CITIZEN BOBCATS: GETTING TO KNOW THE NEW RESIDENTS IN CALGARY NEIGHBOURHOODS

By

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Abstract

As human populations continue to grow and move into city centres globally, historic wildlife habitat is being brought into the urban matrix. Increasingly, cities are acknowledging that biodiversity is important for supporting ecological resilience and the well being of citizens. There is a need to understand how species navigate the human-dominated landscape in the face of continuous global change. In Alberta, bobcats (*Lynx rufus)* are suspected to be expanding their historic range to inhabit new areas including the City of Calgary. Using citizen observations reported to the City and remote camera data, my research sought to understand where bobcats are being seen in the city, how those observations have changed over time and how they relate to an ecological network delineated to support wildlife movement. A total of 4599 bobcat observations to the City of Calgary from May 1, 2005 to July 31, 2020 were included in analysis. Results show a clear increase in bobcat observations over time with a corresponding increase in area covered. Bobcat observations were in or near the ecological network. My study highlights: the importance of green spaces to support biodiversity; the benefits of Calgary's ecological network in supporting animal movement; and provides information to increase ecological literacy. Continued studies of urban wildlife including bobcats will provide guidance for the City of Calgary to achieve the goals in their *Biodiversity Strategic Plan* and *Municipal Development Plan*, ensuring support for non-human wildlife by prioritizing expansion and conservation of high-quality habitat and habitat connectivity.

Citizen Bobcats: Getting to Know the New Residents in Calgary Neighbourhoods

Global landscapes have changed dramatically since the beginning of the Industrial Revolution as human populations have exploded and put pressure on natural systems for resources through anthropogenic activities including oil and gas development, forestry, agriculture, mining and urbanization (Rockström et al., 2009; Seto et al., 2012). So wide-reaching are these changes that scientists have suggested that we are in the midst of the Anthropocene epoch where humans are the biggest direct and indirect driver of global change (Crutzen, 2006). Of these activities, urbanization is one of the most rapidly evolving (Butchart et al., 2010; Seto et al., 2012). Where once rural populations thrived and urban centres were small, today cities around the world are expanding, with over 68% of people expected to be living in them by 2050 (United Nations Department of Economic and Social Affairs, 2018). This expansion for resources and infrastructure to support growing populations is driving the loss and reduction of biodiversity across the globe at an unprecedented rate. Resilience experts have even suggested that biodiversity loss is the most imminent issue threatening the stability and resilience of our planet (Mace et al., 2014). Despite this, some species are adapting and even expanding their range into new areas, including those dominated by humans (Mills, 2015). These native species opportunistically expanding into new habitat have been called “neonative” by some ecologists and their effect on the existing systems they are exploring is yet unknown (Essl et al., 2019). In Canada, several carnivores fall into this category including coyotes (*Canis latrans*) raccoons (*Procyon lotor*) and bobcats (*Lynx rufus*) (Dell’Amore, 2019; Lariviere, 2004; Roberts & Crimmins, 2010). The focus of my study is the expansion of bobcats within the urban environment of Calgary, Alberta.

Bobcats have historically ranged across much of North America including Southern Alberta, up through the Rocky Mountains (Gooliaff & Hodges, 2018) but recent studies suggest their range is increasing (Roberts & Crimmins, 2010). In many cases, they are recolonizing areas where they were extirpated (Anderson & Gibbs, 2015); however, a unique situation is currently unfolding in Alberta where bobcats appear to be expanding their historic range to inhabit the City of Calgary (CBC News, 2017; Government of Alberta [GOA], 2019). Almost no bobcat ecology studies have been published in Canada and what has driven their expansion thus far is unknown. Climate change and anthropogenic landscape changes have been proposed as potential drivers (Gooliaff & Hodges, 2018; Marrotte et al., 2020).

The province of Alberta follows the trend of increasing urbanization with an estimated 81% of Albertans already living in metropolitan areas (World Population Review, 2020). The City of Calgary is home to over a third of the province's roughly 4.4. million people in an area covering over 850 km^2 (City of Calgary [COC], 2013). Despite recent economic challenges, Calgary's population continues to grow with an estimated increase of 1.9% in 2020 to approximately 1.5 million people (Franklin, 2020).

As the city continues to expand, the municipal government has acknowledged the importance of biodiversity by joining over 1750 jurisdictions as a member of the international Local Action for Biodiversity (LAB) program aimed at improving biodiversity management in municipalities (Local Governments for Sustainability [ICLEI], 2017). As part of the program, the City has developed a *Biodiversity Strategic Plan* for the years 2015-2025 which includes the targets of increasing ecological literacy and enhancing the City's ecological resiliency (COC, 2014). The *Biodiversity Strategic Plan* also seeks to gain a better understanding of the complex interactions that occur between a growing city and nature. Given these targets, coupled with a clear knowledge gap in bobcat ecology, Calgary provides an exceptional opportunity to explore how a previously undocumented, medium sized carnivore integrates into an existing system.

As a lifelong resident of Calgary and a member of a wildlife monitoring team in the city, learning how bobcats are acclimating to this new urban environment is of particular interest to me. I am intrigued by the potential to build resilience through the support of biodiversity, therefore understanding how each species fits into the web of life is important. From a municipal perspective, how bobcats are participating in the urban ecosystem and what effect their presence will have over time is integral for landscape management and co-existence strategies that can support resilience as the City continues to grow and change.

Coupled with the *Biodiversity Strategic Plan,* the City has created the *Municipal Development Plan* and *Calgary Transportation Plan* which include policies that relate to managing open spaces to support biodiversity, reducing habitat fragmentation, re-establishing open space connections that link habitat patches and considering wildlife movement in transportation planning (COC, 2014). The focus of these plans is not on restoring former pristine habitats but rather on understanding how we can maintain and enhance biodiversity in an ever-changing environment. To effectively carry out these plans, it becomes imperative to comprehend how different species are utilizing the City's landscape. This again, provides support for studying bobcat ecology in the city.

Research Questions

To create a starting point for understanding how bobcats are coexisting in Calgary, this study addressed three main questions:

1. Where are bobcats currently distributed in the City of Calgary?
2. How has the observed distribution of bobcats changed between 2005 and 2020?

3. How does the observed bobcat presence relate to the City's ecological network?

Objectives

1. Map bobcat observations reported to the City's citizen reporting platform, 311, to calculate naïve area and extent of occupancy (Efford & Dawson, 2012; IUCN, 2019). The 311 platform was initiated in 2005 with improved technology and location identification occurring over time. All records, including telephone, computer and app reports were included in analysis.
2. Compare mapped 311 bobcat observations in four-year time periods to determine if a change in bobcat distribution has occurred.
3. Explore observed bobcat presence in relation to the ecological network using citizen observations reported to the City to identify spatial patterns. Bobcats occupy a variety of habitats with research studies reporting a preference for wetlands, shrubby areas, forests and edge habitat (Donovan et al., 2011; Dunagan et al., 2019). Calgary's ecological network contains all these habitat types with natural and manufactured wetlands, riparian and upland shrub habitat, conifer, aspen and mixed forest and an abundance of edge habitat (COC, 2014). As both natural habitat and manufactured or altered habitat occur within the ecological network, the terms natural area and green space will be used to distinguish between the two. Green space in this context will refer to all altered habitat as classified by the City in their ecological network dataset. Natural areas will be used to describe core, stepping stone and small natural area habitat.
4. Validate bobcat presence in core natural areas within the ecological network through the secondary use of camera trap data.

Methodology

Literature Review

To find relevant articles to explore my research questions I searched the RRU library Discovery search engine and Google Scholar using the keyword combinations of “bobcat, habitat,” “bobcat, urban,” “bobcat, Alberta” and “bobcat, movement”. As well, I reviewed the bibliographies of relevant articles to see if there were more on the same topics that would be ideal to include. Peer reviewed journal articles were prioritized; however, relevant magazine article and book chapters were also included in my search. The bibliographies of book chapters used were reviewed to ensure information was sourced from peer reviewed studies.

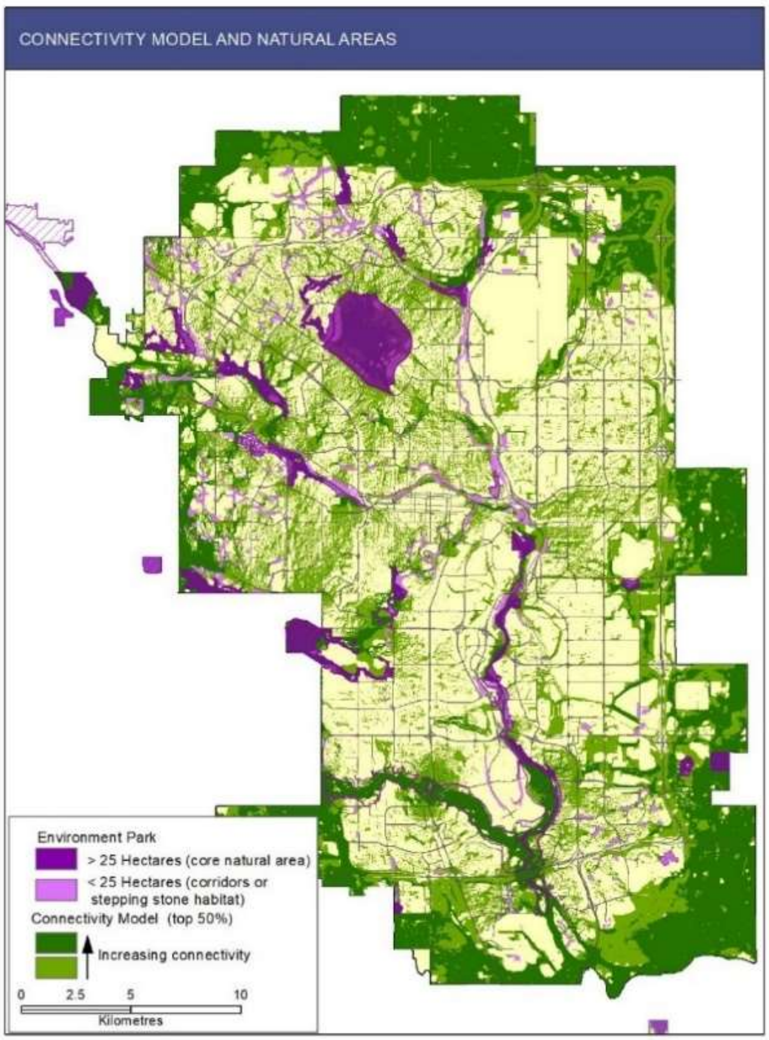
To find articles relevant to urban green infrastructure I used the Google Scholar search engine with keywords “green network,” “green infrastructure,” and “urban green space”. I then used a snowball method of looking through bibliographies of relevant articles and looking at articles that cited relevant articles. Articles for urban wildlife were found using a similar method with keywords “urban wildlife” and “urban carnivores”. Bibliographies and cited references were also reviewed for additional sources.

Study Site

The City of Calgary is found in the Great Plain Ecoregion on the traditional territory of the Blackfoot Confederacy, Treaty 7 Nations which include the Kainai, Piikani, Siksika, Tsuu T’ina and Stoney Nakoda (COC, 2013; Law Society of Alberta, 2021). The City is home to approximately 1.5 million people over an area covering more than 850 km^2 (COC, 2013; Calgary Economic Development, 2020). Within city limits several natural subregions can be found including Foothills Parkland, Central Parkland and Foothills Fescue (GOA, 2009). Established at the confluence of the Elbow and Bow Rivers with a network of natural and manufactured wetlands, a connected matrix of green space covering over 10,000 hectares and over 1000 km of pathways winding through (COC, 2020) (Figure 1), Calgary is well positioned to support a variety of plant and animal life.

Figure 1

Natural Areas and Corridors in the City of Calgary
(Lee, et al., 2019)



Data Collection

My study used a quantitative approach involving an empirical descriptive camera trap survey combined with opportunistic citizen observation reports to assess the known distribution of bobcats in the City and calculate naïve occupancy (Efford & Dawson, 2012). Naïve occupancy in this case is based on definitive presence through citizen observations while acknowledging it is not necessarily exhaustive given the limitations of using only opportunistic data capture (Cove, 2020). To help mitigate the potential areas missed by the naïve occupancy, the extent of occupancy (EOO) was also calculated (International Union for the Conservation of Nature [IUCN], 2019). The EOO expands the area of occupancy (AOO) to include all potential areas an animal may use whether they have been detected or not (IUCN, 2019). In addition, changes in the distribution of bobcat observations over time were analyzed. Finally, as part of the City's work with LAB, efforts have been made to delineate an ecological network throughout the city that is expected to include movement pathways and habitat for wildlife composed of natural and non-natural areas (COC, 2014). Using the observed distribution map, analysis was done to see how bobcat presence corresponds to the City's defined ecological network. Validation of bobcat presence inside the major natural areas was achieved using systematically collected remote camera data.

Citizen Reporting

The City of Calgary currently uses a database consisting of calls to the City's reporting centre, 311, along with the City of Calgary website and 311 app reports to document wildlife observations throughout the city. Information collected includes in as much detail as possible the location of the sighting and the behavior of the animal. Data was provided from the City of Calgary for May 1, 2005-July 31, 2020 totalling 4599 observations. 311 came into use in the city in May of 2005, therefore, bobcat observations prior to 2005 were not documented. Observational reports were edited by the City of Calgary Parks Department prior to being received to remove any personal identifiers ensuring privacy and anonymity of citizens. Since reports were edited for validity prior to be passed along, all records were used in analysis.

Camera Surveys

In May 2017 a project called *Calgary Captured* commenced with the goal of identifying wildlife inhabiting the City's parks (COC, 2018). This study has been set up using a 1 km^2 grid system throughout the larger natural parks in the city. Remote sensor cameras are active in 12 parks using random selection within the grids. A total of 107 camera locations have been deployed over the course of the project with 74 currently in use. Cameras are currently serviced every six weeks and photos are uploaded and classified by experts and volunteers using a camera management database designed by the Alberta Biodiversity Monitoring Institute (ABMI) called *Wildtrax* (ABMI, 2019). Images containing wildlife are further uploaded to a citizen science program called *Zooniverse* to be classified by citizen scientists worldwide (COC & Miistakis Institute for the Rockies, 2019). Images of bobcats recorded on these cameras from May 1, 2017 - May 31, 2020 encompassing three years of data, have been provided to me as a secondary source to assess presence within the parks. 69 cameras were active throughout the first data year, 70 in the second, and 71 in the third. Changes in camera numbers over data years are the result of additional cameras to monitor travel corridors combined with losses due to theft.

Project Participants

Project participants consisted of citizens who reported bobcat observations to the City of Calgary between May 1, 2005 and July 31, 2020. The reports were provided through the Miistakis Institute for the Rockies via a data sharing agreement with the City of Calgary. The data taken from *Calgary Captured* was provided by the Miistakis Institute for the Rockies and only data relating to bobcats was used for the purpose of this study.

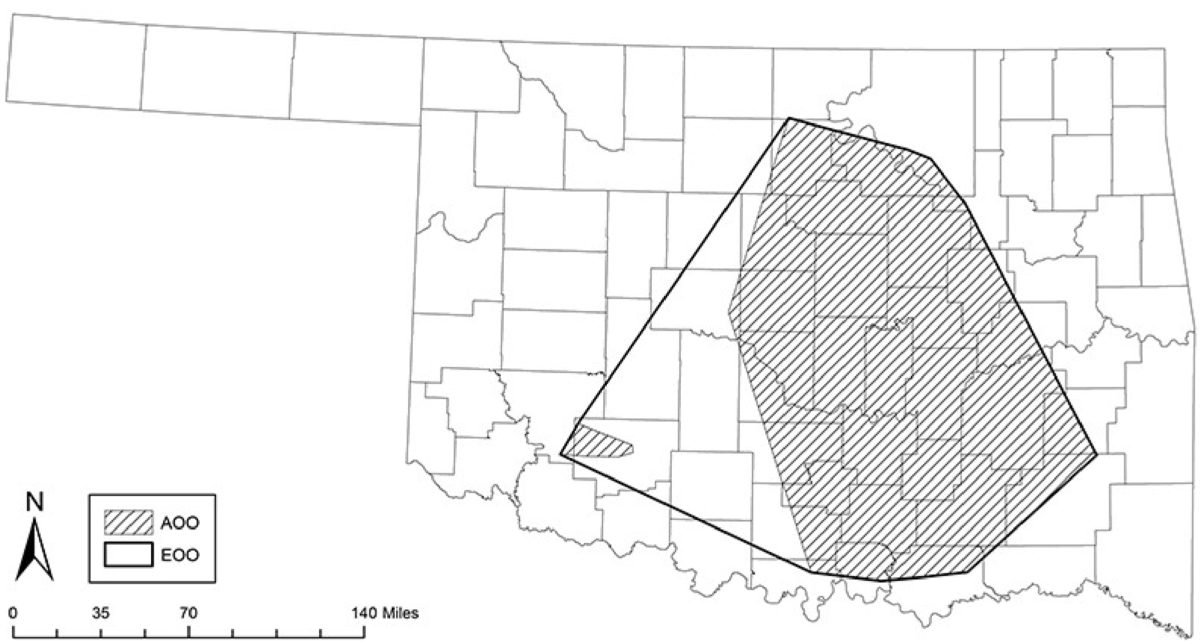
Data Analysis

Current distribution of bobcats in the City

To satisfy the first objective of assessing current bobcat distribution, I analyzed 1973 observations comprising the most recent full year of data from August 1, 2019- July 31, 2020. Locations of observations were mapped using the open-source QGIS geographic information software program. Observations were also input into the open-source Geospatial Conservation Assessment Tool, also known as GeoCat to calculate the AOO and EOO based on a standardized 4 km^2 grid system (Bachman et al., 2011). Figure 2 demonstrates the difference between AOO and EOO where the diagonal-lined area represents the AOO and the encompassing polygon represents the EOO (Messick & Hogland, 2013).

Figure 2

Area of Occupancy compared with Extent of Occupancy (Messick & Hogland, 2013).



Occupancy modeling for species is often conducted using a grid cell size equivalent to the average home range size of that species (IUCN, 2019). Urban home ranges of bobcats have been explored in a few jurisdictions including California where the average home range was 4.93

km^2 (Poessel et al., 2014); Vermont where the average was 2.46 km^2 (Riley et al., 2013); and Texas with an average of 3.8 km^2 (Young et al., 2019). These studies also found the urban bobcat home range size is at least somewhat correlated to development and disturbance including fragmentation by roads (Riley et al., 2003). My study used a standardized 4 km^2 occupancy grid system outlined by the IUCN with the GeoCat program (IUCN, 2019). This number is close to the average of the three studies noted above (3.73 km^2). This standardization helped mitigate uncertainty regarding the unknown home range size of bobcats in Calgary and the potential effects disturbance factors including seasonal construction and road development may have had on the activity patterns and habitat usage of bobcats (ICUN, 2019).

Bobcat distributional changes over time

To meet the second objective of analyzing changes in the distribution of observations over time, I broke the observations into four-year periods between 2005 and 2020; 2005-2008, 2009-2012, 2013-2016, and 2017-2020. This data was then put into GeoCat to calculate the AOO and EOO for each time period. Further to this, a GIS map was created in QGIS for each time period to visualize the changes over time.

Bobcat observations in relation to the ecological network

For the final objective of assessing the relationship of bobcat observations to the City's defined ecological network, I plotted all 4599 points on a QGIS map with the ecological network habitat components shapefile. The network is composed of four habitat classifications: core habitat, stepping stone habitat, smaller natural areas and non-natural parks. Core habitat has been defined as intact areas that support high levels of biodiversity (Landscape Conservation Cooperative Network, n.d.). Stepping stone habitat meanwhile has been defined in the literature as smaller habitat patches that can be used by a species to connect to ideal habitat in an area

(Herrera et al., 2017). The City has defined core habitat as any contiguous natural area larger than 30 hectares while stepping stone habitat are patches between five and 30 hectares in size. The final two categories encompass natural areas smaller than five hectares and non-natural green spaces inclusive of manufactured wetlands, school fields, pathways, community gardens, urban plazas and neighbourhood parks (COC, 2014). Analysis was done using all four categories based on the City's definitions.

To see how the reports relate to the habitat components, I used a *point in polygon* function in QGIS to isolate observations found within all ecological network habitat types. Further to this, to analyze the proximity of points outside the habitat components, I used the QGIS function *nearest neighbour join* which connects layers and provides the distance of points from the polygon layer. Based on this, calculations were made to determine the average distance from the network habitat components. I then further broke down the ecological network layer into the four habitat types and conducted the same analysis to see if bobcat observations were connected to any specific habitat type.

Relationship of bobcat observations to movement corridors

Movement corridors connecting habitat patches are an important part of the ecological network. Primary corridors are defined by the City as pathways in riparian habitat along major rivers and creeks. Secondary corridors are movement pathways that connect core habitat to core habitat and core habitat to other movement pathways. Stepping stone habitat is meant to fall within these secondary corridor pathways. To see how bobcat observations relate to these movement pathways, I took the City's corridor shapefile and conducted *point in polygon* and *nearest neighbour join* functions to find the number of observations within the corridor network and the proximity of observations outside.

Confirmation of bobcat observations using remote camera data

To confirm the presence of bobcats in the larger natural areas in the City, data collected from Calgary Captured for May 1, 2017-May 31, 2020 was provided in an excel format. This data was then broken down by species and bobcat observations were isolated. Cameras that recorded bobcats were plotted using QGIS and tables created based on these captures. Locations of cameras that did not catch bobcats were also plotted to provide presence/absence data.

Data limitations and potential biases

There are limitations found through the secondary use of citizen observations that need to be noted. Firstly, the data reported to 311 provides limited observations from the parks system which may present a distribution that excludes a large part of their potential habitat. These reports are also recorded as closely as possible to the location of the observation however, location accuracy depends on the reliability of cell phone GPS for app reports, physical description of location to 311 operators taking the report, or pinned location chosen by people reporting on the computer. These inaccuracies may result in observations being recorded as outside a natural area or green space when it was in fact inside or vice versa. To mitigate this bias, I used the *extract by attribute* function to isolate observations that were reported between zero and 50 m outside natural areas and green space, followed by the same analysis at 100 m. This provided a good idea of how often bobcats are observed right at the edge of the network habitat components, whether just inside or outside. In addition, given research suggesting bobcat preference for edge habitat (Donovan et al., 2011; Dunagan et al., 2019), whether slightly inside or outside the natural area, these bobcat observations would serve to support their use of edge habitat.

Secondly, while remote camera data was used to validate bobcat presence in the parks, this data is limited to the locations of cameras and therefore can only validate presence in small areas, not throughout the whole park. Thirdly, the motivation of people to report observations may limit both the number and distribution of bobcat reports. Strien et al. (2013) noted that opportunistically collected citizen data may suffer from reporting bias where observers do not necessarily report all species they see, but rather those they find interesting. Fear and excitement may also be motivators to report an observation. This could lead to increased observations reported from areas where people are unfamiliar with bobcats but underrepresent areas where bobcat observations are frequent and therefore perceived as less exciting, scary or interesting. Consequently, bobcat presence may be underestimated in some areas. In addition, detection bias (Strien et al., 2013) could be an issue, where animals may be present, but people simply do not see them. Finally, accessibility and awareness of the reporting platform will influence observational reporting. While there are multiple avenues in which to report including telephone, online and through a mobile app, citizens may be limited by their knowledge of these options and their technological capabilities.

Literature Review

Bobcat Habitat Preferences

Bobcat ecology in Canada is still a novel topic but many aspects have been extensively studied throughout their range in the United States, including habitat preferences. Several studies have documented that the habitat they occupy across their range is variable suggesting high adaptability. In Vermont, a study using GPS collared bobcats addressing home range habitat requirements conducted by Donovan et al. (2011) found a preference for forested areas, shrubby habitat and areas near wetlands. Within their home ranges, bobcats appeared to show a preference for areas with less development, lower road density and more forest, shrub or wetland cover. They were also recorded spending longer periods in parts of their home range within one kilometer of natural habitat. Donovan et al.'s study suggests that bobcats should be seen most often in natural areas or close to them with fewer reports coming from built up areas far from habitat patches.

In California, a GPS collar data study conducted by Emily Ruell et al. (2009) also showed great variability in habitat types with coastal scrub forests, oak forests, arid chaparral regions and forests adjacent to water sources being utilized. In Wisconsin, Clare et al. (2015) used remote camera data to address bobcat population size. Their study found a preference through presence/absence for woody forests and wetland edge habitat. Their study also confirmed remote cameras could be used to study occupancy and effectively derive spatial characteristics.

In a study of urban bobcat habitat use in Texas by Young et al. in 2019, it was found again that bobcats prefer natural habitat, but they are not averse to using built-up areas. They suggested that bobcat use of built-up areas is dependent on connections to natural habitat. This is one of the few studies to be published specific to urban ecology for bobcats and it provides the important suggestion that access to natural areas within the urban matrix may be a limiting factor for the species' presence.

Canadian studies of habitat associations in bobcats have been limited but a study examining bobcats and lynx (*Lynx canadensis*) in British Columbia by Gooliaff and Hodges (2018) showed bobcats inhabiting boreal and montane forests. Their study used reports from trappers and incidental citizen reports to assess the ranges of the conspecifics in the province. Limits did become evident with people not reporting bobcats above certain elevations during the winter. The authors note that this is not necessarily indicative of them not being present at these elevations but rather the lack of people travelling up that high during the winter. This study demonstrates the opportunity to use citizen science reports for the study of carnivore spatial distribution but also demonstrates the limits of opportunistic data collection.

Further publications from British Columbia have noted the inconsistency in range reporting for bobcats in that province and a lack of supporting data (Gooliaff et al., 2018). This seems to be a common theme across Canada where in Alberta, mention of bobcats in recent literature has been limited to an incidental catch in a remote camera study conducted in the mountain region of Kananaskis published by Lobo and Miller (2010). This study set out to understand foraging behavior of small mammals and the record was of a single bobcat's legs, but it was enough to spur excitement. The authors state habitat in the study was composed primarily of sparse white spruce, mossy understory and glacial slopes.

Movement Requirements

While bobcats have been found to be adaptable to a variety of habitat types as well as living among humans, limiting factors to their movements have also been discovered. In a study looking at the sensitivity of carnivores to habitat fragmentation by Kevin Crooks (2002), it was suggested that because carnivores are animals that tend to have large home ranges, habitat fragmentation can negatively affect them. They found that bobcats seem to be able to persist in a fragmented landscape provided there is access to large natural corridors for movement. This is of relevance for my study as it gives an idea of what limitations may be present in the urban landscape for bobcat distribution.

Sharon Poessel et al. (2014) looked at the effects of roads on bobcat movements and found using GPS collared bobcats that females tend to avoid higher volume roads altogether while males only cross them as necessary. This same study also demonstrated a preference for a wide forested buffer for travel, signifying the importance of connected natural areas in the urban matrix to allow for their survival. Calgary has several high-volume roads including a near-complete highway encircling the City and another running North-South through the City. Based on this research, it could be suggested that roads may present a limiting factor to bobcat distribution in the city.

In their study looking at the behavioral responses of bobcats and coyotes to fragmentation and corridors in California, Tigas et al. (2002) found that bobcats were more likely to avoid developed areas for movement than were coyotes, with many bobcats (primarily females) remaining inside a single habitat fragment for the duration of their data collection. They also found that bobcats were more likely to cross over a road than use an easily accessible culvert. Traffic volume appeared to influence their use with higher volumes increasing the likelihood of using the culvert.

Although not yet common in urban areas, wildlife crossings both under and over roads have proven effective for a variety of wildlife (Ng et al., 2004). In their master's thesis, Mark Bellis (2008) found evidence of bobcats using both overpass structures and culverts for crossing. The author did note however, that bobcats do not appear to preferentially cross using mitigation structures and are just as likely to use game trails or junctions between roads to navigate. Calgary is currently exploring wildlife mitigation options for high volume roads which could potentially affect the future distribution of bobcats in the city.

Citizen Science Data for Wildlife Studies

Research has traditionally been conducted using classically trained scientists, but limitations have been noted in the ability of traditional methods to collect large scale data due to constraints on time and effort (McKinley et al., 2017). Increasingly, data collected by citizen scientists is being used to expand datasets and explore new objectives (Altwegg & Nichols, 2019). Programs including iNaturalist and the LEO network capitalize on the interests of the public to be a part of large-scale data collection and at the same time provide an educational opportunity to understand the world around them (Unger et al., 2020). Connecting to the place they make observations may also come from using these programs, increasing the likelihood of continual participation in data collection (Thomashow, 2003).

In a 2019 article, Altwegg and Nichols discuss the potential benefits and drawbacks of using citizen reports to determine occupancy of wildlife. While they acknowledge the potential of false positives through misidentification and false negatives that potentially miss presence through opportunistic data collection, they also note with appropriate design and analysis, the use of citizen science data can be a valuable tool for determining occupancy. Newman et al. (2010) found that socio-economic status of citizens is an important consideration, as a platform that is too difficult to navigate or access will limit participation. In Calgary, the citizen reporting can be done through telephone, online or through the 311 app thereby creating multiple access points for reporting that potentially mitigates this bias.

Green networks in cities

As cities begin to realize the benefits of green space for the well-being of humans and wildlife, green infrastructure is becoming more prominent in the public sphere (Benedict & McMahon, 2002). Described by Benedict and McMahon (2002) as the “natural life support system” (p.12) needed to meet the social, economic and environmental sustainability goals of a community, green infrastructure is found in interconnected natural and manicured spaces that maintain ecosystem services and provide benefits to humans. They note it can include natural parks, wetlands, river systems, and working landscapes that preserve native species and ecosystem functions. The authors go on to state that the creation and maintenance of these networks can benefit communities in several ways. This includes supporting biodiversity and allowing for recreational opportunities to create an overall greater sense of place.

Aronson et al. (2017) also discuss the benefits of green networks for human well-being and biodiversity conservation. They assert that different perceptions of the aesthetics and purposes of green spaces are important to consider in their creation and management. Some people may be drawn to the wildness of an area while others prefer to see groomed green space, thereby influencing management of these areas in a municipal setting. These preferences in turn lead to variability in the ecosystem functions that each green space performs. How people view green spaces may also influence individual motivations to report wildlife observations to the City and thus may play an important role in understanding where bobcats are and how they are using the landscape in the context of my study.

Lepczyk et al. (2017) sought to address which characteristics urban green spaces need to maximally support biodiversity. They concluded that large, high quality habitat was conducive to providing resources for the most species, however, the context of the green space is also important. For instance, a large green space in the middle of the city may not have the same species richness as a large area on the fringes. They propose that urban green spaces create novel ecosystems as the species composition and landscape pressures tend to differ from ex-urban settings. Overall, continued study of how wildlife utilize green space will help guide management and conservation actions in cities.

Urban Wildlife

It has become evident that urban development is going to continue and contrary to previously held beliefs, human dominated areas do, in fact, provide space for a variety of species (Miller & Hobbs, 2002). In Calgary, the *BiodiverCity* report states that the City is home to almost 450 vertebrate species demonstrating this capacity to support biodiversity (COC, 2014). In their 1996 study addressing the tolerance of wildlife to varying levels of urban development, Robert Blair established the concept that there are urban avoiders, adapters and exploiters (Blair, 1996). Avoiders are species whose densities reach their highest levels in natural areas (Fischer et al., 2015). In contrast, urban exploiters are those species who reach their highest densities in highly modified areas (Fischer et al., 2015). Urban adapters fall in the middle of the other two categories as species who are adept at living in moderately modified areas, taking advantage of anthropogenic resources but not becoming dependent on them (Fischer et al., 2015). While useful for a basic understanding of which species can be expected to live in differently developed areas, problems were noted by Fischer et al. in 2015. They found these definitions exclude the complexity that underlies ecological interactions and further proposed a tweaking of the definitions based on an animal's use of natural or developed areas. Urban avoiders, in their view, are those who rarely enter developed areas but who can spend time in habitat patches within the urban environment such as cougars *(Puma concolor).* The authors then recommended urban utilizers and dwellers in place of exploiters and adapters. By their line of thinking, urban dwellers are animals whose populations are independent of development levels while urban utilizers are those who primarily breed inside natural areas but exist in developed areas outside of breeding. These definitions provide a basis for looking at how animals navigate the urban matrix and highlight the importance of green space with potentially important management implications for a variety of species.

In a study looking for clues as to why some species are more successful at living in urban areas than others, Lowry et al. (2013) proposed behavioral flexibility and personality traits of individual animals may drive changes over time leading to the success of a species. They provide the example of birds whose songs change in urban environments in response to more noise. This plasticity has recently been demonstrated in white-throated sparrows whose songs changed in the spring of 2020 during pandemic lockdowns compared to previous years (Derryberry et al., 2020). Being able to quickly adapt to changing conditions and having a high tolerance for disturbance are integral for long-term survival in human-dominated spaces. On an individual level, Lowry et al. (2013) proposed that those with bold temperaments may be more tolerant of the disturbances found in urban environments. This suggests that within species there is likely variability in how individuals utilize the urban landscape.

Bateman et al. (2012) sought to see how carnivores adapt to urban environments. They suggest that large green spaces with connectivity to other green spaces are essential in supporting carnivore populations. Even semi-wild patches such as community and backyard gardens that provide cover can act as stepping stone habitat for carnivores to rest and move through the landscape. Comparative studies of urban versus rural populations of carnivores are sparse but those that have been conducted suggest that access to resources including shelter and reliable food supply may provide benefits for urban carnivores over their rural counterparts (Bateman et al., 2012). Protection from larger predators may also encourage some species to live in proximity to humans. For example, Berger and Gese (2007) found that wolves are a limiting factor for coyotes in rural areas when compared with urban areas. Wolves are urban avoiders so coyotes may be encouraged into urban environments to avoid them.

While reduced competition from larger carnivores in the urban matrix may provide benefits for some species including coyotes and bobcats, other causes of mortality may increase. For bobcats, as mentioned above, roads may limit movement and be a significant source of mortality (Poessel et al., 2014). Research is also beginning to shed light on the effects of disease resulting from anticoagulant poisoning (Riley et al., 2007). The authors found that secondary rodenticide poisoning resulting from ingestion of poisoned prey was increasing susceptibility to a highly infectious form of mange that was in turn reducing survival of urban bobcats. Disease potential also exists from increased proximity to species such as domestic cats and dogs which may increase the exchange of parasites and potentially fatal disease for bobcats and the domestic animals. In Calgary, this has already been noted to be of concern with coyotes and domestic dogs with *Echinococcus multilocularis,* a tapeworm that can be passed from coyotes to domestic dogs and humans (Catalano et al., 2012). While bobcats could also potentially carry *Echinococcus,* greater concern can be found for feline specific parasites and disease such as *Bartonella sp.,* Feline Immunodeficiency Virus (FIV) and *Toxoplasmosis gondii* (Bevins et al., 2012). The latter of these is also zoonotic and therefore could be of concern for human health. Despite this, urban environments have been shown to have higher survivorship compared to rural populations for several wild species including coyotes and raccoons (Bateman et al., 2012).

Overall, current literature suggests carnivores that thrive in cities are habitat and dietary generalists with high behavioral plasticity. While disease, habitat fragmentation, roads and conflict with people present obstacles, many species, including bobcats are proving themselves to be successful at inhabiting the urban landscape (Bateman et al., 2012).

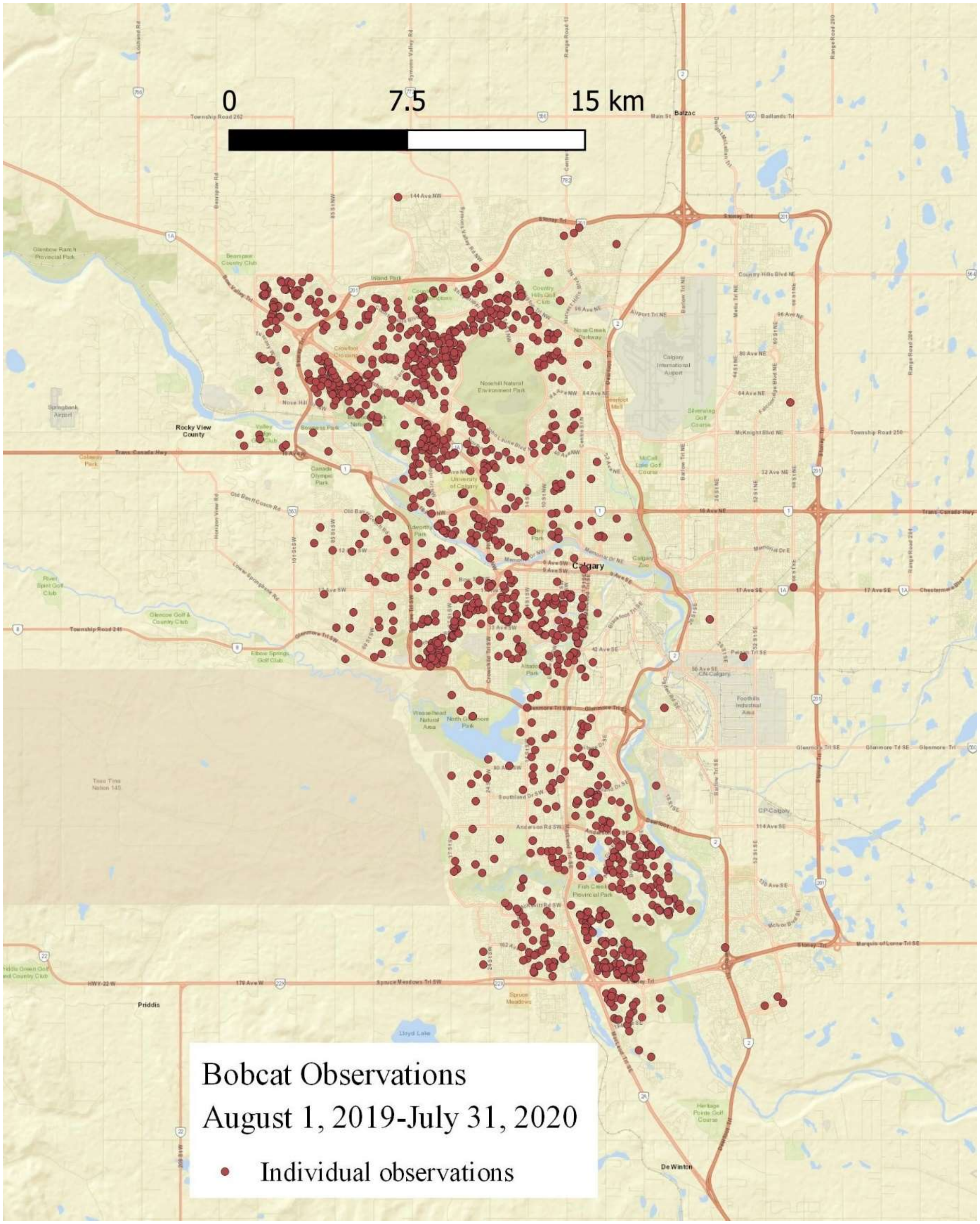
Data Analysis Results

Current Bobcat Distribution in the City of Calgary

Between August 1, 2019 and July 31, 2020, a total of 1373 observations of bobcats were reported to the City of Calgary 311 platform. A polygon created in QGIS using these observations with a 4 km^2 grid overlay provides a current AOO of approximately 428 km^2 for bobcats inside city limits. If extending the potential area occupied to include the space between observation points, the current EOO is 582.2 km^2 (Figure 3). The area of absence in the NE part of the city correlates with a paucity of green spaces, supporting previous studies demonstrating natural areas and green space are necessary for bobcats in the urban matrix (Donovan et al., 2011).

Figure 3

Most Recent Full Year of Observations: August 1, 2019-July 31, 2020



Changes in Bobcat Distribution

From September 1, 2005 to July 31, 2020 a total of 4599 bobcat observations were recorded through the 311 platform. It is clear that over time an increasing number of observations were reported, with a drastic rise in the years 2018 and 2019 (Table 1).

Table 1

Bobcat Reports to 311 by Year

Year	Number of Reports
2005	1
2006	5
2007	29
2008	25
2009	35
2010	38
2011	38
2012	36
2013	72
2014	50
2015	160
2016	227
2017	599
2018	1321
2019	1425
2020 to July 31	537
Total	**4599**

Table 2 demonstrates a dramatic uptick in reported observations when the data is organized in four- year increments.

Table 2

4-Year Interval Bobcat Reports

Interval	Number of Reports	Percentage of Reports	Area of Occupancy (AOO) (km^2)	Extent of Occupancy (EOO) (km^2)
2005-2008	60	1.3%	96.0	274.5
2009-1012	148	3.2%	180.0	349.3
2013-2016	509	11.1%	280.0	509.7
2017-2020	3882	84.4%	516.0	610.1

2017-2020 saw over 84% of all observations, suggesting that bobcats have become more visible on the landscape during this time. The AOO also steadily increased over time with an overall change of 424 km^2 from the first full year of observations in 2006 to the last full year of observations in 2019. The area of the city covered by these observations also increased by 476.5 km^2. Where 2006 saw five reported observations over three distinctly separate areas in the city, 2019 saw 1425 observations coming from neighbourhoods throughout the city. A relative absence of observations is evident on the eastern side, particularly northeast portion of the city across all time periods. Figures 4 through 7 provide a visual representation of observations over four-year intervals.

Figure 4

Bobcat Observations Based on 4-Year Intervals: 2005-2008

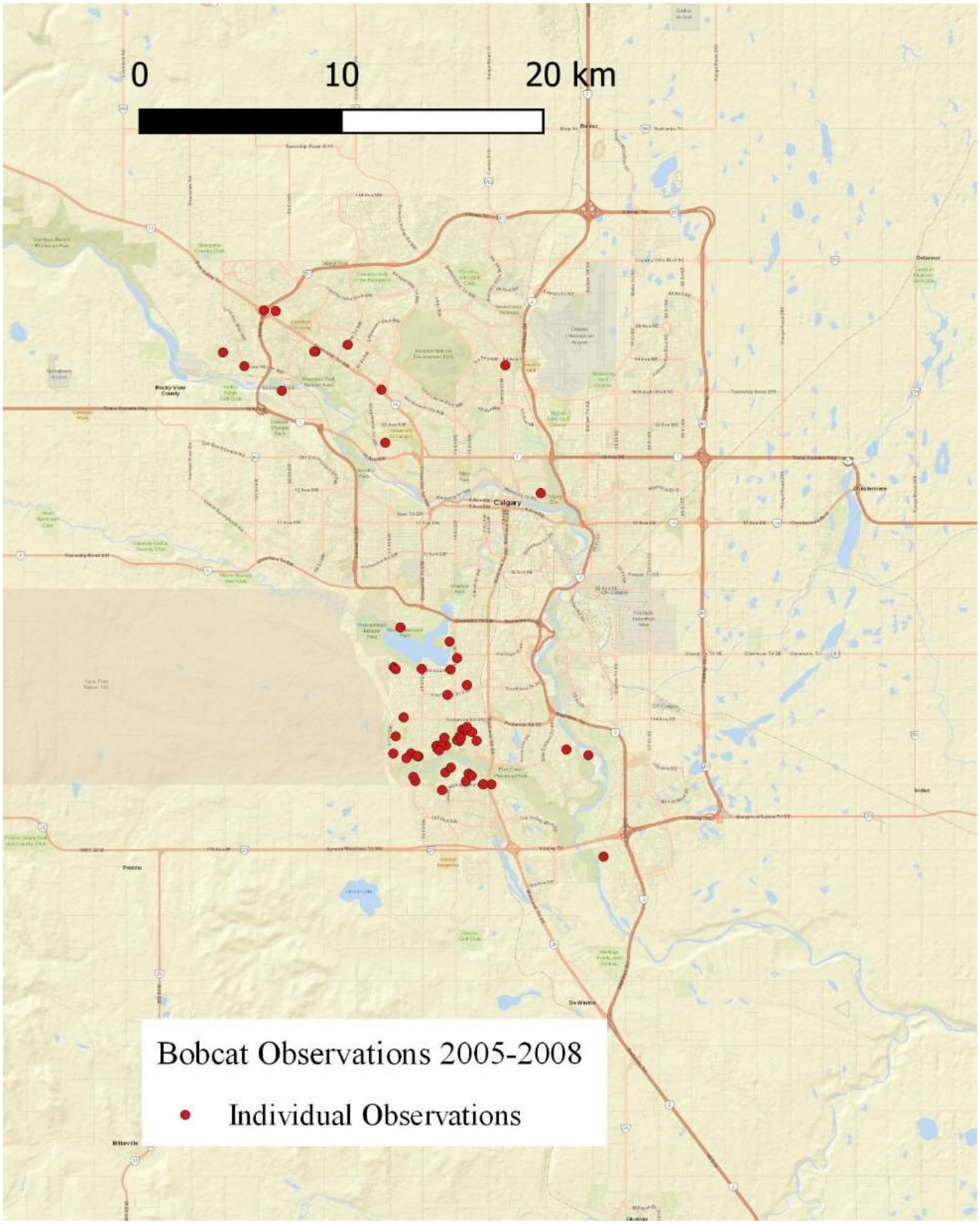


Figure 5

Bobcat Observations Based on 4-Year Intervals: 2009-2012

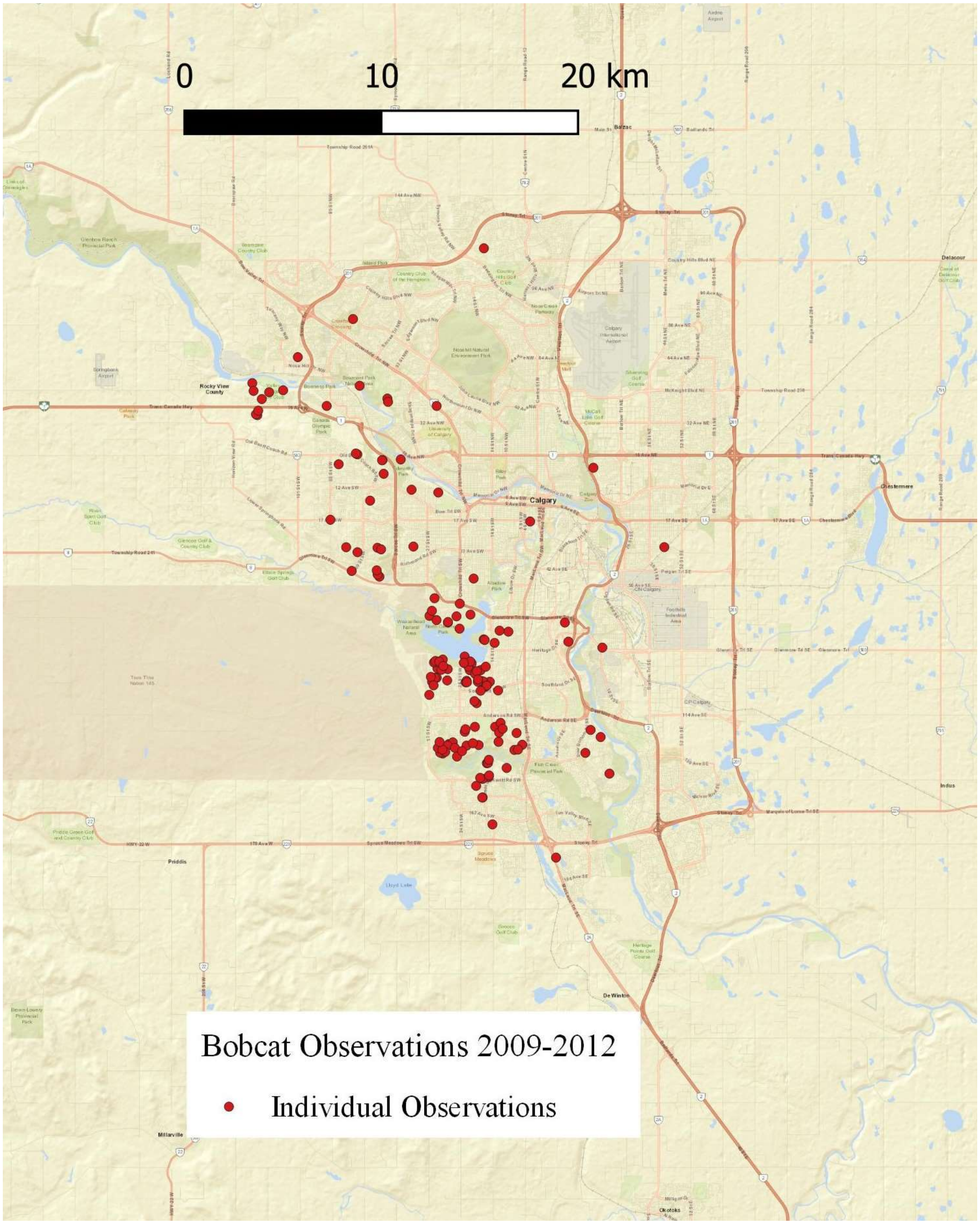


Figure 6

Bobcat Observations Based on 4-Year Intervals: 2013-2016

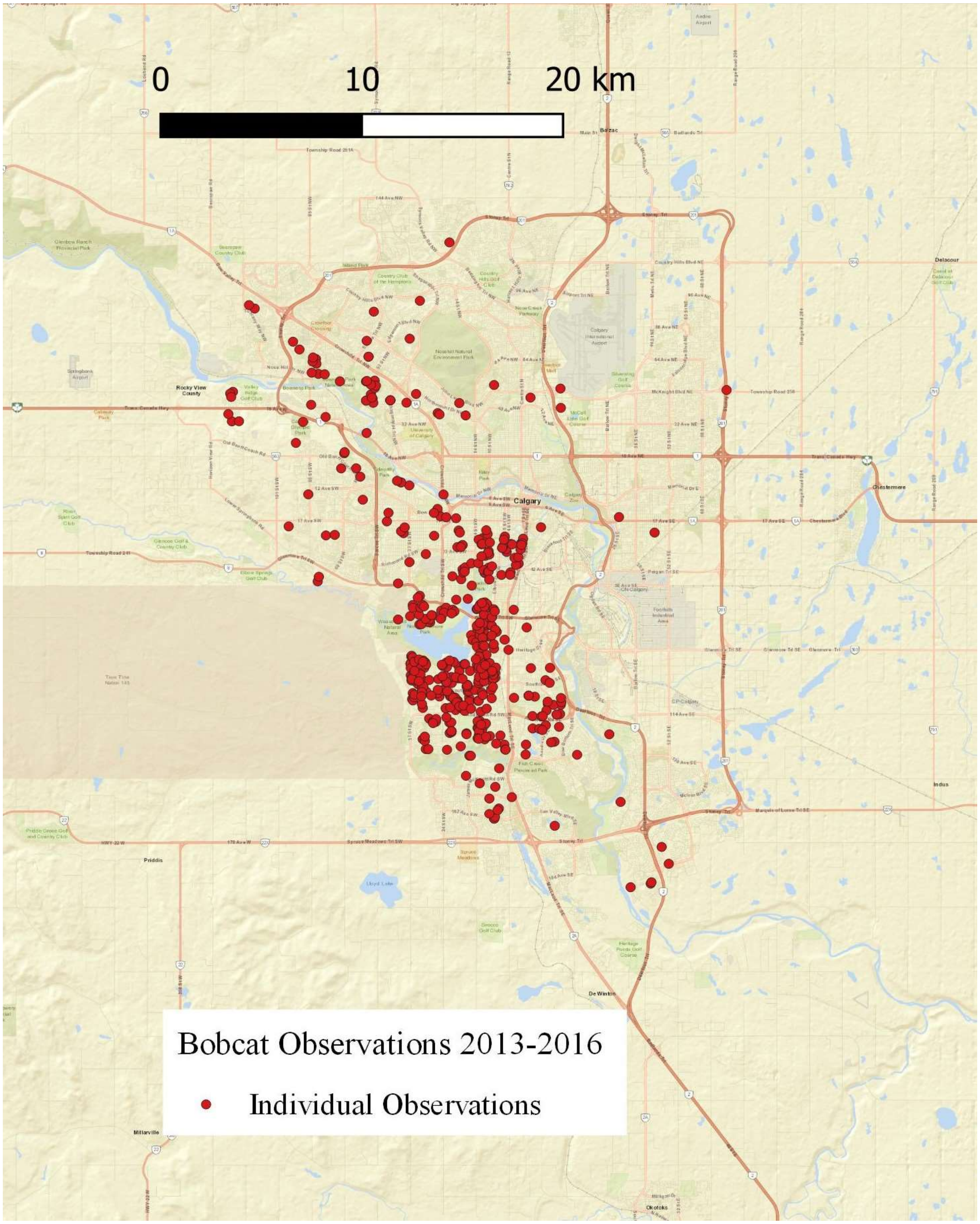
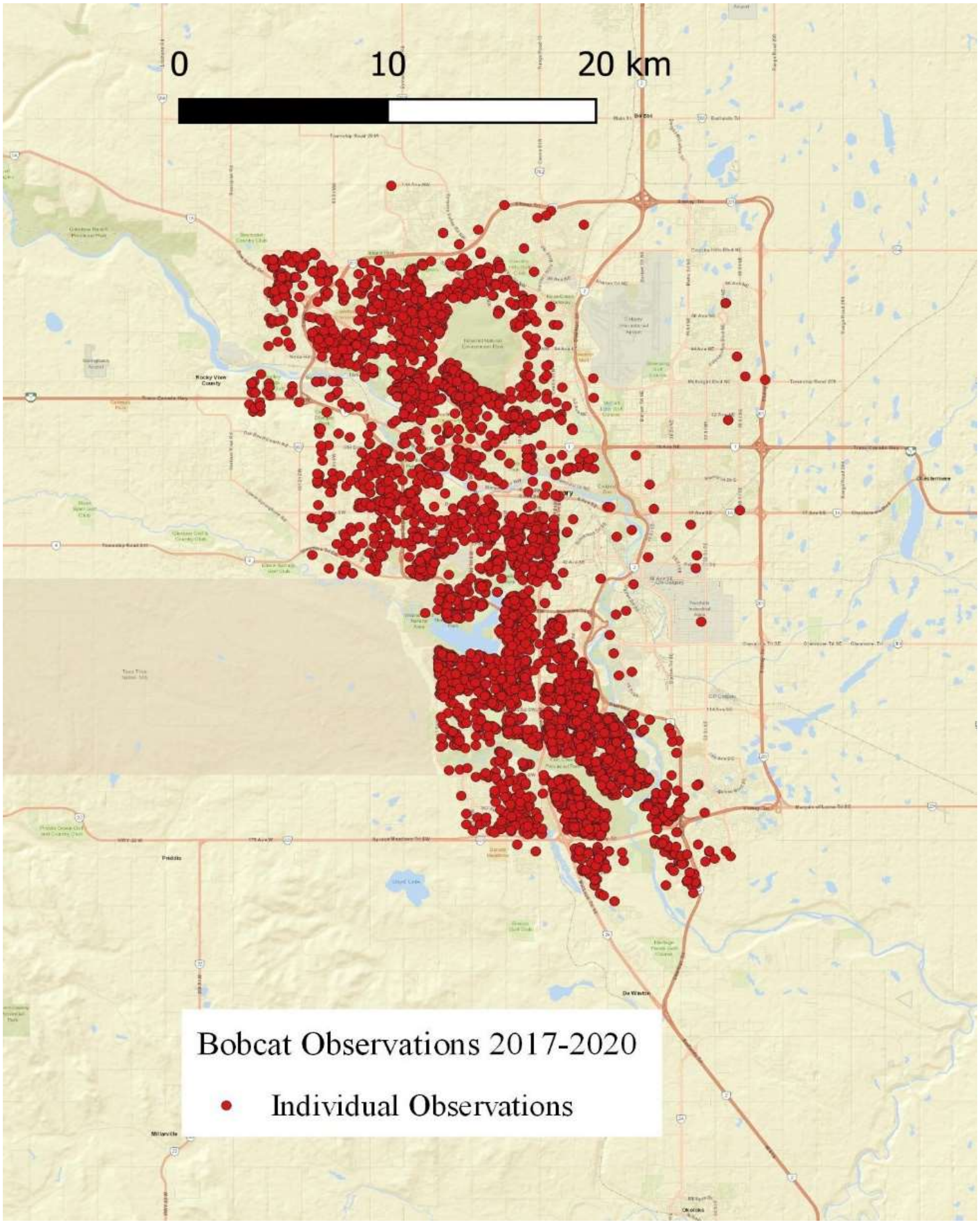


Figure 7

Bobcat Observations Based on 4-Year Intervals: 2017-2020



Bobcat Observations in Relation to the Ecological Network

In the City's *Biodivercity Report,* they state that 19% of Calgary's land coverage is considered natural area (COC, 2014). The ecological network is comprised of these natural areas along with non-natural green space and movement corridors connecting habitat patches. Unbroken natural areas and green space are classified by the City based on size and composition as core habitat, stepping stone habitat, small natural areas and non-natural green spaces (Figure 8). These habitat types will collectively be referred to as habitat patches in my analysis. Table 3 provides a breakdown of habitat types and the space they occupy.

Figure 8

Calgary's Ecological Network

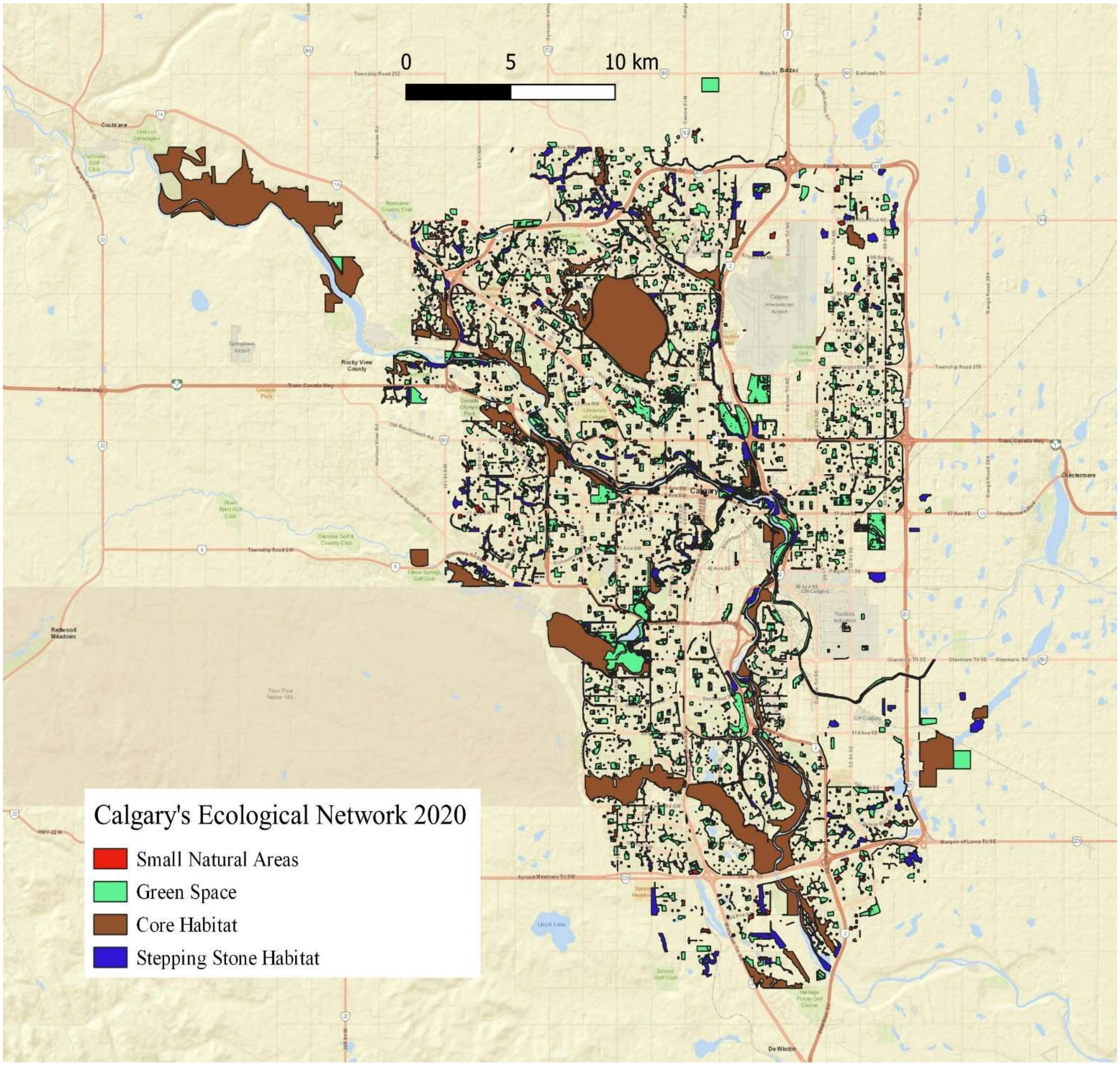


Table 3

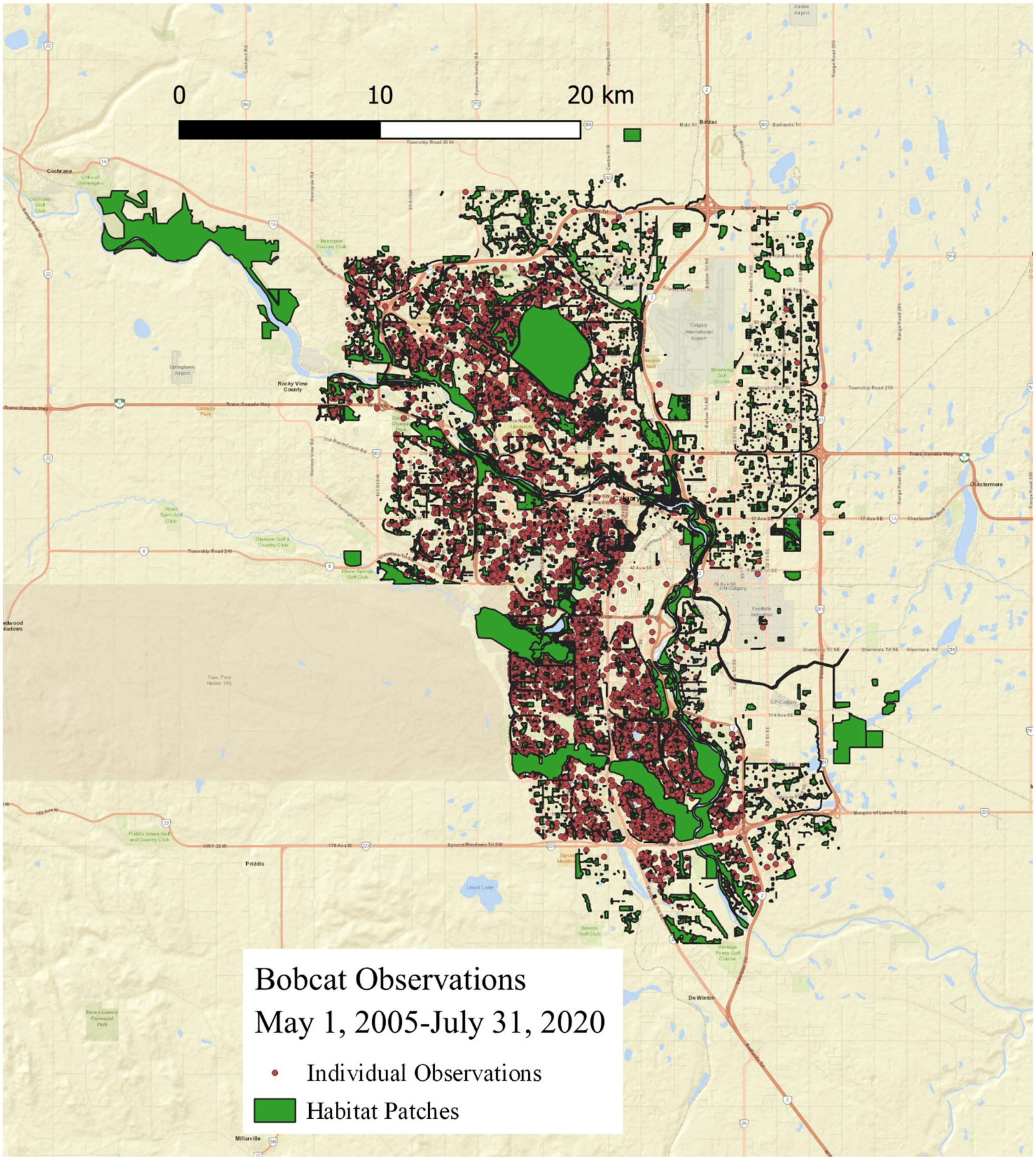
City of Calgary Ecological Network Habitat Classification

Habitat Classification	Number of Areas in the Ecological Network	Total Area Covered (km^2)
Core Habitat (>30 hectares)	36	76.34
Stepping Stone Habitat (between 5-30 hectares)	118	12.93
Small Natural Areas (<5 hectares)	321	4.81
Green Space (non-natural areas)	8376	60.33
Total	8851	154.41

When bobcat observations are overlaid on a map with the ecological network, I found that observations are near the ecological network although not necessarily within it (Figure 9).

Figure 9

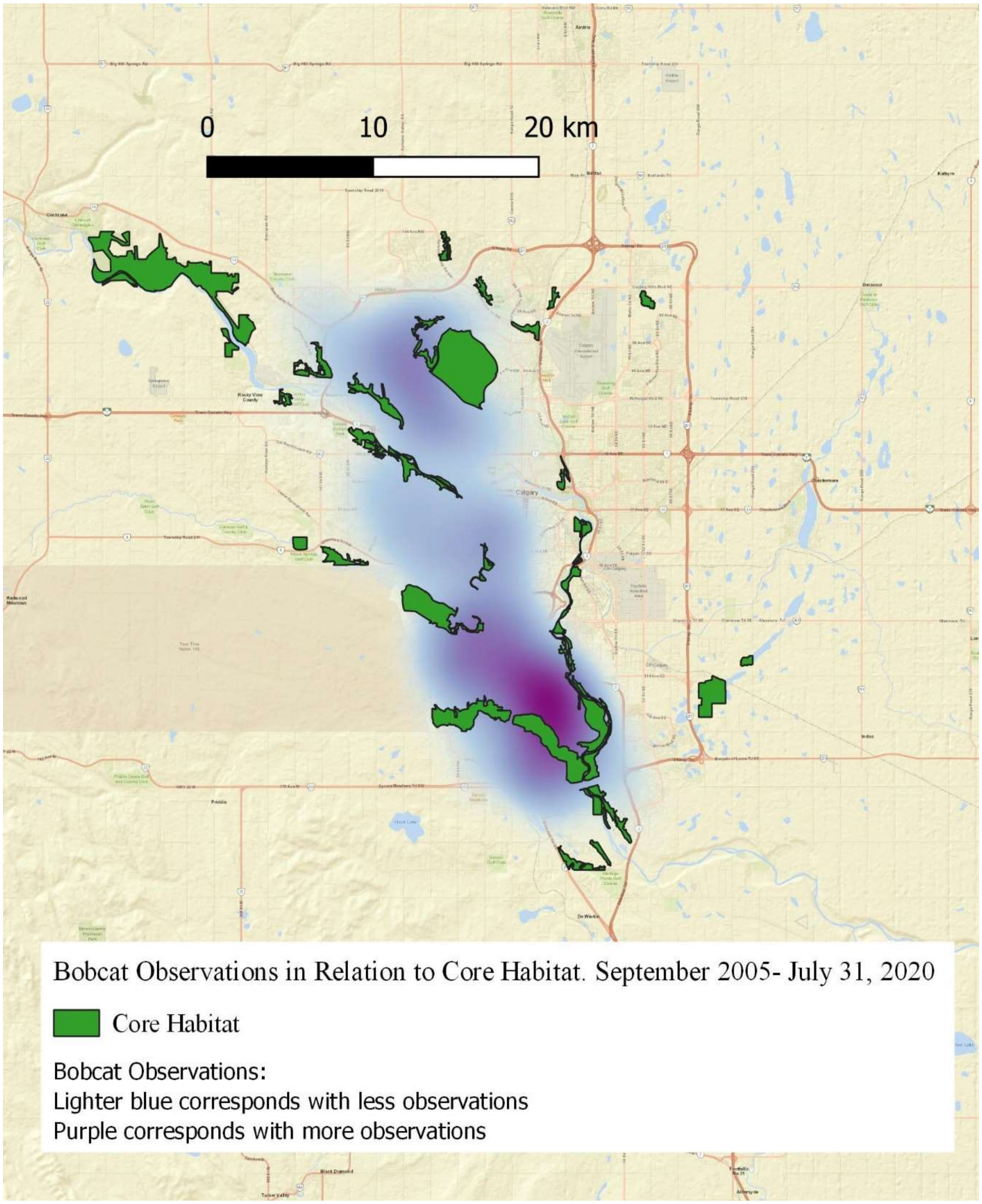
Individual Bobcat Observations in Relation to the Ecological Network



Using a heatmap, Figure 10 shows that most observations are outside rather than inside the large core natural areas.

Figure 10

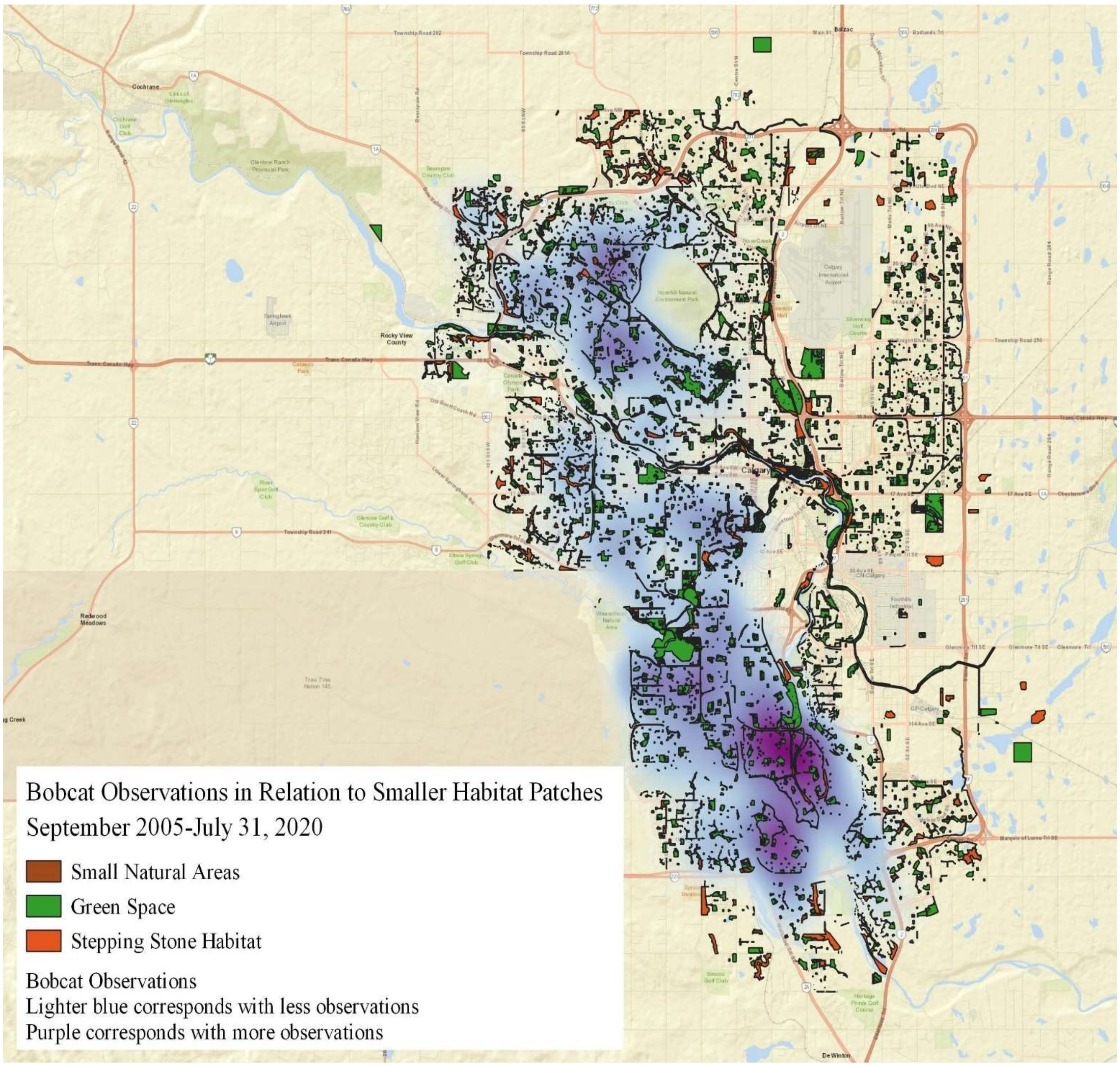
Heatmap of Bobcat Observations in Relation to Core Habitat



When viewed in relation to stepping stone habitat, small natural areas and green space, it is clear many observations are within or intricately connected to these smaller habitat patches (Figure 11).

Figure 11

Heatmap of Bobcat Observations in Relation to Stepping Stone Habitat, Small Natural Areas and Green Space



A breakdown of observations by habitat type reveals that the highest number of observations inside habitat patches are reported from green space (Table 4).

Table 4

Bobcat Observations Reported from each Habitat Type

Habitat Type	**Number of Observations**	**Percentage of Observations in network**	**Percentage of total observations**
Core	10	3	0.07
Stepping stone	2	0.6	0.04
Small natural areas	7	2.0	0.20
Green Space	321	94.4	7
Total	340	100	7.31

As shown in Table 4, 340 or 7.31% of observations were from inside habitat patches. Of those, only ten were reported from inside core habitat. The remaining 4258 or 92.69% of reports were from outside habitat patches, however, my analysis showed not that far outside. All observations fall within 892.8m of a habitat patch in the ecological network supporting previous research by Donovan et al. (2011) suggesting bobcats prefer habitat within a 1 km buffer zone around natural areas and green space. Table 5 shows the minimum and maximum distance from each habitat type.

Table 5

Distance of Observations Outside Habitat Patch to Nearest Habitat Patch

Habitat Type	Minimum distance from habitat patch (m)	Maximum distance from habitat patch (m)	Average distance to habitat patch (m)
Core	0.61	6065.69	1007.62
Stepping Stone	8.16	188.95	68.99
Small Natural Areas	0.71	44.78	79.13
Green Space	0.18	892.8	88.8

Table 5 shows observations were reported a noticeably short distance outside of a habitat patch, in some cases less than 1 m. Due to inaccuracies mentioned in the bias section, these observations may have been inside the habitat patch rather than outside of it, thereby underestimating the observations in habitat patches. An edge buffer analysis helped to illuminate how often bobcats were reported quite close to a habitat patch. A total of 1443 or 31% of observations were recorded within 50 m of a habitat patch. When this analysis was extended to 100 m, the number of observations increased to 2759 which is equal to roughly 60% of all observations. Table 6 shows the observations within 50 m of each habitat type, while Table 7 shows the same information at 100 m. Areas surrounding green spaces are where most observations were reported.

Table 6

Observations Within 50m of a Habitat Patch

Habitat Type	Number of Observations	Minimum distance (m)	Maximum distance (m)	Average Distance (m)
Core Habitat	49	0.61	48.59	30.52
Stepping Stone Habitat	38	8.16	48.28	34.73
Small Natural Area	56	0.71	48.66	23.37
Green Space	1300	0.18	49.97	28.58
Total	1443	n/a	n/a	29.30

Table 7

Observations Within 100m of a Habitat Patch

Habitat Type	Number of Observations	Minimum distance (m)	Maximum distance (m)	Average Distance (m)
Core Habitat	85	0.61	99.71	46.40
Stepping Stone Habitat	69	8.16	95.45	50.56
Small Natural Area	97	0.71	97.66	44.96
Green Space	2507	0.18	99.99	49.47
Total	1443	n/a	n/a	47.85

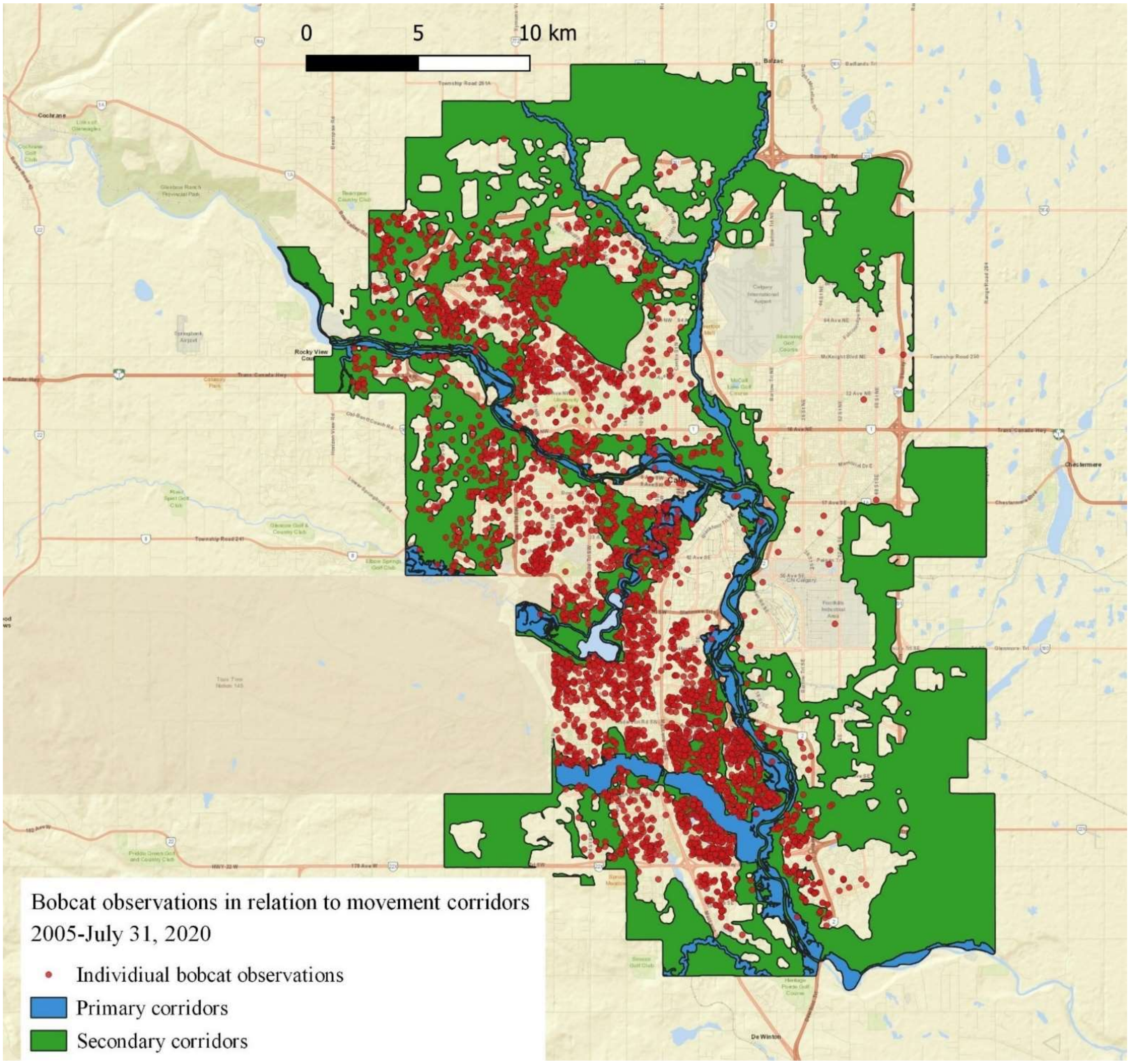
With nearly one third of all observations made within 50 m of a habitat patch, two thirds inside 100 m and no observations outside a 1 km^2 buffer of habitat, a strong habitat association of bobcats with natural areas, green space and the edges around them can be inferred. A higher number of observations from green spaces comparatively to natural areas could speak to detection bias where these artificial environments may be more frequented by people. They are also generally smaller areas that may create a higher probability of seeing wildlife, although small natural areas present this same opportunity yet did not have as many observations. Conversely, a lower number of observations from inside the natural areas may speak to both reporting bias and detection bias. People may expect to see wildlife in a natural area and therefore not report observations to the city, creating a reporting bias. It may also be more difficult to detect bobcats in natural areas unless they are using the same trails as people at the same time, creating a detection bias. Based on these potential biases, a definitive habitat type could not be said to be preferred but I infer that non-natural green space is important for bobcats in the urban environment.

Relationship of bobcat observations to movement corridors

In order to connect habitat patches, the City created a corridor layer composed of primary corridor pathways along riparian habitat. Secondary corridors then connect core habitat to other core habitat and core habitat to other corridor pathways. Primary corridors wind through 54.82 km^2 of the city while secondary corridors cover 385.78 km^2. Together they provide approximately 440 km^2 of pathways for wildlife movement through the city. While these pathways have been delineated, how much wildlife is using them has not been explored. Figure 12 depicts bobcat observations compared to the corridor network.

Figure 12

Bobcat Observations in Relation to Movement Corridors in the Ecological Network



Analysis revealed that 73 or 1.6% of total observations were inside primary corridors and 1456 or 31.6% of total observations were in secondary corridors. Together, a total of 1529, approximately 33% of total observations were inside the movement corridors. Further analysis to assess the distance of observations outside the corridors showed the observations were between

0.4 m to 1882 m outside the corridors. Table 8 shows the distances to primary and secondary movement pathways.

Table 8

Distance of Bobcat Observations Outside Movement Corridors to Movement Corridors

Corridor Type	Minimum distance of observation to corridor (m)	Maximum distance of observation to corridor (m)	Average distance of observation to corridor (m)
Primary	116.33	1576.83	1037.66
Secondary	0.04	1882.95	507.73

Based on this information it can be inferred that while bobcats are using the movement corridors in the network, they are also travelling and utilizing habitat outside of this.

Validation of Bobcat presence through remote cameras

Three data years were available for my analysis, May 1, 2017-May 31, 2020. During these times, photographs of bobcats were taken on 134 separate occasions across eight different parks and 30 different cameras (Table 9).

Table 9

Remote Camera Bobcat Observations by Natural Area

Natural Area	Number of cameras with bobcats	Total number of cameras in the park	Records for 2017-2018	Records for 2018-2019	Records for 2019-2020	Total number of records
Bowmont Park	1	4	0	0	1	1
Edworthy Park	3	4	3	5	6	14
Fish Creek Provincial Park	11	20	4	5	8	17
Griffith Woods Natural Area	4	4	8	0	13	21
North Glenmore Park	2	2	7	5	11	23
Paskapoo Slopes	1	2	0	1	0	1
South Glenmore Park	2	3	9	2	20	31
Weaselhead Natural Area	6	7	6	7	13	26
Total	30	46	37	25	72	134

Bobcats were recorded on 29.4% of active cameras in the project over the three years of data. Out of the 30 cameras that recorded bobcats, 19 were in the same location over the three data years while the other 11 were either stolen or moved. Edworthy Park, Fish Creek Provincial Park, North and South Glenmore Park and Weaselhead Natural Area all recorded bobcats in the three data years. Griffith Woods recorded bobcats in two of the data years while Bowmont Park and the Paskapoo Slopes only had one record each. Figure 13 shows the locations of cameras that recorded bobcats as well as those that did not.

Figure 13

Remote Camera Locations in Natural Areas with and without Bobcat Records Over Three Data Years

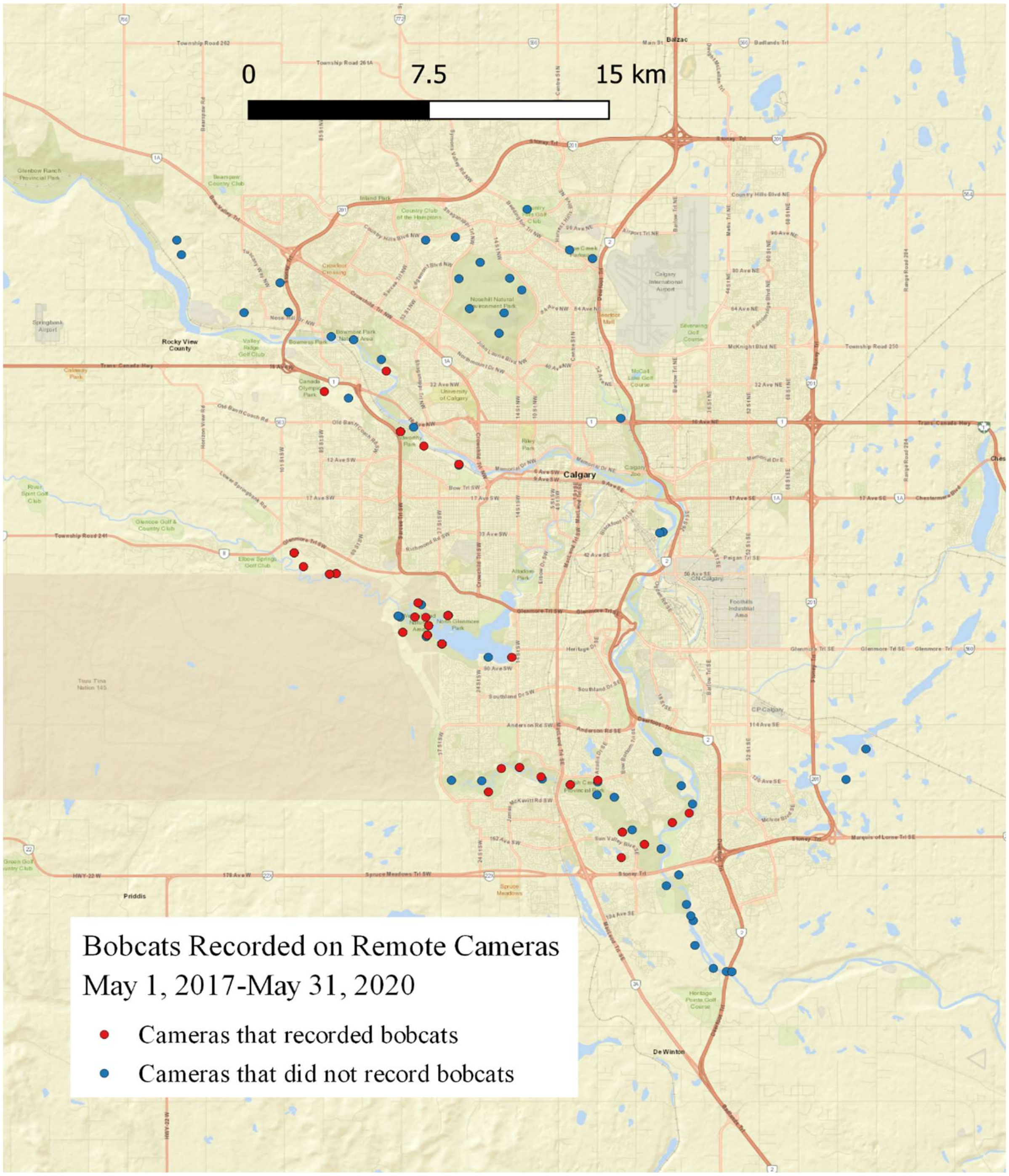


Figure 13 shows cameras that recorded bobcats are primarily on the west side of the City with 80 records accounting for 60% of all records being from cameras in the connected natural areas of Glenmore Park and Weaselhead Natural Area. Fish Creek Provincial Park, the park with the most cameras accounted for 12.6% of records. This goes contrary to the citizen observation data which showed a higher number of observations around Fish Creek Park comparatively to the Weaselhead Natural Area and Glenmore Park (Figure 10). This difference in camera records compared to citizen observations may speak to edge habitat preference resulting in higher observations around the edge of the park or detection bias in the park that underestimates habitat use. Fish Creek Park Cameras are the only ones to have recorded bobcats on the east side of the City. These 134 events validate the presence of bobcats within eight core natural areas. The absence of records from the other natural parks does not necessarily mean bobcats are not present but rather they were not recorded on camera. Figures 14 through 16 show some of the clearest images of bobcats recorded.

Figure 14

Bobcat Image from Remote Camera in North Glenmore Park

Figure 15

Bobcat Image from Remote Camera in Weaselhead Natural Area

Figure 16

Bobcat Image from Remote Camera in Fish Creek Provincial Park

Discussion

Bobcats are a species known to be adaptable to a variety of habitat across North America. Changes in landscapes and attitudes towards carnivores by humans has provided unprecedented opportunity for these bobcats to grow their populations from historic lows and expand into areas they previously have not inhabited, including the City of Calgary. Using citizen bobcat observations, I have shown that bobcats have expanded their range throughout the city since 2005 with drastic increases in observations since 2018 (Table 2). The proximity of bobcat observations to natural areas and green space and the camera-trap validation of bobcat presence within natural areas supports previous literature that highlights the importance of natural areas and green space for bobcats (Donovan et al, 2010). The alignment of bobcat observations around the ecological network supports bobcat's preference for edge habitat and buffer zones around natural areas for their activities. With one third of observations reported within 50 m of a habitat patch in the network and nearly two thirds within 100 m, the use of edge habitat appears to be significant.

It is worth noting that 99.2% of observations are to the west of Deerfoot Trail, a high-volume road that bisects the city and on which an estimated 180,000 vehicles travel per day (CBC News, 2021). Previous studies have shown high volume roads to be a barrier to bobcat movement (Poessel et al., 2014) therefore, with just 38 observations reported to the east of Deerfoot Trail over the entire study period, I infer that Deerfoot Trail may be limiting bobcat movement on the east side of the city. Those observations that do occur on the east side continue to be associated with smaller habitat patches encompassed in the ecological network.

These results suggest that bobcats are what Fischer et al. (2015) would refer to as an urban utilizer; a species who is able to use anthropogenic resources for food and shelter but prefers not to venture too far from green space or natural habitat. Based on this, it could be expected that future observations will continue to centre around green spaces both natural and manufactured, regardless of size. Although bobcats are being observed close to habitat patches, their use of delineated movement corridors to get between them does not appear to be a given. With two thirds of observations outside of the movement corridors, bobcat use of these pathways appears to be opportunistic rather than preferential.

My findings have several implications for further research and management. For one, this study provides insight into where bobcats have been observed but it does not elaborate on the behavior or activities of the cats. This data was analyzed from a quantitative perspective, but there is opportunity to utilize these records for qualitative studies providing further insight into how bobcats are surviving and what limitations may exist to maintaining or expanding their population. Secondly, it is currently unknown how bobcats utilize different habitat types in the urban matrix throughout their life cycle, but notes included by citizens in their 311 observations provide some clues. For instance, several observations reported that female bobcats were denning under decks or sheds. Whether denning in these areas confers any benefit to survivorship of kittens is unknown and could be an area of future research. If bobcats are selecting human dominated spaces for breeding, this becomes an important area for citizen education as conflict is certainly possible. Other 311 observations indicate bobcats were hunting or had already caught prey when seen. From this we can infer bobcats are using human dominated spaces for food resources but how important this habitat is for them compared to natural areas is unknown. Studies conducted in Calgary have provided evidence of urban coyote diet (Lukasik & Alexander, 2008) which has led to suggestions for improved management of yards, waste and domestic animals. Likewise, taking a closer look at the diet of urban bobcats could lead to citizen education to reduce conflict and enhance ecological literacy. Providing to citizens the knowledge and lessons from other jurisdictions demonstrating bobcats are not a danger to people can help mitigate fears and reduce potential conflicts. Highlighting the use of the 311 platform for informing science and engaging citizens in data collection may also be of value for further study.

From a landscape management perspective, my analysis shows that bobcats prefer to stay close to natural areas and green space, but they are by no means limited by them. Their use of smaller habitat patches, both natural and manufactured is substantial with many reports found within a few to a few hundred metres of a green space, no matter how small. At this point it is unknown how much time is spent in natural areas comparatively to outside of them and whether the bobcat's use of human dominated spaces is preferential or dictated by other factors such as lack of suitable habitat, low prey abundance or competition from other bobcats or sympatric carnivores in the city. Coyotes, raccoons and foxes could act as potential competition for bobcats but how these species all interact temporally and spatially is currently unknown. Further investigation into these interspecific relationships could be of interest for a greater understanding of ecosystem dynamics that can enhance ecological resiliency. In addition, further research into how bobcats are using natural areas will help gauge their importance for supporting urban wildlife populations. While it is important to understand how bobcats are using natural areas and green spaces, it is also important to understand how they move between them. My study has shown that bobcats are using movement corridors outlined by the city, but they are also extensively travelling outside of these movement pathways. Their travel outside these areas is also likely echoed by other species with which bobcats interact including prey such as rodents and hares (Larson et al., 2015). Bobcat habitat usage inferred from my research has implications going forward for natural area management in the city, highlighting the need for habitat connectivity to support species such as bobcats and their prey. By expanding the availability and connectivity of natural areas and green space, conflict with people may be reduced and species richness in these areas may increase (Lepczyk et al., 2017).

Conclusion

Bobcats are a relatively new species to the human dominated landscape of Calgary, Alberta and as such little is known of their distribution and ecology in the city. Through the analysis of citizen reports, I was able to show that bobcats are integrating themselves quite comfortably into the urban landscape. Since September 2005 when citizen reports began, bobcat observations have grown substantially over time in both number and distribution. The proximity of reported observations to the City's natural areas and green spaces that make up the ecological network suggests these habitats are important for bobcats and their movements, although they are clearly not limited by them and are quite adept at using human dominated spaces. This information can be used by the city to support the goals laid out in the *Biodiversity Strategic Plan,* including expanding green space connectivity, supporting education campaigns to reduce potential conflict, increasing ecological literacy and engaging the public in the lives of these new citizens. As a baseline for bobcat ecology in Calgary, this study paves the way for further investigations into diet, activity patterns and interactions with people, pets, and other wildlife in the city.

With the continued expansion of Calgary and urban centres worldwide, the need to understand how wildlife is adapting to living around us is important for co-existence and biodiversity conservation. Cities cannot restore the ecosystems of the past, but they can incorporate new ideas for a wide variety of life to thrive. Supporting ecological literacy in citizens can help bring about innovative ideas for co-existence and support for the great variety of life that lives among us. These novel ecosystems, with the support of human stewards, have the potential to build biodiverse pockets that can create ecological resiliency and boost the health of human and non-human life on this planet as we continue to face the global changes ahead.

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