Black-tailed Deer Population Density Estimate and Response to Immuno-Contraception Trial in Oak Bay, B.C.

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Prepared for:

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Executive Summary

Public complaints about human-deer conflicts in Oak Bay, British Columbia suggest the population density of native Columbia black-tailed deer (*Odocoileus hemionus columbianus*) has increased from past decades. Lethal removal programs (i.e., culling) and translocation are tools approved by the Government of British Columbia, but these are contentious, and empirical evidence suggests they are also ineffective. We are exploring population control by reducing deer reproductive output using immuno-contraceptive (IC) vaccines. Like any wildlife management action, IC requires rigorous monitoring to ensure effectiveness. To evaluate the effectiveness of IC vaccines for managing an urban deer population, we are using remotely operated cameras to estimate adult deer density before and after treatment with IC. In 2019 and 2020, we administered IC to 120 female black-tailed deer, and applied booster vaccines in 2021 to 71 previously treated deer. We compared the adult deer population density in September 2018 to September 2021 & 2022 to evaluate the effect of three years of treatment with IC. Preliminary results indicate that mean population density estimates have decreased from 14.14 adult deer/km^2 in 2018 to 9.82 adult deer/km^2 in 2022. We anticipate further reductions in the adult deer population in September 2023 resulting from the effect of suppressed reproductive output in 2022 from IC administered in 2021. However, urban forage opportunities combined with no predation pressure will likely prolong the time required to observe a population density decline, since removal of individuals relies on natural deaths. Current efforts are underway to model the population density for September 2023 and camera imagery data from 2019 and 2020 are being re-catalogued to allow for inclusion in the density analysis. Continued monitoring of the Oak Bay deer population will reveal the population response following a pause in IC during 2022 and 2023, and provide important insights into the long-term effectiveness of IC as a wildlife management strategy.

Introduction

Black-tailed deer (*Odocoileus hemionus columbianus*, hereafter "BTD") are native to British Columbia (BC), and fill several important ecological roles (Ballard et al. 2001). The changing landscape of BC's suburban areas has benefited BTD populations, due to increased foraging opportunities (Fisher et al. 2023) and also likely due to reductions in predator presence. Native predators such as wolves (*Canis lupus*), and cougars (*Puma concolor*) are kept at low density from most urban areas, effectively excluding them from their ecological roles in deer-population control (Hatter and MacDermott 2021). An additional benefit to BTD populations in suburban/urban environments is the presence of high-energy and high-nutrient forage plants. Urban and suburban areas may contain abundant backyard gardens and agricultural crops, which provide ample food resources for deer, potentially allowing BTD to breed more often and more successfully than in unaltered landscapes (Bender et al. 2004). In BC's suburban environments, deer have been shown to select for areas with high vegetation greenness, a high proportion of large-sized residential lots, and proximity to parks and golf courses (Fisher et al. 2023) suggesting that human-driven changes to the landscape are key to maintaining urban deer populations. As BTD populations are very sensitive to factors affecting recruitment (Gilbert and Raedeke 2004, Forrester and Wittmer 2013), the lack of natural predation coupled with the abundance of high-quality food resources in suburban and urban landscapes has likely contributed to greater reproductive output and subsequent population growth for BTD.

With BTD populations increasing in suburban and urban areas, various human-deer coexistence challenges may arise. Urban deer can be perceived as "pests" by foraging on gardens or agricultural crops (Sullivan et al. 1985), may act as vectors of disease (Honda et al. 2018), and lead to increased traffic accidents (Conover et al. 1995, Found and Boyce 2011), although human perceptions of wildlife impacts vary (Frank et al. 2019, König et al. 2020). To address these challenges, some municipalities have implemented culling programs to directly reduce the number of deer present in communities (DeNicola and Williams 2008). Unfortunately, these culls have thus far been based on little scientific data and results are highly variable (Wäber et al. 2013). Moreover, the culling of wildlife can be a contentious and politicized issue, leading to divided communities and even legal battles (CBC 2012, 2013).

One urban deer management strategy that is growing in popularity is the use of immuno-contraceptive (IC) treatments to reduce reproductive output (Warren and Warnell 2000, Rutberg et al. 2004, Evans et al. 2016). Immuno-contraceptive vaccines trigger an animal's immune system to prevent fertilization of the egg (Muller et al. 1997), and vaccines such as porcine zona pellucida (PZP) have been applied to various urban deer populations as means of non-lethal deer population (Walter et al. 2002, Rutberg et al. 2004, Rutberg and Naugle 2008, Rutberg et al. 2013). Prior to the fall reproductive season (i.e., rut), IC vaccines can be delivered remotely to adult female deer to suppress her ability to produce young the following spring, thus eliminating the need to lethally remove individuals in a growing population.

To estimate the effectiveness of any wildlife population management strategy, it is necessary to estimate "baseline" levels of population density prior to- and after treatment. However, collecting precise estimates for deer population density in urban environments comes with challenges. Traditional surveys are based on herd counts - which provide useful distribution information but generally provide low-precision results with wide confidence limits (McCullough et al. 1994) – or aerial surveys which are nearly impossible in suburban areas. Citizen-based herd count surveys engage the public, but do not produce reliable estimates; they lack the statistical rigor to justify management actions scientifically or legally. Collecting precise estimates of urban BTD population density requires the application of rigorous surveying approaches using a combination of remote cameras and novel statistical techniques.

Remote cameras are rapidly becoming a popular wildlife research tool because they produce large volumes of data at low cost (Burton et al. 2015, Steenweg et al. 2016). Their reliability in surveying wildlife species can be quantified (Nichols et al. 2008) and cameras have been shown to have very high accuracy at detecting deer (Fisher and Burton 2020, Fisher et al. 2020). Remote camera surveys are an increasingly common approach for surveying ungulate occurrence (Jacobson et al. 1997, Koerth et al. 1997, Fisher et al. 2016), and they have been used to monitor deer in urban areas but previously without the statistical ability to estimate density from the data (Curtis et al. 2009). The advent of novel statistical techniques has provided important opportunities to collect reliable population density estimates from camera data, allowing for the comparison of urban deer population response before and after management actions.

As part of the Oak Bay Urban Deer Research Program, we are evaluating population response of the adult BTD population following three years of treatment with IC. Using an array of remote cameras to collect images of marked and unmarked adult deer, we apply spatial mark-resight models (Royle et al. 2014) to estimate adult deer population density before and after application of IC. We hypothesize that deer density will decrease in years following IC treatment, with the first decrease observed two years after our first year of IC treatment followed by a more significant decrease two years after the second year of IC treatment.

Methods

Study Area

This research took place in the 10.5km^2 District of Oak Bay, Vancouver Island, British Columbia (Figure 1). The study area is largely urban environment, dominated by small and large residential lots, commercial development, golf courses, and district-managed natural park areas. The eastern and southern edge of the district is bordered by the Salish Sea. The district is home to approximately 18,000 people.

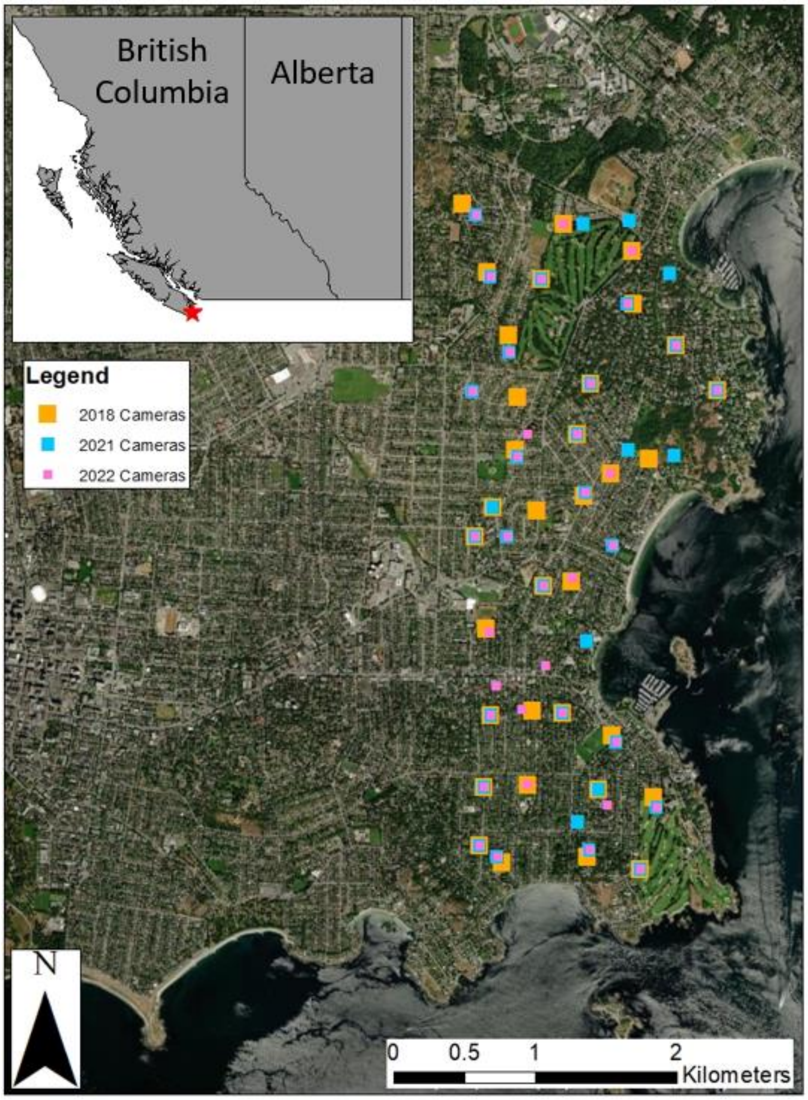

Figure 1. Remote camera array to monitor urban deer population response to immune-contraceptive treatment in Oak Bay, B.C.

Deer Capture, Marking, and Immuno-contraceptive Treatment

In February-March 2018, we captured 20 female BTD to mark as our control population. We applied GPS-collars fitted with coloured plastic tags to allow for individual identification of marked deer. Data collected by the GPS collars were used to examine urban deer habitat use (Fisher et al. 2023).

We commenced our IC program in September 2019 and administered the PZP IC-vaccine Zonastat-D to adult female BTD prior to the fall rut. We generally selected for mature (>1.5 year old) does based on body size and/or presence of fawns. We searched for deer in the early morning by conducting road surveys throughout the entirety of our study area to attempt an even coverage of treatment across Oak Bay. Chemical immobilization was delivered via telemetry darting by an experienced wildlife veterinarian (A. Hering) using current regulatory approvals and field protocols. On capture, each animal was injected with 100 ug of Zonastat-D. Captured deer were marked using a combination of coloured marker collars and/or numbered ear tags to allow for individual-level identification (Figure 2).

In September-October 2019, we administered IC to 60 female BTD. Two to six weeks after treatment with the primary PZP vaccine, we were able to locate 55 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. In September-October 2020, we administered IC vaccines to an additional 60 female BTD that were not treated the previous fall. Of these 60 newly treated individuals, we administered booster vaccines to 57 individuals. We also administered booster vaccines to 48 of the deer treated with IC in 2019. In September-October 2021, we did not administer primary IC vaccines to any new female BTD but administered IC booster vaccines to 71 BTD previously treated in 2019 and 2020. This totalled to 120 deer marked for IC, plus an additional 19 “control” deer marked in spring 2020 (although mortalities of marked deer were observed between 2019-2021).

Figure 2. Remote camera image of a female black-tailed deer fitted with numbered ear tags and a marker collar.

Camera Monitoring and Image Review

In August 2018, we deployed 39 Bushnell™ infra-red camera on both public and private properties across Oak Bay, secured to a tree about 0.5 – 1.5 m off the ground. Camera sites were selected using a grid pattern overlaid on the district of Oak Bay. Cameras were programmed to take 3 pictures in sequence when movement was detected by the infrared trigger, followed by a ten second trigger delay. Following a targeted theft of cameras in winter 2019, we moved some cameras from public properties to private, and replaced older Bushnell models with Browning™ cameras using similar settings.

We serviced cameras regularly to refresh batteries and download the collected images. Trained technicians manually reviewed and catalogued collected camera imagery using Timelapse image software. For each deer detection on camera, we collected information on the camera location, date, time, the number of adult deer, and the number of fawns present in the image. For marked deer, we also noted any information on ear tag number and marker collars to allow for individual identification, which provides the basis of our population density estimation models prior to- and after IC treatment.

Due to the significant time investment of manually processing camera imagery, we subset our dataset to only examine deer detections in the month of September. We selected this month as does are easily distinguished from bucks due to the presence of antlers, while fawns (<1 year) could be easily distinguished from yearlings (>1 year). Due to challenges with including an iteratively increasing population of marked deer in September 2019 and 2020 (when female BTD were being marked and treated with IC), we were unable to include data from these two years for this analysis. We are currently in the process of cataloguing images collected in October-November for these two sampling years, when the same advantages in age/class identification hold true, and when the marked population was stable following completion of the primary IC vaccines (and associated markings) being administered in the month of September.

We considered detections of deer at a camera to be independent if consecutive images were > 30 minutes apart, or if a different individual could be distinguished. For example, if an unmarked deer was detected on a camera at 10:15am, and another detection of an unmarked deer occurred at 10:30am, these would be considered part of the same detection as there is no way to distinguish the individuals. Conversely, images collected at 10:15am and 10:50am would be considered two independent detections. As our primary interest was in density of adults, we did not consider fawns as independent detections. Images containing multiple identifiable individuals were recorded as unique events, as we could clearly identify the time and location for each individual. Further, images containing both marked and unmarked individuals were separated into distinct counts of a marked and unmarked detection.

Population Density Estimation

We used a novel extension of spatial capture-recapture models termed Spatial Mark Resight Models (SMR), which have been developed to estimate density from repeated detections of known individuals in a partially-marked population (Chandler and Royle 2013, Sollmann et al. 2013, Royle et al. 2014). In traditional mark-recapture models, researchers capture animals on an initial survey occasion, mark the animals and then release them back into the population. On the second and subsequent survey occasions, a new set of animals are captured and the number of previously captured animals (possessing a mark, e.g. collar or ear tags) are counted, along with the total number of animals captured. All new animals are likewise marked and then released back into the population. This continues for as many survey occasions as necessary to reliably estimate the density. Assuming all animals can be captured with equal probability, the higher number of marked animals re-captured within each survey occasion, the smaller the overall population.

SMR models are slightly different in that we consider animals as “marked” if they were collared/tagged, and “captured” if detected on a camera. Thus, we start and end with a pool of collared animals that are observed repeatedly (hence mark-resight survey, rather than a mark-recapture survey). SMR models use the detections, or “resights”, of both unmarked and marked individuals to estimate the density of a population (Sollmann et al. 2013, Whittington et al. 2018). The frequency at which collared animals are observed at neighbouring cameras is important: animals that are seen at many cameras are thought to range widely and suggest a smaller number of deer than animals that are seen on only a few cameras close together. SMR statistical models are very recently developed—yet scientifically accepted—and enable movement pattern and encounter rate of collared (“marked”) BTD to be extrapolated to the whole un-collared (“unmarked”) camera-sampled BTD population to estimate density.

We fit SMR models using the *secr* package in R-Studio v4.1.2 (R Core Team 2017). We specified 30 sampling occasions for September of each year, accounting for variation in camera operability if a camera was not operational for specific days in September (Figure 3). For each camera and sampling occasion, we recorded the sum of independent detections of unmarked deer and detections of identifiable deer. We visually examined plots of individual detections at cameras to determine if errors in identification occurred (Figure 4). For example, it would be unlikely that the same individual was detected on cameras on the northern and southern extend of the study area on the same day. Models were fit in *secr* specifying a “count” detector type, which allows multiple detections and records presence of individuals without restricting movement. No marking occasions were specified during the sampling occasions, as individuals were not added the sampled population during September 2018, 2020, and 2021. We allowed a 1000m buffer around the camera trap array to allow a sufficiently large state-space such that an individuals activity center at the edge of the range would be included.

Results

During the three analyzed years of camera data in Oak Bay, we collected data from 104 cameras representing 2,707 camera days in the month of September from each year (Table 1). Mean deployment periods varied each year but were typically high and presented adequate coverage in the months of September (Figure 3).

Table 1. Summary of camera deployment in Oak Bay, British Columbia, in 2018, 2021, and 2022.

Year	Number of Cameras	Camera Days	Mean Deployment ± SD	Range of Days
2018	34	961	19.22 ± 9.34	1 – 30
2021	34	737	13.91 ± 11.94	1 – 30
2022	36	1009	27.27 ± 7.6	3 – 30

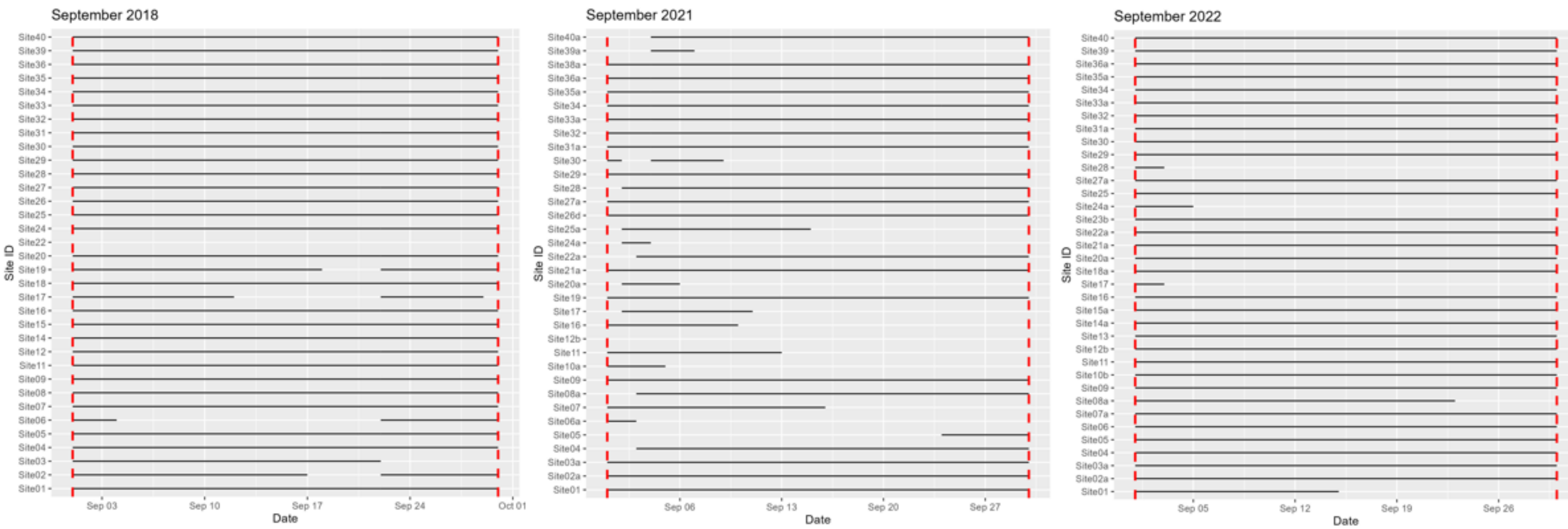

Figure 3. Camera operability for each year during the month of September. Red dashed lines indicate boundaries for September 1st and 30th respectively.

We detected variable numbers of deer in each year. In 2018 we observed 50 detections of 10 marked individuals, and 1037 independent detections of unmarked individuals. In 2021 we observed 155 detections of 36 marked individuals, and 639 independent detections of unmarked individuals. In 2022 we observed 117 detections of 34 marked individuals, and 640 independent detections of unmarked individuals. Detections of marked individuals were relatively uniform throughout the study area (Figure 4).

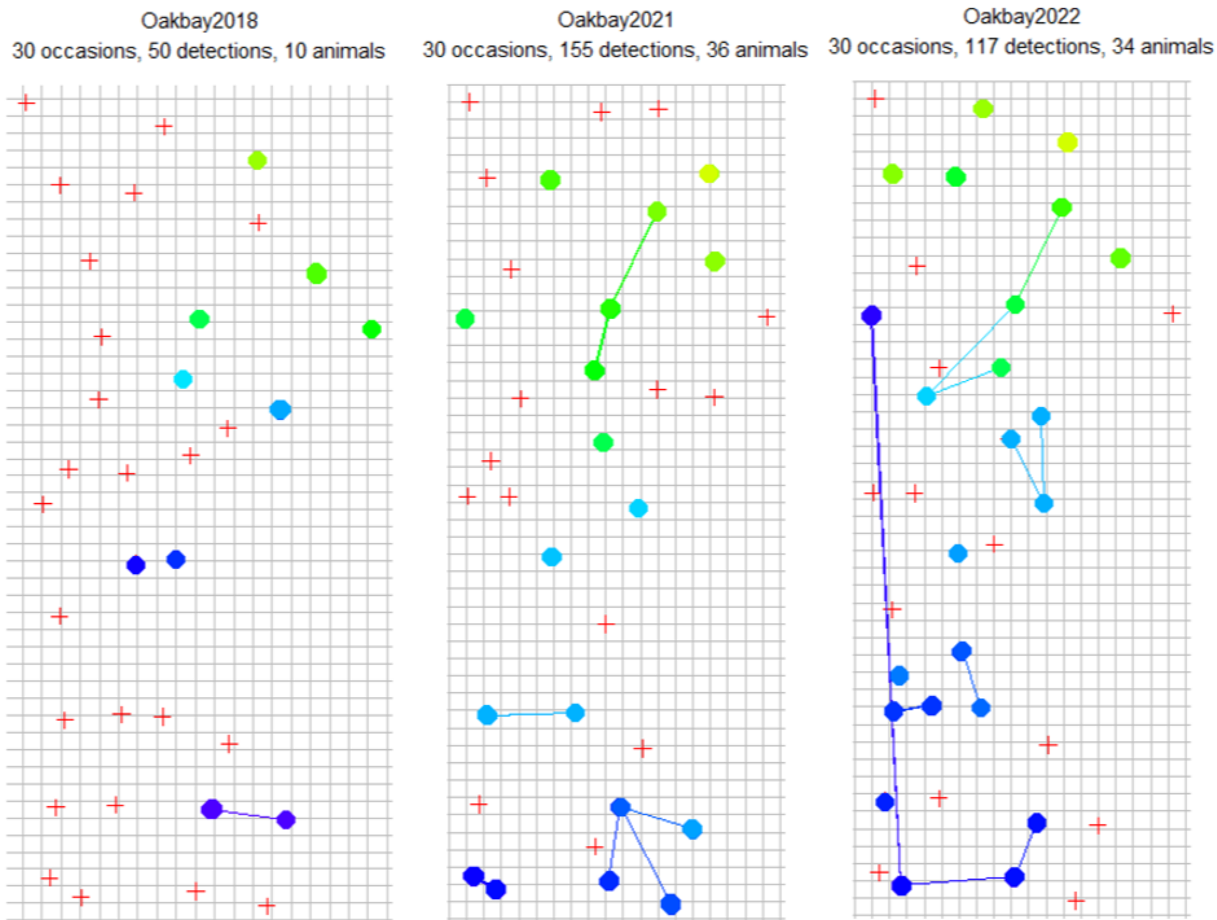

Figure 4. Camera grid array in each study area, overlain with detections of marked individuals. Distinct colours represent unique individuals, and connecting lines indicate detection of the same individual at different cameras. Red cross indicates camera location with zero detections of marked individuals.

Mean population density estimates decreased throughout the study period, with an initial estimate of 14.14 adult deer/km^2 [95% CI: 7.04 – 28. 41] in 2018, 13.67 adult deer/km^2 in 2021 [95% CI: 9.45 – 19.78], and 9.82 adult deer/km^2 in 2022 [95% CI: 6.78 – 14.21] (Figure 5).

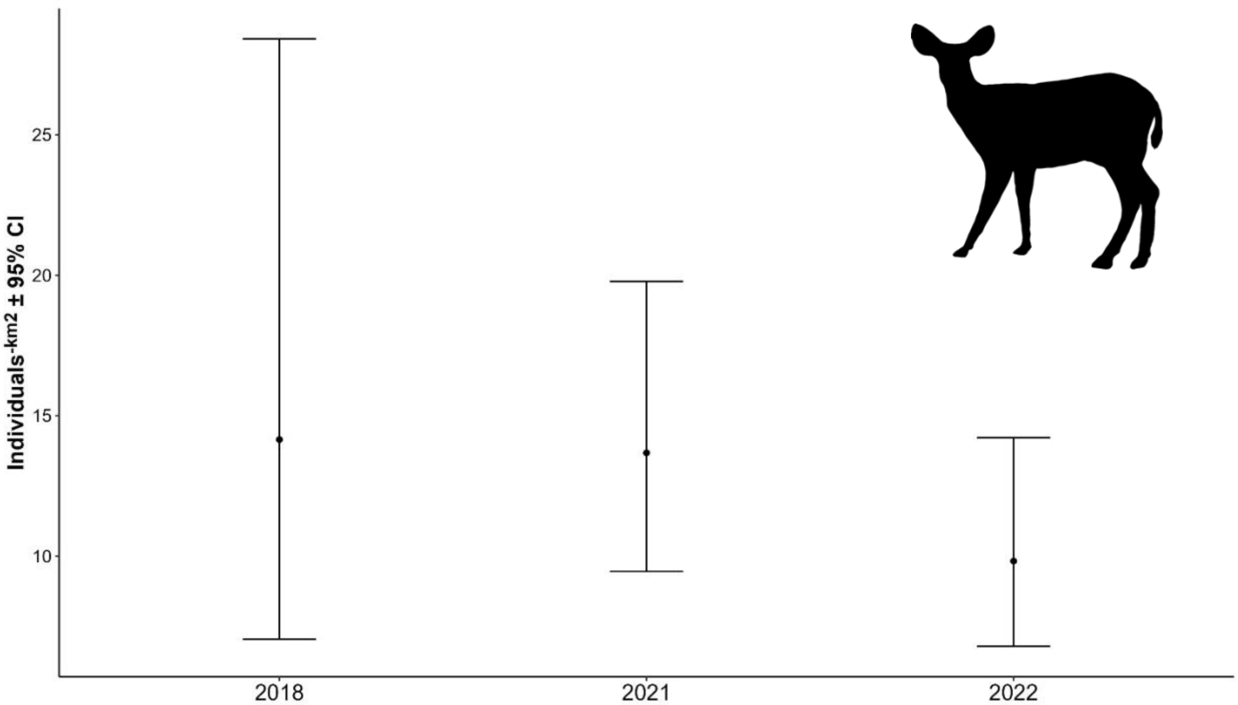

Figure X Population density estimates of urban black-tailed deer in Oak Bay, British Columbia, in 2018, 2021, and 2022. Graphic by Gabriela Palomo-Munoz under CC license https://creativecommons.org/licenses/by-nc/3.0/.

Discussion

Our results indicate an estimated 31% reduction in the mean population density of adult BTD in Oak Bay between 2018 and 2022. We attribute this estimated decrease to the 120 female BTD that were treated with IC between 2019 and 2020, which reduced fawning rates (Aubertin-Young et al. 2023, *in preparation*), followed by natural mortality of adult deer. As we anticipate a lag time of a few years between the application of IC and decrease in the overall adult deer population following suppressed reproductive output (i.e. fewer fawns) and recruitment into the adult contingent of Oak Bay's BTD population, we expect to observe further decreases in September 2023 when the effects of the 71 boosters applied in 2021 will manifest. Deer population density estimates for 2019 and 2020 will also reveal whether the magnitude in response is potentially greater than reported here, if Oak Bay's deer population increased between 2018 – 2020 prior to the effects of IC.

Our camera array deployed in Oak Bay proved effective for monitoring urban BTD, providing high detections of both marked and unmarked individuals. As the number of marked deer in the population increased, the number of unmarked detections decreased. This confirms that a high proportion of the population is marked, which improves accuracy and precision of spatial mark resight models. Precision of a mean estimate is measured with confidence intervals: wider intervals mean less confidence (95% of the time, estimates of the true population size lay within these intervals). For example, the smallest number of tagged deer was in 2018, and the wide confidence intervals around that estimate indicates low precision. Smaller confidence intervals appear in later years with more tagged deer. Due to the large confidence intervals around our population density estimate for 2018 (7.04 – 28.41 adult deer/km^2), the confidence intervals of the pre- and post-treatment density estimates overlap. This does not mean the results are not statistically significant; it means that there is a small chance that the mean population estimates between 2018 and 2022 are actually the same (that is, not truly represented by the mean densities we calculated). Modelling the population densities for October 2019 & 2020 (when an additional 120 deer were added to the marked population following treatment with IC in September) will help reveal the statistical and ecological significance of any observed decreases in population density in the post-treatment period (2021 onwards) for this research trial. Continued monitoring in 2024 and beyond will also reveal the adult deer population response following a pause in IC treatment. No IC was administered in fall 2022 or 2023, resulting in potential increased recruitment of fawns into the adult population in as early as 2024. Monitoring of the adult population in 2024 and 2025 will provide insights into how long the effects of IC treatment can suppress population density to levels observed in the pre-treatment period. Continued monitoring is a critical step for evaluating the long-term effectiveness of IC for urban deer population control and help guide whether alternative IC vaccines with increased longevity of the triggered immune response would provide improved cost-effectiveness.

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