance of deer detected on camera before and after the application of IC in 2019. In camera trapping studies, relative abundance indices (RAIs) are measured as the number of collected images of the focal species (in this case, BTD fawns) divided by the number of days that the camera was operational (i.e. "camera trap days"). RAIs are the most commonly used index for measuring the relative abundance of species that cannot be individually identified from photographs[17]. RAIs are not the same as a true population estimate, but rather, have been shown to be correlated with true population size[17-19], which is more difficult to estimate. By comparing relative fawn abundance before (2018 – 2019) and after (2020) implementation of IC, we can use this change in relative fawn abundance as a measure of the effectiveness of a single year of IC treatment.

Methods

Deer Capture for Immunocontraceptive Vaccination:

In September-October 2019, we administered the PZP IC-vaccine Zonastat-D to 60 adult female BTD. This provides sufficient time for the vaccine to induce the adaptive immune response and contracept does prior to the fall rut. We generally selected for mature (>1.5 year old) BTD based on body size and presence of fawns. Mature females are easily distinguished from bucks during this time of year based on the presence or absence of antlers.

We searched for deer in the morning by conducting road surveys throughout the entirety of our study area to attempt an even coverage of treatment across Oak Bay. However, some areas contained a higher density of deer than others, and therefore a higher number of female BTD were treated in some neighbourhoods over others where few or no suitable deer were found. Chemical immobilization was delivered via telemetry darting by an experienced wildlife veterinarian using current regulatory approvals and field protocols. On capture, each animal was injected with 100 ug of Zonastat-D. Each captured deer was fitted with a numbered ear tag in each ear for individual-level identification, and 40 out of the 60 captured BTD also received a simple marker collar. Two to six weeks after treatment with the primary PZP vaccine, we located 48 of our 60 initially treated deer to administer a booster of the same vaccine. Booster vaccination did not require live capture of our study deer, but was delivered remotely via darting.

Camera Trapping:

In July 2018, we deployed a total of 39 wildlife cameras in a systematic grid-design across Oak Bay, Victoria (Figure 1). Cameras were deployed across both public and private property and serviced every 4 – 8 weeks to replenish batteries and download images.

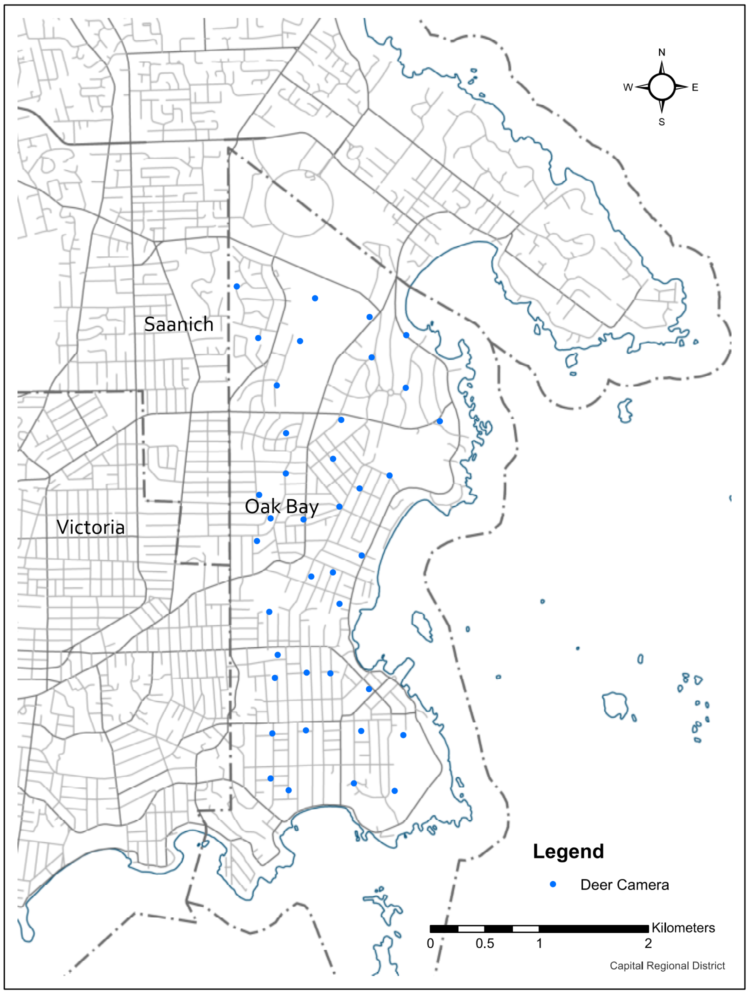

Figure 1. Remote cameras (blue dots) deployed on public and private properties across the municipality of Oak Bay, British Columbia. A total of 39 cameras have been continuously monitoring the Oak Bay urban black-tailed deer population since July 2018.

Camera Image Processing:

Collected images were manually processed using TimeLapse[20] image classification software. For each image, we collected information on the camera location, date, time, the number of adult deer, and the number of fawns present in the image. For 2019 and 2020, we also noted how many individual fawns were observed to be travelling together during a sequence of images containing the same group of deer.

Due to the significant time investment of manually processing camera imagery, we focused on a single month of camera data for each of 2018, 2019, and 2020. We selected the month of September as fawns are sufficiently mobile to maximize detection probability on cameras but small enough to distinguish from >1 year old fawns (i.e. "yearlings") produced the previous spring. We truncated our camera data to September 1 – 30th for each of the three years.

Classification of Adults versus Fawns on Camera:

Deer were classified as fawns if they were less than 1 year old ("young of the year"). Yearlings produced the previous year were classed as adults as they have reached a reproductive age by their second fall. For 2018, we classified fawns (<1 year old) based solely on presence of spots on their coats. For 2019 and 2020, we applied a more comprehensive classification protocol for fawn identification beyond presence of spots, as many of the young-of-the-year fawns were observed to lose their spots throughout September. For juvenile deer without spots, we classified them as fawns *versus* adults based on a combination of body size and snout length relative to head size.

Due to this difference in fawn identification between 2018 and 2019/2020, relative fawn abundance is likely underestimated for 2018 due to the misclassification of young-of-the-year fawns as yearlings, and therefore, adults. We therefore focus our results on relative fawn abundances between 2019 and 2020, where the methods were the same. This captures a direct year-to-year comparison of pre-IC (2019) to post-IC (2020) fawn abundance, while a more reliable 2018 to 2020 comparison will be made following re-classification of the 2018 camera images at a later date.

Camera Trapping Effort:

For each year, we determined the total camera trapping effort for the month of September across the 39 cameras. Any days during which cameras were non-operational are not included in our calculation of camera trapping effort. Therefore, the maximum number of camera trapping days over 30 days in September and across 39 active cameras would be 1,170 for each year. However, camera malfunctions throughout part or all of the sampling period resulted in lower and varied final camera trapping days for each year.

Relative Abundance of Adults and Fawns:

For each year, we determined the relative abundance of adults and fawns by dividing the total number of images containing adults/fawns by the number of camera trapping days. To determine relative fawn abundance, we divided the total number of images containing fawns by the total number of camera trapping days (or "camera effort"). To gain insight into the degree of variation around fawn relative abundance across camera sites, we also calculated average fawn and adult relative abundance indices. We determined the average number of adults/fawns per camera trapping day by averaging the relative abundance of adults/fawns at each camera site. We calculated confidence intervals around this measure of average relative adult/fawn abundance which are derived from the natural variation in the number of adults/fawns observed at each site. Small confidence intervals mean we are *more* confident in the estimates, because there is less natural variation in the measure. (Confidence intervals can be thought of as the range of values within which we are confident that the true measure falls. We want a small range for a tight, accurate measurement). If confidence intervals around relative abundances overlap between years, this suggests that any observed changes in mean relative abundance of adults/fawns could be due to either IC treatment or natural variation in the population, or both, but are not statistically significant. If intervals in annual estimates of relative abundance do not overlap, then we have confidence that our treatment effect resulted in a difference in relative deer abundance that is statistically significant.

Results

Camera Trapping Effort

The number of active camera sites and operational days varied between our three years of September data. September 2019 experienced a significant number of camera failures, with only 28 out of 39 cameras operational during this month for a total of 694 camera trapping days (Table 1). The best coverage of the camera array was observed for 2020, with 35 cameras active throughout this period for a total of 935 operational camera days (Table 1).

Table 1. Camera trapping effort for September 1 – 30th, 2018, 2019, and 2020.

	2018	2019	2020
# Camera Trapping Days	781	694	935
# Active Cameras	33	28	35
Mean Days Operational	23.7	24.8	26.7
Minimum Days Operational	3	15	5

Relative Abundance of Adults and Fawns:

Total relative fawn abundance differed between years, with a 58% reduction in relative fawn abundance observed between 2019 and 2020 following application of IC (Figure 2). We observed a lower relative fawn abundance for 2018 relative to 2019, but a 28% reduction in fawn detection frequencies between 2018 and 2020. (Recall that fawns were underrepresented in our data for September 2018 due to a difference in our fawn classification protocol). Total relative abundance for adults remained fairly consistent between the three study years, with the highest adult relative abundance of 13.64 observed during 2019 (Figure 2).

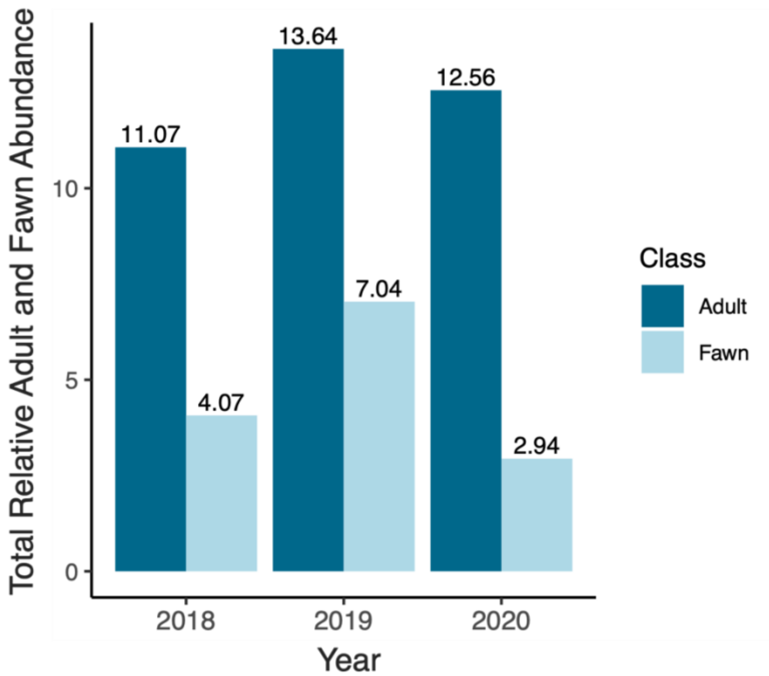

Figure 2. Total relative abundance of adult (dark blue) and fawn (light blue) between September 2018, 2019, and 2020. Total relative abundance was calculated as the total number of images captured for each age class divided by the total number of operational camera trapping days during the month of September.

Relative fawn abundance averaged across active camera sites revealed a similar reduction of 61% in relative fawn abundance between 2019 and 2020 (Figure 3). We observed the greatest variation in relative fawn abundance across camera sites for September 2019, likely due to a low number of operational camera sites. However, non-overlapping confidence intervals for average relative fawn abundances between 2019 and 2020 indicate a statistically significant reduction following implementation of IC.

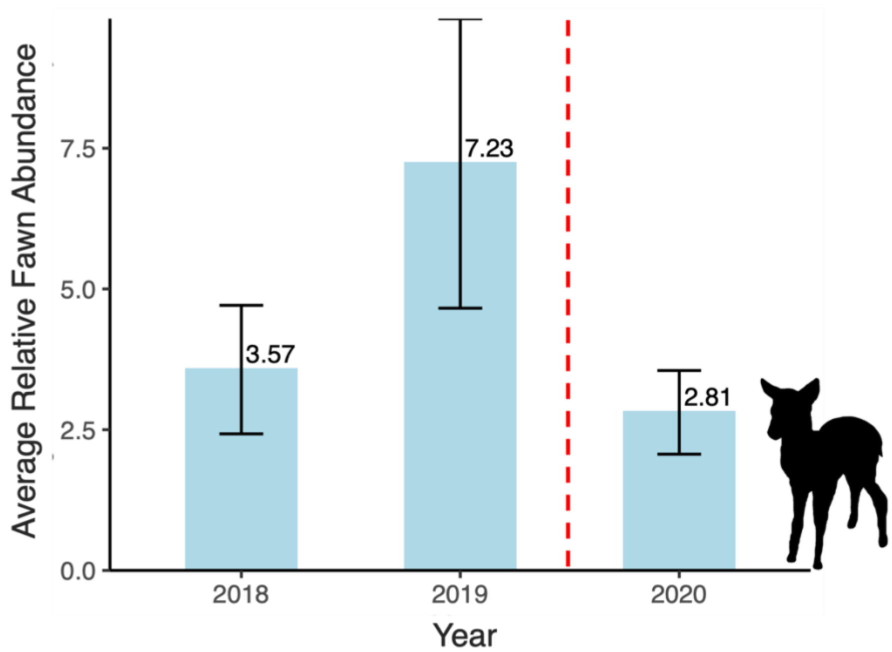

Figure 3. Relative abundance of fawns averaged across active camera sites between September 2018, 2019, and 2020. Average relative fawn abundance was calculated as the total number of fawn images captured at each site divided by the number of operational camera trapping days during the month of September. The red dashed line divides the pre-IC (2018 & 2019) and post-IC (2020) years. Confidence intervals (black I-bars) between 2019 and 2020 do not overlap, indicating a significant treatment effect.

Relative adult abundance averaged across camera sites revealed no statistically significant change in mean adult relative abundance between our three study years (Figure 4).

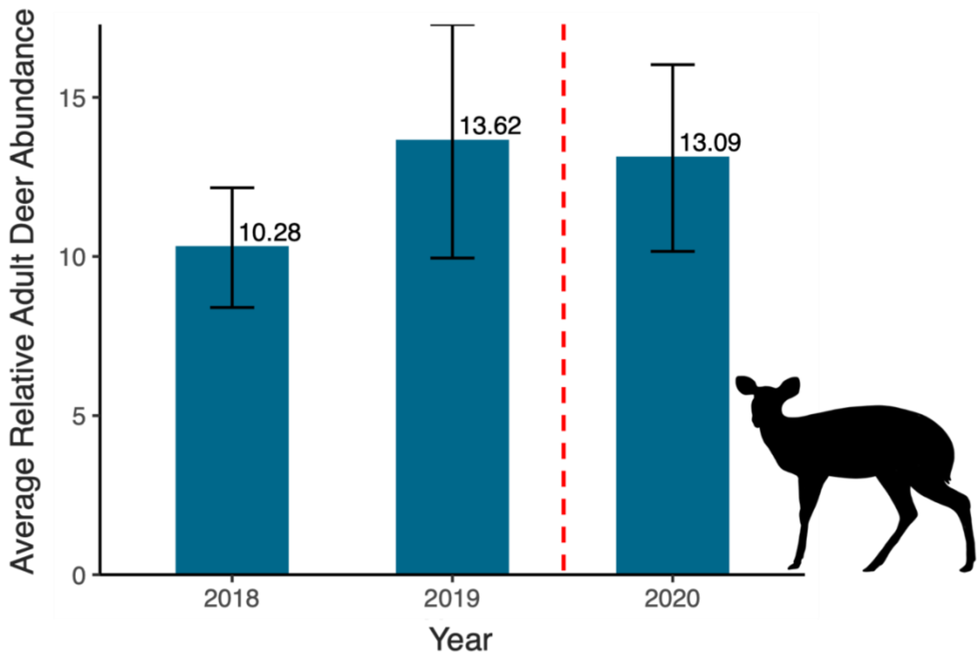

Figure 4. Relative abundance of adult detections averaged across active camera sites between September 2018, 2019, and 2020. Relative adult abundance was calculated as the total number of adult images captured at each site divided by the number of operational camera trapping days during the month of September. The red dashed line divides the pre-IC (2018 & 2019) and post-IC (2020) years. Confidence intervals (black I-bars) overlap among the three years, indicating no significant treatment effect.

Discussion

We observed a significant reduction in relative fawn abundance in Oak Bay, B.C. following a single year of IC treatment of urban female black-tailed deer. Treatment of 60 female BTD in 2019 – estimated as at least 63% of the female population – resulted in a 58% reduction in total relative fawn abundance for 2020. As relative abundance is correlated with population size, our data show a significant reduction to the total fawn population size in Oak Bay as a result of IC.

We observed a reduction in total fawn relative abundance after a single application of IC that was at the higher end of what we expected to see based on the estimated proportion of female BTD treated. This may be the result of a high degree of variation in the relative fawn abundance estimate for 2019, for which fewer active cameras resulted in a lower degree of precision in our calculations (Table 1). It is also possible that the IC vaccine may have been effective in suppressing reproductive output (i.e. number of fawns per treated doe), even when it was not effective in fully preventing pregnancy. For 2019, we observed an average of 1.25 fawns travelling together while in 2020, we observed an average of 1.18 fawns travelling together (Supplementary Information Table S1). This suggests that rates of twinning may have been reduced in BTD following treatment with IC, and further investigation using multi-state models – which can compare probabilities of single-fawns to double-fawns[21] – will test this hypothesis. Ultimately, our data show a statistically significant reduction in relative fawn abundance after a single year of treatment, but as of yet without a corresponding population response – which is as we expected.

Caveats:

Relative abundance indices are a useful proxy for population size and density, but the relationship depends on a stable probability of detection on camera across time and space[22,23]. Changes in movement can affect these parameters[24-26]. For example, a species' detection probability might be higher in winter rather than summer, and therefore measures of relative abundance taken across different seasons would be expected to differ even if there were no changes to the true population size.

We assumed that fawn detection probabilities did not change between years as we always sampled during the same period (i.e. September). Movement of urban BTD females is small and stable[6]. Furthermore, wildlife cameras remained almost exclusively in the same location between 2018 and 2020, with the exception of a few cameras that had to be relocated due to theft or vandalism. Therefore, there is no evidence that suggests relative abundance does not scale to true abundance in our system.

Note that camera angle and positioning was refined in the early months of our study (summer/fall 2018) to maximize deer detection probability. Therefore, the improvements in detection probability over the first year may have created an artificially lower relative abundance indices for 2018 compared to 2019/2020. We therefore caution readers against assuming that the observed increase in adult and fawn relative abundance between 2018 and 2019 is a true signal of an increased population size between these years.

Year to year variation in forage availability, weather, and disease can all influence fawn survival[1]. We assume that forage availability in Oak Bay remains largely constant between years, as there is no evidence of anomalous weather patterns among study years. Likewise, there were no reported major outbreaks in deer diseases in our study area among our study years. Therefore, we can assume that the observed reduction in relative fawn abundance in 2020 is primarily the result of suppressed pregnancy rates in female BTD as a result of IC in 2019.

Continued Monitoring:

The two research studies examining a population response to urban deer (in Maryland and New York, USA)[5,12] showed a 27% (over 5 years) to 58% population decline (over 9 years) depending on the proportion of females treated. We had no expectation of a population response in a single year, and we did not observe one. A population response may take a few years, given the data from Maryland and New York, and low natural mortality rates observed in Oak Bay. Continued monitoring of the Oak Bay BTD population will reveal if a reduction in the relative abundance of fawns directly results in a reduction in the relative abundance of adult deer, as adults die and fewer fawns are "recruited" – mature and join the breeding adult population.

Most wildlife population studies focus on the number of breeding adults, as juveniles do not contribute to population growth until they reach a breeding[27,28]. Evaluating the effectiveness of IC on managing urban deer populations therefore requires an understanding of responses in the adult deer population after fawns recruit into it. Certainly, if the abundance of fawns is impacted by application of IC, then logically, we expect the size of the adult population to also be impacted in subsequent years. Evaluation of adult deer relative abundance for September 2021 will provide direct insight into whether we observe a significant reduction in adult BTD as a result of IC implemented in fall 2019.

Continued monitoring will also provide insight into the effects of a second year of IC in suppressing relative fawn abundance. In Fall 2020, we administered IC to an additional 60 mature female BTD. Many of these are assumed to have been yearling fawns in 2019 that reached maturity (>1.5 years old) by fall 2020 and were subsequently treated with IC. We also administered booster vaccines to 49 of the 60 IC does treated in 2019. Based on our preliminary population estimate for 2018, the combined number of mature does treated in 2019 and 2020 should therefore represent a substantial majority of the total adult female BTD population in Oak Bay. Evaluating the effects of IC application in 2019 and 2020 on relative fawn abundance and the overall deer population-level response will therefore require continued monitoring until at least fall 2022.

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Supplementary Information

Table S1. Total and averaged relative abundances of adult and fawn black-tailed deer for September 2018 – 2020.

September	2018	2019	2020
Camera Trapping Effort			
Number of Camera Trapping Days	781	694	935
Number of Cameras Active	33	28	35
Total Detections			
Total Adult Detections	8646	9468	11742
Total Adult Detections / Camera Trap Day	11.07	13.64	12.56
Total Fawn Detections	3177	4886	2753
Total Fawn Detections / Camera Trap Day	4.07	7.04	2.94
Average Detections			
Average Adult Detections / Camera Trap Day	10.28 (+/- 1.88)	13.62(+/- 3.67)	13.09(+/-2.94)
Average Fawn Detections / Camera Trap Day	3.57 (+/- 1.14)	7.23 (+/- 2.57)	2.81 (+/- 0.74)
Fawns Group Size			
Average Number of Fawns / Fawn Image Sequence	NA	1.25	1.18