drones

Article

Applications of Unmanned Aerial Vehicles to Survey Mesocarnivores

Jacob D. Bushaw [1], Kevin M. Ringelman [1,*] and Frank C. Rohwer [2]

1 Louisiana State University AgCenter, 312 Renewable Natural Resources Building, Baton Rouge, LA 70803, USA; jbusha1@lsu.edu
2 Delta Waterfowl Foundation, 1312 Basin Avenue, Bismarck, ND 58504, USA; frohwer@deltawaterfowl.org
* Correspondence: kringelman@agcenter.lsu.edu

Received: 26 February 2019; Accepted: 20 March 2019; Published: 22 March 2019

Abstract: With the widespread extirpation of top predators over the past two centuries, mesocarnivores play an increasingly important role in structuring terrestrial trophic webs. However, mesocarnivores are difficult to survey at a population level because their widely spaced territories and nocturnal behavior result in low detection probability. Existing field survey techniques such as track plates and motion-sensitive camera traps are time-consuming and expensive, and yet still yield data prone to systematic errors. Unmanned Aerial Vehicles (UAVs) have recently emerged as a new tool for conducting population surveys on a wide variety of wildlife, eclipsing the efficiency and even accuracy of traditional methods. We used a UAV equipped with a thermal imaging camera to conduct nighttime mesocarnivore surveys in the prairie pothole region of southern Manitoba, Canada. This was part of a much larger ecological study evaluating how lethal removal of mesocarnivores affects duck nest success. Here, our objective was to describe methods and equipment that were successful in detecting mesocarnivores. We used a modified point-count survey from six waypoints that surveyed a spatial extent of 29.5 ha. We conducted a total of 200 flights over 53 survey nights during which we detected 32 mesocarnivores of eight different species. Given the large home ranges of mesocarnivores relative to the spatial and temporal scale of our spot sampling approach, results of these types of point-count surveys should be considered estimates of minimum abundance and not a population census. However, more frequent sampling and advanced statistics could be used to formally estimate population occupancy and abundance. UAV-mounted thermal imaging cameras appear to be an effective tool for conducting nocturnal population surveys on mesocarnivores at a moderate spatial scale.

Keywords: coyote; drone; prairie; point count; fox; skunk; survey; thermal imaging

1. Introduction

With the widespread extirpation of apex predators from most modern landscapes, mesocarnivores (carnivores with a body weight <15 kg) such as coyotes (*Canis latrans*) play an increasingly important role in mediating predator-prey interactions and structuring terrestrial food webs [1–3]. Mesocarnivores have been shown to play a larger role in influencing biological communities than their population size would indicate [4,5], most clearly observed when mesocarnivores are introduced onto islands, which can have severe detrimental impacts on native species [6]. On the other hand, mesocarnivores can provide beneficial ecosystem services in some contexts, such as carcass removal and crop pest control [7]. Given their relatively high trophic position in many ecosystems, it is important to be able to accurately estimate the population size and densities of these mesocarnivores, which has historically proven to be frustratingly difficult.

Mesocarnivores are typically territorial, have large area requirements that vary by geography, habitat, and season, and so tend to occur at low population densities [8]. Moreover, mesocarnivores are mostly nocturnal and in natural environments are wary of humans, though they do make use of human structures (e.g., roads for travel, barns for denning) [8]. Traditional survey methods for mesocarnivores include camera traps, track plates, snow tracking, and hair snares [5,8–10]. Baited camera traps have proven successful for certain species such as Raccoons (*Procyon lotor*), however, other species such as the coyote have been shown to avoid the cameras [5,11]. Camera traps also tend to miss smaller species such as American mink (*Neovison vison*) and weasels (*Mustela* spp.) [8]. Track stations have proven to be useful in certain situations [12], but their effectiveness can depend on the weather: in one study 65% of exposed track plates were rendered useless by heavy rains [13]. Snow tracking can be effective in locating wary species (e.g., coyote), but snow tracking requires good snow conditions, which may only be present in certain areas and for short periods of time [13]. In addition, snow tracking obviously only works in some geographies and with species which are active during the winter; species such as raccoons (*Procyon lotor*) and striped skunks (*Mephitis mephitis*) will not be detected because they are hibernating [8]. Hair snares are often used as a noninvasive way to survey for mesocarnivores, but results have been mixed. Depue and Ben-David [14] used hair snares to survey river otter (*Lontra canadensis*) population densities with great success, with over 90% of their snares detecting river otters. On the other hand, hair snares set to survey bobcat (*Lynx rufus*) and fisher (*Pekania pennanti*) populations in Vermont failed to detect a single animal, even though they were known to be in the area [8]. Acknowledging the importance of mesocarnivores as ecological drivers, there is a clear research need to develop more effective population survey methods for these animals.

Recent advances in Unmanned Aerial Vehicles (UAVs) may provide biologists with more accurate survey methods for a variety of vertebrate species. Already UAVs have been used for a variety of tasks, ranging from locating American alligator (*Alligator mississippiensis*) nests in Louisiana [15], preventing African elephant (*Loxodonta africana*) poaching in Kenya [16], to surveying large flocks of geese [17]. One of the main uses of UAVs has been to obtain population estimates from a variety of colonial nesting birds. Chabot and Bird [18] compared traditional ground surveys for nesting colonial birds with a UAV survey and found that the UAV was able to detect 91%–98% of the nests located by ground crews with minimal disturbance. Sarda-Palomera, et al. [19] evaluated the feasibility of using a UAV to conduct nesting surveys of black-headed gulls (*Chroicocephalus ridibundus*), and showed that nest counts differed from traditional ground surveys by as little as 0.8%–6.1%, while causing significantly less disturbance. Weissensteiner, et al. [20] used a UAV to study canopy-nesting birds, which are traditionally time-consuming and dangerous to study, and found that not only could they accurately determine number of fledglings and their age but could also do it in 15% of the time and with less disturbance.

UAVs have been used extensively in the study of marine mammals including the families of Pinnipeds, Trichechidaes, and Delphinidaes [21–23]. Hodgson, et al. [24] found that population surveys for large marine mammals, such as humpback whales (*Megaptera novaeangliae*) conducted with a UAV are more accurate than traditional survey techniques. In additional to counting it is also possible to accurately obtain morphological measurements, such as length and girth of leopard seals (*Hydrurga leptonyx*) [25]. There is clearly utility in obtaining high-resolution aerial imagery of wildlife for a variety of purposes. Equipping cameras that sense beyond the range of the visual light spectrum may further increase the utility of UAVs for conducting wildlife surveys.

Thermal imaging technology has been used by biologists for years to study everything from honey bee (*Apis spp.*) behavior [26] to surveying population sizes of large mammals such as white-tailed deer (*Odocoileus virginianus*) [27]. Miniaturization of thermal imaging cameras has allowed them to be attached to an UAV and used for everything from monitoring wildfires [28], flying search and rescue missions [29], searching farm land for animals before mowing operations [30], and conducting wildlife surveys [31–33]. Witczuk, et al. [34] utilized UAVs and thermal cameras to survey for ungulates in forested habitats and were able to accurately and reliably detect large ungulate heat signatures, although they had difficulty identifying them to species. UAVs and thermal cameras have also been used to survey for large marine mammals such as grey seals (*Halichoerus grypus*) with nearly identical detection rates as field teams [35]. To our knowledge, no study has attempted to use UAVs and thermal imaging cameras to survey for smaller mammalian predators. Here, we evaluated the ability of a UAV equipped with a thermal imaging camera to locate small- to medium-sized nocturnal mesocarnivores in southern Manitoba, Canada. The methods described here are part of a much larger ecological study evaluating how lethal removal of mesocarnivores affects duck nest success. Lethal removal of nest predators has been shown to increase nest survival of upland-nesting ducks [36] but it is unclear whether managing mesocarnivores also benefits overwater-nesting diving ducks. Despite the fact that mesocarnivore removal is a common management practice for improving duck nest survival [37], evaluating predator populations before and after removal has heretofore been logistically impractical, creating the impetus for our work with the UAV and thermal camera. Our objective in this paper is to describe equipment and methods that were successful in detecting mesocarnivores in prairie landscapes.

2. Methods

2.1. Study Area

Our study area consisted of four 12.9 km^2 study blocks located near the town of Minnedosa, Manitoba in the prairie pothole region of Canada (50.20°N 99.77°W); each block was separated by at least 1.6 km. Our study was conducted primarily on private land consisting of cereal grains, mainly canola (*Brassica napus*) and spring wheat (*Triticum aestivum*). The remaining areas were either actively grazed pasture land or native grasslands, described in detail by Kiel et al. [38]. Vegetation height and density varied greatly among survey sites and between survey rounds. On two of our study blocks (Elphinstone and Minnedosa), professional trappers were hired to lethally remove mesocarnivores, in conjunction with an ongoing (2015–present) experimental study examining how the removal of mesocarnivores affects the nesting success of diving ducks. The remaining two study blocks (Odanah and Raven Lake) were (untrapped) control blocks. Each block was further broken into 25 study plots. Flight restrictions put in place by Transport Canada limited our horizontal flight distance to 500 m and so combined with logistical constraints on land access and launch protocols, we limited our surveys to 30 ha per study plot.

2.2. Equipment

We used a battery-powered DJI Inspire 1 quadcopter UAV (3.1-kg weight, 570 mm wingspan), powered by a 22.2 V lithium ion battery, allowing us a flight time of ~15 minutes. We used a portable battery charger and generator to charge up to 12 batteries in the field, thereby allowing us to operate continuously until we had completed our surveys. The UAV was equipped with a DJI Zenmuse XT2 R thermal imaging camera (640 × 512 resolution; 19 mm lens; 30 Hz) to detect thermal radiation given off by mesocarnivores. The amount of radiation emitted is dependent on both the temperature of the object and emissivity, which is a measure of the reflectivity of an object. The image generated by the thermal camera is therefore not a depiction of the absolute temperature or infrared radiation of an organism, but a combination of the targets' radiation, emissivity and environmental factors such as humidity and cloud cover, and (critically) the temperature of the background against which the animal is observed.

2.3. Sampling Protocol

Using ArcGIS 10.3 and the DJI Ground Station Pro v 2.1 iPad application we designed a point count survey which allowed us to cover the entire study area systematically, and to take advantage of easily-programmable flight routes and autopilot flight options. Although it should be possible to use trigonometry to titrate the camera field-of-view at different tilt angles and optimize sample point spacing, we encountered issues with both the rectangular image on the screen (x and y dimensions not equal) and some fisheye distortion near the edge. We concluded that empirical tests would be more reliable than math in this case, and so we conducted simple field trials using a warm (23 °C) plastic water bottle. We began with the UAV at a height of 75 m above ground level with the camera pointed straight down. We placed the bottle at the edge of the camera's field of view, and then tilted the camera toward the horizon until the bottle was on the opposite edge of the camera view. We repeated this procedure until the water bottle was no longer detectable with the thermal camera: a ground-line distance of 300 m. On a separate occasion, we evaluated detection probability using a medium-sized (15 kg) domestic dog (*Canis lupus familiaris*) as a convenient proxy for a wild mesocarnivore. The dog was placed at varying distances from the UAV pilot (up to 300 m). Without foreknowledge of the dog's location, the UAV pilot was able to locate it with 100% reliability from 75 m above the ground, allowing us to be reasonably confident that we could locate mesocarnivores from this height and ground-line distance. Preliminary testing was conducted in early evening under conditions of low humidity, ~12 °C air temperature, low grass cover, but after the ground had experienced a full period of daytime heating.

Given our maximum detection range of 300 m, we chose 125 m as a highly conservative value at which detectability of mesocarnivores would approach 100% under the full range of field conditions where drone flight would be possible. Using 125 m as the radius, we designed a point count survey with points approximately 250 m apart. Using ArcGIS and DJI's Ground Station Pro app we determined that 6 points spaced 250 m apart would allow us to cover 29.5 ha of each survey plot (Figure 1). We programmed the UAV to fly to each point, whereupon we stopped and rotated the drone 360 degrees three times, adjusting the camera angle on each rotation (as per our testing) to sweep out ever-larger observational arcs (Figure 2). While flying at these heights we could readily detect the heat sources given off by mesocarnivores and much smaller animals. For example, during our first survey we were easily able to detect mice (*Mus spp.*) running through the vegetation from a height of 75 m, and so we were highly confident that our detection probability for mesocarnivores approached 100%, given they were present and aboveground during the survey. However, we could not always determine the species identity of every heat source at these heights and dropped to elevations of 15 m–40 m to confirm species identity. We would capture both videos and still photos of every mesocarnivore and these were reviewed later to facilitate identification to species.

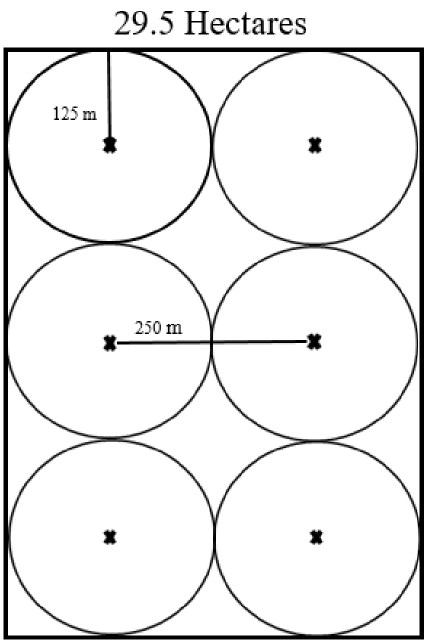

Figure 1. Point count survey designed for an unmanned aerial vehicle (UAV) to fly at a height of 75 m. From each of the 6 point-count locations the UAV was able to survey 4.9 ha for a total of at least 29.5 ha. Surveys for mesocarnivores were flown in Minnedosa, MB, Canada following this protocol.

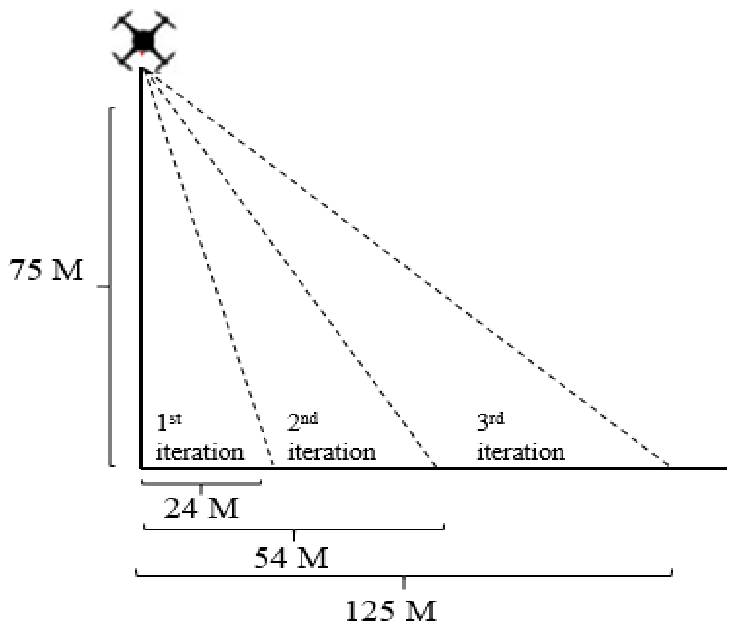

Figure 2. At each point count location, we conducted surveys with the unmanned aerial vehicle (UAV) in broadening observational arcs. We began by pointing the camera 90° straight down, and then tilting the camera towards the horizon twice, each time rotating the UAV 360°. We restricted our sampling to 125 m, but 300 m was our maximum detection distance of a heat source approximating a mesocarnivore.

We conducted two rounds of mesocarnivore surveys that corresponded with the predator removal experiment at our site: the first round spanned 25 April–3 June 2017 (before trapping), and the second spanned 16 July–28 July 2017 (after trapping). All surveys were conducted at least 30 min after sunset to maximize mesocarnivore detection [39]. Surveys were not conducted during inclement weather (precipitation, winds in excess of 32 km/h), and per our Transport Canada Special Flight Operations Certificate (SFOC) permits we were also not permitted to operate the UAV if the cloud cover was below 305 m. All work was conducted by a licensed UAV pilot operating under the SFOC permit 5812-17-132. Data are presented as means ± standard error unless otherwise noted.

3. Results

We conducted a total of 200 surveys using our point count survey method. Each mesocarnivore survey lasted 19.8 ± 6.0 min, and we were able to conduct 10.0 ± 4.5 surveys each night. The first round of sampling (25 April–3 June) took longer than expected—40 survey nights—due to inclement weather (winds in excess of 32 km/h and rain) that made flying the UAV impossible. We detected a total of 17 individual mesocarnivores during the first round of sampling including red foxes (*Vulpes vulpes*), coyotes, and striped skunks: four of these we located on trapped sites, and 13 on control sites (Table 1). We experienced fewer weather delays during the second round of sampling and completed surveying over the course of 13 nights (15 July–28 July). During the second round we located a total of 15 mesocarnivores: six on trapped blocks, and nine on control blocks (Table 1). We were required to briefly drop to heights of 15 m to definitively identify mesocarnivores down to species (Figure 3a–d). In addition to mesocarnivores, we also located several other species including white-tailed deer, moose (*Alces alces*), American porcupines (*Erethizon dorsatum*), and several species of the Leporidae family and the Rodentia order.

Table 1. Mesocarnivores detected at each study site across two sampling periods. (**a**) Round one was conducted from 23 April–3 June and total of 90 surveys were conducted. (**b**) Round two was conducted from 15–23 July and a total of 100 surveys were conducted.

(a)

Round 1	**Trapped**		**Control**		**Total**
	Elphinstone	**Minnedosa**	**Odanah**	**Raven Lake**	
American badger	0	1	2	0	3
coyote	0	0	3	1	4
red fox	2	0	1	3	6
striped skunk	0	1	1	2	4
Total	2	2	7	6	17

(b)

Round 2	**Trapped**		**Control**		**Total**
	Elphinstone	**Minnedosa**	**Odanah**	**Raven Lake**	
coyote	0	1	0	1	2
red fox	1	0	3	3	7
striped skunk	0	1	0	1	2
American mink	1	0	0	0	1
raccoon	0	0	1	0	1
weasel	0	1	0	0	1
feral cat	1	0	0	0	1
Total	3	3	4	5	15

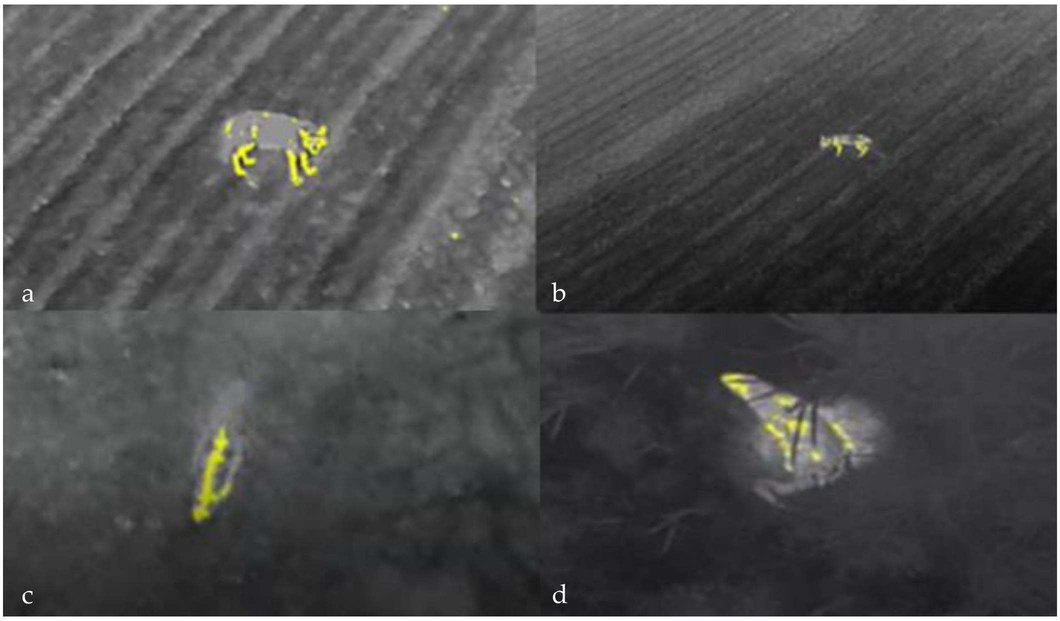

Figure 3. Images of a coyote (**a**), red fox (**b**), striped skunk (**c**), and American mink (**d**), standing in unplanted fields or in a cattail slough. Note that though all images were taken from a height of 15 m, some were taken from different angle or the images were zoomed in to allow us to better identify them.

While surveying for mesocarnivores we also qualitatively noted any disturbance caused by the UAV. While flying at the point count survey height of 75 m, mesocarnivores did not measurably respond to the UAV. The only exception were several red foxes that were in full flight when located when we were flying to our first survey point. We suspect that these animals were actually fleeing from our noisy and well-lit arrival in a truck. Cattle adjacent to our study plots reacted negatively to the UAV, and often fled to the other side of the field as soon as the UAV was airborne. Henceforth, we avoided flying over cattle. When we dropped to lower elevations to identify mesocarnivores, reactions ranged from no visible reaction to running away.

4. Discussion

Extensive surveying and testing under various conditions gave us confidence that we were able to reliably detect mesocarnivore-sized animals if they were present on our study sites, as we were often able to locate mice and small birds. It is generally assumed that there are several problems with aerial surveys including double-counting, perception error, and misidentification [40]. Because mesocarnivores are territorial and home ranges are large on the prairies, we only counted >1 mesocarnivore per survey on four occasions: twice we observed different species and twice we captured both animals in view simultaneously, and so we are confident that we did not double-count animals within a survey. However, we acknowledge the possibility of double-counting animals across the two survey periods; without individually marking animals this issue is difficult to overcome. Because we dropped the UAV to elevations lower than 75 m with the express purpose of identifying mesocarnivores to species, species identity was resolvable for all animals. The only perception error that seems plausible is unusually low detectability of raccoons. We only located one raccoon over the course of 200 surveys, even though we know (from trapping data and camera traps placed at duck nests) that raccoons were common throughout the landscape. This could be attributed to several factors, including the fact that raccoons tend to prefer wetland habitats, and so may be less visible due to wet fur and heavy vegetative cover. Additionally, water has a very high emissivity, which has the potential to interfere with detection of animals with the thermal imaging camera.

UAV surveys were relatively efficient at detecting mesocarnivores: during ~66 hours of flight time, we detected 32 mesocarnivores (latency of ~2 hours between detections). For perspective, mesocarnivore camera trapping studies conducted over many trap-nights often have latencies ~30 hours [41]. Our data represent a sample of the mesocarnivore community at each site. Given the large home ranges of many of these mesocarnivores and variable nocturnal activity schedules, our counts of mesocarnivores represent a minimum abundance. More to the point, while we are confident we detected mesocarnivores (except possibly raccoons) if they were present and aboveground during our survey, given the brevity of our survey (20 min) and the large home ranges of mesocarnivores, it is likely that we did not detect all animals that do in fact use the sites we sampled. To estimate populations, we suggest future researcher consider frequent repeat surveys. Even though animals are not individually marked, with new hierarchical N-mixture models it may be possible to use this sampling strategy to estimate mesocarnivore occupancy and abundance [42].

Our results suggest that UAVs equipped with thermal imaging cameras are a viable tool for monitoring mesocarnivores at scales up to 30 ha. Because we often needed to hover above animals and drop elevation to identify them to species, we recommend rotor-based UAV platforms (as opposed to fixed-wing) for these type of mammal surveys. The primary constraint that limits expansion to larger survey areas is permitting restrictions, which vary across federal and local governments. Flight time is limited by batteries, but in the one year since this study was conducted, operational flight time for similar quadcopter UAVs has increased to ~25 minutes per battery. The area sampled by the methods described here is small compared to the home ranges of most mesocarnivores, but detection probability would increase with repeated surveys flown at different times of night. Unmanned Aerial Vehicles are an increasingly common tool for remotely monitoring wildlife populations, and our results demonstrate the utility of combining aerial surveys with thermal imaging cameras to survey animal species that are otherwise difficult to observe.

Author Contributions: Conceptualization, F.C.R.; Data curation, J.D.B.; Funding acquisition, F.C.R.; Investigation, J.D.B.; Methodology, J.D.B. and K.M.R.; Project administration, K.M.R.; Resources, K.M.R. and F.C.R.; Visualization, J.D.B.; Writing – original draft, J.D.B.; Writing – review & editing, K.M.R.

Funding: This work was funded by Delta Waterfowl Foundation and the Louisiana State University AgCenter.

Acknowledgments: We thank Delta Waterfowl Foundation, Louisiana State University AgCenter, and Ducks Unlimited Canada for funding and logistical support. We thank Joel Brice and all the private landowners for their assistance in providing funding, equipment, data, and field housing, and access to their properties. We also thank T. Potter and M. Davis for their assistance with data collection.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Terborgh, J.; Estes, J.A.; Paquet, P.; Ralls, K.; Boyd-Herger, D.; Miller, B.J.; Noss, R.F. *The Role of Top Carnivores in Regulating Terrestrial Ecosystems*; Island Press: Washington, DC, USA, 1999.
2. Laliberte, A.S.; Ripple, W.J. Range contractions of North American carnivores and ungulates. *Bioscience* **2004**, *54*, 123–138. [CrossRef]
3. Crooks, K.R.; Soule, M.E. Mesopredator release and avifaunal extinctions in a fragmented system. *Nature* **1999**, *400*, 563–566. [CrossRef]
4. Ray, J.; Redford, K.H.; Steneck, R.; Berger, J. *Large Carnivores and the Conservation of Biodiversity*; Island Press: Washington, DC, USA, 12013.
5. Gompper, M.E.; Kays, R.W.; Ray, J.C.; Lapoint, S.D.; Bogan, D.A.; Cryan, J.R. A comparison of noninvasive techniques to survey carnivore communities in northeastern North America. *Wildl. Soc. Bull.* **2006**, *34*, 1142–1151. [CrossRef]
6. Nordström, M.; Korpimäki, E. Effects of island isolation and feral mink removal on bird communities on small islands in the Baltic Sea. *J. Anim. Ecol.* **2004**, *73*, 424–433. [CrossRef]
7. Cirovic, D.; Penezic, A.; Krofel, M. Jackals as cleaners: Ecosystem services provided by a mesocarnivore in human-dominated landscapes. *Biol. Conserv.* **2016**, *199*, 51–55. [CrossRef]
8. Long, R.A.; Donovan, T.M.; Mackay, P.; Zielinski, W.J.; Buzas, J.S. Comparing scat detection dogs, cameras, and hair snares for surveying carnivores. *J. Wildl. Manag.* **2007**, *71*, 2018–2025. [CrossRef]
9. Barrett, R.H. Smoked aluminum track plots for determining furbearer distribution and relative abundance. *Calif. Fish Game* **1983**, *69*, 188–190.
10. Hamel, S.; Killengreen, S.T.; Henden, J.A.; Eide, N.E.; Roed-Eriksen, L.; Ims, R.A.; Yoccoz, N.G. Towards good practice guidance in using camera-traps in ecology: Influence of sampling design on validity of ecological inferences. *Methods Ecol. Evol.* **2013**, *4*, 105–113. [CrossRef]
11. O'Connell, A.F.; Talancy, N.W.; Bailey, L.L.; Sauer, J.R.; Cook, R.; Gilbert, A.T. Estimating site occupancy and detection probability parameters for meso- and large mammals in a coastal ecosystem. *J. Wildl. Manag.* **2006**, *70*, 1625–1633. [CrossRef]
12. O'Neil, E.; Swanson, B.J. Using Track-plate Footprints in Fisher Mark Recapture Population Estimation. *Am. Midl. Nat.* **2010**, *164*, 165–171. [CrossRef]
13. Foresman, K.R.; Pearson, D.E. Comparison of proposed survey procedures for detection of forest carnivores. *J. Wildl. Manag.* **1998**, *62*, 1217–1226. [CrossRef]
14. Depue, J.E.; Ben-David, M. Hair sampling techniques for River Otters. *J. Wildl. Manag.* **2007**, *71*, 671–674. [CrossRef]
15. Elsey, R.M.; Trosclair, P.L. The use of an unmanned aerial vehicle to locate alligator nests. *Southeast. Nat.* **2016**, *15*, 76–82. [CrossRef]
16. Bergenas, J.; Stohl, R.; Georgieff, A. The other side of drones: Saving wildlife in Africa and managing global crime. *Conflict Trends* **2013**, *2013*, 3–9.
17. Chabot, D.; Bird, D.M. Evaluation of an off-the-shelf unmanned aircraft system for surveying flocks of geese. *Waterbirds* **2012**, *35*, 170–174. [CrossRef]
18. Chabot, D.; Bird, D.M. Wildlife research and management methods in the 21st century: Where do unmanned aircraft fit in? *J. Unmanned Veh. Syst.* **2015**, *3*, 137–155. [CrossRef]
19. Sarda-Palomera, F.; Bota, G.; Vinolo, C.; Pallares, O.; Sazatornil, V.; Brotons, L.; Gomariz, S.; Sarda, F. Fine-scale bird monitoring from light unmanned aircraft systems. *Ibis* **2012**, *154*, 177–183. [CrossRef]
20. Weissensteiner, M.H.; Poelstra, J.W.; Wolf, J.B.W. Low-budget ready-to-fly unmanned aerial vehicles: An effective tool for evaluating the nesting status of canopy-breeding bird species. *J. Avian Biol.* **2015**, *46*, 425–430. [CrossRef]
21. Flamm, R.O.; Owen, E.C.G.; Owen, C.F.W.; Wells, R.S.; Nowacek, D. Aerial videogrammetry from a tethered airship to assess manatee life-stage structure. *Mar. Mamm. Sci.* **2000**, *16*, 617–630. [CrossRef]

22. Koski, W.R.; Gamage, G.; Davis, A.R.; Mathews, T.; LeBlanc, B.; Ferguson, S.H. Evaluation of UAS for photographic re-identification of bowhead whales, Balaena mysticetus. *J. Unmanned Veh. Syst.* **2015**, *3*, 22–29. [CrossRef]
23. Nilssen, K.T.; Storvold, R.; Stødle, D.; Solbø, S.A.; Johansen, K.-S.; Poltermann, M.; Haug, T. *Testing UAVs to Perform Aerial Photographic Survey of Harp and Hooded Seals in the West Ice Area*; Havforskningsinstituttet: Bergen, Norway, 2014.
24. Hodgson, A.; Peel, D.; Kelly, N. Unmanned aerial vehicles for surveying marine fauna: Assessing detection probability. *Ecol. Appl.* **2017**, *27*, 1253–1267. [CrossRef] [PubMed]
25. Krause, D.J.; Hinke, J.T.; Perryman, W.L.; Goebel, M.E.; LeRoi, D.J. An accurate and adaptable photogrammetric approach for estimating the mass and body condition of pinnipeds using an unmanned aerial system. *PLoS ONE* **2017**, *12*. [CrossRef] [PubMed]
26. Kastberger, G.; Stachl, R. Infrared imaging technology and biological applications. *Behav. Res. Methods Instrum. Comput.* **2003**, *35*, 429–439. [CrossRef]
27. Collier, B.A.; Ditchkoff, S.S.; Raglin, J.B.; Smith, J.M. Detection probability and sources of variation in white-tailed deer spotlight surveys. *J. Wildl. Manag.* **2007**, *71*, 277–281. [CrossRef]
28. Ambrosia, V.G.; Wegener, S.S.; Sullivan, D.V.; Buechel, S.W.; Dunagan, S.E.; Brass, J.A.; Stoneburner, J.; Schoenung, S.M. Demonstrating UAV-acquired real-time thermal data over fires. *Photogramm. Eng. Remote Sens.* **2003**, *69*, 391–402. [CrossRef]
29. Rudol, P.; Doherty, P. Human body detection and geolocalization for UAV search and rescue missions using color and thermal imagery. In Proceedings of the 2008 IEEE Aerospace Conference, Big Sky, MT, USA, 1–8 March 2008; pp. 1–8.
30. Israel, M. A UAV-based roe deer fawn detection system. *Int. Arch. Photogramm. Remote Sens.* **2011**, *38*, 1–5. [CrossRef]
31. Haschberger, P.; Bundschuh, M.; Tank, V. Infrared sensor for the detection and protection of wildlife. *Opt. Eng.* **1996**, *35*, 882–889. [CrossRef]
32. Christiansen, P.; Steen, A.K.; Jørgensen, N.R.; Karstoft, H. Automated Detection and Recognition of Wildlife Using Thermal Cameras. *Sensors* **2014**, *14*, 13778–13793. [CrossRef] [PubMed]
33. Ward, S.; Hensler, J.; Alsalam, B.; Gonzalez, L.F. Autonomous UAVs wildlife detection using thermal imaging, predictive navigation and computer vision. In Proceedings of the 2016 IEEE Aerospace Conference, Big Sky, MT, USA, 5–12 March 2016; pp. 1–8.
34. Witczuk, J.; Pagacz, S.; Zmarz, A.; Cypel, M. Exploring the feasibility of unmanned aerial vehicles and thermal imaging for ungulate surveys in forests—Preliminary results. *Int. J. Remote Sens.* **2018**, *39*, 5504–5521. [CrossRef]
35. Seymour, A.C.; Dale, J.; Hammill, M.; Halpin, P.N.; Johnston, D.W. Automated detection and enumeration of marine wildlife using unmanned aircraft systems (UAS) and thermal imagery. *Sci. Rep.* **2017**, *7*. [CrossRef]
36. Garrettson, P.R.; Rohwer, F.C. Effects of mammalian predator removal on production of upland-nesting ducks in North Dakota. *J. Wildl. Manag.* **2001**, *65*, 398–405. [CrossRef]
37. Amundson, C.L.; Pieron, M.R.; Arnold, T.W.; Beudoin, L.A. The effects of predator removal on Mallard production and population change in northeastern North Dakota. *J. Wildl. Manag.* **2013**, *77*, 143–152. [CrossRef]
38. Kiel, W.H.; Hawkins, A.S.; Perret, N.G. *Waterfowl Habitat Trends in the Aspen Parkland of Manitoba*; Information Canada: Ottawa, ON, USA, 1972.
39. Urban, D. Raccoon Populations, Movement Patterns, and Predation on a Managed Waterfowl Marsh. *J. Wildl. Manag.* **1970**, *34*, 372–382. [CrossRef]
40. Brack, I.V.; Kindel, A.; Oliveira, L.F.B. Detection errors in wildlife abundance estimates from Unmanned Aerial Systems (UAS) surveys: Synthesis, solutions, and challenges. *Methods Ecol. Evol.* **2018**, *9*, 1864–1873. [CrossRef]
41. Jordan, M.J.; Barrett, R.H.; Purcell, K.L. Camera trapping estimates of density and survival of fishers Martes Pennanti. *Widlife Biol.* **2011**, *17*, 266–277. [CrossRef]
42. Carrlson, K.M.; Gue, C.T.; Loesch, C.R.; Walker, J.A. Assessment of repeat-visit surveys as a viable method for estimating brood abundance at the 10.4-km^2 scale. *Wildl. Soc. Bull.* **2018**, *41*, 72–77. [CrossRef]