

Article

The Role of Citizen Science in Conservation under the Telecoupling Framework

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Abstract: Citizen science is increasingly utilized to empower people to participate in conservation work and research. Despite the profusion of citizen science projects in conservation, many lacked a coherent analytical framework for understanding broad-scale transnational human–species interactions. The telecoupling framework provides a means to overcome this limitation. In this study, we use the monarch butterfly, a migratory species of high conservation value, to illustrate how citizen science data can be utilized in telecoupling research to help inform conservation decisions. We also address the challenges and limitations of this approach and provide recommendations on the future direction of citizen-based projects to overcome these challenges. The integration of citizen-based science and the telecoupling framework can become the new frontier in conservation because the applications of citizen science data in distant human–environment relationships have rarely been explored, especially from coupled human and natural systems (CHANS) perspectives.

Keywords: monarch butterfly; citizen science; migratory species; telecoupling

1. Introduction

Humans are the most influential agent of environmental change in the Anthropocene [1]. Our ecological footprints have reached all corners of the planet [2]. Consequently, many species have been adversely impacted [3,4]. While human impacts on the environment are often detrimental and contribute significantly to irreversible consequences such as climate change and biodiversity loss [5], the number of people who act as a positive force toward a desirable and sustainable future is also growing, with organizations, government agencies, and volunteers participating in conservation efforts increasing each year.

Citizen science, by which researchers collaborate with people to conduct studies [6], is a positive human influence that is growing rapidly in support of many disciplines, particularly in conservation and environmental research. Citizen science empowers any individual, including both professionally trained scientists and amateur citizens, to make a direct contribution to conservation and research.

In biological conservation, there is a long history of incorporating citizen science. It can be traced back to the 1950s, when Fred Urquhart and his hundreds of volunteers placed tags on monarch butterflies. This eventually led to the discovery of wintering locations of the monarch butterfly in Michoacán, Mexico [7]. Since then, the application of citizen science in biological conservation has continued to evolve [8]. For example, recent developments of affordable mobile computing and

communication technologies increase the potential and ability of citizens to collect and share data [9]. Information created and disseminated by citizens via volunteered geographic information (VGI), a web-based mapping interface, has been widely used in conservation mapping, which facilitates the enhancement, updating, and completion of many spatial datasets for research [10,11]. Public databases with data collected largely by citizens (e.g., eBird, eButterfly, iNaturalist) have been increasingly used by researchers for conducting studies [12–14]. Moreover, citizen science provides opportunities for gathering unique information, such as traditional knowledge and local needs and conditions, by and from local people who are often more aware of the surrounding situations than outsiders [15–17].

Citizen science can increase our understanding of coupled human and natural systems (CHANS) while engaging the public at local, regional, and global scales to study their environment. For example, citizen-contributed data from the New York Breeding Bird Atlas detected the potential of colonization, extinction and absence of bird species due to forest fragmentations [18]. Involving citizen science in land-use management and conservation practices can usually lead to more effective outcomes because it raises awareness and garners support of the project among the public. The growing trend of citizen science has the potential to provide CHANS a world audience. The studies of citizen science and spatial analytical techniques are rapidly moving towards a “Big Era”, where nearly everything in day-to-day life will be able to be coupled and connected [6,8–17].

The telecoupling framework is an integrated analytical tool for understanding CHANS over distances [19,20]. Telecoupling research evaluates distant interactions between human and natural systems [20,21]. Because citizen science has been applied to a wide range of CHANS topics [10,11,22,23], it should have a high potential to synergize with telecoupling research. Nevertheless, previous studies that adopted the telecoupling framework rarely incorporated citizen science or citizen-based data. Moreover, telecouplings of migratory species are one of the least studied processes [24].

In this study, we aim to demonstrate how citizen science can be applied in different locations to conservation research under the lens of the telecoupling framework, and to explore the potential application of citizen-based data to help resolve some of the challenges in telecoupling research previously proposed. We accomplished this by using a migratory species of high conservation value, the monarch butterfly (*Danaus plexippus*), as an example and incorporating citizen-based data into the telecoupling framework. Previous studies on migratory species mostly focused on either the environmental or the social dimension alone [25,26]. Spatially, these studies often focused on local populations within a small study area or on a section of the species’ migration pathway. However, because species migration takes place across broad regions and over a long distance, understanding the interaction between the human and migratory species requires broad-scale studies that examine multiple distant sites [27,28]. We began by providing an overview of the components of the telecoupling framework, and then demonstrated how citizen science data can be used to quantify and analyze each component of the telecoupling framework.

2. Overview of Telecoupling Framework and Citizen Science for Monarch Butterflies

2.1. Telecoupling Framework

Telecouplings are interactions between humans and environment that occur over long distances [20,21]. Different sites under the telecoupling framework can be treated as different coupled human and natural systems to clarify the relationships across distant sites and to help us understand the systems at different spatial scales [29]. The telecoupling framework consists of five interconnected components: systems, agents, flows, causes and effects [29]. Systems are classified into sending, receiving or spillover systems based on the directions of the dynamic flows (e.g., movement of energy, organisms, materials and information, etc.) between the systems. Agents represent the decision-making entities (e.g., governments, tourists, etc.) that affect the flows. Cause are the factors that generate the telecouplings, while effects are consequences (including feedback) from the telecouplings.

Although the telecoupling framework is only developed recently in the last 5 years, there have already been a number of applications to address human–environment related issues in a variety of topics [30–32], including species invasion [20], land use change [33], ecosystem services [34], energy [35], forest management [36] and migratory species conservation [26,34,37,38]. Applications of the telecoupling framework are also filling research gaps in sustainable resource management, such as the spillover systems [39].

The telecoupling framework has also been applied to study relationships between human and migratory species. For example, Hulina et al. (2017) applied the telecoupling framework to study migratory species of Kirtland’s warbler (*Setophaga kirtlandii*) and illustrated that the migration-caused energy and biological flows affected ecosystem services at distant locations [25]. In this study, we will demonstrate the potential of using citizen-based data to derive large-scale databases and study the hidden linkages across distant CHANS under the telecoupling framework.

2.2. Case Study Species: Monarch Butterfly

We chose the monarch butterfly as a case study species to demonstrate the integration of citizen science in the telecoupling framework for understanding distant CHANS. The monarch butterfly is an iconic and highly studied migratory species that is heavily affected by human activities, such as logging, land-use change, climate change, pesticide application and collisions with automobiles [40]. In North America, the migration of the monarch butterfly is divided by the Rocky Mountains, creating the east and the west migration routes. Each year, monarch butterflies migrate ~4500 km between overwintering sites in central Mexico and breeding sites in northeastern North America (Figure 1). Most monarch butterflies in the east group migrate from southern Canada and the northern United States to the mountains of central Mexico to overwinter, whereas monarch butterflies west of the Rocky Mountains migrate to coastal California to overwinter (Figure 1). The seasonal migration pattern for the monarch butterfly is characterized by northward migration during the spring season, and southward migration during the fall season. After the spring migration, monarch butterflies spend the summer season in northern United States. During the winter season following the fall migration, monarch butterflies concentrate in central Mexico [7,41]. The monarch butterfly has suffered a rapid population decline in recent decades; according to a recent World Wide Fund for Nature (WWF) report, the monarch butterfly population has reached an all-time low over the past 25 years [40]. Conservation efforts on the long-term survival of the species include the North American Monarch Conservation Plan, which provides a framework for conserving monarch butterfly breeding and overwintering habitats [37]. As the milkweed (*A. Syriaca*) is the primary host plant of the monarch butterfly over the North America continent [42], the North American Monarch Conservation plan also calls for the public and local agencies to protect the species. Restoring milkweed-breeding habitat is one of the most important conservation strategies for the monarch butterfly, especially in the breeding areas in the central United States. Restoration potential should also be considered for areas surrounding the monarch migration pathway. However, the implementation of such conservation strategy is challenging because a large proportion of these areas are private land.

The monarch butterfly is an ideal species for this study because: (1). The ecosystem services provided by the monarch butterfly are estimated to offer up to \$127 million in economic value per year, and the habitat in Mexico alone provides up to an estimated \$13 million of benefits to the United States and Canada annually [38]. (2) People in the United States are estimated to be willing to pay \$4.78 to \$6.64 billion for the monarch conservation program [43], which will greatly enhance surrounding ecosystem services and functions [44]. (3) The pathways of the migration are associated with multiple country jurisdictional borders, which capture different values in cultural ecosystem services. Different conservation strategies across various countries along the migration pathway play a key role in maintaining and conserving the monarch butterfly population. (4) The monarch butterfly has a long migration distance across many geographic regions. The massive migration of the monarch butterfly is one of the “most spectacular natural phenomena” at the global scale [44,45]. Compared

to most migratory birds, butterflies are more exposed to human dimensions, have closer interactions with the lands, and are less resilient to regional weather and climate change [46]. (5) Different land-use strategies affect the milkweed land coverage [47,48].

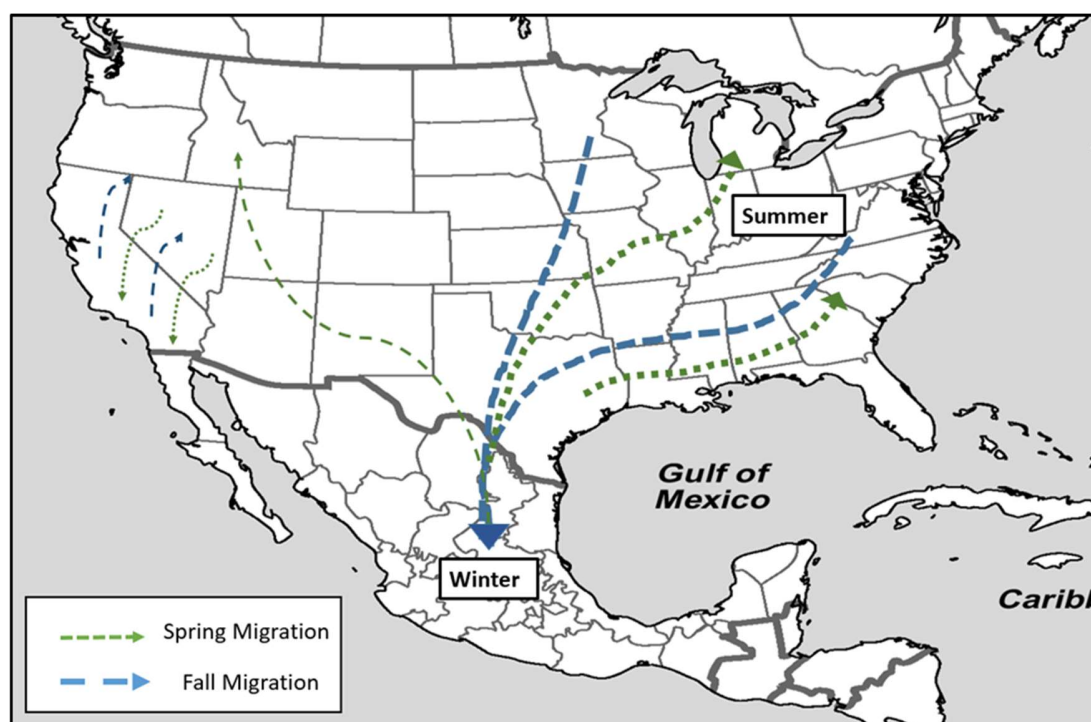


Figure 1. Monarch butterfly migration pathways, generalized based on description given by Urquhart et al., 1978 [41].

2.3. Citizen-Based Data

We compiled monarch butterfly presence location data that were collected between May 2017 and May 2018 from Journey North database (Journey North). Journey North is a citizen-based web platform where citizens report sightings, migration routes, and seasonal movement patterns of many wildlife species. Sightings of monarch butterflies were reported with marked Global Positioning System (GPS) coordinates and dates and by life cycle stages including (1) adult, (2) egg, (3) larva, and (4) peak migration (Figure 2). The whole dataset was assembled and submitted online by Journey North participants during the monarch butterfly migration season. For each observation record, the observed time, geographic location, and the number of butterflies encountered by the observer were reported. A large proportion of the contributed observations include photographs, which allow researchers to determine the physical status and life cycle stage of the butterfly. We mapped the citizen-based monarch sightings of the North America by categorizing the monarch butterfly sightings into five categories: 0–5, 6–10, 11–50, 51–100, 100–100,000 (Figure 2). The sightings were then incorporated and plotted by using ArcGIS based on the geotags of the observation data. The resulting map showed a monarch butterfly migration “roadmap”, and also a representation of overwintering and breeding sights (Figure 2).

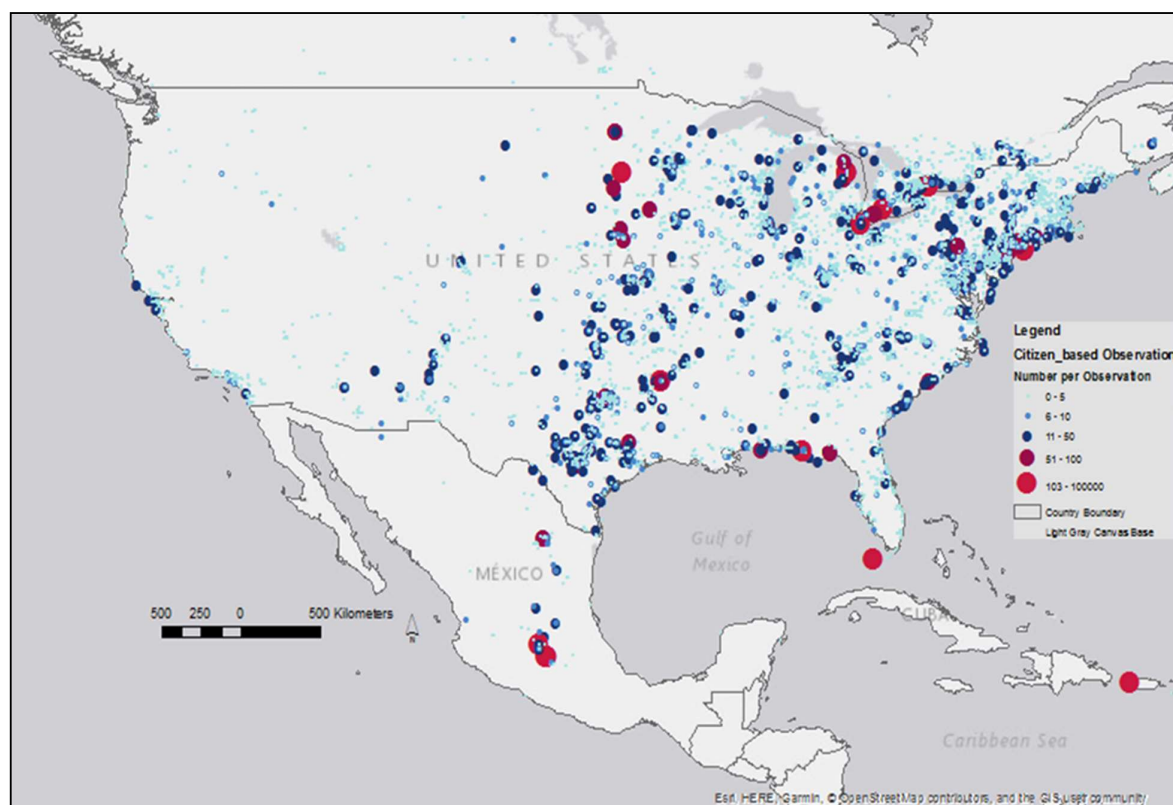


Figure 2. Spatial distribution of monarch butterfly data from citizen-based monitoring. Data of all life cycle stages (i.e., adult, egg, larva, and peak migration) were combined with the number of observed monarch butterflies per observation (data source: Journey North).

A total of 14,246 sightings of citizen-based monarch butterfly observations were reported in 2017–2018. A total of 89 states and provinces in the North American countries (i.e., the United States, Canada and Mexico) contributed to the observation data, and 10 states and provinces from the United States and Canada contributed > 50% of the data (Texas, Ontario, New York, Minnesota, Illinois, Pennsylvania, Oklahoma, Michigan, and Wisconsin; Table A2). Volunteers who reported sightings of the monarch butterfly could be traced to every state in the contiguous United States, as well as Canadian provinces that have high monarch butterfly populations (i.e., Ontario). The proliferation of sighting reports provided by volunteers along key locations of the monarch butterfly migration pathways is a positive sign of using citizen science as a broad-scale and long-term monitoring tool for the species.

3. Integrating Citizen-Based Data with the Telecoupling Framework

Below, we describe each major telecoupling component in connection to monarch butterfly migration and provide examples on the potential use of citizen-based contributions to help understand CHANS (Figure 3).

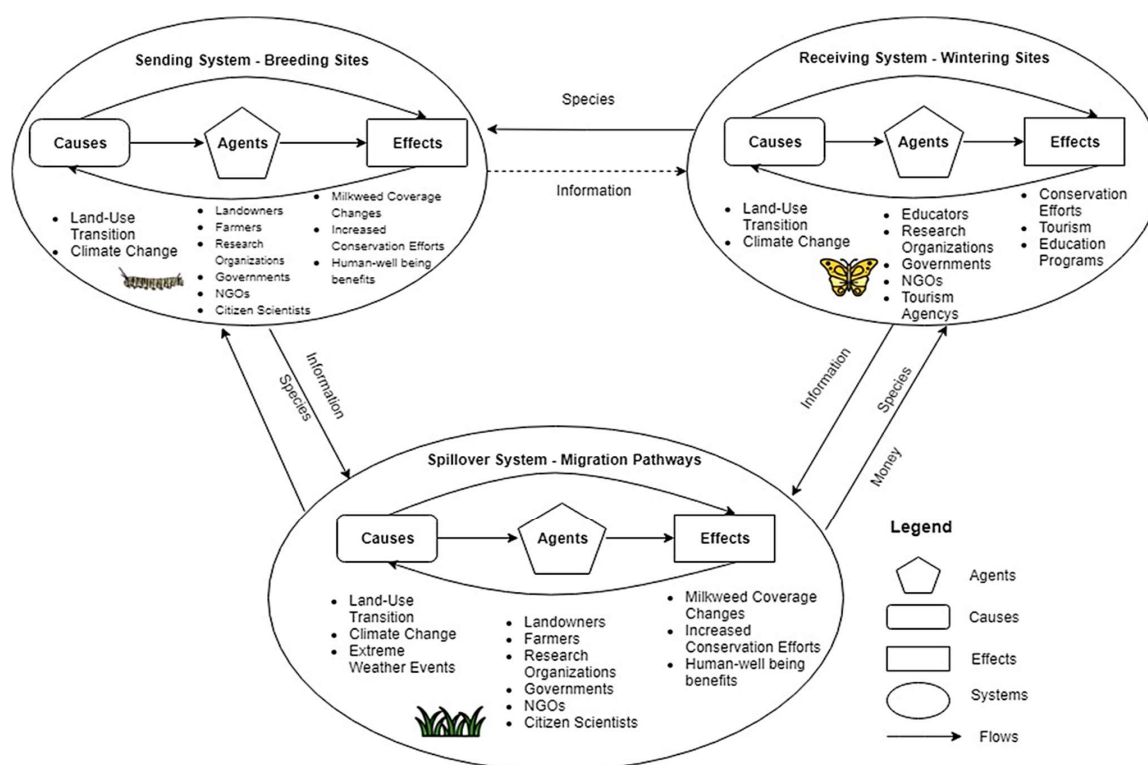


Figure 3. Citizen-based monarch butterfly telecoupling framework.

Coupled human and natural systems: in the conservation telecoupling framework, the systems are classified into sending, receiving and spillover systems. For the eastern monarch butterfly migration pathways, breeding ranges (middle eastern USA, northeastern USA and southern Canada) are considered the sending system while the overwintering sites (central Mexico) are the receiving system. The total receiving system in Mexico forests consists of approximately 42,000 ha of oyamel fir (*Oyamel mexicana* (Dougl.)) with the average elevation of 2400–3500 m [49]. Spillover systems include monarch butterfly migration stopover sites. During the years from 2017 to 2018, more than 14,000 local residents or tourists contributed to observing and reporting the sightings of monarch butterflies through individual observations, ecotours and education programs. Monarch butterflies have been marked by citizen scientists over different vegetation types, mostly milkweed plants (Table 1). Most of the comprehensive ecological research of monarch butterfly migration and its habitat loss have been focus either on receiving or sending systems.

The major principle of telecoupling citizen science is to integrate public conservation outreach and scientific data collection at different scales to mark the monarch butterfly sightings and also provide positive feedbacks. With the change in the global environment, the breeding and wintering sites of monarch butterfly may also change. With the VGI information, we can figure out the geospatial information for the occurrence of the monarch butterfly and define the sending, receiving and spillover systems. Currently, most of the citizens in spillover systems (on the pathways of monarch butterfly migration) are not well engaged in collaborative management strategies.

Agents: a number of agents are involved in citizen-based telecoupling research on monarch butterflies, and they contribute to influence the information and energy flows. For example, landowners convert milkweed land into croplands on the pathway of monarch butterfly migration, which interrupt and reduce the milkweed coverage. On the other hand, government agencies, non-governmental organizations (NGOs), education organizations and especially local residents facilitate the migration of monarch butterflies. The most significant research gap for agents under the telecoupling framework is to understand agents that affect monarch butterfly migration in spillover systems, such as farmers

or land managers. They might affect monarch butterfly migration by converting the milkweed land cover to other land cover types that do not allow the monarch butterfly to stop and breed.

Table 1. Description of new conservation actions Using citizen-based telecoupling framework.

Telecoupling Framework Components		Citizen Science Data for Quantification and Available Data Sources
Systems	Coupled human and natural systems	<ul style="list-style-type: none"> • Spring and fall migration: Journey North, Correo Real, eButterfly • Breeding: Journey North, Western Monarch Milkweed Mapper • Overwintering: Monarch Alert, Western Monarch Count • Other places affecting migrations directly and indirectly: Journey North
	<ul style="list-style-type: none"> • Breeding • Overwintering • Spring and fall migration ○ Stopover sites • Other places affecting migrations directly and indirectly 	
Agents	<ul style="list-style-type: none"> • Biologists and wildlife managers, • Land owners, • Scientific institutions • Governments; • Other agents affecting flows of information 	<ul style="list-style-type: none"> • Local land managers (local citizens) • Community groups • Local institutions • Industry • Academia
Flows	Environmental and socio-economic connections <ul style="list-style-type: none"> • Nutrients • Information • Money • Materials 	<ul style="list-style-type: none"> • Number count: Journey North, Western Monarch Milkweed Mapper, Western Monarch Count (data exportable)
Causes Environmental and Socio-economic Factors	<ul style="list-style-type: none"> • Land-use change • Materials 	<ul style="list-style-type: none"> • Land-use Data: OpenStreetMap, GLOBE • Land Cover (milkweed monitoring): Journey North, Western Monarch Milkweed Mapper • Extreme Weather • Climate change
Effects	<ul style="list-style-type: none"> • Habitat loss • Population decline 	<ul style="list-style-type: none"> • Population: Journey North, eButterfly • Milkweed: Journey North

For the roles of open communities, monarch butterfly citizen science programs report, share, and make the output available for the public to view and download. With the user and uploader information in the science platform, we can identify the potential stakeholders who care about monarch conservation. By using citizen science programs, the number of people enrolled in conserving monarch butterfly can be expanded to organizations, agencies, local citizens, tourists, and educational groups. For example, we mapped the spatial distribution of the number of contributors per city based on the Journey North citizen science database (Figure 4). The frequency distribution of citizen scientists' volunteered time (represented as "day of year" (DOY)) was also calculated in Figure 4. The DOY distribution ranges from 1 to 331, which covers most of the monarch butterfly migration time spans. Among those contributions, the spatial distribution of the citizen science mappers indicates that there is a high potential for linking citizens to monitoring monarch butterfly migrations.



Figure 4. Number of citizen contributors per city in the United States and Canada (data source: Journey North).

Citizen science can be used to facilitate the collaboration between agents across different systems, including spillover systems. Open data is the key in citizen science programs, mediated by information and communication technologies [50]. Citizen science programs, NGOs, and education organizations collaborate from various locations [51] form the coupled networks for conserving monarch butterflies. Local residents, individuals can also assist with active conservation by engaging themselves in outreach activities and contribute financial aids [37]. Such programs represent a type of coupled scientific collaboration [52].

Flows: the major flows of citizen-based telecoupling framework in this case study is the study species (i.e., the monarch butterfly) and the benefits and ecosystem services (e.g., information, money, etc.) it provides. With the platform of citizen science, we can connect sending, receiving and spillover systems with the information flow in the platform. At the local scale, ecotourism located at both breeding and overwintering sites can generate monetary flows from tourists (citizens) to local business (agents) via donations, purchases, and lodgings to support land management. Ries et al., visualized the citizen science contributions on monarch butterflies' annual cycle in four stages: overwintering, spring migration and breeding, summer expansion and breeding and fall migration [53]. These citizen science program collections, of some are monarch-centric, reveal how the monarch butterfly move (organisms, data and time) beyond the map pattern-based exploration. The telecoupling framework expands the horizon of species conservation management from a local site-centered perspective to a holistic flow-centered perspective [25].

Causes: the causes of the citizen-based telecoupling framework of monarch butterflies can be seen in all systems in the aforementioned systems section. There are a number of environmental and anthropological factors that affect the monarch butterfly migrations.

For the causes of the telecoupling framework, little is known about how diverse environmental and socioeconomic factors interact with each other on monarch butterfly migrations [25]. Climate

change and land-use transitions affect each other, and they are key factors affecting monarch butterfly migrations. To understand the interrelationships of those processes, land-use information provided by citizens would help quantify the land dynamics that threaten monarch butterfly migrations. Citizen science can be adapted to monitoring regional land use [54], with the major principle of utilizing citizen-contributed geotags as training samples for mapping land cover and land use. Using the VGI platform, the land-use information provided by citizens can be integrated and has the feasibility to classify regional land-use, which is expensive, time consuming and difficult by traditional methods. For example, Shultz et al. and Yang et al. successfully bridged the research gaps in global open land cover products by using interpreted citizen-contributed land-use tags as training samples in building land-use classifiers [54,55]. The overall accuracy of the whole Southeastern United States land-use can reach 74.8% [54]. This might lead to new land resources management and decision-making strategy when the lands' coverage located on the migration pathways and beyond. One of the solutions is to monitor the land use along and surrounding the monarch butterfly migration pathway. In addition, increases in opportunities to understand Monarch butterfly migration story and view monarch butterfly may also play a role in improving spiritual welfare of tourists in those butterfly conservation programs.

Effects: there are complex effects including feedbacks of the land-use change along and surrounding monarch butterfly migration pathways. The land-use changes, especially the utilization process among the monarch butterfly migration pathways, have a critical impact on the population of monarch butterflies. The habitat loss of milkweed caused by crop cultivation and urbanization has become the major contribution to monarch butterfly population decrease. Milkweed serves as the sole food for the caterpillars of monarch butterflies, produces high-quality nectar for many other species, and provides a nest for natural predator insects. Citizen science is also applied to mark and conserve the milkweed (Figure 5); however, the contributors are far less compared with the butterfly's monitors (Figure 4). In addition, citizen science principles are also used to conserving milkweed fields. The United States Department of Agriculture's (USDA) Natural Resources Conservation Services (NRCS) enables farmers and ranchers to plant milkweed on their properties at the recently updated Conservation Stewardship Program.

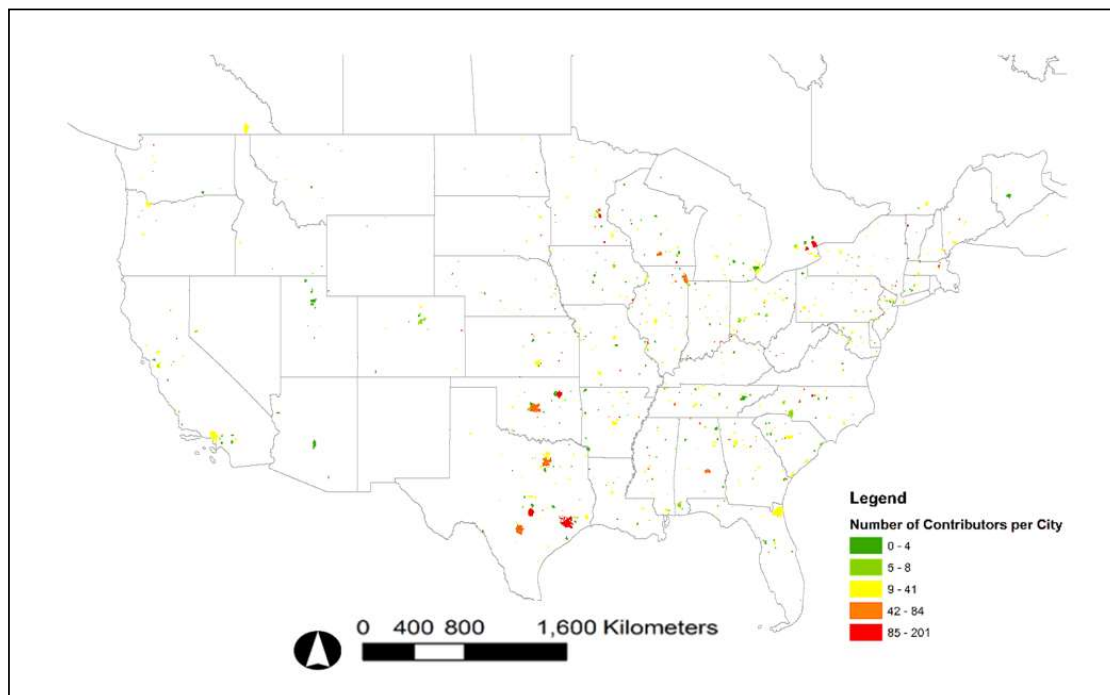


Figure 5. The number of citizen contributors marking milkweed per city in the United States and Canada (data source: Journey North).

Of the 13 current active monarch butterfly related citizen science programs that were analyzed, 10 contribute to monarch butterfly sightings, 8 record the monarch butterfly breeding status, and 7 mark the conditions of the milkweed (Figure 6).

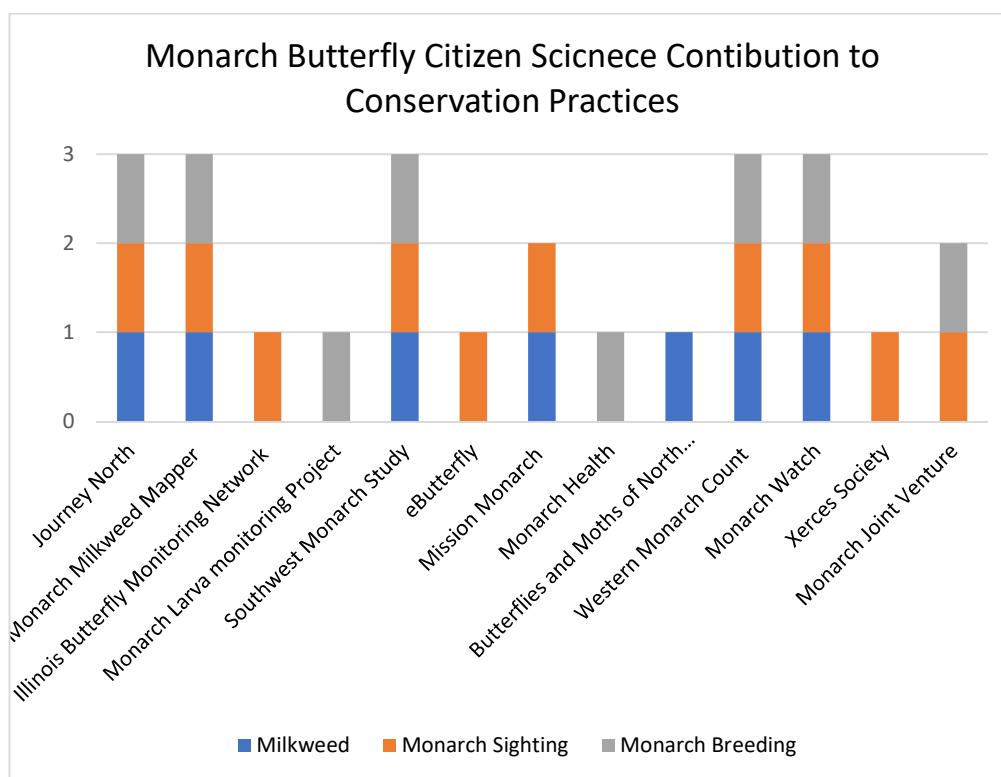


Figure 6. The frequency of monarch butterfly conservation practice types in the Combined citizen science programs.

4. Discussion

4.1. New Conservation Actions from Incorporating Citizen Science

The importance of including human dimensions in conservation and sustainability planning and management is well recognized [56]. Along the monarch butterfly migration routes, the citizen-based telecoupling framework will aid the evaluation of linkages across sending, receiving and spillover systems over long distance, and engage local residents to participate in conserving breeding, wintering and stopover sites for the purpose of conserving the species. Using information and inputs from lay citizens as the basis for developing research and conservation projects (i.e., a bottom-up approach), provide numerous opportunities. For example, recognizing citizens as conservation and research partners can promote and garner support for the planning and implementation of conservation management and policy. The role of spillover systems might be more important in the future, if the petition of listing monarch butterfly as an endangered species in United States is implemented in 2019 [57], which will require huge revisions to the whole management and conservation funding sources.

The application of citizen-based data and the telecoupling framework is not limited to the monarch butterfly but can also be used for studying other species. It has been used to monitor sharks by volunteer scuba divers, who found documented more than 83,000 declines [58]. Birds condition and population are often studied incorporated with citizen science information, such as Tucson bird in urban areas [59]. By aiming at the understanding of the habitat of specific endangered space and the ecosystems, citizen science will help facilitate collaboration among education organizations, governments and local citizens [60].

4.2. Implications of Citizen-Based Telecouplings in Land Management

Politically, the practice of land management over the entire migration region of the monarch butterfly is difficult due to complex land ownerships among the three North American countries. For example, in Mexico, a large amount of vegetated lands is owned by ejidos and the communities. The lack of land ownership among local residents might lead to a higher deforestation rate [61], and thus increased habitat loss for the monarch butterfly.

The representations (such as geotagged map, volunteered species monitoring) of citizen-contributed patterns are complex and heterogeneous. The scale is the key to analyzing the level of heterogeneity of those complex coupled human-natural systems [62]. Spatial scales dictate the interrelationships among coupled human-natural systems. There are a number of citizen-based platforms that mark and report species occupancy (Table A1), with various observation scales from local to continental. Better understanding among citizens can provide opportunities and insights to assess information flows and improve the data quality at different scales, which has the potential to translate the telecoupling conceptual framework into more bottom-up applications. The incorporation of citizen science will reveal many hidden assumptions in the telecoupling framework and represent a more concrete monarch conservation pattern.

4.3. Challenges and Opportunities

In the current citizen-based platforms, especially in biological studies citizens are often regarded as data collectors. However, there exist more adaptive approaches where citizens can play additional roles (e.g., designing and evaluating studies) in this telecoupled world.

Much more needs to be done in terms of quantifying and estimating flows, causes and effects in the complete telecoupled human-natural systems for monarch butterflies at macrosystems scales. Citizen science provides the researchers a developing tool for expanding the data sources, science knowledge and research scopes. Researchers should continue to discover better ways to analyze and interpret the tremendous amount of citizen-derived data. For example, OpenStreetMap is one platform of open sources road network maps. The hidden information reflecting the land use was extracted and used as training samples to map how people use their lands [63].

There are regional limitations to the application of citizen science. For example, citizen science for the monarch butterfly is not prevalent in Mexico (Figure 2). Also, with the exception of national parks and some conservation eco-tourism hotspots, it is not common in many areas along the monarch butterfly migration pathways to have citizens involved, with some areas not even accessible to the public. To minimize the potential bias caused by different land governances, we need to utilize the feedback from the other systems (spillover and receiving) to initialize and trigger the changes.

Another aspect of representing citizens' opinions is the use of social media. Social media like Facebooks, blogs, Instagram are increasingly being used to capture environmental changes. Researchers can also interpret useful information from geo-tagged social media (data mining). For example, in the platform of Instagram, geotagged pictures showing monarch butterfly habitats and migrations are in more than 500,000 posts. The number demonstrates great potential for monitoring and observing monarch butterfly migrations and habitats. In addition, those posts contribute near-real time information compared with the traditional ecological monitoring programs. With high qualities, citizen science communities offer valuable contributions by providing opportunistic data sources and contributing to citizen science programmers. Representations (such as geotagged map, volunteered species monitoring) of citizen-contributed patterns are complex and heterogeneous. The combination of telecoupling and citizen science is especially useful for studying species that are trans-jurisdictional and have broad-range and long-distance dispersal ability, such as birds and sharks.

5. Conclusions and Future Works

Citizen scientists are contributing to telecoupling-related researches in new ways. The use of methodological tools and platforms from diverse disciplines enable the application of citizen science in the telecoupling framework. Our proposed strategies by using the monarch butterfly as a case study seek contributions that demonstrate the application of citizen science projects supporting telecoupling-related research by complementing satellite observations and discussing novel methods for data collection and new ways of conservation.

The integration of citizen-based science and a telecoupling framework gives rise to new opportunities and challenges. We envision citizen-science based data to continue to broaden in scope and to improve in quantity and quality. While such data may help answer bigger and more important questions, making sense of these large data sets requires a systematic analytical framework that takes into account both human dimensions and natural systems. In this context, the telecoupling framework will be useful in citizen-science studies. Citizen science has greater coverage, both in time and space, and hence might be more flexible to show the migration patterns and the variations of them. With the telecoupling framework, stakeholders and policymaker can understand the ecosystem services such as bird watching, hunting, pest control relies on land use from a distance [26]. Studies show that when the general public is informed by such information, they are willing to invest and donate in the conservation activities in the neighbor countries [64,65]. More and more researchers are using the telecoupling framework to understand the ecosystem services provided by migratory species [34,37,38]. With the telecoupling framework, we are able to analyze the key players and factors in the framework such as flows, agents, causes, and effects. We are also able to analyze the impact on the spillover system and its feedback, which previous studies on breeding and winter grounds have been unable to do.

Under the unstable environmental background, local citizens need to play an active, effective and dynamic role in maintaining and managing the resources. On a broader scale, expanding telecoupling to metacoupling (human–nature interactions within as well as between adjacent and distant systems, Liu 2017) will help citizen science tie more systems together (e.g., not just distant systems but also adjacent systems) [21]. The linkages between citizens and surrounding ecosystems reaffirm the need for citizens to participate in wellbeing-related behaviors. Those proposed approaches can help open science to broader participation and perspective.

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

Appendix A

Table A1. Citizen-contributed monarch butterfly-related programs. Only Journey North was incorporated in the main context. Other datasets were used to make various arguments about incorporating citizen science at multiple scales.

Dataset	Scale	Website
Journey North	Global	https://journeynorth.org/monarchs
Western Monarch Milkweed Mapper	Western U.S.	https://www.monarchmilkweedmapper.org/
Illinois Butterfly Monitoring Network	Illinois and Indiana	http://bfly.org/
Monarch Larva monitoring Project	North America	https://monarchlab.org/mlmp
Southwest Monarch Study	Southwestern U.S.	https://www.swmonarchs.org/
eButterfly	Global	http://www.e-butterfly.org/
Mission Monarch	Northern U.S. and Canada	http://www.mission-monarch.org/
Monarch Health	U.S. and Canada	http://www.monarchparasites.org/
Butterflies and Moths of North America	U.S. and Canada	https://www.butterfliesandmoths.org/
Western Monarch Count	Western U.S.	https://www.westernmonarchcount.org/
Monarch Watch	U.S. and Canada	https://monarchwatch.org/
Xerces Society	Western U.S.	https://www.westernmonarchcount.org/
Monarch Joint Venture	Global	https://monarchjointventure.org/

Table A2. Monarch butterfly citizen-based records by states and provinces.

State/Province Name	Number of Sighting Reports
Texas	1683
Ontario	1316
New York	789
Minnesota	685
Illinois	675
Pennsylvania	639
Oklahoma	550
Michigan	547
Ohio	499
Wisconsin	491
Maryland	451
Missouri	427
New Jersey	396
North Carolina	374
Virginia	353
Indiana	331
Florida	299
California	278
Kansas	270
Georgia	251
Massachusetts	237
Iowa	206
Connecticut	194
New Hampshire	174
New Mexico	169
Tennessee	165
Maine	160
Kentucky	152
South Carolina	142
Vermont	128
Quebec	127
Arkansas	119
Nebraska	100
Louisiana	95
Alabama	93
Colorado	55
Mississippi	54
Arizona	45
Rhode Island	43
Nova Scotia	39
West Virginia	39
Guanajuato	38
Nebraska	31
Washington D.C.	29
Utah	28
Coahuila.	25
Newfoundland and Labrador	25
South Dakota	25
Nevada	21
Idaho	20
Oregon	20
Delaware	19
Manitoba	17
North Dakota	12
Tamaulipas	11
Alberta	8
Saskatchewan	8
Wyoming	8
Nuevo Leon	456
Michoacán	785

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