Aaron Phalin
IHRTLUHC
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Assessing the Urban Potential for Monarch Repopulation

For the past few decades, the population of the monarch butterfly has been declining dramatically. Since this trend has been reported by researchers, studies have been published attempting to identify the source of the butterflies' untimely decline. An answer to this research question could help guide field ecologist to develop management strategies that efficiently and effectively reestablish the monarch population. However, where the modern literature stands – questions are all around. Where should field ecologist focus their efforts? What environmental factors should be managed? How can models be incorporated into an effective repopulation strategy?

This paper will focus on one of three central hypotheses for monarch decline: that monarchs are declining due to a concurrent decline in their plant companion, the milkweed. Furthermore, I will focus on the urban ecosystem of Chicago and its potential impact on the monarch population through milkweed repopulation programs. Such repopulation programs have been prevalent since 2010 in Chicago, beginning with conservation efforts in the various suburbs and culminating in 2012 with the "Mayor's Pledge",[1] which is a non-binding agreement by the city government to begin developing milkweed replanting programs for various regions throughout the city.

This paper's focus on the impact of milkweed repopulation programs in urban Chicago fits into the emerging trend in monarch ecology studies, where researchers are beginning to acknowledge the relevance of the urban environment as a strong contributor to monarch habitation. The current literature has spent time with different data sets to track the spatial and temporal trends of the monarch population, suggesting that the overall monarch population declines may have some significant relationship to a concurrent decline in milkweed plants found in the Midwestern breeding period. Most studies on the so-

[1] Chicago Field Museum. (2018). *Urban Monarch Conservation Guidebook.* Chicago: The Chicago Field Museum.

called "Milkweed Limitation Hypothesis" have focused on midwestern croplands and natural areas. This paper will enter the relatively unexplored urban environment in a few midwestern cities, like Chicago, which have made significant pushes to repopulate yards and parks with milkweed (Chicago Field Museum, 2018). [2] In doing so, I will generate some of the first analysis on the urban ecosystem to Monarch repopulation.

The literature supporting some assumptions this paper uses, such as the relationship between Milkweed and Monarchs, has been fraught with a degree of uncertainty. This paper will fall into some similar shortcomings, due to limited sampling and measurement errors, but will resolve some issues in modeling by focusing on larvae counts and less dispersed sampling sites (a focus on Chicago is more centered and controlled than, say, across the midwestern farmland).

My research question is, in short: **"which sectors of the urban environment are most conducive to monarch repopulation?"**

A Modern Understanding of the "Milkweed Limitation Hypothesis"

Since a 2011 study of the monarch butterfly revealed a significant population decline of monarchs found in their overwintering Mexico habitats, the butterflies have reached an upsurge of academic attention[3]. The authors of this study opened a commentary on the possible cause of this decline, detailing the many territories and stressors the migratory insects face. Three main features in the ecological niche and behavior of the monarch butterflies have been proven to be useful for the future studies on its decline. These features highlight the monarch's vulnerability to changing ecological changes. The first ecological feature is that the Monarch, as a flying insect that travels north and south between Mexico and the

[2] Chicago Field Museum. (2018). *Urban Monarch Conservation Guidebook.* Chicago: The Chicago Field Museum.

[3] Lincoln P. Brower, Taylor, O., Williams, E., Slayback, D., Zubieta, R., & Ramirez, M. (2011). Decline of monarch butterflies overwintering in Mexico: is the migratory phenomenon at risk? *Insect Conservation and Diversity*, 95-100.

Northern-Midwest of the United States, is highly vulnerable to climatic changes and pathogens during its long and seasonally-dependent travels. Second, the monarchs must cluster in specific local areas during different stages of their migration (overwintering, fall-spring travel, and summer breeding periods), and so are highly dependent on the ecological conditions of these specific regions. Lastly, the monarchs are highly dependent on a plant family, *Asclepias*, (with the common name "Milkweed", as is referred to in this paper) for the growth and longevity of their larvae during the breeding period. These circumstances underlying the Monarch's livelihood manifested three non-exclusive hypotheses, that monarch decline was caused by: changes in the overwintering ecosystem in Mexico, changes in climate and weather over the Monarch's migratory pathway, or the decline of crucial Milkweeds in their breeding territories.[4] The latter hypothesis will be the subject matter of this paper.

The earliest studies in the monarch literature examined the ecological conditions of the Monarch's overwintering location in Mexico. Brower et al. 11 discusses lower-temperature trends in the weather and finds higher deforestation rates in the same areas of high monarch density[5]. Other studies, predating Brower's, predicted that variations in Mexico's climate, coupled with higher deforestation, threatened Monarchs past survivable thresholds (Oberhauser et al. 3)[6] through ecological simulations. Both the trends analyzed in 2011 and the ecological models built in Oberhauser's study suggest the impact changing overwintering conditions could have on monarch populations. However, most of these studies were also fraught with unique modeling complications; both Brower's and Oberhauser's study were relatively focused on "known overwintering sites"[7]. Because monarch populations have been known

[4] Davis, A., & Dyer, L. (2015). Long-Term Trends in Eastern North American Monarch. *Entomological Society of America*, 661-663.

[5] Lincoln P. Brower, Taylor, O., Williams, E., Slayback, D., Zubieta, R., & Ramirez, M. (2011). Decline of monarch butterflies overwintering in Mexico: is the migratory phenomenon at risk? *Insect Conservation and Diversity*, 95-100.

[6] Oberhauser, K., & Townshend, P. (2003). Modeling current and future potential wintering. *PNAS*, 14063-14068.

[7] Oberhauser, K., & Townshend, P. (2003). Modeling current and future potential wintering. *PNAS*, 14063-14068.

to, over time, adjust their migratory pathway[8], these studies are subjected to omitted variable bias and poor sampling when they fail to consider the potential for immigration in the long run. The omitted variable bias stems from disregarding the impact of monarchs relocating to a different Mexico habitat. Consequently, the study's sampling sites, which did not vary from year to year to accommodate potential migration, may be less representational of the whole monarch population. These sampling errors are similar to what will be found in studies focused on the midwestern "milkweed limitation" hypothesis, however, they are unique in that as the butterflies move northward from their Mexico overwintering habitats their population becomes more dispersed; the tight but shifty clustering of Monarchs during their overwintering makes previous studies' smaller sample sizes less generalizable across the entire spatial area. This paper, taking heed from the measurement and sampling errors of these prior studies, will benefit from focusing on Chicago, which covers a less dispersed and larger sample size than previous research.

Because of modeling errors and the lack of scope in the research focused on overwintering sites, a new wave of unsatisfied researchers began looking into the other central hypothesis for Monarch decline: the loss of milkweeds in summering sites. The studies in this line of research provide the foundations from which this paper stands on, as they establish useful trends on Milkweed and Monarch populations and diverse frameworks for modeling this question. These studies, mainly challenged by difficult modeling choices and sparse data, had many holes underlining their results. A study by Pleasants et al. had fashioned their data on Milkweed counts into a variable measuring both the count of Milkweed stems in selected cropland territories and another variable computing the average density of larvae on each stem during peak breeding periods[9]. The researchers found through a series of regressions that Milkweed populations were indeed declining as the "milkweed limitation" hypothesis suggested (in fact the authors

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[8] Zaya, D., Pearse, I., & Spyreas, G. (2017). Long-Term Trends in Midwestern. *Bioscience*, 343-356.

[9] Pleasants, J., Zalucki, M., Oberhauser, K., Brower, L., Taylor, O., & Thogmartin, W. (2017). Interpreting surveys to estimate the size of the Monarch population: pitfalls and prospects. *PLOS one*, 1-16.

found an exponential decline, nearly 72% in 10 years). However, the study also admitted a statistic that may challenge any causal relationship between that and Monarch decline, reporting that the density of larvae among the increasingly scarce Milkweed stems were not increasing. If milkweed decline was the causing factor behind the monarch population decline, researchers would've expected to count higher density of monarch larvae per stem due to scarcer real estate to accommodate a typical population of monarchs. Without an increasing trend in monarch density, the paper suggests that less Monarchs were initially even entering the region and therefore did not need to take up more space on the declining milkweed space. A study a few years later mirrored the results Pleasants et al. found regarding the significant decline of overall Milkweed, but then added a variable to differentiate different species of Milkweed and another variable to make the distinction between "natural areas" and "croplands".[10] By nuancing the data into more levels of dummy classifications, the study found that Milkweeds that were less useful to the Monarchs (smaller Milkweed species, such as "Whorled Milkweed", which had less surface area for larvae to rest on) were the ones facing greater decline than more ecologically crucial species. The study supported this claim this by comparing trends across time of species in different sampling sites, running simple OLS regressions. Simultaneously, the data suggested that only croplands, not "natural areas," were experiencing Milkweed decline. These two studies, approaching Milkweed modeling in different ways, both added important conditions to the "Milkweed Limitation" Hypothesis: that if there was a connection between Milkweed and Monarch decline, it would likely be a) from areas more disturbed and covering greater breadth of land (croplands, as opposed to scattered natural areas), and b) would be the result of the decline of milkweeds species particularly catered to hosting Monarch larvae. The former condition will be a useful springboard into this paper's discussion on the implications for Milkweed populations in the Urban territory, as the Urban environment contains mainly disturbed and developed areas with a large spread of potential locations for Milkweed growth (yards, parks, storefronts, etc.), akin to the croplands explored in Pleasant et al. and Zaya et al.'s papers. In this paper, I will borrow

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[10] Zaya, D., Pearse, I., & Spyreas, G. (2017). Long-Term Trends in Midwestern. *Bioscience*, 343-356.

Zaya et al.'s dummy variable classification approach to employ different land-use types by a certain dummy subscript.

The impact milkweed populations in Urban territories have on monarch butterflies has just begun to enter the research field as a natural extension of the works performed by previous "Milkweed Limitation" studies. The Chicago Field Museum, pioneering for the Chicago urban monarch program, has started developing a framework for accessing milkweed growth potential and began collecting data on milkweed stems and monarch sightings for trend explorations.[11] The Field Museum's recently-released guidebook strongly suggests that urban cities like Chicago have a great potential to influence Monarch populations, (while making assumptions about the relationship between Milkweed and Monarchs). The researchers own analysis on Chicago forecasted the city to have a current 16 million Milkweed stems that, with programs like the Mayor's Pledge and other Milkweed repopulation programs, could increase to 35 million Milkweed stems in the next few decades. The guidebook also focused on developing a framework to compute a baseline potential given the location's natural biome (in other words, ignoring development, how much Milkweed would grow in this territory?) and then spatially lining up GIS information with land-use patterns to categorize the Milkweed potential of the city. Another study by Thogmartin et al. '17,[12] was the one of the first research designs to consider land-use types outside of croplands and natural areas by adding dummy variables to a simple linear regression, including features of the urban environment like highways and parking lots. By running scenarios where different land-sectors planted a certain amount of milkweed, the researchers attempt to predict which scenarios (which cross-sector collaboration of milkweed replanting) resulted in enough midwestern milkweed to support a doubling of the monarch population. The benchmark for "doubling" the population was derived by a panel of previous research done by ecologists, referenced in the paper. The conclusion Thogmartin '17 reached, which

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[11] Chicago Field Museum. (2018). *Urban Monarch Conservation Guidebook.* Chicago: The Chicago Field Museum.
[12]Thogmartin, W. E., Lopez-Hoffman, L., Rodweder, J., Diffendorfer, J., Drum, R., Semmens, D., & Black, S. (2017). Restoring Monarch Butterfly habitat in the Midwestern US: 'all hands on deck'. *Environmental Research Letters*.

serves as another important springboard to the models used in this paper, is that the best monarch repopulation strategy is an “all hands on deck” approach. This approach requires a combination of the urban, natural, and agricultural sectors in the Midwest share the burden of milkweed replanting. Both the Chicago Field Museum and the Thogmartin study provide the most recent and influential foundations for this paper. The Field Museum introduces a comprehensive land-use composition guide and data on a number of city block samplings, including larvae density estimates and the number of milkweed stems present. The Thogmartin study heavily influenced this paper’s modeling choices, where land-use types are differentiated and analyzed independently for their potential milkweed repopulation potential. Combining the new-found data from the Field Museum, I intend to refocus the Thogmartin land-use approach into the urban landscape.

Before moving forward from this literature review, it is important to connect this entire field of studies to several important statistical shortcomings and challenges as this accounts for the high degree of uncertainty in each study’s outcome. First, most of the studies relied primarily on citizen data. Citizen data, by definition, is data recorded based on the will and effort of volunteers. Monarch programs collect a number of motivated individuals without technical research experience and develop a mainstream database on the input these volunteers provide. Because of the lack of stringent sampling standards with citizen data and the uncoordinated nature of their availability to sample, most studies using this citizen-style data are subject to sampling bias. This data-collection strategy is forced to rely on a limited sample size that was collected not randomly, and with a high risk of measurement error. In this way, most previous studies did not have a transparent estimate of true Milkweed and Monarch populations and their limited sample may not be generalizable to the entire Monarch migration.

The second shortcoming in most of these studies is that researchers often take considerable liberty in developing their variables and their models, which may drive results in considerably different directions. One manner in which researchers have developed their models uniquely is to create new forms of interaction variables, such as the “Natural Resource Availability” dependent variable in Zaya et al.’s model. In this model, the "Resource Availability" behaves differently than "Milkweed Count" variables (like Pleasant et al.'s) because different weights are given to different milkweed species. A decline in a less usable plant would have a lower magnitude negative impact, leading to perhaps less overestimation in terms of how disadvantaged monarch habitats are becoming. However, the weight system used in this paper is subject to discretion of the researchers and thus to criticism. The Pleasant's paper reports a less dramatic negative habitat impact than does Zaya's. As data is considerably scarce, researchers are forced to make certain modeling decisions that may shape the story the study ends up telling.

Determining Chicago's Potential in Monarch Rehabilitation: A Methodology

This paper will analyze the change in milkweed count across time and the subsequent change in larvae density across time for different land-use types in the midwestern city composition. Since data is only available at this time for Chicago, we will be purposing our model to the Chicago landscape.

The Data: The Chicago Field Museum's 2016 Monarch Conservation Project

In 2015, the Chicago Field Museum began to collect data on Milkweed counts and larvae density in city blocks across the Chicago area on a yearly basis. Measurements and recordings from these Field Museum researchers come from hands-on larvae surveying strategies. Ecological researchers or capable citizen volunteers[13] are assigned a certain city block to survey at least once a year, beginning in 2015. These surveys would be done through a simple counting method, where surveyors attempted to walk through the city block and count the number of milkweeds stems present using a "divide and conquer" method depicted in the Field Museum's guidebook. An estimate would also be made for how many monarch larvae are on each stem (a difficult task given the tiny size of some younger caterpillars). Because of time and resource constraints, a limited sampling of city blocks in the Chicago area was chosen based on two conditions: the first is the availability of researchers or volunteer surveyors. The

[13] Volunteers are discussed in terms of methodology shortcomings at the end of the literature review on "citizen data".

second factor is the researcher's own choice of a city block sampling site. In the guidebook, the researchers describe their motivation for providing a "fair mix" of different land-use types. These land-use types were categorized by the researchers into 16 broad types that are lumped into four broader categories: commercial, industrial, residential, and other[14].

The data provided by the Chicago Field Museum has several useful merits for the regression analysis in this paper. Data collection is ongoingly and done annually, giving my study the opportunity to analyze trends in milkweed count and larvae density across time. The data, furthermore, involves a comprehensive categorization of the land use type in each city block examined, giving me the opportunity to differentiate trends by land-use type. Being able to differentiate my coefficients and data results by land-use type allows me to closely look at how the composition of the urban landscape impacts the monarch population, as key to my research question.

It is fair to admit, however, that the lack of random sampling may suggests some sampling bias among the city blocks chosen. For instance, perhaps residential territories in wealthier neighborhoods are overrepresented in the data because they were more likely to contain volunteer surveyors. This challenge of sampling bias is one that has been ubiquitous in the previous literature in this research field and opens this study along with the previous studies on the question subject to criticism.

Larvae Density as a Proxy for Monarch Population Size

I will gauge the current size of the Monarch population in the Chicago territory through a useful variable measuring larvae density per milkweed stem. This strategy is borrowed from similar studies which focused on croplands and natural areas (Pleasants et al. and Zaya et al.). The justification for using this proxy has multiple arguments: first is that counting larvae density, as opposed to "mature butterfly sightings" or other methods used in previous studies, is easier for surveyors as the caterpillars are more fixed to one location. As a result of a more manageable surveying technique, it is less likely that a single

[14] This will be explained deeper in the model section of this methodology.

caterpillar is double-counted or missed altogether. The second justification is that, given the crucial importance of Milkweed to Monarch caterpillar growth, examining the larvae on Milkweed plants allows for researchers to get a more holistic sense of the total Monarch population in a territory. Researchers will get a more accurate reading of the total population because they are able to reduce the territories needed for measurement to simply milkweed plants and a certain few square feet from any individual stem or milkweed cluster. Any caterpillar that is too far from a milkweed will likely starve to death due to the absolute dependency each caterpillar places on the milkweed for its maturity into the chrysalis developmental stage. The third justification is that a larvae density measure allows me to control for migration-related study issues that researchers who've used different measurement methods have experienced. More specifically, researchers have found it hard to control for butterflies from a region of interest since many butterflies in more mature stages fly around to different locations of the Midwest. Using larvae as the paper's observation allows me to more accurately consider Monarchs dependent specifically on the conditions of the Chicago urban environment.

However, larvae density has a few notable shortcomings worth addressing. The first is that there are two causes for higher larvae density. The first possible cause for higher larvae density is that the Monarch population is increasing, which this paper relies on to justify the use of larvae density to predict the total population. The second, however, is that Milkweed resource available to Monarchs is decreasing. In this case, it will be misleading for researchers to claim that Monarchs were increasing solely because of a greater Monarch population without considering whether Milkweed availability was changing in that same place and time. To control for this issue, this study includes a count of overall Milkweed stem, the subject of the first regression model.

The second challenge to using the larvae density proxy is that larvae are not guaranteed to reach maturity. Several factors such as adverse weather or predation may cause variation in the larvae mortality rates. The data currently available on the Monarch population in the Chicago urban environment does not include a more detailed analysis of the mortality of larvae across time, so our use of larvae counts, and larvae plant density may be inconsistent with the actual size of mature butterflies that fly into the south during the fall season. This could be especially true for more hostile land-use types, such as commercial land uses that have high levels of foot traffic. Such locations could be plagued with higher larvae mortality after the time researchers sampled the area, and so there could be a higher overestimation for the monarch population emerging from more volatile land-use types.

The Models

I will run two separate regression model to answer my research question. The first model is a simple OLS regression that will answer for the "repopulation potential" of each land-use type. The second model is another OLS regression that answers for the "biological impact" of each land-use type.

Model A: "Repopulation Potential"

For the repopulation potential model, I am asking the specific sub-research question***: which sectors (land-use types) are most responsive to the ongoing repopulation programs in Chicago?*** This question gets at the responsiveness of each land-use type to milkweed repopulation programs like the "Mayor's Pledge", or whether certain land-use types, on average, carry more space that can be repurposed for milkweed plantings and monarch gardens.

The model used to answer this question is the following:

$$Milkweed\_Count_{it} = a_j + \beta_j * \sqrt{Year_{it}} + \gamma * Size_i + \varepsilon_{it}$$

Where Milkweed Count is the dependent variable, describing the number of milkweed stems in city block i and year t. The j subscript, belonging to our β and α, represents one of the 16 different land-use types as catalogued by the Chicago Field Museum.[15] Size is a control for the square footage of each city block.

[15] These 15 different land-use types are, with a base land use type being the "Other: Water", from 1-15: 1 is Open Space Conservation, 2 is Open Space Non-Conservation, 3 is Vacant Lots, 4 is Agricultural Land, 5 is Residential Single, 6 is Residential: Multi-Family, 7 is Corporate/Medical Campus, 8 is Commercial, 9 is Community/Cultural, 10 is Industrial: Small, 11 is Industrial: Large, 12 is Major Right-of-Wars, 13 is Lower Opportunity Right of Ways, 14 is Other: Low Opportunities, 15 is Minor Roads.

The key variable of interest in this model, the β, tells us the rate of change in milkweed count over time, suggesting each land use's responsiveness to repopulation programs. I square root the index variable, Year, to reflect the carry capacity limit of the individual city blocks. If a land-use is responsive to milkweed repopulation programs and has available space, I expect the milkweed population to increase faster in the earlier years, and then flatline in population change later as available planting space declines. I expect all land-use types to have a positive β coefficient, while some land types will have varying magnitudes. All land-use types will likely have an upward change in milkweed stem total because, on average, it is less likely that more milkweeds will be killed off than planted in. This is because each city block in the time of the data-collection (2015 onward) has likely been fully developed, and so greater habitat disturbance would be less common. I expect high rates of change observed on our beta variable to belong to agricultural and open-space conservation land types.

The j subscript enables me to produce independent estimates for the intercept, α, and slope, β, of each land use type. The base-group used in this model, "Other: Water", should likely have close to 0 in terms of milkweed count because no aquatic milkweed exists. Using a land-use type like this as a base group will lend to easy interpretation of all other land-use types by comparing the positive magnitude of each beta coefficient. A higher coefficient estimate suggests the land-use type will be more responsive to repopulation programs, observed by higher rates of change in milkweed across time.

Model B: "Biological Impact"

The second model takes our dependent variable, milkweed count, from model one and then uses it to predict the monarch larvae density in each city block. Here, we ask about the biological impact of an additional milkweed stem in each area. In other words, the sub-research question for this model is: **"Which sectors provide the highest rate of larvae counts per milkweed stem?"**. While understanding the responsiveness each land-use type has to milkweed programs in the city, it is important to notice that not every area is treated equally when it comes to accessibility and safety for monarchs. Some areas may have plant, for example, milkweed in parking lot green spaces, which are limited and surrounded by vehicle traffic. In a scenario like this, we expect that each additional milkweed stem would have a considerably lower biological impact on the monarch population compared to, say, an additional milkweed in a forest preserve with relatively low foot traffic.

The model for this research question is:

$$Larvae\_Density_{it} = a_j + \beta_j * \sqrt{MilkweedCount_{it}} + \gamma * Size_i + \varepsilon_{it}$$

This model behaves similarly to the previous, but with larvae density representing the average amount of monarch caterpillars per milkweed stem in city block i at time t. The j subscript recalls the same land-use types vector as the previous model, with the base group being the "non-productive: water" category. Milkweed Count is the amount of milkweed stems recorded in city block i and year t. Like the previous model, we use a square root of the milkweed count variable to suggest the carrying capacity limit of milkweed in an area. The amount of space used up in each individual milkweed will increase only to a certain extent, or until milkweed "real estate" runs out. The size control variable measures the size of the city block as a relevant control.

The β here will tell us the biological impact of an additional milkweed stem in land-use type j. We expect that certain land-use types to have higher magnitudes of biological impact per milkweed stem than others, as suggested by the "mall" versus "forest preserve" example previously mentioned.

Model Assumptions and Shortcomings/Prospects

This regression relies on a number of key assumptions. First, this model assumes that the monarch migration patterns will not dramatically change over time. Chicago, as it stands, is currently in the middle-most region of the migratory pathway. This paper assumes that from 2015 to the end of the data collected by the Field Museum, monarchs will be expected to fly into the Chicagoland area in the same manner. The second set of assumptions is based on our use of the Chicago Field Museum data, in which despite sampling shortcomings, I assume the data collected is a fair representation of the monarch population. The last, and perhaps most important assumption this model relies on, is that there is a significant relationship between monarch population and the current milkweed population in the Midwest. This assumption does not hold for some studies that have come out (discussed in the literature review at greater length) on the current cause of monarch population decline. In the scenario where this assumption isn't upheld (changings in Mexico habitats are the sole cause of monarch decline, for example), this paper would no longer be able to make the connection between higher larvae density and milkweed density. Since this paper lacks a clear discontinuity or natural experiment, our claim for causation is reliant the assumptions borrowed from previous research on the "milkweed limitation hypothesis".

These two simple OLS regressions will provide meaningful results specific to each of the 16 different land-use types in Chicago's city landscape composition. The two models capture the research question in two different angles and make intuitive sense in their "story" together. Model A will provide estimates for the average rate of change in terms of milkweed stem for each of the 16 land-use types. We allow 16 different trend lines to exist, and non-linearity to express the "carrying capacity" limit to how much milkweed can be feasibly planted in each location. Model A, however, does not connect us yet into the monarch population present in the city. It could well be that milkweed is growing exponentially greater in population in Chicago from 2015-2017 for most land-use types, but this does not fully suggest that monarchs are benefiting from it. Model B answers for the impact of the monarch population due to the changes found in milkweed from model A. By using larvae density as the dependent variable and milkweed stem counts for the key explanatory, we allow for our new beta coefficient to tell us the rate of change in larvae present in each land-use per additional milkweed stem. In other words, Model A is telling us the trend of milkweed, and Model B is connecting that trend to changes in monarch population.

While these models are is simplistic, it provides a useful base for more meaningful control variables to be added as data is collected. Ecological estimates for predation or larvae mortality in each of the sites would be a helpful measurement to reduce omitted variable bias due to larval death. The lack of larvae mortality recognition in this model is one of the key shortcomings, as most of the larvae measured may not reach adult maturity. Our model may be overestimating the true monarch population which successful migrates south during the winter. Other specific characteristics to be included would be a dummy variable vector taking on the various species of Milkweed, as previous research suggested that some species may have a higher biological impact than others due to, primarily, size (Zaya et al.). While omitted variable bias is a shortcoming in this model, one of the central benefits of the simple OLS mechanics used in this study is the ease by which these variables can be included once data is available.

Sample size, like most of the papers reviewed in the background section, is a clear shortcoming of this study's methodology. This effect is amplified by the challenge this study faces when land-use types are changed in each city block. As it stands, this paper assumes that an individual city block will take on only one type of land-use. In the instance where a city block goes from, say, recreational park to parking lot, this simple model would not be able to adjust to the transition in the j subscript used for the city block, i. In this case, I will have to drop the city block overall from the data. While sample city blocks are currently limited due to researcher and volunteer feasibility from data collectors, the consequence of having a few dropped observations may be significant to challenge the results of this model.

Conclusion and Generalizability

The research proposed in this paper can be generalized, with caution, to other cities. Specifically, I feel that the 16 land-use classifications can be generalized to all urban landscapes present in the Midwest. We may expect that different cities will have varying estimates due to differences in monarch programs and geographic location relative to the monarch's migratory pathway. However, these differences do not discredit that all cities are more-or-less composed of the same general "building blocks" of land-use types. Because of this, we can reasonably expect that a general model like the one proposed in this paper can be used in future research once data from other midwestern cities are collected.

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