

Article

Using Citizen Science to Document Biodiversity on a University Campus: A Year-Long Case Study

Peter M. Baker , Brendon Samuels  and Timothy J. A. Hain 

Department of Biology, Western University, 1151 Richmond Street, London, ON N6A 3K7, Canada; bsamuel2@uwo.ca (B.S.); thain@uwo.ca (T.J.A.H.)

* Correspondence: pbaker26@uwo.ca

Abstract: Citizen science is a rapidly growing field, particularly among young scientists. In this case study, we review a year-long citizen science initiative hosted at Western University, Canada, which aimed to document and highlight biodiversity on campus while simultaneously seeking to improve community engagement with the environment. Using the popular citizen science platform iNaturalist, we facilitated data collection and community engagement through a combination of informal field surveys, undergraduate-level course assignments, social media, and passive data submission. Throughout the first year of the initiative, nearly 300 community members submitted 3716 observations of 1225 species, including observations of 103 species documented on iNaturalist for the first time in the region, and other species of ecological significance. This citizen science project underscores the strengths and utility of citizen science and provides a framework for other higher education institutions to develop similar initiatives.

Keywords: citizen science; biodiversity; iNaturalist



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1. Introduction

Citizen science, broadly defined as voluntary public participation in science, has grown substantially in popularity in recent decades. Citizen science is particularly useful for facilitating research on a large temporal and spatial scale and raising community awareness of science [1,2]. Engaging in research in the natural world offers various benefits to participants that can significantly improve their quality of life, including stress reduction, increased social cohesion, and improved physical and mental health [3]. Aside from the benefits to personal well-being, scientific projects involving community members are valuable for higher education institutions, especially those making strategic efforts to improve sustainability [4]. Indeed, increased interest in sustainability led an analytics firm conducting ranking assessments of worldwide higher education institutions to amend its methodology in 2023 by including a score for sustainability [5]. Further, because of their high density of educated people, academic campuses can be especially productive settings for hosting citizen science projects [6]. With the rise in the perceived importance of sustainability, spotlighting campus biodiversity through citizen science is a way for universities to improve research outcomes while gaining reputational benefits and meeting strategic priorities. The growth of the Campus Biodiversity Network [7] underscores the interest in documenting biodiversity on the campuses of higher education institutions.

Citizen science projects can be organized and implemented in a wide variety of ways depending on the needs and goals of each individual project. In general, citizen science projects can be categorized into three types: collaborative, co-produced, and participatory [8]. Collaborative citizen science includes projects that are developed by researchers and involve participants in multiple facets, such as data collection, data analysis, and development of methodology [8]. Co-produced citizen science includes projects where participants are involved at every stage of the project, from research question development

to the application of the results, and generally garner the highest degree of participation of the three groups [8]. Participatory citizen science includes projects where participants are involved only in data collection, and generally foster the lowest degree of participation [8]. Participatory citizen science can further be broken down into projects where data are collected through the passive submission of incidental observations, and others where participants are trained and guided on a data collection protocol. Regardless of the type of project, organizers of citizen science projects often face challenges in how to encourage participation and retain participants. Citizen science projects that generate the highest degree of initial participation tend to be those that are advertised broadly, appeal to the motivation of participants, and are accessible to a diversity of participants [9]. Sustained participation in citizen science projects is generally achieved when projects are supported by regular communication, the motivation of participants remains aligned with project goals, and participants are rewarded for their efforts [9]. Understanding the factors that influence levels of participation can ultimately influence the success of citizen science projects.

One of the largest and most widely utilized citizen science platforms is iNaturalist (www.inaturalist.org, accessed on 24 March 2024). iNaturalist is a web- and mobile-based social network platform that allows users to upload photos or audio recordings (referred to as ‘observations’) of individual organisms they encounter and to identify the observations of others. The taxonomic identification of observations in iNaturalist are determined by a combination of an automated species identification tool and/or manual identification by community members. Data submitted through iNaturalist can be useful to scientists and conservation practitioners as each observation is annotated with metadata such as date, time, location, taxonomic identification, and other user-defined fields. Further, iNaturalist is user-friendly, its data are publicly available, and it is widely used—especially among young scientists [6]. Indeed, 41.4 million observations of nearly 300,000 species were submitted to iNaturalist by over 1.1 million different users in 2023 according to iNaturalist’s 2023 Year in Review [10]. Data from iNaturalist have been analyzed by scientists to answer a variety of questions, including those pertaining to student learning and engagement [11,12], species distributions [13,14], and biodiversity [15–17]. iNaturalist has also been useful for facilitating the documentation of rare and invasive organisms [18–21].

Here, we outline and review the first year of a long-term citizen science project hosted at Western University in London, Ontario, Canada, titled the Biodiversity Inventory at Western (herein referred to as “the Inventory”). The goals of the Inventory were to (1) provide opportunities for campus users to develop or improve their sense of place and a connection to the campus grounds; (2) generate data that could be used in undergraduate teaching; (3) provide species occurrence data that could be used as a baseline, or to compare with historical data to examine ecosystem change; (4) create a framework for other institutions to develop similar initiatives. In this study, we reflect on what was achieved in the first year of the Inventory. We summarize the project’s results by reporting on the number of events run, the number of participants, retention of participants, and by highlighting observations of species documented for the first time in the region using iNaturalist and other species of ecological significance.

2. Materials and Methods

2.1. Study Area

Western University and its affiliate institutions (Huron University College, Kings University College, and formerly Brescia University College, hereafter referred to as “campus”) are located in London, Ontario, Canada. The campus is approximately 455 hectares (1120 acres) in area and is situated along the Thames River (Figure 1). Western University encompasses a variety of natural and semi-natural land cover types including deciduous forest, creeks, wetlands, meadows, and significant valleylands, many of which are adjacent to human-built features such as buildings, outdoor recreation areas, roads, and parking lots. In addition, the campus has several areas that are designated for biodiversity conservation. For example, the Sherwood Fox Arboretum on campus is a registered botanical garden

that features hundreds of native and exotic plantings. The campus grounds also extend into the Medway Valley Heritage Forest, which is recognized by the City of London as an Environmentally Significant Area.

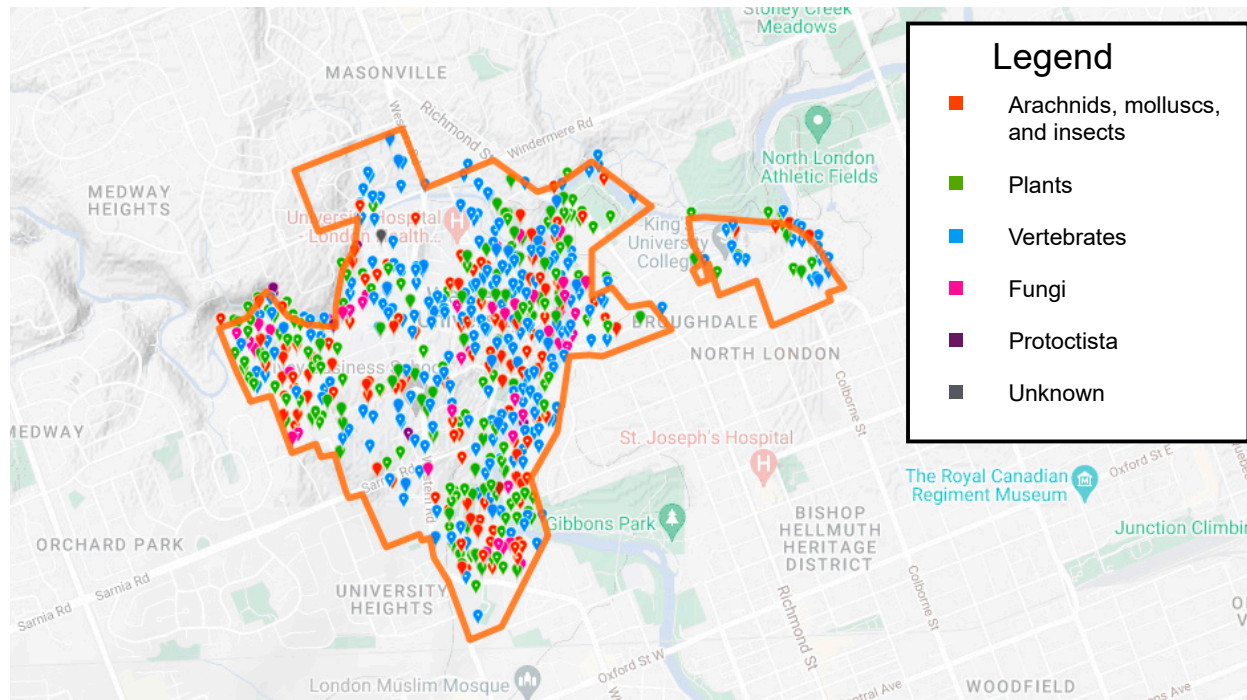


Figure 1. A map of London, Ontario, with the study area outlined in orange, produced by iNaturalist. Each pin represents an observation submitted to the Inventory, with the different colors representing different taxa.

2.2. Project Creation in iNaturalist

Using the iNaturalist website, we created a collection-type project with a project boundary that encompassed the grounds of Western University's main campus and its affiliates. The project boundary was created by manually tracing these properties in Google Earth Version 7.3.2 (Google 2019) and uploading the traced boundary as a KML file to the project on iNaturalist. Observations that are provided a taxonomic identification in iNaturalist are grouped into the following taxa: plants (Plantae), insects (Insecta), birds (Aves), mammals (Mammalia), fungi, amphibians (Amphibia), reptiles (Reptilia), ray-finned fishes (Actinopterygii), arachnids (Arachnida), mollusks (Mollusca), chromista, protozoans (Protozoa), other animals (Animalia), and unknown. Under the 'Observation Requirements' portion of the 'Project Details' page, we chose to include all taxa from all users regardless of whether they manually joined the project on iNaturalist. Observations are also tagged with a status indicator of data quality, either: Verifiable Observation, Needs ID, Research Grade, or Casual. Observations are considered to be Verifiable Observations (high quality) if they contain a date, location, a photo or audio recording, and are not depicting a captive/cultivated organism; observations of captive/cultivated organisms are considered Casual. Research Grade observations refer to those where at least two-thirds of community contributors agree on a species-level identification. Observations that are labelled as Needs ID either have not yet been identified by other users or cannot be identified with the media provided. Under 'Data Quality', we chose to include all observation types. The project page on iNaturalist can be accessed at <https://inaturalist.ca/projects/biodiversity-inventory-at-western> (accessed on 17 September 2024).

2.3. Project Design

Prior to the launch of the project, we carried out community consultations within the Department of Biology and with other stakeholders on campus (Office of Indigenous Initiatives, the Department of Geography, and Facilities Management). Feedback shared in these consultations helped to refine the scope, objectives, and rigor of this project. In particular, consultation with the curator of the Zoological Collections within the Department of Biology identified examples of rare species within the Collections that were historically collected from campus; these records helped to inform surveys that were to be carried out. We also acquired consent from the administration for Western University Facilities Management and Physical Plant offices for Western's affiliate colleges. By liaising with university staff and sustainability groups, the Inventory had an immediate audience for its data and additional promotional capacity for its events. The Inventory was also subject to a project agreement with Western Facilities Management under the Campus as a Living Lab program aimed at bringing together collaborations of faculty, staff, students, and community partners to support research and educational activities using outdoor spaces on campus [22].

A key component of implementing the Inventory was to ensure that the campus community received information to support participation. These details were explained to participants through an instructional video with demonstrations narrated by the project organizers. All information for participants, including the instructional video, was incorporated into a webpage on Western University's Department of Biology website (<https://www.uwo.ca/biology/community/biodiversity-inventory.html> (accessed on 17 September 2024)). This video familiarized participants with how to use the iNaturalist mobile interface and explained the rules for accessing green spaces on campus while limiting impacts to habitats, ensuring personal safety, and avoiding risks of encroachment and conflicts with wildlife. Institutional media coverage of the project helped to grow awareness among the campus community with the intention of increasing participation and understanding of the purpose behind the project (<https://news.westernu.ca/2022/04/western-biologists-crowdsources-biodiversity-data/> (accessed on 17 September 2024)).

Data collection for the Inventory officially commenced 1 April 2022. To facilitate data collection and community engagement, we hosted 14 informal BioBlitz-style events that included bird surveys, plant identification workshops, general ecological inventory collection, and other events that highlighted the importance of citizen science in the context of the Inventory (Table 1). Several events were hosted in collaboration with clubs at Western University and were open to all faculty and students, while others were either exclusive to undergraduate-level courses, or open to the general public (Table 1). Advertising for the events used social media accounts (Instagram and Twitter; Table S1), and the events appeared on an institutional calendar hosted by the office of Western Sustainability. Print posters were also used to promote the Inventory at events and within buildings across campus (Figure S1). Lastly, several undergraduate courses in the Faculty of Science with learning objectives that were relevant to the Inventory contributed to data collection either as a voluntary or mandatory course activity. These courses included Spatial Ecology & GIS (Geography 3224), Patterns in the Diversity of Life (Biology 3484), and Sustainability and the Environment (Integrated Science 2001).

Table 1. List and descriptions of events hosted as part of the Biodiversity Inventory at Western to facilitate data collection.

Event	Date (mm/dd/yy)	Description
Guided Birdwatching Hike	04/29/22	A guided hike focused on finding migratory birds in the MVHF behind Brescia University College. Open to all students and faculty.
Science Rendezvous	05/07/22	An annual all-day science festival hosted at Western University. Displayed a booth with live demonstrations of how to contribute to the project. Open to the general public.
Swift Night Out	05/31/22	Hosted in collaboration with Nature London at Huron University College to survey Chimney Swifts (<i>Chaetura pelagica</i>). Open to the general public.
Find the Nighthawk	—	An asynchronous contest to find and document breeding evidence of Common Nighthawk (<i>Chordeiles minor</i>) on campus. Open to all students and faculty.
Shad Camp	07/12/22	A 50-min presentation on environmental consulting with iNaturalist training, followed by a self-directed 30-min walk. Participants were high school-aged summer campers.
Western O-serves Bioblitz	09/12/22	Hosted in collaboration with Western Sustainability as part of orientation week programming. Open only to first year students.
ESA Day Bioblitz	09/18/22	A guided general biodiversity hike through the MVHF. Open to all students.
Biodiversity Hike	09/29/22	A general biodiversity hike hosted for an undergraduate philosophy course. Open only to individuals in this class.
Nocturnal Insect Survey	10/05/22	An event geared at documenting nocturnal biodiversity on campus using light traps. Open to all faculty and students.
Benthic Diversity Survey	10/17/22	An aquatic benthic diversity survey hosted for an undergraduate writing course. Open only to individuals in this class.
Plant Identification Hike	10/25/22	A guided hike through the MVHF focusing primarily on plant diversity. Open to all faculty and students.
Nature Canada COP 15	11/30/22	Advertised the inventory with live demonstrations as part of the NatureBUS tour for COP 15.
Winter Bird Count	12/14/22	A guided hike focused on finding winter birds throughout campus. Open to all faculty and students.
Plant Identification Hike	03/29/23	A guided hike through the MVHF focusing primarily on plant diversity. Open to all faculty and students.

Note: MVHF, Medway Valley Heritage Forest; ESA, Environmentally Significant Area.

2.4. Data Extraction

Data for the Inventory were downloaded from iNaturalist on 7 April 2023. One week was allotted past the end date of the project before data were downloaded to allow for any late observations to be submitted. From the project page, data were extracted by navigating to the Observations page and selecting Export Observations. All observation types were included in the download. However, only Verifiable Observations were included in the presentation of results in this paper. To identify species of conservation concern found within the study area, we cross-referenced our dataset with species listed under Ontario's Endangered Species Act [23] and Schedule 1 of Canada's Species at Risk Act [24]. We similarly referenced Ontario's Invading Species Awareness Program [25] to identify priority invasive species occurring in the study area.

3. Results

3.1. Participation

Throughout the first year of the Inventory (1 April 2022–31 March 2023), 3716 observations spanning 1225 species were submitted by 295 different observers. Of these contributions, 3606 observations (97.0%) of 1182 species were designated as Verifiable Observations, 2315 observations (62.3%) of 837 species were considered Research Grade, and 111 observations (3.0%) of 63 species were designated as Casual observations at the time of data extraction. Among the observers that contributed to the first year of the Inventory, 98 (33.2%) were using iNaturalist for the first time and 32.6% of these new users continued to make observations more than a week after their first post. Event and course

participation contributed to 20.4% (11.3% from events, 9.1% from undergraduate courses) of total observations in the Inventory (Table 2) with the remaining observations being submitted by individual users independently.

Table 2. Participation in events or courses as part of the Biodiversity Inventory at Western to facilitate data collection.

Event/Course	Number of Observations	Number of Taxa	Number of iNaturalist Observers	Total Number of Participants or Class Size
Guided Birdwatching Hike	22	18	4	10
Science Rendezvous	29	19	5	>100
Swift Night Out	—	—	—	5
Find the Nighthawk	—	—	—	—
Shad Camp	81	40	12	70
Western O-serves Bioblitz	19	19	6	>100
ESA Day Bioblitz	32	29	6	30
Biodiversity Hike	10	9	5	20
Nocturnal Insect Survey	139	79	10	20
Benthic Diversity Survey	12	11	1	10
Plant Identification Hike	48	36	7	10
Nature Canada COP 15	—	—	—	>50
Winter Bird Count	3	3	1	10
Plant Identification Hike	23	20	6	15
Geography 3224	33	5	NA	NA
Integrated Science 2001	58	27	22	34
Biology 3484	248	64	59	150

Note: Geography 3224 had all of its observations submitted under a course account, so only one iNaturalist account was used for all submissions. For entries with “—”, data were not available.

3.2. Natural History Observations

The majority of observations submitted were of plants and insects (1148 [30.9%] and 994 observations [26.7%], respectively), while protozoa, amphibians, and reptiles were observed the most infrequently (Figure 2). The greatest number of taxa observed were insects (543 different taxa [44.3%]) whereas amphibians and reptiles had the fewest taxa observed (4 [0.3%] and 6 species [0.5%], respectively; Figure 3). Notably, a substantial number of the records collected by the Inventory represented taxa that were submitted to iNaturalist for the first time in the region. Of the 1182 Verifiable taxa observed during the first year of the Inventory, 594 taxa were observed for the first time on iNaturalist within the campus boundary. Further, 103 taxa were observed in Middlesex County for the first time on iNaturalist, and 3 taxa were observed for the first time in Ontario on iNaturalist (Table 3).

Table 3. List of taxa observed for the first time in Middlesex County on iNaturalist during the first year of the Biodiversity Inventory at Western.

Common Name	Scientific Name	Taxon
	Naiedidae	Animalia
Agrarian Sac Spider	<i>Cheiracanthium inclusum</i>	Arachnida
Squirrel Mange Mite	<i>Notoedres centrifera</i> *	Arachnida
False Pirate Spider	<i>Platnickina tinctoria</i> †	Arachnida
	<i>Ganoderma lobatum</i>	Fungi
Foetid Parachute	<i>Gymnopus foetidus</i>	Fungi
Spreading Yellow Tooth	<i>Hydnophlebia chrysorhiza</i>	Fungi
Birch Woodwart	<i>Jackrogersella multiformis</i>	Fungi
Decorated Pholiota	<i>Leucopholiota decorosa</i>	Fungi
Rooting Shank	<i>Oudemansiella radicata</i>	Fungi

Table 3. Cont.

Common Name	Scientific Name	Taxon
Powdery-margined Cryptic Shade Lichen	<i>Physciella chloantha</i>	Fungi
Leopard Earthball	<i>Sclerodermaareolatum</i>	Fungi
Birch Witch's-Broom	<i>Taphrina betulina</i>	Fungi
	<i>Tirchia varia</i>	Fungi
Deer-colored Trametes	<i>Trametopsis cervina</i>	Fungi
Lesser Maple Leafroller	<i>Acleris chalybeana</i>	Insecta
Marbled Button	<i>Acleris maccana</i>	Insecta
Orange-legged Miner Bee	<i>Adrena hippotes</i>	Insecta
Reddish Aethes	<i>Aethes biscana</i>	Insecta
Curved-lined Agonopterix Moth	<i>Agonopterix curvilineella</i>	Insecta
Venerable Dart	<i>Agrotis venerabilis</i>	Insecta
	<i>Amblysellus curtisii</i>	Insecta
Agrimony Anacamptis Moth	<i>Anacamptis agrimoniella</i>	Insecta
	<i>Anametis granulata</i>	Insecta
Red-headed Ancyliis Moth	<i>Ancyliis muricana</i>	Insecta
	<i>Anthomyia procellaris</i>	Insecta
Tennessee Collared Ant	<i>Aphaenogaster tennesseensis</i>	Insecta
Cowpea Aphid	<i>Aphis craccivora</i>	Insecta
	<i>Arthaldeus pascuellus</i>	Insecta
	<i>Axarus festivus</i>	Insecta
	<i>Baris</i>	Insecta
	<i>Bibio articulatus</i>	Insecta
	<i>Byturus</i>	Insecta
Potato Mirid	<i>Closterotomus norvegicus</i> [†]	Insecta
	<i>Compsobata univittata</i>	Insecta
Winter Midges	<i>Diamesa</i>	Insecta
Many-spotted Dichomeris Moth	<i>Dichomeris punctipennella</i>	Insecta
Willow Weevils	<i>Dorytomus</i>	Insecta
	<i>Draeculacephala antica</i>	Insecta
Sharp-headed Sharpshooter	<i>Draeculacephala robinsoni</i>	Insecta
	<i>Drymus</i>	Insecta
	<i>Dryomyza</i>	Insecta
	<i>Ectobius lucidus</i> [†]	Insecta
	<i>Elampus</i>	Insecta
Marsh Ground Beetles	<i>Elaphrus</i>	Insecta
Pale Enargia	<i>Enargia decolor</i>	Insecta
	<i>Eustictus</i>	Insecta
	<i>Euthycera flavescens</i>	Insecta
Wafer Ash Leafminer Moth	<i>Fomoria pteliaeella</i>	Insecta
	<i>Gasteruption assectator</i>	Insecta
	<i>Glipa oculata</i>	Insecta
	<i>Glypta</i>	Insecta
F-winged Barklouse	<i>Graphopsocus cruciatus</i> [†]	Insecta
Emergent Mayfly	<i>Hexagenia bilineata</i>	Insecta
	<i>Hydrophoria</i>	Insecta
	<i>Isotominiae</i>	Insecta
Hermit Sphinx	<i>Lintneria eremitus</i>	Insecta
	<i>Liriomyza eupatoriella</i>	Insecta
Blue-green Bottle Fly	<i>Lucilia coeruleiviridis</i>	Insecta
	<i>Maccaffertium terminatum</i>	Insecta
	<i>Machimus notatus</i>	Insecta
	<i>Marmara fraxinicola</i>	Insecta
Mulsant's Water Treader	<i>Mesovelia mulsanti</i>	Insecta
	<i>Messatoporus</i>	Insecta
	<i>Microvelia americana</i>	Insecta
	<i>Neopachygaster</i> *	Insecta

Table 3. Cont.

Common Name	Scientific Name	Taxon
Mantid Shoreflies	<i>Ochthera</i>	Insecta
Orange-tufted Oneida Moth	<i>Olethreutes quadrifidum</i>	Insecta
	<i>Oneida lunulalis</i>	Insecta
	<i>Pachytychius</i>	Insecta
Ash Tip Borer Moth	<i>Papaipema furcata</i>	Insecta
	<i>Pediopsoidea distinctus</i>	Insecta
	<i>Pedontus</i>	Insecta
Chocolate-and-cream Sedge	<i>Platycentropus radiatus</i>	Insecta
Black-shaded Platynota Moth	<i>Platynota flavedana</i>	Insecta
Marsh Meadow Grasshopper	<i>Pseudochorthippus curtipennis</i>	Insecta
	<i>Pseudotephritina</i>	Insecta
Sociable Renia Moth	<i>Renia factiosalis</i>	Insecta
	<i>Rhagovalia obesa</i>	Insecta
	<i>Rhyacophila</i>	Insecta
	<i>Scathophaga furcata</i>	Insecta
Strawberry Root Weevil	<i>Sciaphilus asperatus</i> [†]	Insecta
Simple Wave	<i>Scopula junctaria</i>	Insecta
Oblique-banded Pond Fly	<i>Sericomys chrysotoxoides</i>	Insecta
	<i>Strauzia vittigera</i>	Insecta
	<i>Tasgius melanarius</i> [†]	Insecta
Florida Tetanolita Moth	<i>Tetanolita floridana</i>	Insecta
Obscure Pygmy Grasshopper	<i>Tetrix arenosa</i>	Insecta
	<i>Therion circumflexum</i>	Insecta
	<i>Trepobates inermis</i> *	Insecta
Cave Bristletail	<i>Trigonophthalmus alternatus</i>	Insecta
	<i>Triplax aenea</i>	Insecta
	<i>Xantholinini</i>	Insecta
	<i>Orthops</i>	Insects
Hedgehog Slug	<i>Arion intermedius</i> [†]	Mollusca
Spider Flower	<i>Cleome houtteana</i> [†]	Plantae
Hazel Dodder	<i>Cuscuta coryli</i>	Plantae
Chinese Forget-Me-Not	<i>Cynoglossum amabile</i> [†]	Plantae
Wood Bristle-Moss	<i>Lewinskya affinis</i>	Plantae
Russian Sage	<i>Salvia × floriferia</i> [†]	Plantae
Clary	<i>Salvia sclarea</i> [†]	Plantae
	<i>Diderma</i>	Protista
	<i>Tulasnella aurantiaca</i>	Protista

Note: Taxa with an asterisk (*) were observed for the first time in Ontario on iNaturalist. Taxa with a dagger (†) are considered non-native to the region. Only Verifiable observations were included in this table.

From the 3606 verifiable observations submitted within the first year of the Inventory, many species were documented that are a priority for conservation, either because they are listed as being at risk of extinction, or they are invasive species that can impact native biodiversity. We identified 22 Species at Risk that are listed under the Ontario Endangered Species Act and/or Schedule 1 of the Canadian Federal Species at Risk Act [23,24] (Table 4). Nineteen of those species at risk were present during their respective breeding seasons, while three species (Golden-winged Warbler [*Vermivora chrysoptera*], Olive-sided Flycatcher [*Contopus cooperi*], and Canada Warbler [*Cardellina canadensis*]) were observed during their migration. In addition, 252 out of the 1225 (20.6%) species documented were non-native; 20 of which are considered to be invasive according to Ontario's Invading Species Awareness Program [25] (Table 5).

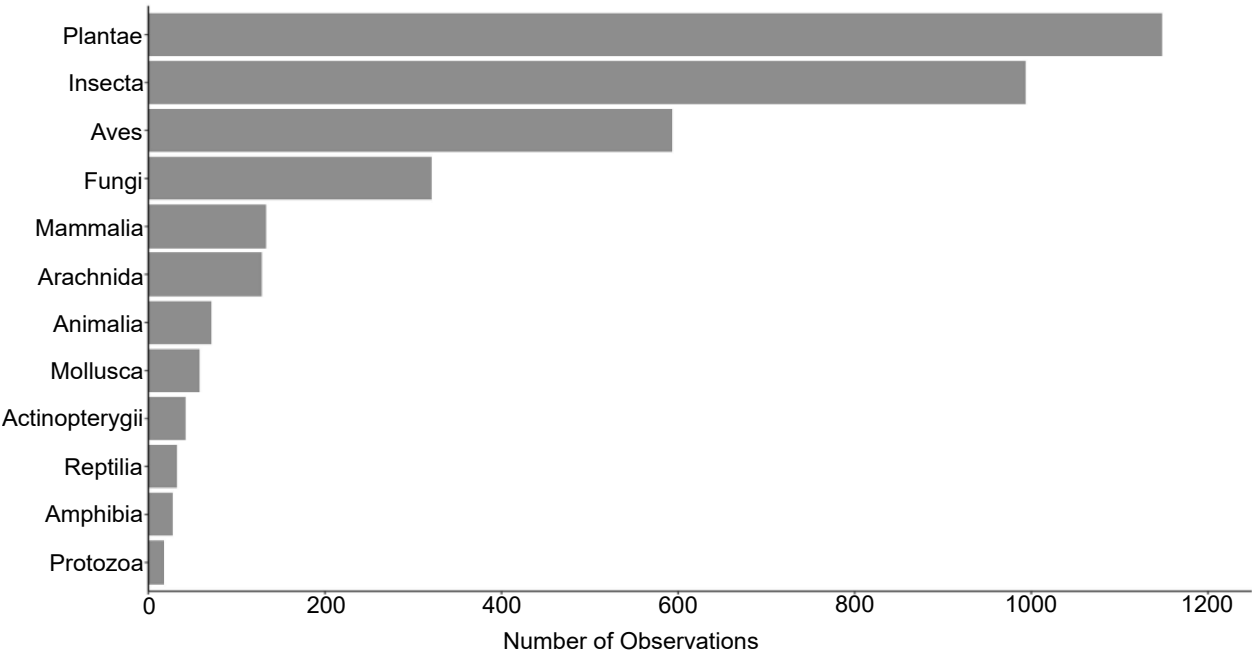


Figure 2. Number of observations by taxon submitted to the Biodiversity Inventory at Western between 1 April 2022 and 31 March 2023. Note: Only Verifiable observations were included in this figure.

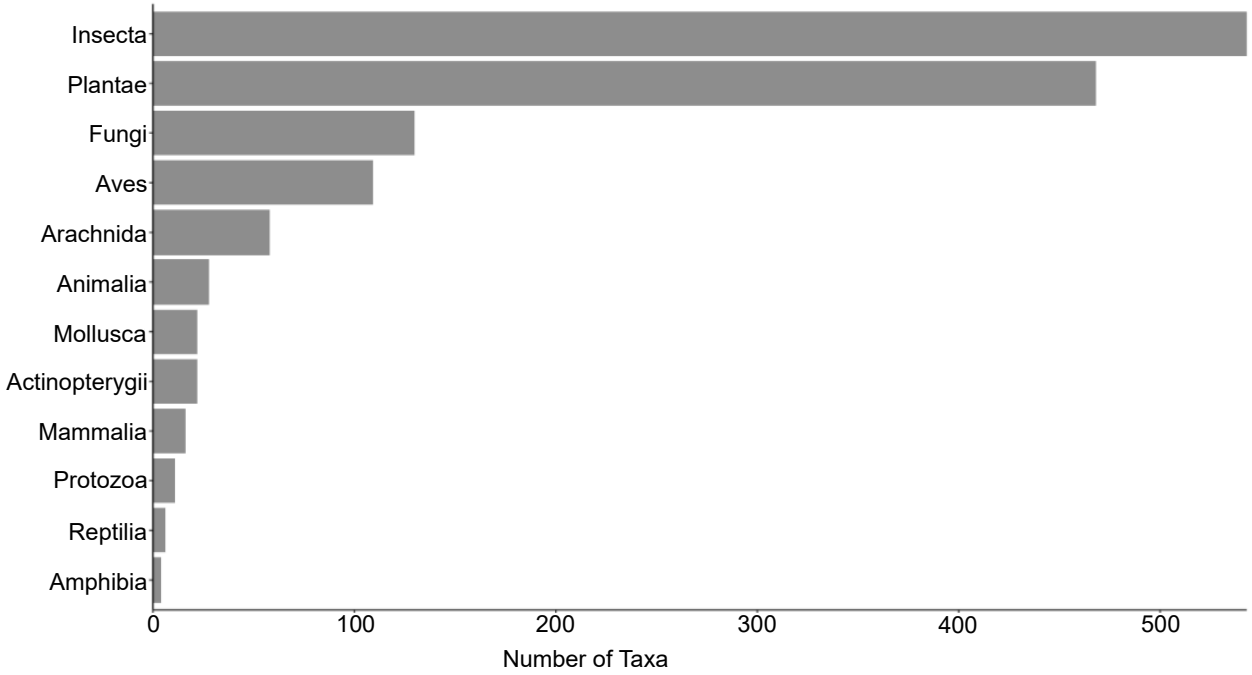


Figure 3. Number of taxa by taxon submitted to the Biodiversity Inventory at Western between 1 April 2022 and 31 March 2023. Note: Only Verifiable observations were included in this figure.

Table 4. List of Species at Risk observed at Western University during the first year of the Biodiversity Inventory at Western.

Common Name	Scientific Name	Status	
		SARA	ESA
Spiny Softshell	<i>Apalone spinifera</i>	Endangered	Endangered
Green Dragon	<i>Arisaema dracontium</i>	Special Concern	Special Concern
Canada Warbler [†]	<i>Cardellina canadensis</i>	Threatened	Special Concern
Chimney Swift	<i>Chaetura pelagica</i>	Threatened	Threatened
Snapping Turtle	<i>Chelydra serpentina</i>	Special Concern	Special Concern
Common Nighthawk	<i>Chordeiles minor</i>	Special Concern	Special Concern
Olive-sided Flycatcher [†]	<i>Contopus cooperi</i>	Special Concern	Special Concern
Eastern Wood-Pewee	<i>Contopus virens</i>	Special Concern	Special Concern
Monarch	<i>Danaus plexippus</i>	Special Concern	Special Concern
Greenside Darter	<i>Etheostoma blennioides</i>	Special Concern	No status
Northern Map Turtle	<i>Graptemys geographica</i>	Special Concern	Special Concern
Bald Eagle	<i>Haliaeetus leucocephalus</i>	No status	Special Concern
Barn Swallow	<i>Hirundo rustica</i>	Threatened	Special Concern
Wood Thrush	<i>Hylocichla mustelina</i>	Threatened	Special Concern
Butternut	<i>Juglans cinerea</i>	Endangered	Endangered
Eastern Milksnake	<i>Lampropeltis triangulum</i>	Special Concern	No status
Wavy-rayed Lampmussel	<i>Lampsilis fasciola</i>	Special Concern	Threatened
Dense Blazing Star *	<i>Liatris spicata</i>	Threatened	Threatened
Cucumber Tree *	<i>Magnolia acuminata</i>	Endangered	Endangered
Silver Shiner	<i>Notropis photogenis</i>	Threatened	Threatened
Common Hoptree	<i>Ptelea trifoliata</i>	Special Concern	Special Concern
Golden-winged Warbler [†]	<i>Vermivora chrysoptera</i>	Threatened	Special Concern

Note: SARA, Federal Species at Risk Act (Government of Canada 2023); ESA, Ontario Endangered Species Act (Government of Ontario 2023). Species with an asterisk (*) are suspected to be either planted or spreading from cultivated plants. Species with a dagger (†) were only observed during their migration and are not suspected to be breeding on campus. Only Verifiable observations were included in this table.

Table 5. List of species observed at Western University during the first year of the Biodiversity Inventory at Western that are classified as invasive according to Ontario's Invading Species Awareness Program (2023).

Common Name	Scientific Name
Goutweed	<i>Aegopodium podagraria</i>
Emerald Ash Borer	<i>Agrilus planipennis</i>
Garlic Mustard	<i>Alliaria petiolata</i>
Japanese Barberry	<i>Berberis thunbergii</i>
Quagga Mussel	<i>Dreissena bugensis</i>
Zebra Mussel	<i>Dreissena polymorpha</i>
Winged Euonymus	<i>Euonymus alatus</i>
Common Ivy	<i>Hedera helix</i>
Himalayan Balsam	<i>Impatiens glandulifera</i>
Yellow Iris	<i>Iris pseudacorus</i>
Amur Honeysuckle	<i>Lonicera mackii</i>
Morrow Honeysuckle	<i>Lonicera morrowii</i>
Tatarian Honeysuckle	<i>Lonicera tatarica</i>
Common Earthworm	<i>Lumbricus terrestris</i>
Spongy Moth	<i>Lymantria dispar</i>
Purple Loosestrife	<i>Lythrum salicaria</i>
Japanese Knotweed	<i>Reynoutria japonica</i>
Common Buckthorn	<i>Rhamnus cathartica</i>
Lesser Periwinkle	<i>Vinca Minor</i>
European Swallow-Wort	<i>Vincetoxicum rossicum</i>

Note: Only Verifiable observations were included in this table.

4. Discussion

Through the Inventory, we documented numerous species occurring within the study area that may represent priorities for conservation management, either because they are at

risk of extirpation or extinction, are keystone species, are indicator species, or are introduced invasive species that can impact native biodiversity. Most observations of Species at Risk were recorded in natural or semi-natural habitats on campus, primarily along trails adjacent to the Thames River or in the Medway Valley Heritage Forest ESA. Concerningly, some of the Species at Risk that were observed in the developed areas of campus were of deceased birds, primarily Barn Swallows (*Hirundo rustica*), from presumed collisions with building windows. Most observations of invasive species were recorded within or near the natural or semi-natural areas of campus, with common buckthorn (*Rhamnus cathartica*) being recorded most frequently.

Many authors have noted the power of citizen science and iNaturalist for documenting rare species [18,19,26,27]. In this project, 103 taxa were observed for the first time on iNaturalist in Middlesex County, and 3 taxa were observed in Ontario for the first time on iNaturalist. Most of the new taxa for Middlesex County were insects (82), whose documentation could be attributed in-part to an insect-focused survey held as part of the Inventory, either directly through participation at the event or indirectly as community members continued to observe insects using learned techniques after the event.

We did not collect voucher specimens associated with any observations made during this study. Documentation of rare species occurrence obtained through citizen science methods, such as photographs taken by participants of specimens in the wild, may be of variable quality that falls short of providing robust evidence needed to confirm rare species occurrence. However, we found that the contribution of such records can alert taxonomic and conservation experts in research and iNaturalist user communities, which may then result in further confirmatory studies such as site visits and sample collection. This was the case for some of the rare species' records captured by the Inventory that attracted attention from naturalists specializing in those species (e.g., Hazel Dodder [*Cuscuta coryli*]), and it is also a practice now used by conservation authorities such as the Natural Heritage Information Centre of Ontario. Data quality can be improved by ensuring participants are informed about how to take proper photographs to support species identification. Positive identifications should be screened using reputable indices. For instance, some rare species of mussels and fungi may not be discerned from visual characteristics alone, and additional genetic testing may be required in such cases to confirm a positive identification.

One set of outcomes from the Inventory has involved translating records of these species of conservation concern on campus into recommendations for future site-specific environmental stewardship activities, including the following: (1) further surveys for Species at Risk in natural and artificial habitats on campus; (2) removal of invasive plant species from woodlots and roadsides; (3) monitoring and management of risks associated with emerging tree pests and diseases; and (4) alignment of the timing of human activities (e.g., landscaping, construction, building maintenance) around sensitive periods for species that are present. In each case, collaboration with the Facilities Management staff, as well as partnering instructors and clubs on campus, has been essential for mobilizing evidence-based solutions to achieve environmental and pedagogical benefits. Records from the Inventory have also informed coordinated activities with external partners, such as the local conservation authority, to recover eggs from vulnerable nests of Species at Risk turtles in the study area to promote their breeding success.

Organizers of citizen science projects often face challenges in how to encourage community participation and how to retain participants once they become involved [28]. In the first year of the Inventory, we found that events with the greatest participation were ones designed to maximize opportunities for participants to submit observations with high-quality photos that were correctly identified. These events had experienced leaders and focused on species that would remain stationary for photos, such as plants and insects that had landed on illuminated sheets. By offering knowledgeable guides, these events delivered on expectations that participants would learn to identify species and take good photos for their enjoyment. By meeting expectations, participants have enhanced enthusiasm for a project and may be more likely to continue to participate in the future [29].

Citizen science projects aspire to have a large community of participants who continue to be involved in the project year-after-year, but retention rates for such projects are often not reported (e.g., [30]). The one-week retention rate of participants in the Inventory (32.6%) was lower than the year-to-year retention rates in some published natural science projects (45–55%) [31]. Thus, to increase participant retention in the future, the Inventory has established a series of guided walks on campus during the school year, with a mailing list that alerts individuals to these upcoming events. Further, future projects may wish to implement a survey for participant knowledge, motivation, and satisfaction to gain a better understanding of the factors influencing engagement.

An unexpected benefit of establishing the Inventory was that it created organizational capacity to support our institution participating in broader community outreach events. In 2023, London, Ontario participated for the first time in the City Nature Challenge [32], an international event in which cities compete to observe the most species within their borders over a weekend in April. The local organizer of the City Nature Challenge knew who to contact to get Western University involved, and that facilitated the participation of the campus community.

Knowledge gained and relationships developed through the first year of the Inventory may provide opportunities for continuing and expanding the program in the future. Additional targeted surveys during seasonal timing windows may help to fill gaps in the current Inventory dataset, particularly where the occurrence of species with historical records was expected but not recorded. To build upon existing species occurrence data, surveys may be carried out to estimate the abundance of priority species, and to characterize local distribution and habitat use (e.g., breeding bird surveys). Future research could compare current data collected by the Inventory with historical data to track changes in the occurrence of rare species in the study area. For example, Western Sustainability has requested that the Inventory collect species occurrence data from ongoing ecological restoration projects to measure the success of those projects over the long-term. Sources of baseline data on species occurrence could perhaps include records accompanying specimens in the Western University Department of Biology's Zoological Collections that were collected from campus, as well as datasets from previous surveys carried out as part of research and teaching activities or supporting environmental impact studies associated with past development and infrastructure projects.

Since individuals and groups participating in the Inventory were introduced to iNaturalist, their sustained use of the platform continues to contribute data to the Inventory itself as well as to other projects in the local community, such as the City Nature Challenge and collection projects focused on monitoring specific taxa, geographic locations, and sources of wildlife mortality. An important area for social science research could be to explore long-term patterns in use of iNaturalist and awareness of biodiversity and co-benefits to human wellbeing beyond participating in projects like the Inventory. Many ongoing initiatives on Western University's campus and in the City of London are linked to encouraging and appreciating native biodiversity, such as gardening for pollinators, issuing nature prescriptions, and documenting wildlife in public parks and natural areas. A variety of organizations in the community have begun incorporating iNaturalist into programming with youth and adults. Broader awareness of iNaturalist as a tool for citizen science may enhance engagement and information produced by these initiatives and cultivate greater appreciation and conservation of local biodiversity.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/conservation4030032/s1>, Figure S1: Promotional poster for the Biodiversity Inventory at Western; Table S1: Links to social media accounts used to advertise the Biodiversity Inventory at Western.

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