Journal for Nature Conservation 81 (2024) 126689

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.com/locate/jnc

Citizen science engagement reveals patterns of long-term persistence of an at risk butterfly in three metropolitan centers

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ARTICLE INFO

Keywords:
Urban wildlife
Urban gardens
Long-term data
NABA
Insect conservation
Biodiversity

ABSTRACT

Insect declines have been documented for about twenty years worldwide, and the more recent Bee Colony Collapse Disorder has brought public attention to the issue. With this in mind, the persistence and thriving of an iconic, once-extirpated butterfly, the Atala (*Eumaeus atala*), in three major metropolitan centers located in southeastern Florida is remarkable and deserves close examination as to how it happened. The Atala butterfly is a charismatic species mostly residing in an urban dominated landscape, and has been a prime target of citizen science engagement since the second re-discovery of the species in 1979 in coastal Miami. Three citizen science actions were instrumental in this recovery: reintroductions, year-long population monitoring afterwards, and participation in annual butterfly counts. In this research, we analyzed three different sets of monitoring data gathered by citizen volunteers to help us determine factors that may influence the Atala butterfly's persistence. We found that the most labor- and time-demanding citizen science data allowed us to define fine scale population phenological dynamics enabling us to quantify the anecdotal biannual "crash and eruption" cycles, while the median level long-term engagement data revealed a coarse, multiple year crash and eruption population cycle. Our analyses illustrated that the contribution of on-going data collection gained through committed citizen science actions play a critical part in the species conservation strategy, allowing us to apprehend new integral knowledge of the butterfly's biology, as well as factors influencing its population persistence and distribution.

1. Introduction

Declining butterfly and other insect populations have been reported in scientific journals for decades (Thomas et al., 2004; Dirzo et al., 2014; Wagner et al., 2021). Butterflies are among the few insects that have been monitored over long time periods of time, beginning in 1830 by the Proceedings of the Royal Society B in Britain. In the United States, concern for insects was illuminated by the Xerces Society for Invertebrate Conservation, founded by Robert Michael Pyle in 1971. Named after the first butterfly to become extinct in the United States, Xerces has been carefully observing dragonflies, fireflies, butterflies, bees and other insects, often using trained citizen scientists (Pyle, 2012).

The appearance of "Bee Colony Collapse Disorder" in 2006 brought awareness of insect pollinators to the mainstream, but scientists were aware long before this (Allen-Wardell et al., 1998), including the environmental factors that may have caused the declines, e.g. wide spread herbicide and pesticide usages, and habitat deterioration and loss (Berenbaum, 2007; Sánchez-Bayo and Wyckhuys, 2019).

In 1992, Jeffrey Glassberg created the North American Butterfly Association (NABA), which also promotes and utilizes trained citizen scientists to monitor butterfly populations, researching migration, distribution and range patterns, to assess conservation statuses nationwide. NABA's annual butterfly counts are modeled after National Audubon Society's annual Christmas bird counts, held for over 120 years nation wide (Pranty and Anderson, 2022).

An iconic and charismatic Florida hairstreak butterfly called the Atala (*Eumaeus atala)* was thought to be extinct as early as 1937 in Florida (Klots, 1951) because its sole host plant, the only native North American cycad locally known as "coontie" (*Zamia integrifolia*), had been exploited to near extinction by the early settlers for flour production (Small, 1921). The coontie is still listed as "Commercially Exploited" by the State of Florida (Coine and Garland, 2003) and is currently very rare in natural areas.

The Atala butterfly was rediscovered a second time in 1979 after the

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https://doi.org/10.1016/j.jnc.2024.126689
Received 14 January 2024; Received in revised form 17 July 2024; Accepted 18 July 2024
Available online 3 August 2024
1617-1381/

first recovery attempt was decimated by Hurricane Donna in 1960 (Rawson, 1961). It has greatly recovered over the past twenty plus years, as more of its host plants were raised in nurseries (Haynes, 2000) and incorporated into gardens and public venues. The native plant was increasingly used in ornamental landscaping over that time, where it is also known to cause serious pest management issues because the butterfly's larvae cause severe herbivory (Culbert, 1994; Koi and Hall, 2016). However, residential gardens also planted coontie and nectar resources, playing a critical role in the insect's recovery. We delve further into the vital role of these gardens in a companion paper to this publication.

To further understand the Atala butterfly's dynamic life cycle fluctuations, the environmental factors influencing its survival and persistence, as well as to document its newly expanding range and distribution, we examined three different sets of data collected by volunteer citizen scientists in NABA. Our questions were: (1) What does each of the data sets inform us about the butterfly's dynamic population patterns? (2)What do the fine and coarse grain scale analyses tell us?, (3) What factors may influence the presence of the Atala?, and (4) What is the current conservation status of the butterfly?

In addition, a fourth data set compares "Presence-Only" records sent to the first author from 2004 to 2022 by citizens not associated with the first three data sets. These individuals recorded the Atala in various locations, sending photographs and/or videos. This data set was not analyzed except to note types of locations where the Atala was seen, and was used to visually compare the presented range to the iNaturalist data.

2. Methods and materials

2.1. Study species

The study species, the Atala butterfly (*Eumaeus atala)*, is a native subtropical hairstreak found in Florida, the Caribbean and Cuba (Klots, 1951; Smith, et al., 1994) which has been documented by members of the North American Butterfly Association (Fig. 1A-C) and other volunteers. It is a specialist, using only cycads as a larval host plant, and has a strong site fidelity once established (Whittaker and Salzman, 2020). However, the colonies "wink in and out" of existence in erratic cycles throughout the state of Florida, ephemeral in some and more persistent in others. The butterfly's basic biology has been covered in detail in previous research (Koi, 2013; Koi and Daniels, 2015). For this study, we used data collected from a mosaic of populations within the Atala butterfly's historic range in Southeast Florida (Brown and Opler, 1990), representing citizen science engagement at different scale levels as explained below.

2.2. Data set #1: Residential garden weekly Atala butterfly counts

Atala butterflies in all life stages were counted weekly by thirteen (13) self-selected citizen scientists to record the life cycles (Koi, 2013; Koi and Daniels, 2015; Koi and Hall, 2016). Of the thirteen gardens, 11 homeowners also participated in introductions of immature stages (larvae and pupae) of the Atala, collected from a cycad research center in Miami-Dade County; this helped reduce herbivory for the research center as well as help expand Atala butterfly colony sites. There was no attempt to control which life stages were collected, as this was dependent on the species itself, and the herbivory level at the garden. Nor did we control to where the immature stages were distributed, as the homeowners decided themselves whether or not to accept additional immatures. Eggs were generally not collected as the survival rate was low (Koi, 2013). Non-adult counts were converted to number of potential adults as described below (Section 1.3.3). This gave us fine-grain weekly data.

2.3. Data set #2: Public garden Atala weekly butterfly counts

In addition to residential gardens, counts of Atala butterflies across all life cycles were recorded by volunteers in several public venues, a botanical garden (Miami-Dade County), a median strip (Broward County) and a nature center (Palm Beach County); this also gave us fine-grain data. Non-adult counts were converted to number of potential adults as described below (Section 1.3.3).

2.4. Data set #3: Annual North American butterfly counts

The annual North American Butterfly Association (NABA) counts occur within fifteen-mile radius circles, strategically located within each county so as to cover as many different ecosystems as possible using

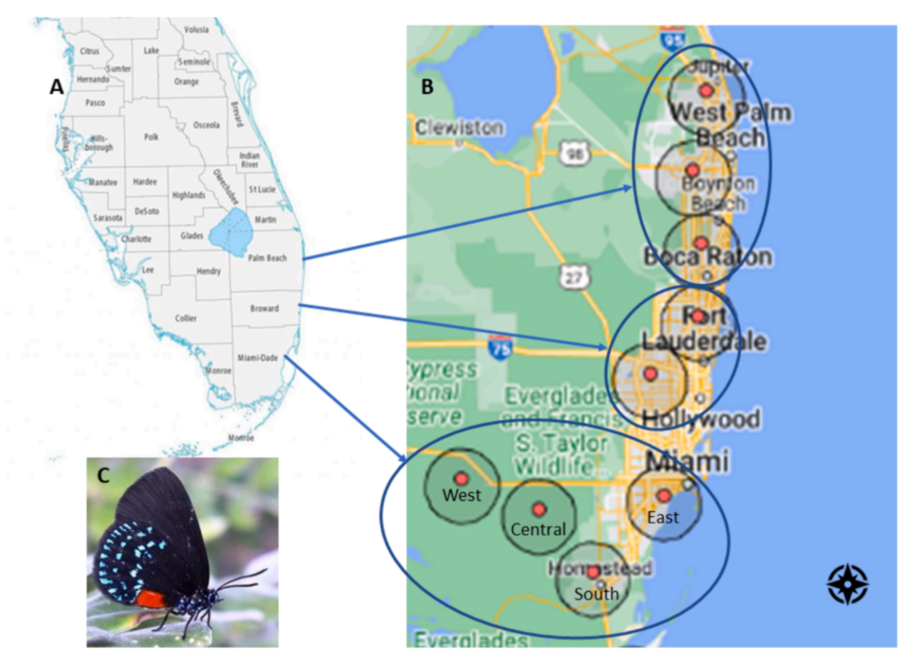

Fig. 1. A.) The southern tip of peninsular Florida, USA. B.) The Southeast Florida counties where the annual North American Butterfly Association counts occur in Palm Beach, Broward and Miami-Dade, and the fifteen-mile radius circles within each county. C.) The Atala butterfly. (Source: Koi).

designated sites. Nationwide butterfly counts are performed on or near July 4th, as northern climes preclude seeing butterflies prior to summer. The long-term data is compiled yearly by the national NABA headquarters in New Jersey, which helps determine the conservation status of local butterflies nationwide.

The first NABA chapter in Florida was started in Palm Beach County (PBC) in 1995, followed soon thereafter by Miami-Dade County (MDC) in 1997 and Broward County (BC) in 2004. Although new Florida chapters have been springing up throughout the state in recent years, the first three southeast Florida chapters have been instrumental in the recovery of the Atala butterfly and were the originally recorded locations (Rawson, 1961; Schwartz, 1888; Scudder, 1875). Although all butterflies were counted, we only noted the Atala populations in the NABA counts for this study. Population counts of butterflies were performed by NABA volunteers using the standardized method commonly referred to as a "Pollard Walk" (Pollard et al., 1973) (Fig. S2).

Annual Summer NABA count data from Palm Beach, Broward and Miami-Dade county chapters were downloaded from the national or county chapter archives (NABA, n.d.). Palm Beach County contains three circles (north, central and south); Broward County contains two circles (north and south), while Miami-Dade County designates four widely separated circles (north, south, east, west). NABA members may also choose to count butterflies in their residential gardens if they are located within the designated count circles, rather than participate in the annual Pollard Walks. We excluded locations that never recorded the Atala butterfly and only used consistently monitored long-term sites. Temporarily monitored sites without long-term data were also excluded.

We also eliminated all but the consistently used long-term sites, as new sites may have been tried temporarily in different years and we do not have long-term data for those locations. Locations that never recorded the Atala butterfly were eliminated from the annual analyses. Although Broward County also conducts counts in Spring and Fall, we only included the Summer counts for comparison between the three counties. We only used records of the adults, even if immature data were collected. The annual NABA counts provided a coarse-grain phenological model of Atala populations in Southeast Florida for 18 to 27 years.

2.5. *Data set #4: randomly reported Atala activity*

We include a report of randomly reported Atala activity over 18 years (2004–2022), which were presented to one author (SK) by different people and at different times than the similar iNaturalist data. It is included because it represents a robust picture of the butterfly's extended range and distribution, and its ability to find its host plants in hazardous urban environments. These data are supported by, and corroborates with, the iNaturalist information.

3. Statistical analyses

<u>*Bayesian Regression*</u>

3.1. *Identifying predictors for Atala abundance*

Data analyses of garden and natural area characteristics and butterfly abundance were completed using the Bayesian R package brms (Bürkner, 2017). We fitted a full model with all predictors, followed by models with individual predictors. We selected the best model using Leave-One-Out Cross-Validation, preferring the most parsimonious model within one standard error of the best model. Bayesian analysis allowed us to maximize sample size and incorporate prior knowledge on Atala abundance variation. For all models, we specified a normal prior distribution for the intercept, having a mean value of 25 for the median abundance of butterflies based on the median of initial counts (our response variable), while the standard deviation was 25 to allow the model flexibility in generating accurate estimates. For the slope, we specified a normal distribution with a mean of 0 and a standard deviation of 75, to allow the relationship to be negative, positive, or flat. The Bayesian 95 % Credibility Interval then allowed us to extract precise estimates for the relationship between the predictors and the abundance of the Atala.

We plotted the population points in the residential gardens and drew the vertical dashed lines (for the residential gardens) to visualize when introductions were performed. While for the county NABA surveys, we plotted the data as reported, and added a trendline and R-squared value.

3.2. *Visualizing Within-Year changes in Atala Abundance: Residential and public gardens*

To visualize temporal fluctuations in the abundance of the Atala across residential and public gardens, we used Generalized Additive Models (GAMs) – a statistical tool that is becoming increasingly used in ecological research (Pedersen et al., 2019). The GAMs allowed us to fit the Atala's abundance as a smooth function of calendar days, while accounting for site-level differences (i.e., from which residential garden or public garden the data was collected) by specifying site as a random effect in each model. The resulting splines were then plotted to identify how the abundance of the Atala changes in both public and private gardens. The peak in abundance was then identified with a vertical red dashed line on the x-axis.

3.3. *Quantifying temporal changes in Atala abundance across Southeastern Florida*

We used a Bayesian Generalized Linear Model (GLM) to examine how the abundance of the Atala changed over time in the three southeastern Florida counties. The response variable was the abundance of Atala adults which we collected from annual NABA surveys. The two fixed effects were the year of the survey and the county in which the survey was conducted. We used a negative binomial distribution family to account for overdispersion in the annual abundance. For the prior distribution of the intercept, we used a normal distribution with a mean of 150 and standard deviation of 100. This time, we specified a normal prior of the mean as 0 and the standard deviation as 10 for the slope. After fitting the model, we extracted the summary table of the model which indicates the effect sizes and the 95 % CI for each predictor.

We normalized collected data of immature life stages (eggs, larvae, and pupae) to calculate expected survival rates to adulthood, in order to format the median number of adults per week for our crash-eruption graph. We know that on average 36 % of eggs will successfully develop into larvae, 58 % of larvae successfully become pupae, and 94 % of pupae successfully eclose as adult butterflies (Koi, 2013; Koi and Daniels, 2015).

4. Results

4.1. *Data set #1 residential garden life stage counts*

The records clearly showed a crash-eruption cycles (Fig. 2). Wild colonies self-established in two gardens (PB1, PB3), and are still extant. One property (BC2) had one introduction and has reestablished on its own without intervention since, including 2023. One garden, BC1, had a natural population in the 'crash cycle' when one introduction was made, which flourished and became a source for reintroductions to other gardens.

Two volunteers from NABA, one from Miami-Dade and another from Broward, removed immature stages of the Atala butterfly from a cycad research station in Miami-Dade, to reduce the excessive herbivory caused by the larvae, which were then distributed to gardeners who wanted to augment their populations or start a new colony.

The thirteen residential garden sites clearly document the crash-eruption cycles of the Atala butterfly and provide the first quantified data to prove the butterfly's bi-annual population cycle. It also

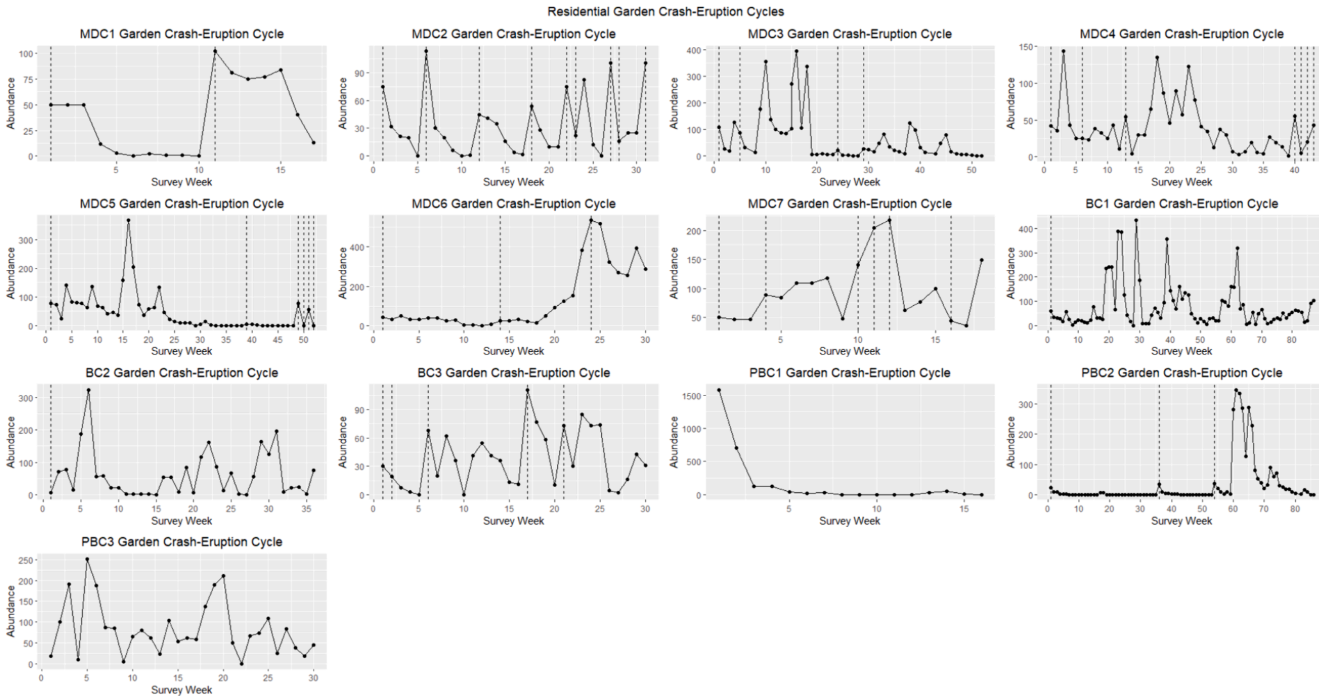

Fig. 2. The typical crash eruption population cycles of the Atala butterfly as recorded by homeowners in thirteen residential gardens in Miami-Dade (MDC), Broward (BC) and Palm Beach (PBC) counties in Southeast Florida between 2011–2014. Vertical dotted lines represent Atala introductions, as larvae or pupae. (Source: Koi & Figueroa).

demonstrates that the peak of Atala activity is generally recorded around July 2nd, with a second high point being recorded in October. The population fluctuations are also apparent in the spline graph (Fig. 3). This biannual cycle has been noted before (Koi and Daniels, 2015; Ramírez-Restrepo et al., 2017), but never quantified in residential gardens. The garden owners documented Atala butterfly life-cycle populations for at least a year, allowing fine-grain examination of the life cycle in a residential garden.

4.2. Data set # 2 public garden counts

Three highly-trained volunteers and one staff counted the Atala life stages weekly at Fairchild Tropical Botanic Garden (FTBG), in MDC from March 2011 to August 2015. Although the counts were taken in two areas of this public garden, known as the "Lowlands" and the "Uplands", the posterior distribution of the populations in our Bayesian analysis overlapped to a significant degree, indicating that there was little population difference between the two locations. Therefore, they were

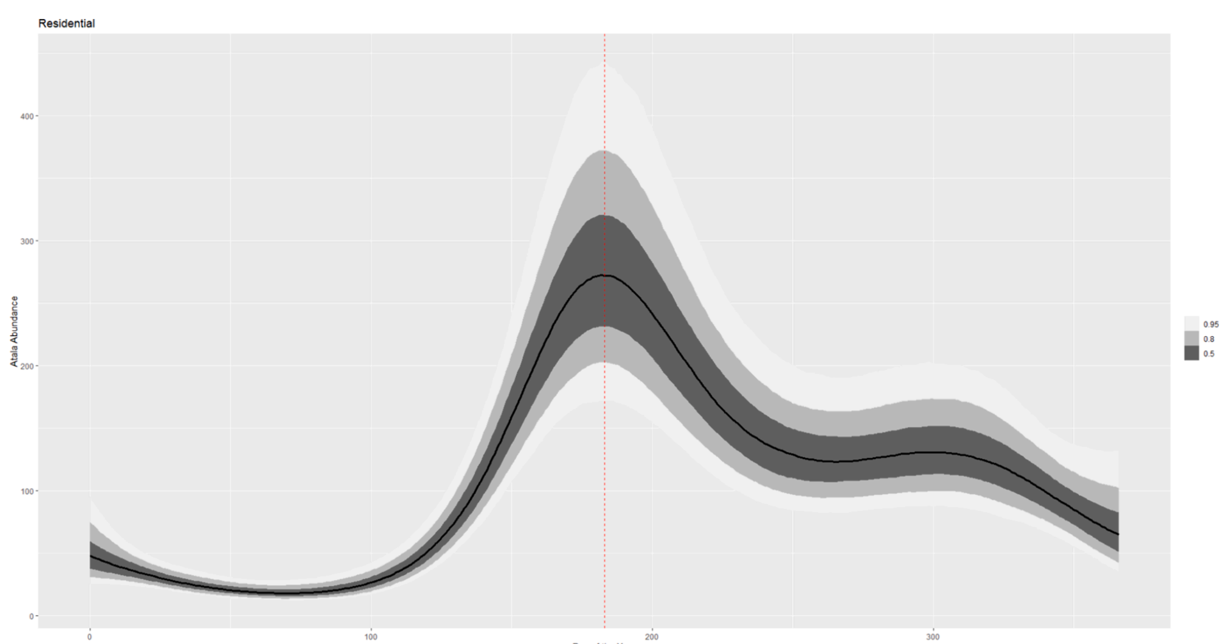

Fig. 3. A spline representation of the population the typical "crash-eruption" cycles of the Atala butterfly in thirteen residential gardens spanning Miami-Dade, Broward and Palm Beach Counties. Note the second smaller eruption, that often takes place in late Fall/early Winter. (Source: Koi & Figueroa).

combined for analyses (Fig. 4A). The peak Atala activity was on June 3, indicated by the vertical dotted line and there is a slight increase in the population evident toward the end and beginning of the year (i.e., late winter).

To our knowledge, the Pompano Beach colony in Broward was self-established; it is located on a five-block long median strip on a two-lane residential street, with no nectar resources planted specifically for them (Fig. 4B). The coontie was installed as an ornamental landscape plant along with small trees and palms in some sections; there were random weedy areas or lawn flowers such as *Richardia* species, where the butterfly could find nectar year-round (Fig. 5). When the palms were in bloom, there was a flurry of activity, seen in the population peak around July 3, indicated by the dotted vertical line.

This site was originally a random report, but the volunteer continued to monitor the site for 15 months from June 2013 until July 2014. The location is designated as an 'Urban Lot' on the random sightings map (Fig. 12) and continues to host the Atala without any intervention at the time of this writing in 2023.

At Gumbo Limbo Nature Center in Palm Beach County, volunteers counted Atala life stages in the butterfly garden. The counts took place from July 2012 until December 2014. The bi-annual 'crash-eruption' cycle is starkly evident in the graph (Fig. 4C), with the peak activity, indicated by the dotted vertical line, occurring much later in the year in August 2014. Although the spline smoothed out the population levels, the numbers started out high in July 2012, crashed in February 2012 until July 2013, and remained fairly low until a sudden explosion in late August 2014, where it remained high until the last count in 2014.

Tri-county spline graphs of the Atala populations in the public sites compared to the residential sites shows the peak of activity occurring summer, on July 2, with the residential populations peaking 24 days later in the residential areas (Fig. 5A-B).

4.3. Data set #3 annual NABA counts

Florida has good weather year-round, with tropical storms and hurricanes generally occurring between June 1 and November 30, but fortunately the annual NABA counts have missed the hurricanes. Tropical butterflies have survived millennia in spite of the heavy storms in

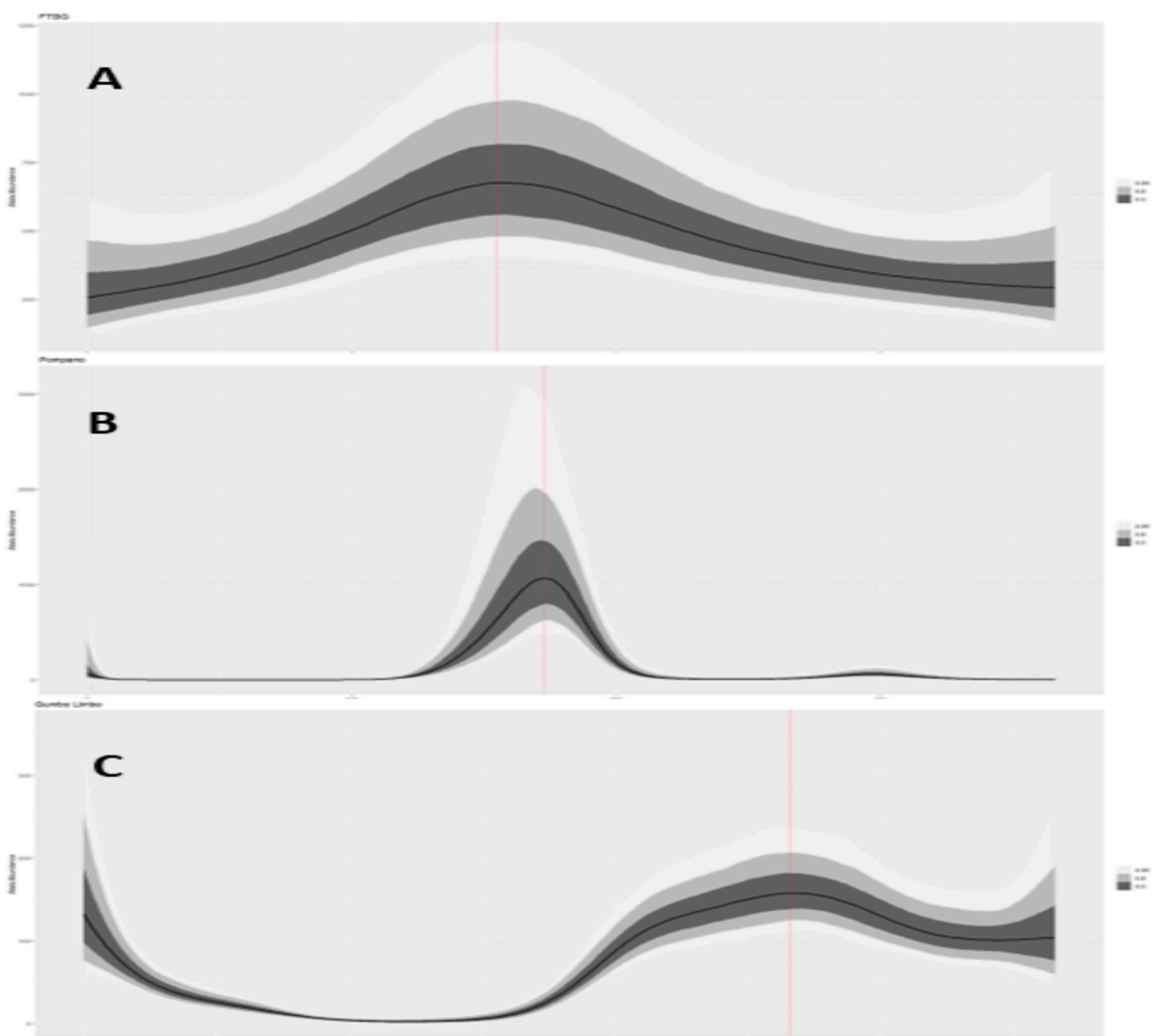

Fig. 4. A.) The spline graph for the Atala population in Fairchild Tropical Botanic Center in Miami-Dade County, FL. The vertical line indicates the peak activity period on Day 155, around June 3. The spline also shows the biannual cycle, in the winter peak more subtly. Atala population numbers were collected by volunteers from 2011 to 2015. B.) This self-established Atala butterfly colony in Pompano Beach in Broward County, FL, was first reported as a "Random Report"; the volunteer then counted weekly from July 2012 until December 2014. Although the second peak later in the year is small, it is visible C.) This Atala colony was monitored with weekly counts by volunteers at Gumbo Limbo Nature Center in Palm Beach, FL, from 2012 to 2014. The biannual 'crash-eruption' cycle is starkly evident in this graph even with a spline smoothing the data, but the peak activity was much later than expected, occurring in August with a second peak in December. (Source: Koi & Figueroa).

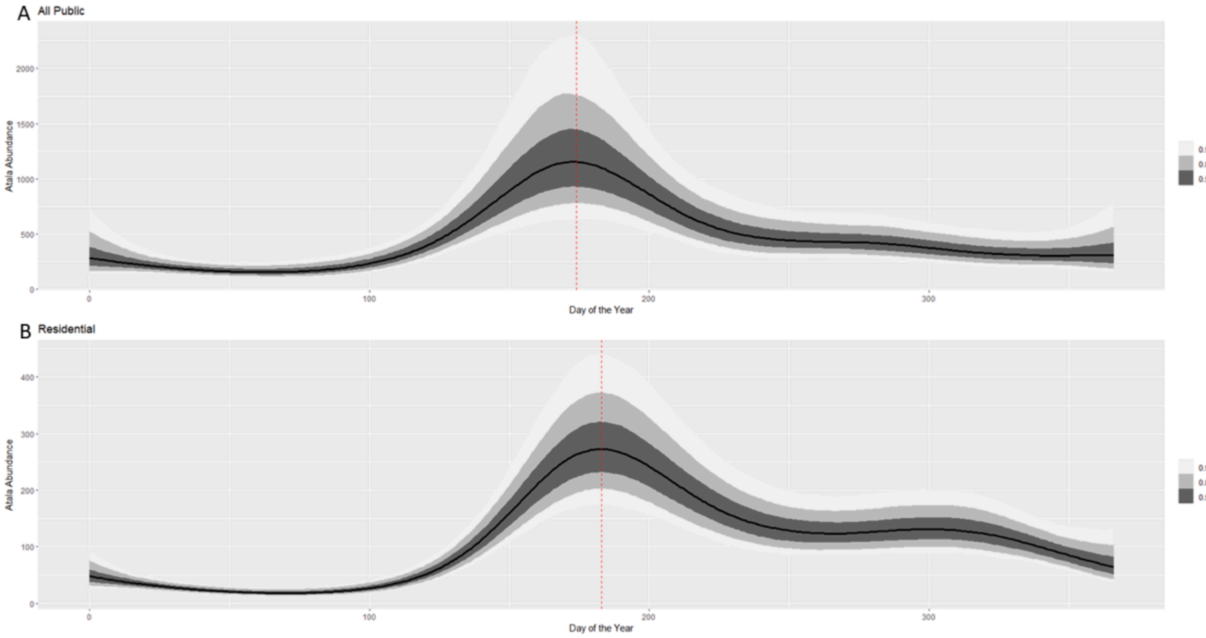

Fig. 5. A.) A tri-county area spline of Atala butterfly populations in three public garden sites. B.) A spline representing the thirteen residential gardens. Residential gardens show a slight increase in abundance in late Fall and early Winter. (Source: Koi & Figueroa).

Florida and the Caribbean, and the Atala was present in the annual NABA summer butterfly counts regardless of adverse weather.

Atala butterfly populations also show extreme numbers in "crash-eruption" annual cycles, well-known in lepidopteran and many other insect species (Bigger, 1976; Wallin and Raffa, 2004; Koi and Daniels, 2015; Schachat and Labandeira, 2021). The drivers may be so varied that a definitive answer of causes may not be firmly identified, but insect population fluctuations are evident in NABA counts since 1997 in Miami-Dade County (Fig. 6A), since 2004 in Broward (Fig. 6B), and since 1995 in Palm Beach County Fig. 6C).

Atala colonies in Miami-Dade were only recorded in the East circle during the Summer counts, although some sightings have been recorded in Homestead on iNaturalist. The Miami-Dade records display the typical 'crash-eruption' patterns, with the highest number (35) being recorded in 2020. The lowest points were recorded in 2009 and 2013 (none recorded). However, there is an overall increasing trend, although the R^2 value is low (0.0318).

In Broward, the same pattern is seen in 18 years of data, but the highest numbers recorded were in 2015 (355), and the lowest numbers in 2005 (5) and 2011 (3). Again, there is an overall increase trend in the population with a low R^2 value (0.2407), closing out 2022 with a population count of 285 individuals.

Palm Beach County provides 27 years of data and quantifies the same crash-eruption cycles. The low counts took place in 2000 (15), 2001 (10) and 2010 (6). The highest count for PBC recorded 1414 adults, not an unusual number for the Atala in locations where it is thriving. The R^2 value for Palm Beach is also low at 0.1476, but the trend nonetheless shows a slight increase.

All in all, the populations of the Atala butterfly are increasing in Southeast Florida as shown in the spline graph, which smooths out the differences between the annual counts in the three counties. It does not show the crash-eruption pattern (Fig. 7).

4.4. *Data set #4 randomly reported Atala activity*

A collage of randomly reported Atala activity reported between 2004 and 2022 to SK (Fig. 8A) compared to iNaturalist sightings (Fig. 8B) during the same time period. The sites where the Atala was observed varied greatly, from isolated gas stations to a McDonald's parking lot, virtually anywhere that coontie was planted as ornamental foliage. These were not pampered botanical, or carefully looked after residential gardens, but rough-shod urban environments that may indeed mirror the harsh native pine rockland ecosystem where the butterfly lived before the turn of the century. Tri-county comparisons of randomly reported Atala butterfly colony sites are delineated in seven site categories as Residential Gardens, Natural Areas, School Gardens, Preserves, Urban Lots, Public Venues and Nurseries (Fig. 9).

Comparisons of garden types and natural areas are shown in Fig. 10. Two examples of the extremely urbanized locations where the Atala can be found are depicted in Fig. 11. The screen shot was from a video taken

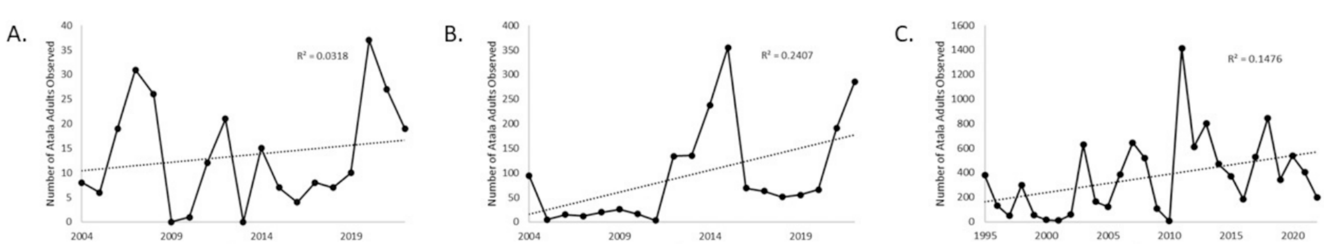

Fig. 6. Comparison of long-term annual NABA population data for the Atala Butterfly from A.) Miami-Dade, B.) Broward and C.) Palm Beach counties, showing a typical 'crash-eruption' cycle, which is particularly pronounced in Palm Beach. The Palm Beach chapter started counting in 1995, with Miami-Dade and Broward starting in 2004. Although the trend line and R^2 are not strong, the general trend indicated increasing population. (Source: Koi).

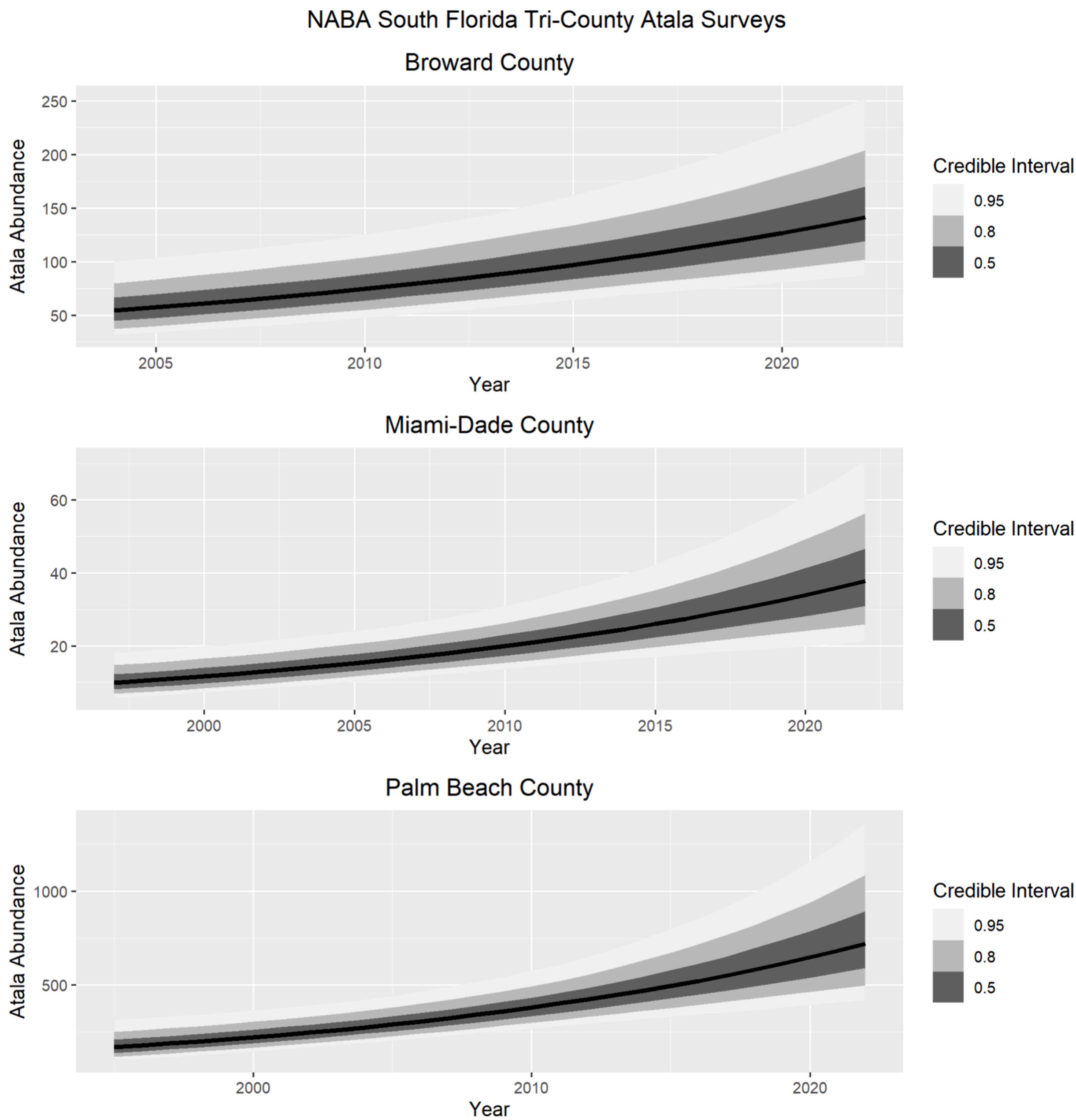

Fig. 7. A tri-county spline graphs of NABA count data showing continual increases in Atala butterfly populations in Miami-Dade, Broward and Palm Beach counties. The typical 'crash-eruption' cycles are not evident in these graphs as the spline program smooths the differences between them, and locations that had zero or near-zero Atala activity were not used. (Source: Koi & Figueroa).

on the ramp going into Little Havana by a woman who had Atalas in her yard and had reported numerous neighbors who planted for the Atala in the community. The video was filmed while she was in a traffic jam at the top of the ramp. The Random Sightings are depicted in Fig. 12, differentiated by categories or landscape type. Examples of site locations which hosted the Atala butterfly are depicted in Fig. 13.

5. Discussion

Our study is certainly not the first to use citizen science for monitoring a species, but ours is unique in regard to the intensity with which our dedicated volunteers counted life stages of the Atala in specific gardens for a year or more, as well as supplied data during annual NABA counts.

5.1. What does each data set inform us about the butterfly's dynamic population patterns?

The residential garden data gave us detailed population data about the Atala butterfly's classic "crash-eruption" population cycle on a fine scale never before quantified in such a manner over time. When all is considered, it is evident that these 'small scale gardens' are providing much needed refugia and a safe haven for not only Atala butterflies, but also for other at-risk species. Although the surrounding matrix may not be compatible to butterflies or other insects in light of the many detrimental effects in urban environs (Nowicki et al., 2014; Young et al., 2016; Crone and Schultz, 2022; Dániel-Ferreira et al., 2022;), urban gardens may act as 'pocket parks' and stepping stones in an otherwise inhospitable matrix (Rudd et al., 2002; Dennis and Hardy, 2007; Loram et al., 2007; Beumer and Martens, 2016; Soanes et al., 2019; Soanes and Lentini, 2019; Van Helden et al., 2021; Seitz et al., 2022). Volenec

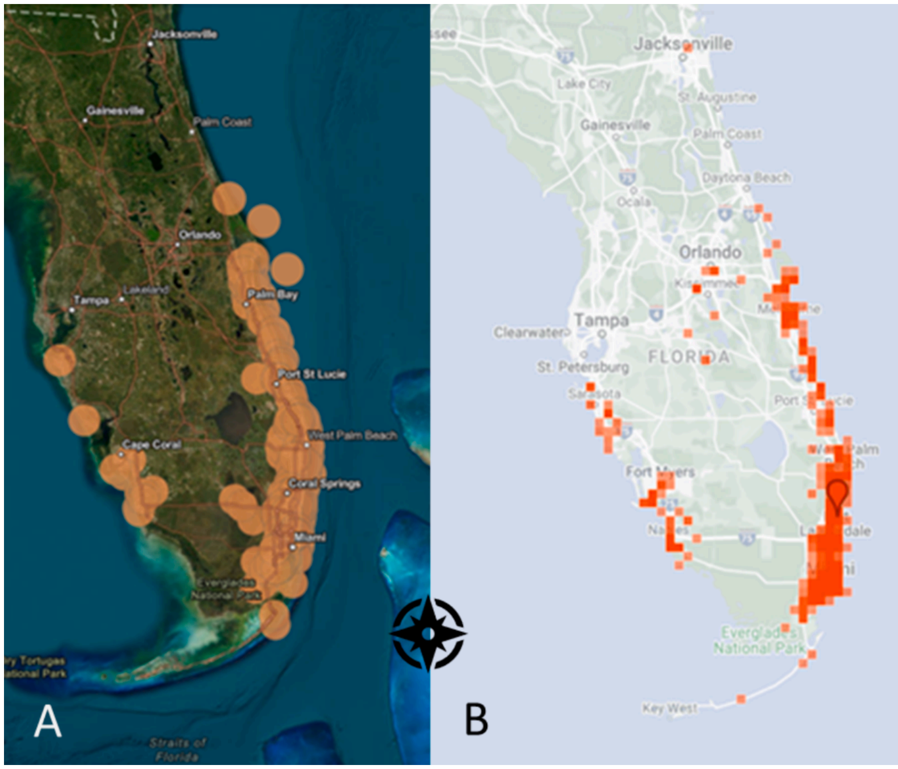

Fig. 8. A.) Randomly reported Atala butterfly colony sites (2004–2022) compared to sites recorded in iNaturalist (as of 5-29-2023). Most sites outside of the Southeastern Florida tri-county area were introduced by scientists as the University of Florida, including at the Jacksonville Zoo in the northeast, the Disney Preserve, Naples Zoo on the west coast, and the Orlando area. Butterfly enthusiasts also introduced the butterfly into cities from Tampa to Ft. Myers on the west coast of Florida, where the Atala both self-dispersed into neighboring gardens and natural areas. (Source: Koi) B.) iNaturalist screen shot of Atala presence recorded during the same time frame. (Source: iNaturalist).

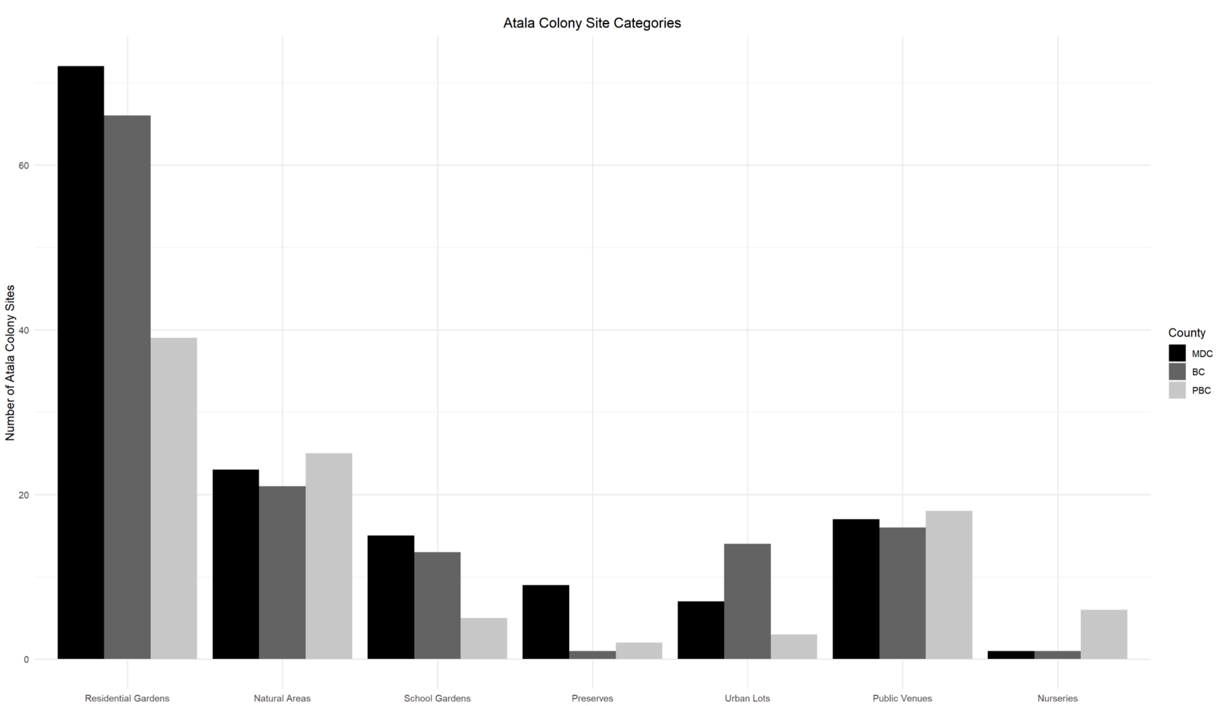

Fig. 9. Tri-county comparisons of randomly reported Atala butterfly colony sites. The site categories are Residential Gardens, Natural Areas, School Gardens, Preserves, Urban Lots, Public Venues and Nurseries. Miami-Dade County (MDC) had 144 reports, Broward County (BC) had 132 reports and Palm Beach County (PBC) had 98 reports. (Source: Koi & Figueroa).

Fig. 10. Examples of colony site categorization: A.) Residential Garden, with a National Wildlife Federation Certification sign (Source: Koi) B.) Natural Area (Source: Long Key Natural Area and Nature Center, Broward County) C.) School Garden (Source: Koi) D.) Preserve (Trinity Preserve, Miami-Dade County) (Source: Klein) E.) Urban Lot (abandoned parking lot that had a thriving colony until it was developed; plants and butterflies were rescued beforehand, Palm Beach County) (Source: Koi) F.) Public Venue (Walmart Parking Lot, Broward County) (Source: Google) G.) Nursery (One Stop Shop, Loxahatchee, Palm Beach County) (Source: Google).

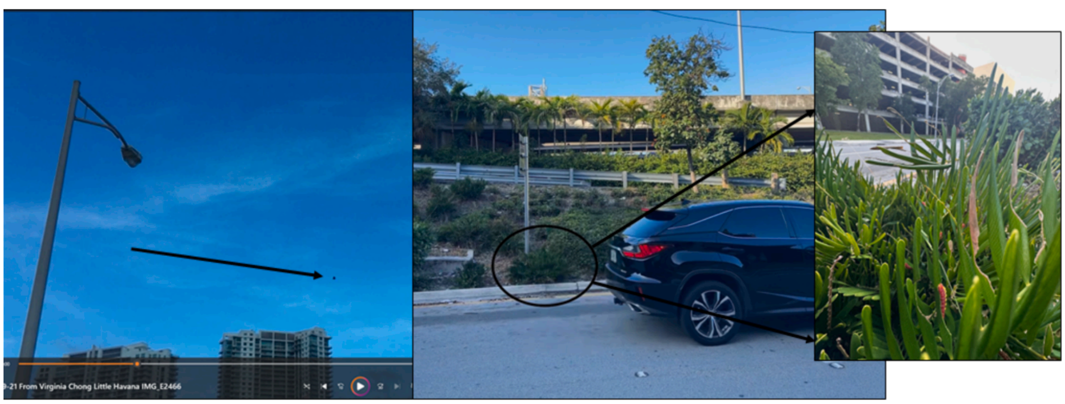

Fig. 11. Two examples of Atala resiliency. A.) A clip from a video of an Atala flying above a highway ramp into Little Havana, Miami, where there are several viable residential colonies (the photographer was stuck in a traffic jam). (Source: Chong) B.) The Atala butterfly residing in an ornamental coontie wedged between a highway ramp and downtown Miami. (Source: King).

(2019) reports that small reserves that mimic a natural environment will support the native assemblage of wildlife that would be in that native environment if it still existed. Some of the gardens we report here were much closer to a natural habitat than others and the numbers and persistence of the Atala populations in those gardens lends support to that.

Many conservation programs focus on large animals, whether terrestrial (e.g., elephants, giraffes, bison, wolves) and equally large tracts of land, but overlook the fact that although butterflies, beetles, bees and other pollinators, are very small species, they are immensely important foundational species in any ecosystem (Wilson, 1987). Residential gardens, although generally less than an acre in size, provide vital support for these species as well as improving the surrounding urbanized matrix. While much conservation biology focuses on large species over very large areas protected areas (Heinen, 2012), our study is also demonstrative of the importance of small tracts of land for the conservation of myriad species of plants and invertebrates (Giannini and Heinen, 2014; Diamond, 2016) and the importance that private lands and public/private partnerships can play in this endeavor(Braddock and Heinen, 2021). Even homeowners with large expanses of lawn can be supportive of grass-feeding species, micromoths and other small insects that would often be ignored and most lawns supply weedy nectar sources such as Mexican clover (*Richardia* spp.), fogfruit *(Phyla nodiflora*), Indigofera (*Indigofera* spp.), and other tiny nectar or host sources (for moths or beetles), as well as the nearly ubiquitous and valuable nectar resource, Spanish needles (*Bidens alba)*; most of these weedy species were not listed by homeowners.

The annual NABA counts demonstrated the persistence of the butterfly throughout the locations where it has been found historically and this on-going surveying is an extremely crucial tool for keeping tabs on the conservation status of butterfly species nationwide. Because of long-term data such as this, we have a clearer picture of the conservation status of wildlife populations. What we are missing in most of our invertebrate species, however, is the baseline data; hopefully, as new NABA chapters unfold, that will begin to make a difference.

5.2. *What do the fine and coarse grain scale analyses tell us?*

The population data from both weekly counts in residential gardens and yearly NABA counts supports that the Atala butterfly is recovering from its near extinction status fifty years ago. We see a definite increase in range and distribution, and an increase in colony numbers.

Our data sets also illustrate a quantifiable 'crash-eruption' cycle for the Atala.

Reduced Atala numbers evident in Broward County during 2011 may be associated with a colder than normal winter, but the same patterns are not evident in Miami-Dade or Palm Beach. Colder temperatures may have severe effects on many tropical taxa (Borrero, et al., 2022;

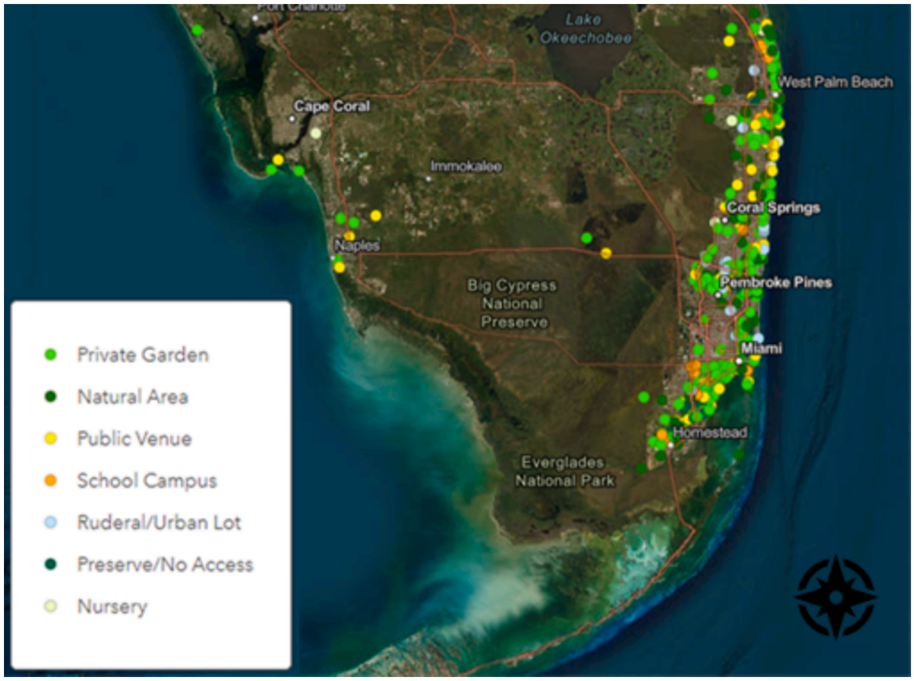

Fig. 12. Randomly reported Atala sightings in Southeast Florida recorded from 2004 to 2022 and categorized according to landscape type. (Source: Koi).

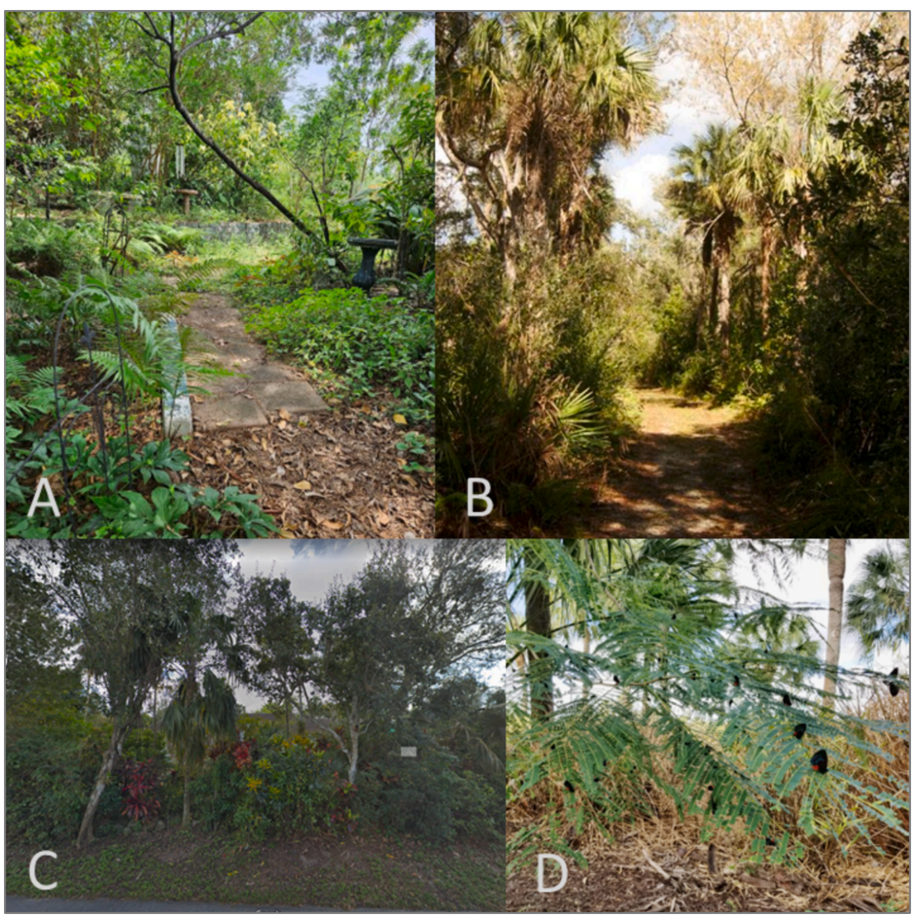

Fig. 13. A.) The backyard garden of site BC2, a highly natural site, has hosted the Atala butterfly since 2006. (Source: Johnston) B.) A natural area in Miami-Dade County, illustrating unmanaged natural Florida vegetation. (Source: Koi) C.) The front yard of residential garden MDC7 providing host plants, nectar sources and tree cover. (Source: Google) D.) A weedy gas station categorized as an "Urban Lot" with ornamental coontie and a weedy understory, is one of many ephemeral Atala colonies taking advantage of free resources. (Source: Smith).

Downing,et al., 2016). Higher recorded numbers in Miami-Dade during 2020 may reflect the fact that more butterfly enthusiasts were out looking for butterflies regardless of lockdowns occurring in other areas of the country, but again, this trend is not evident in all three counties. Pesticide use and mosquito spraying have proven detrimental effects on butterfly populations (Bargar et al., 2020a; Hoang et al., 2011); although we do not have data specific to the use by residential gardeners, discussions with homeowners indicated that very few used pesticides and many called the county mosquito control to request no spraying by their property.

While climate change has affected some butterfly species (Thomas et al., 2004; Forister et al., 2010; Preston, et al., 2012; Bonoan et al., 2021), the slight differences in temperatures in Southeast Florida may not have a detrimental impact, as we see the species increasing its range state-wide as well as persisting in new territories. The butterfly was reported in the random sightings category as "self-established" in Martin County as early as 2011 (Koi, unpublished), and the insect survived the lowest 2011 winter temperature of −2.22 °C (28°F) in a screened–in outdoor colony in Gainesville, FL (Koi, 2013; Koi and Daniels, 2017). Tolerance of changing temperatures is highly variable in both taxa and individuals (Bale et al., 2002; MacMillan and Sinclair, 2011a, 2011b; Curtis et al., 2015; Boucek, et al., 2016; Downing, et al., 2016; Wang, X. et al., 2016).

5.3. *Other factors influencing the Atala butterfly's population dynamics and persistence*

There are many factors that could affect the butterfly's persistence or abundance. There is some evidence that roadside mortality can be a detrimental factor for urban butterflies (Baxter-Gilbert et al., 2015; Keilsohn et al., 2018), but also that the road verges can be planted in such a way as to prevent vehicular mortality (Dániel-Ferreira et al., 2022). It is also known that small spaces, such as pocket parks and even power line rights-of way can act as important refugia for butterflies and other pollinators (Berg et al., 2013; Campbell et al., 2023; Volenec and Dobson, 2020). Although many of the gardens are located in densely urbanized locations, the species' fairly sedentary behavior seems to keep it from experiencing too many vehicular deaths. We have observed the butterfly flying over a 4-story building on campus, which is normal insect behavior in order to maintain sun azimuth while in flight, which is witnessed in migratory insect species. We also have a video record of an Atala flying above a highway ramp in Little Havana, Miami, where there are a handful of residential colonies. The butterfly will move when seeking mates or host plants.

It is also known that adult food availability is not necessarily an indication of butterfly abundance, but that host plant availability has been shown to be a key driver in some butterfly populations (Curtis et al., 2015). Considering some of the relatively 'hostile' non-garden sites where the Atala has been observed, we come to the conclusion that host plant availability is a keystone element, regardless of native status or other factors, such as nectar (Dennis et al., 2004).

Native plants may not always predict whether a species persists in a location and we were surprised that native nectar species, while desirable from an ecological perspective, were not always necessary or indicative of Atala butterfly persistence. Nevertheless, the uses of non-native cycads in particular may be an 'ecological trap' (Schlaepfer et al., 2002) because they draw the butterfly to use a host plant that may be detrimental in the long-term for species survival (Boughton, 1999; Halsch et al., 2020; Iles et al., 2018; Koi, 2016; Pulliam, 2016). The use of non-native plants has been shown to negatively impact some species, such as the widespread use of non-native milkweed species in an attempt to support the Monarch butterfly (Halsch et al., 2020; Majewska and Altizer, 2019).

In these cases, the location may become a 'sink,' or a dead end, for the butterfly population, especially if the non-native food plants prevent normal migratory behaviors, or cause detrimental physiological damage (Koi, 2016). In other situations, a species may be trapped in a location because of anthropogenic alterations to the surrounding matrix. Environmental clues that the species normally uses to assess suitability may lead to a poor life cycle decision; examples include using a host plant that prevents normal immature ecdysis (shedding skin), or a novel environment, such as a garden, located in an area where aerial mosquito spraying may take place, or a neighboring property uses pesticides (Bargar et al., 2020a, 2020b; Hoang et al., 2011).

5.4. *What is the current conservation status of the butterfly?*

The Atala butterfly is NOT state or federally listed because it was thought extinct when the Endangered Species Act was passed in 1973. We consider this fortunate because it has been possible for scientists and laypersons to move it between colonies without permits or other restrictions since it was rediscovered in 1979 (Culbert, 2016; Hammer, 1995; Koi, 2017, 2004; Smith, 2000). The Atala is listed as "S2" (Imperiled in Florida) by Florida Natural Areas Inventory (FNAI) due to our stochastic weather, and because of the butterfly's specialist diet. FNAI itself relied heavily on trained citizen scientists to monitor hundreds of species for their research (Jue and Daniels, 2015). In addition, all of the cycad species are in trouble globally and our native coontie is still rare in the wild.

Because of this unlisted status, citizen scientists were free to become fully engaged in helping a native species re-establish in its former territory as well as expand its range and distribution. The contribution of citizen science has been recognized more than ever as scientists are often understaffed, and underfunded (Schultz et al., 2017; DiCecco et al. 2021; Sidoti, B.J., et al., 2023). Comparing our presence-only data to iNaturalist data not only corroborates the current expanded range distribution of the Atala butterfly, it also highlights that the public is actively involved in conservation.

The NABA reintroduction program was started in early 2011 to establish new colonies by removing caterpillars from a botanical center in MDC, and NABA volunteers currently continue to participate in the program; this has benefitted the butterfly, but importantly, it has also helped the botanical garden by preventing heavy damage to their cycad collection, many of which are listed as endangered or threatened by conservation organizations. In addition, removing the voracious herbivore reduced the need for pesticides, increasing the survival of both removed immature stages, as well as perhaps increasing the possibility that the butterfly may self-disperse into other suitable locations. While there may be corridor connections within the individual counties from the public sites to the residential gardens, it is highly unlikely that an Atala butterfly in Miami-Dade County would successfully navigate to Broward or Palm Beach without human assistance, due to lack of sufficient habitats or safe corridors to get there.

6. Conclusion

All in all, our data sets indicate that the Atala is one of the few insects that has documented increases in population, range and distribution, including the silver-spotted skipper(Davies et al., 2005), Fender's blue (Bonoan et al., 2021) and even a few Monarch butterfly locales (Davis et al., 2021). Even with the very destructive hurricanes in 2004 & 2005, the annual NABA counts took place before the storms arrived, and Atala butterfly activity continued after the storms passed. The Atala evolved in the tropics with stochastic climes, which was one of the many factors we considered as possibly enabling Atala populations to weather the tropical storms. This data does not directly indicate a storm effect because the counts took place out of sync with the storms and we do not know how the hurricanes have affected the Atala populations indirectly in consequent years.

One of the original habitats for the Atala butterfly was the now Endangered pine rocklands in Miami-Dade County (Scudder, 1875), a naturally fire-driven ecosystem. Scudder wrote that "untold thousands [of Atalas] die in the frequent fires" and we know that fires may adversely affect the other small sedentary hairstreaks and organisms that still live there (Edwards, 2001; Figueroa et al., 2023). This ability to live in such a harsh environment may be its genetically predisposed toughness for living in places such as abandoned ruderal areas in metropolitan areas.

Regarding the trends in population increases, there is also an increase in participation in the NABA count, as well as an increase in NABA Chapters throughout Florida and an increased interest in participating in ways to help the at-risk butterflies in different communities. Citizen science participation has been recognized as a valuable contribution to data collection and well as offering new observations about insect behavior (Silvertown, 2009; Di Cecco et al., 2021), biodiversity (O'Brien et al., 2011; Ramírez-Restrepo and Halffter, 2013; Schultz et al., 2017; Huang et al., 2021; Plummer et al., 2023;), life cycles (Dennis et al., 2017; Schultz et al., 2017; Bonoan et al., 2021; Plummer et al., 2023;), as well as range and distribution (Davies et al., 2005; Forister et al., 2011; Nowicki et al., 2014). Our data sets also show that there is a quantifiable crash-eruption cycle for this butterfly, both on a fine-scale in residential gardens as well as in a coarse-scale in the annual NABA counts, that does not stop continued persistence in a site.

The late E.O. Wilson referred to insects as "the little things that run the world" (Wilson, 1987) and we hope that more citizens are joining the efforts to support the foundations of life by planting gardens for invertebrate wildlife. As has been written, "Butterflies are not grizzly bears" (Longcore and Osbourne, 2015)–providing for wildlife, butterflies in particular, does not require Herculean effort or acres of land, but each garden does provide much needed resources for species who cannot plant for themselves.

CRediT authorship contribution statement

Sandy Koi: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Adrian Figueroa:** Writing – review & editing. **Hong Liu:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Some locations cannot be released because they are private homes.

Acknowledgements

Counting butterfly populations is hard work. Great appreciation is given to the tri-county NABA volunteers who do the annual butterfly counts, and who have been instrumental in the recovery of the Atala, especially Jason Vollmer, Peggy Strumski, Teri Jabour, Barbara DeWitt, Linda Evans and Adam Skowronski for their help. We thank the many dedicated people who counted butterflies in their gardens for a year or longer. We sincerely thank Marilyn Griffiths, Tighe Shomer, Glenn Huberman and Susan Shapiro from Fairchild Tropical Botanic Garden. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2024.126689.

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