# Disclaimer

*This report, developed by Braden Judson, Julia Carr, and Dr. Brian M. Starzomski in May 2023 under the instruction of the Ministry of Water, Land and Resource Stewardship, offers valuable insights into community science in British Columbia. It is important to note that this report does not represent an official government position or program. Instead, it is intended to serve as a catalyst for discussions with Indigenous peoples and stakeholders in the development and implementation of wildlife and habitat community science initiatives throughout B.C.*

*The Ministry of Water, Land and Resource Stewardship will carefully consider the recommendations presented in this report, taking into account government priorities, budgetary constraints, and legal, social, and economic factors. The successful development of a community science framework and implementation plan relies on the cooperation and commitment of partners and stakeholders throughout the province. The Together for Wildlife team will undertake engagement with government staff, Indigenous communities, academia and stakeholders to define our path forward. These factors will be fundamental to the effective execution of community science in B.C. to support wildlife and habitat stewardship.*

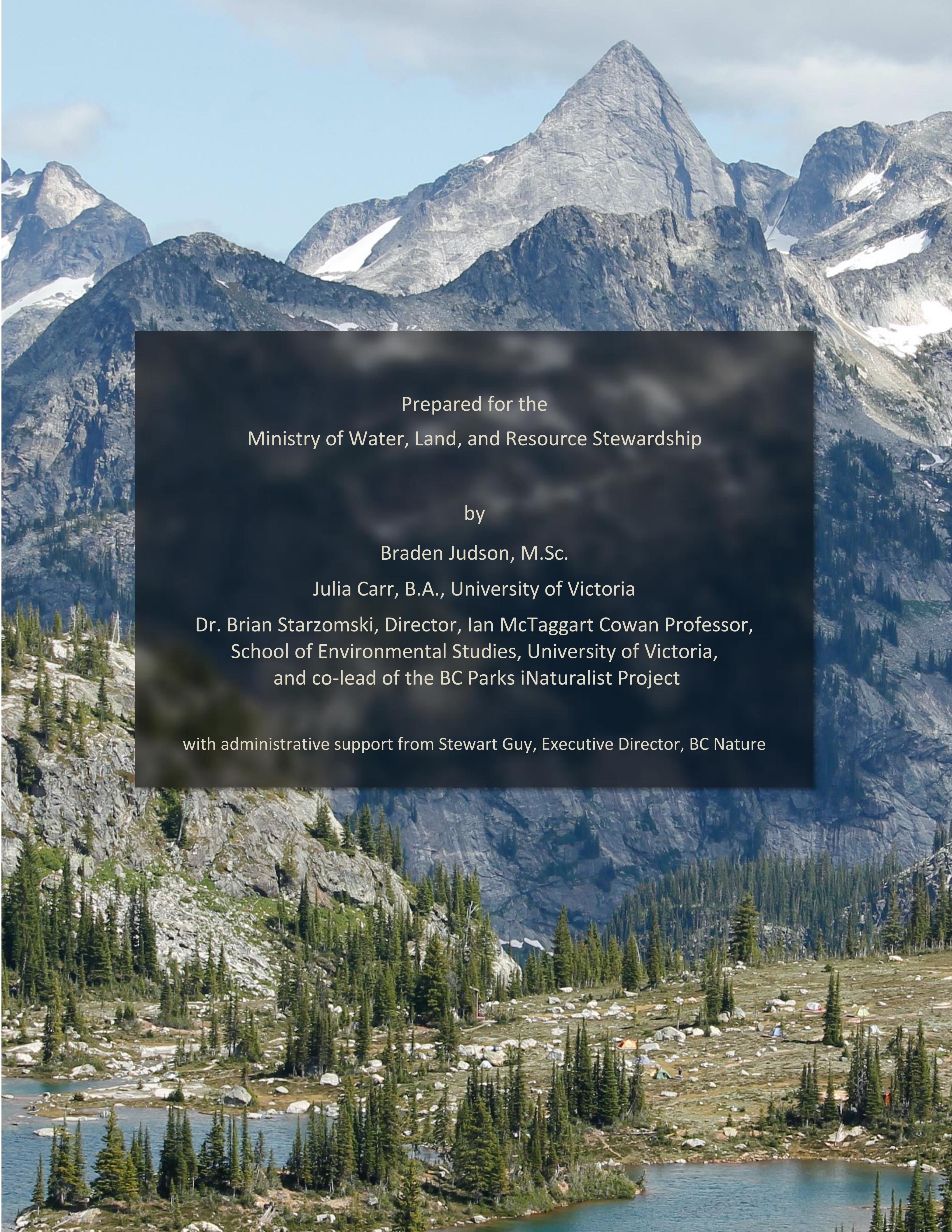
# Together for Wildlife Strategy

## Goal 2, Action 6:

## Community Science Framework for Together for Wildlife

May 2023

Braden Judson, Julia Carr, and Brian M. Starzomski




Prepared for the
Ministry of Water, Land, and Resource Stewardship

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# Summary

British Columbia is the most biodiverse province in Canada. The management of this biodiversity will benefit from the collaborative efforts of the public, and many of the provincial organizations already focused on wildlife conservation. Through community science (CS), the Province can engage volunteers in collecting, curating, and communicating wildlife data while providing options for in-the-field volunteerism. For this report, we discussed CS with more than 130 British Columbians of varying backgrounds through an online survey to better understand the landscape of CS throughout the Province. We first characterize many of the digital platforms active in the Province and relate these observations to our data, which suggest that a select few platforms dominate the digital CS landscape in B.C. Volunteers predominantly cited that contributing to science and conservation was their primary motive for participating in CS. Alternatively, those yet to contribute to CS claimed they were unsure how to direct their efforts meaningfully. Data users frequently claimed that potential biases and low data quality made CS data challenging and often suggested using standardized data collection protocols. We follow this notion by exploring how structured and opportunistically collected CS data are useful to specific groups (e.g., groups studying population trends vs. groups studying invasive species). We ended our survey by asking our respondents what the future of provincial CS should look like, to which people overwhelmingly indicated that the Province should prioritize education and engagement with the public. Our survey data also suggested that improving data quality is another priority, whereas investing in analyzing and processing these data is a lower priority.

An overview is provided for three different styles of CS, with provincial examples for each. First, we describe some digital CS platforms that our survey respondents use to partake in *Contributory CS.* We characterize some of the unique aspects of these applications while detailing the different data types these platforms offer and how these platforms are used throughout the Province. *Participatory CS* is a format of CS that doesn't directly deal with data but instead relies on volunteers to perform actions, such as field activities or processing samples. There are many options for participatory CS throughout B.C., many of which rely on local institutions or the digital CS platforms described above, although some activities are more specialized and may require training and professional oversight. We term some of these projects as *Structured CS*, as they prioritize the standardized data collection and adhere to methodological protocols to ensure that data are consistent and comparable.

Volunteerism is at the core of Community Science; therefore, we discuss several engagement strategies and patterns commonly cited in the scientific literature. Programs that involve youth in nature and science have a direct link to future volunteer efforts and are thus valuable in maintaining a flourishing CS community throughout the Province. From discussions with volunteers and published data, we emphasize that volunteers want clear communication from project leaders about goals and progress while being provided opportunities to grow and contribute to something meaningful. While prioritizing these points will likely help retain volunteers, alternative patterns, such as the gradual decline of volunteer interest, are more likely without hosting events and other recurring opportunities for engagement. For example, a "bioblitz" is an effective means of engagement where participants aim to quickly collect as much biodiversity data as possible. Therefore, we highlight the outcomes of recent bioblitzes in the Province and offer some high-level strategies for conducting future events.

The data produced by CS projects can be valuable when distributed, handled, and communicated effectively. To encourage open scientific practices, we suggest that CS projects prioritize sharing their data with other project(s) whenever possible and provide several flexible options.

Government data-sharing processes and platforms are outlined, and we emphasize the value of using open data licensing. However, we note that some data should not be openly shared, such as potentially revealing personal information or the locations of sensitive species, habitats, or culturally important sites. For Contributory CS projects, personalized settings can enable data-sharing with multiple organizations, such as the Global Biodiversity Information Facility (GBIF). Some of the biases inherent to many Contributory CS platforms are explored (e.g., platforms biasing against specific groups of organisms), and recommendations are provided for analysts working with these data types. For example, when working with checklist-oriented or presence-only data from various platforms, each has strengths and limitations that are important to acknowledge. Data standards for multiple tasks (e.g., species inventories) can guide project leaders to collect data valuable to provincial programs, avoiding some of these potential biases. Together, CS data come in many forms that can be used to answer various questions. As such, data users are reminded to acknowledge the volunteers who are the backbone of CS, including appropriately citing data from online CS sources or writing an acknowledgement letter to the volunteers driving the work.

Our findings indicate that CS data can be used to address a variety of pressing management, conservation, and scientific issues. These data can be incorporated into traditional workflows to expedite and improve decision-making regarding species conservation or land use protocols. However, CS is not without limitations, and provincial wildlife science will always rely on the joint efforts of volunteers and professionals. For example, projects requiring expensive equipment or extensive training can have difficulty recruiting volunteers. Projects coordinated by professionals are encouraged to engage volunteers whenever appropriate.

Through our discussions and research, we have developed a concise series of recommendations for enhancing CS in B.C. **1)** Improving engagement by developing a provincial CS channel (e.g., blog, newsletters, emails) and supporting inclusive collaboration between First Nations, academics, the public and the government via webinars, bioblitzes and training events. **2)** We suggest the Province develop a CS conference and explore supporting regional gear libraries for local organizations and CS projects. **3)** CS data quality would be improved if the Province developed guiding documents that outline data standards, collection methods, and potentially relevant laws and policies that project leaders should be mindful of. **4)** To make CS data more relevant to data users in remote areas, the Province could develop a Biodiversity Team to facilitate and partake in collecting biodiversity data in priority areas while communicating techniques for collecting high-quality data. **5)** To create and distribute documents that enable CS projects to adopt an open science framework while encouraging provincial data users to do the same. **6)** Continue supporting the development of provincial data management tools and incorporating CS data into traditional decision-making workflows. **7)** As there is currently a gap in the provincial government for the coordination and leadership of CS, we recommend creating at least one dedicated CS Biologist position within the provincial government to liaise between data contributors and data users while identifying knowledge gaps addressable with CS and communicating CS developments to the public. Together, these recommendations have the potential to empower existing CS projects while fostering a collaborative environment that will maintain and enhance B.C.'s position as a leader of CS excellence.

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# Introduction

## British Columbian biodiversity and biodiversity management

British Columbia (B.C.) hosts more biodiversity than any other province or territory in Canada (Cannings et al., 2005), with more than 50,000 documented species to date (NatureServe 2022). For this report, however, we will focus on w*ildlife*, including all terrestrial vertebrates, invertebrates, plants and fungi. In B.C., more than 1,800 wildlife species have been described as "at risk" by the B.C. Conservation Data Centre (CDC) (Westwood et al., 2019). In addition, by some measures, more than 140 endemic plants and animals occur in B.C. (B.C. Endemics iNaturalist Project; Gaerber (admin.) 2022). As of 2019, only 214 of the 278 wildlife species at risk of extinction in B.C. that have been nationally assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) are federally listed under the federal *Species at Risk Act* (Westwood et al., 2019). Many of these organisms are distributed throughout B.C.'s 16 biogeoclimatic zones, some of which (e.g. Ponderosa Pine) exist nowhere else in Canada (Meidinger and Pojar, 1991). The Province's high species and ecosystem diversity can likely be attributed to the Province's large size (944,735 $km^2$), relatively low density of human occupation (4.8 people $km^{-2}$, Environmental Reporting B.C. 2018), and complex geological history (Hebda 2007). However, while these factors are generally associated with high biodiversity, they also pose potential challenges for scientists and managers alike, given that much of the Province is difficult to access and is often inadequately surveyed. In conjunction with the often limited funds from any source for conservation programs, these challenges have resulted in the Province falling short on several conservation priorities. The United Nations Convention on Biological Diversity demonstrated that the Province failed in four out of five categories, highlighting shortcomings in recovering species at risk, ecosystem conservation, reducing habitat loss, and protecting species through industry-specific laws and regulations (Nixon et al., 2021). While the Province has come closer to its targets for establishing parks and protected areas (1.5% lower than the 2020 target of 17%), clear opportunities remain to improve its management and protection of species and habitats.

Wildlife management in B.C. requires diverse and high-quality data and collaboration among many peoples, groups, and agencies. The interdisciplinary nature of these challenges in B.C. is exemplified most recently in Premier David Eby's mandate letters to the provincial Minister of Water, Land and Resource Stewardship (Nathan Cullen) and the Minister of Forests (Bruce Ralston). These letters emphasized a need for British Columbians from various sectors to work collaboratively and effectively to ensure long-term environmental, ecological, and economic sustainability. British Columbia has one of the largest and most diverse land protection systems in Canada, with over 1,000 parks and protected areas, which, along with the more than 30 wildlife management areas as part of the Conservation Lands Program, play an essential role in providing wildlife habitat while supplying ecosystem services and recreational opportunities for the public. Expanding protected areas through various means, such as B.C.'s protected areas network, Key Biodiversity Areas, and Indigenous Protected and Conserved Areas, remains a priority for the provincial government and will undoubtedly benefit wildlife conservation in B.C. Notably, the mandate letter to Nathan Cullen references B.C.'s recent commitment to protecting 30% of its landmass by 2030 (known internationally as 30 by 30), representing an important milestone for Canadian wildlife conservation efforts. Coordinating these conservation initiatives will require supporting and advancing provincial scientific endeavours while promoting solid and collaborative relationships between First Nations, provincial stakeholders, and the public.

Black Bear (*Ursus americanus*)
Photo by Thomas Barbin (link)

# Together for Wildlife

To further provincial wildlife conservation, Premier David Eby's letter to Minister Cullen also mandated the implementation of the Together for Wildlife strategy, a framework published in August 2020 by the then Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). This initiative fostered collaboration among representatives from First Nations, academia, industry, tourism, guiding, conservation groups, and the public to identify the Province's goals and priorities for future wildlife and wildlife habitat stewardship and conservation.

At a high level, the Together for Wildlife strategy identified five primary goals encompassing 24 actions, which provincial government ministries and organizations are currently addressing. While the Together for Wildlife strategy focuses on terrestrial species that are not at risk (including their habitats), many aspects of the initiative indirectly benefit aquatic species groups and at-risk species. At a high level, these goals include developing inclusive platforms and infrastructure to ensure that all British Columbians have a voice in wildlife stewardship (Goal 1); refining knowledge and data collection, accessibility, communication and mobilization practices to make the most informed decisions possible (Goal 2); assessing and modifying current tools (e.g., policies, legislation) such that they effectively and transparently address tangible objectives (Goal 3); implementing strategies for openly communicating current actions, how effective these actions are, and plans for future investments (Goal 4); and to address the goals in a collaborative framework with First Nations to develop co-management systems and work towards reconciliation (Goal 5). We note that these goals contain multiple actions and encourage readers to view the original Together for Wildlife report for the specific details of each goal. Together, these goals and their respective actions aim to support the science, systems, people, and cultures that are the collective backbone of provincial wildlife conservation.

In this report, we address Goal 2, Action 6 of the Together for Wildlife strategy, which states:

> *"[W]e will develop a citizen science framework to provide new opportunities for British Columbians to partner in wildlife stewardship data collection and monitoring. We will build on existing citizen science initiatives in British Columbia and examples from other jurisdictions and use this information to support decision-making."*

Therefore, this report provides a framework for integrating community science (CS) initiatives and data into the current model of wildlife management and land stewardship in B.C. As such, we aim to provide a conceptual framework for the following topics while ending the document with recommendations for expanding and enhancing provincial CS. These ideas are addressed in the following order:

1. Liaise with British Columbians to better understand provincial data needs and to explore the current CS landscape throughout the Province.
    a. By conducting interviews and distributing an online questionnaire, we characterize contemporary patterns of provincial CS engagement and
    b. Identify and link common data needs with existing projects and volunteer motives.

2. Define CS and provide an overview of the existing CS initiatives throughout the Province.
    a. Synthesize existing literature to describe CS and some common forms CS projects may take.
    b. Describe how volunteers are contributing to provincial CS efforts.
    c. Use the above two points to identify current and future opportunities for engagement and improved data collection.

3. Integrate information from the literature, interviews, and surveys we conducted to highlight volunteer recruitment and engagement patterns.
    a. By discussing common volunteer motives and behaviours, we provide high-level recommendations for recruiting new volunteers and optimizing engagement for existing participants.

4. Explore some of the types of CS within the Province and describe common patterns of data collection, privacy, storage, usage, ownership, and accessibility.
    a. Stress the value of open, accessible, and transparent science while overviewing existing tools and systems for incorporating open science practices into a CS framework.

b. Summarize privacy and ownership issues associated with CS data and how these issues may be addressed for structured and contributory CS projects.
c. Discuss the value of standardized and structured data collection while providing pre-existing options for collecting and distributing these data.
d. Recognize some of the typical biases and limitations among data collected by volunteers while emphasizing how biases can potentially be accounted for.

5. Using the above information, we provide a brief overview of the potential applications and limitations of CS before providing recommendations for the future of CS in B.C.
    a. We recommend avenues for increasing public engagement with projects led by government and environmental non-governmental organizations (ENGOs) while fostering an environment conducive to CS collaboration and support throughout the Province.
    b. Increase the quality, coverage and accessibility of structured and contributory CS data and incorporate these data into an open science framework. We also provide high-level advice for addressing data ownership issues and appropriately acknowledging project contributors and collaborators.
    c. We propose priorities for future CS project leaders to ensure that projects are mindful of provincial policies and laws.
    d. Lastly, we identify the need for future work to develop an implementation plan for the above recommendations. We suggest that government biologists and project leaders are consulted when determining delivery and prioritization options for the recommendations discussed here.

Jointly, the above points offer a framework for Together for Wildlife to expand and enhance CS efforts throughout the Province. By supporting CS, the Province provides opportunities for involving the public in wildlife management while enabling increased education opportunities and widespread and transparent data collection. These processes generate data and knowledge that can be used to inform management practices and can be conducted in a collaborative framework with various partnering organizations.

Mountain Emerald
(*Somatochlora semicircularis*)
Photo by Braden Judson (link)

# What is community science?

*Community science* (CS), sometimes known as *citizen science*, refers to the public's engagement in an activity with a scientific objective. This broad definition encompasses many volunteer activities, ranging from unsupervised data collection to co-development of hypothesis-driven research projects. Here, we use the more inclusive term *Community science* as it is impartial to national citizenship. Despite its origins in the early 1900s, CS is a relatively young field that was popularized in the 1990s and has since flourished with the advent of personal electronics, the internet, and the associated ease of data sharing and collaboration (Miller-Rushing et al., 2012; Vohland et al., 2021). Consequently, through traditional survey methods, CS has enabled managers and researchers to collect data over vast spatial and temporal scales that would otherwise be impractical and prohibitively costly. As opportunities for CS continue to grow, these data have become an increasingly valuable resource to researchers, managers, and conservationists. While CS data cannot replace traditional standardized survey methods, its application and regular integration into classical management frameworks can be beneficial for many reasons. For example, the combined efforts of many community scientists enable data collection over a broader scale and a shorter time than is typical of several dedicated researchers. Therefore, the relatively inexpensive collection of widespread biodiversity data via CS offers a valuable resource to practitioners with varying backgrounds and objectives.

Although used in many fields, such as astronomy (Odenwald 2018) and the physical sciences (Lee et al., 2020), the integration of CS into an ecological framework has been met with particular success (Dickinson et al., 2012). Long-term ecological monitoring by the public has provided valuable insights into population trends, range extensions (Martel et al., 2022; Smith and Nimbs, 2022), biological cycles (Soroye et al., 2018; Nowak et al., 2020) and species interactions (Gazdic and Groom, 2019; Doherty et al., 2021) of many native, invasive, and at-risk species. Indeed, most COSEWIC Status Reports now feature CS data, including trend analyses and range extension data. These data also provide baseline information on the distribution and composition of biodiversity that can be used to assess the effects of future environmental changes and disturbances. Ecological data collected by the public have been used in thousands of publications worldwide, which decision-makers can use to make informed choices regarding environmental management, research, and legislation. Therefore, the abundance of ecological data underlies the value of CS, whereby the existing and exponentially growing (Heberling et al., 2020) data available to researchers can be used to assess contemporary scientific questions and unforeseen ecological concerns that may arise.


Photo by Kate McKeown

Ecologically focused CS efforts can take various forms to address many objectives. For this report, we follow Bonney et al. (2009) and define three main categories of CS (detailed in Table 1): i) **Participatory** CS, which offers volunteers the opportunity to contribute to science and conservation without directly dealing with data, including anything from volunteers digitizing herbarium specimens to removing invasive plants. ii) **Contributory** CS, where volunteers are mainly independent and often collect data opportunistically without an *a priori* hypothesis, such as with online platforms where users voluntarily submit their observations. iii) **Structured** CS, which typically addresses specific research questions developed before data collection, where volunteers engage in data collection in collaboration with a biologist or project coordinator to ensure that data is collected in a standardized and meaningful way. An example of structured CS would be volunteers undertaking breeding bird surveys and reporting those data to a biologist and *co-created projects*, where volunteers contribute to experimental design, analyses and communicating results (Bonney et al., 2009). Structured projects can vary substantially in the support they receive, from projects operating on a sole volunteer basis to projects with a staffed coordinator or numerous staff members working with a network of volunteers. Furthermore, there is potential overlap between these categories, as many projects carry out elements from some combination of these groups. Among these three styles of CS, there are numerous opportunities for engagement, each with its levels of responsibility and commitment. In the following sections, these types of CS are explored in greater detail while highlighting their relative values and potential limitations in a provincial context.

**Table 1.** The three styles of community science engagement are defined and used for this report. The CS style examples in this table are not exhaustive, and numerous others are active within B.C. and beyond. Unstructured data refers to those collected without a predetermined protocol, whereas structured data collection follows standardized guidelines (see text for more details).

| Engagement style | Participants | Data | Examples |
|---|---|---|---|
| Participatory | Volunteers | None | - Digitizing herbarium specimens<br>- Invasive plant removal |
| Contributory | Volunteers | Unstructured | - Uploading photographs of wild species to CS platforms<br>- Submitting wildlife count checklists to the appropriate CS platform |
| Structured | Volunteers and possibly staff | Structured | - Nicola Naturalists Society Amphibian Monitoring Project<br>- North American Bat Monitoring Program, B.C. |

## Why use community science?

Given that the Province has prioritized high-quality data collection and public engagement in wildlife conservation, CS offers numerous opportunities that may otherwise be difficult to achieve with traditional methods. For instance, by effectively communicating data needs, volunteers from around the Province can simultaneously collect data while providing data over larger spatial and temporal scales than a small team of dedicated professionals could achieve. Furthermore, engaging volunteers in data collection allows education opportunities and the public to contribute to the science guiding provincial wildlife and habitat stewardship decisions. Due to the variety of CS platforms available, the methods and applications used in data collection can vary depending on the group's needs. CS can be one part of a cost-effective means of widespread and collaborative data collection that can be used to conserve wildlife while building and strengthening relationships between data users and participants from all backgrounds. CS, therefore, has the potential to simultaneously address multiple Together for Wildlife priorities at a scale and rate unattainable by existing initiatives.

Mylitta Crescent (*Phyciodes mylitta*)
Photo by Kate McKeown (link)

# Community Science Landscape in B.C.

The community involved with wildlife conservation in B.C. comprises numerous groups, including academics, government scientists and representatives, First Nations, the public, and many environmental non-governmental organizations (ENGOs) such as naturalist clubs. As the value and utility of CS varies between these groups, it is important to recognize the various scientific needs of the communities throughout the Province. To better understand how and why British Columbians are engaging (or *not* engaging) with CS efforts, we conducted a series of interviews followed up with a widely distributed questionnaire.

We hosted online interviews with more than 30 British Columbians representing various aspects of academia, government, and non-government conservation work within the Province. Interviewees represented programs that i) worked directly with community scientists or CS data,

ii) occasionally used CS data, and iii) did not use CS data at present. Additionally, interviewees worked on various conservation issues, such as large game management, biodiversity monitoring, invasive species, biodiversity informatics, and education. Interviews were mainly focused on understanding the challenges and limitations associated with using CS data and what provincial CS efforts can or should look like in the future. Feedback, comments, and ideas have been integrated into the appropriate sections throughout this document.

# Community Science Survey

We complemented our interviews with an online survey to reach a broader audience. In brief, this survey included a variety of multiple choice, ranking, and short answer questions. Respondent answers were used to skip specific questions (e.g., if you had never been involved with CS before, you were not asked questions about data usage). For all multiple choice questions, the order of the selections was randomized for each respondent.

## Respondents

Throughout the Province, the survey was distributed to government departments, academics, non-government organizations, and First Nations groups working with CS in some form. Survey respondents were also encouraged to forward the survey to interested individuals. The survey was done from February 17$^{th}$ to March 17$^{th}$, 2023 and was completed by 126 British Columbians and several out-of-Province respondents from Alberta ($n$ = 1), the Yukon ($n$ = 1), Ontario ($n$ = 3), Quebec ($n$ = 1), Newfoundland and Labrador ($n$ = 1), and the United States ($n$ = 7). All the following quantitative analyses were performed using data from British Columbian respondents only to emphasize provincial interests. British Columbian respondents were distributed throughout the Province, with high densities of respondents from southern Vancouver Island and the Lower Mainland and fewer from less populated regions, such as the Northern Rockies and the Central Coast (Figure 1). We consciously tried to get feedback from individuals throughout the Province to avoid biasing our data towards the perspectives of people living in more populated and urban areas.

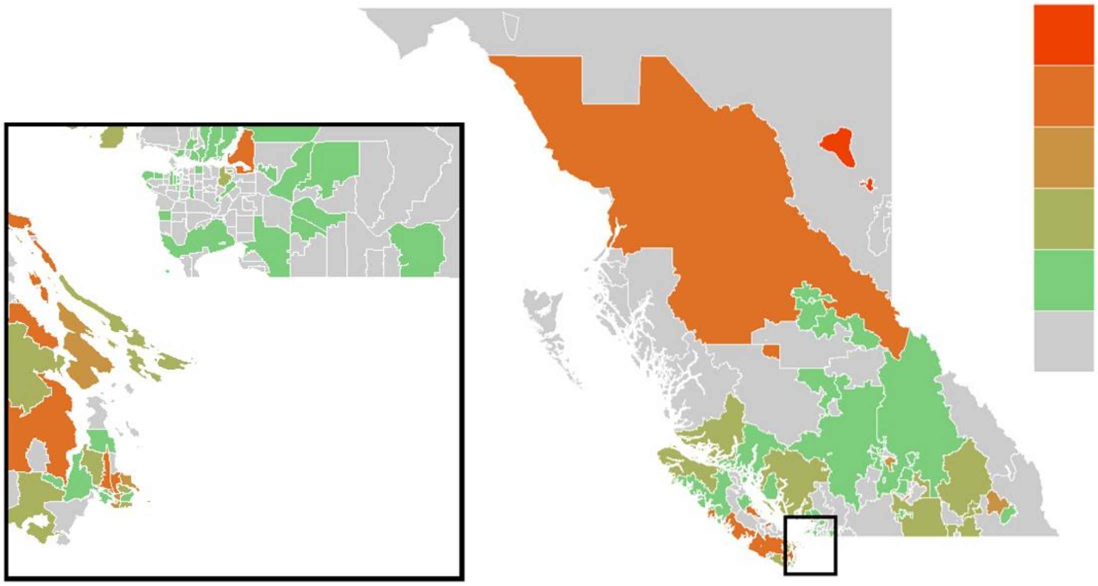



**Figure 1.** Distribution of survey respondents (n = 126) throughout British Columbia. Survey respondents self-reported their postal code, which is outlined here using shapefiles retrieved from Statistics Canada (2011). Darker colors represent a higher count of respondents and gray polygons (outlined in white) represent areas with zero survey respondents. To enable the visualization of smaller postal code areas, the inset figure in the bottom left corner illustrates the distribution of survey respondents from southern Vancouver Island and the lower Mainland.

Respondents identified as being involved in numerous organizations, including (in descending order) non-government organizations, education and outreach, the provincial or federal government, and academic institutions (Figure 2). Other less-represented groups include individuals from resource management, First Nations organizations, and university students. Future work would benefit from more thorough discussions with First Nations representatives and partners. Regardless of organizational involvement, most respondents had experience as a CS volunteer, project leader, organizer, or researcher analyzing CS data (Figure 2). Only 8 (6%) had not yet participated in CS, and 53 individuals (37%) had experienced some combination of the above groups (Figure 2).

## Patterns of community science engagement

Survey respondents similarly used CS applications to the usage proposed by Runyan et al. (2019). iNaturalist and eBird were by far the most widely used applications (n = 103 and n = 62, respectively). From the survey options, respondents also indicated using the provincial Report Invasives app (n = 22), eButterfly (n = 10), and BugGuide (n = 9) (Figure 3). Less frequently, users indicated using a variety of other applications, including Odonata Central, Nature Counts (Birds Canada), and the B.C. Moose Tracker app, eTick, and custom applications for structured CS projects. However, our survey indicated that these infrequently used applications typically had two or fewer users, suggesting limited engagement throughout the Province. Furthermore, more than 50% of respondents used two or fewer applications, with only eight using four or more.

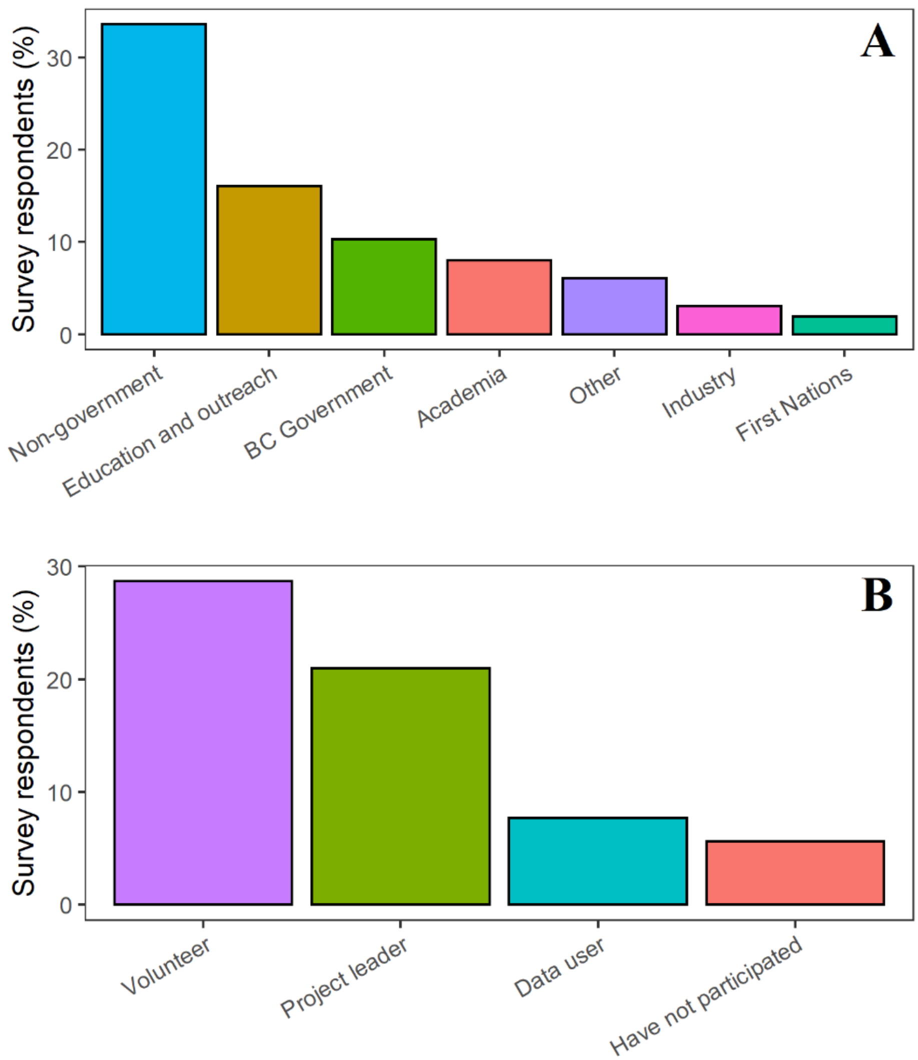



**Figure 2.** Self-reported associations (A) and identities (B) of the 126 British Columbian respondents who completed our CS survey. Survey respondents were able to make multiple selections about the organizations they were affiliated with. For panel (B), respondents were asked to choose the option that best represented their interaction with community science.

A lack of time was the most common explanation for the small number (n = 8) of survey respondents who were not yet engaged in CS. Others expressed feelings of not knowing where to contribute their effort or lack of instruction. This observation is consistent with other studies indicating that volunteers feel more engaged and enthusiastic with some direction and knowledge that their actions are meaningful (West and Pateman 2016). Collecting additional data from individuals not engaging in CS would help us better understand the factors preventing engagement.

We also asked our survey respondents about their rationale for contributing to CS and allowed respondents to select multiple choices. For the respondents who contributed data to some projects, the most common reason for volunteering was to contribute to science and conservation

(>40%). Other common responses were more personal in nature and included using CS platforms to learn about nature (>25%) and to keep a record of personal biodiversity observations and lists (15%). Other responses emphasized the importance of community and using CS as a tool for public engagement, socializing, and networking (15%). These data provide insights into the motivations of some volunteers around the Province and emphasize the importance of having volunteers feel like their contributions have scientific value while providing opportunities for personal fulfillment and social engagement.

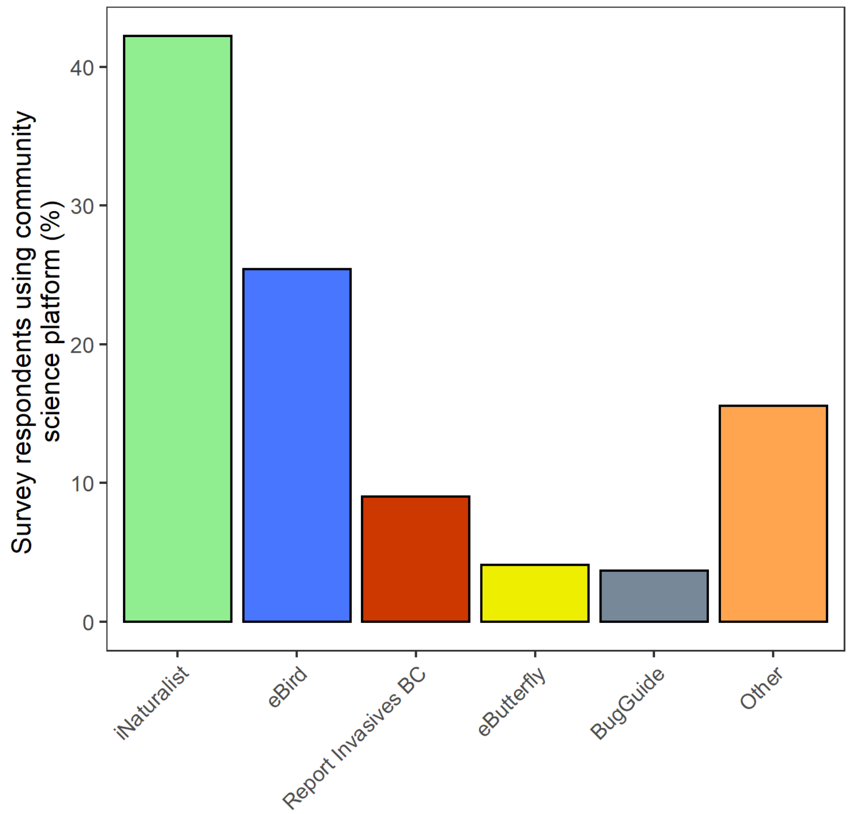



**Figure 3.** Digital community science application usage among British Columbian Survey respondents (n = 126). Survey respondents could select as many applications as they used, although more than half used two or fewer.

## Using Community Science Data

Several survey questions were aimed at analysts or project leaders using data collected from CS projects. First, we assessed the potential factors preventing CS data from being used or from being more effectively used by the respondent. Most respondents (>45%) indicated that data quality was their primary reason for not using CS data, in addition to data also having insufficient coverage to be useful for their purposes (16%). Comments on these questions and interview feedback indicate that this primarily reflects how these data are collected (e.g., standardized vs. opportunistic) and how CS data are vetted. These responses, however, address both structured and contributory CS projects, and it is difficult to determine which CS types contribute to these perceived biases and data inadequacies. For example, other comments on this question indicate that non-standardized or inconsistent data collection makes interpretation difficult or even impossible, which is typically less of a concern among structured CS projects that adhere to standardized protocols. Future work will be required to characterize better everyday data needs throughout the Province and how CS projects can collect relevant data of the highest possible quality. For instance, our interviewees claimed that many CS data were inconsistent over time, and using them to assess population trends of particular species groups was impossible. Identifying issues like this and distributing data collection protocols to potential volunteer collaborators would greatly aid standardized data collection.

Survey respondents work in various fields and consequently have varying needs regarding wildlife data. Two main camps of data users were described in survey responses. First, most respondents (25%) worked primarily on species abundances and monitoring population changes, which professionals and several structured CS projects mainly address. Suitable data from online sources are limited to select species groups (e.g., birds and butterflies, Table 2) and often lack Provincewide coverage. These data may reflect the propensity of wildlife biologists in the Province to work with species groups of economic significance, such as fish or large game. On the other hand, presence-only data were valued among many respondents studying invasive species (20%), at-risk species groups (15%), and community composition (13%). Survey respondents and interviewees using these data were interested in presence-only and checklist data, although checklist data are generally unavailable for most species groups and rely on more structured and localized projects (Table 2).


Northern Scorpion (*Paruroctonus boreus*)
Photo by Jason Headley (link)

## The future of community science in B.C.

We asked our survey respondents if the provincial government were to invest in CS, which of the following should be prioritized: i) data quality, ii) data coverage, iii) data analyses, iv) bridging CS with existing projects, and v) public education and engagement. Respondents were given the choice to rank each option, with their first choice being the highest priority for investment and their last choice being the lowest priority). Our results indicate that education and engagement were the highest priority among almost all respondent groups (Figure 4). Respondents focusing on analytical work were perhaps the exception, selecting data quality as the highest priority for the future (Figure 4). Data coverage and quality were, on average, the next highest priority objectives for respondents of all groups. These data indicate that the public, researchers, and project leaders would benefit from increased data coverage throughout the Province and improved data quality. Data quality, however, varies between

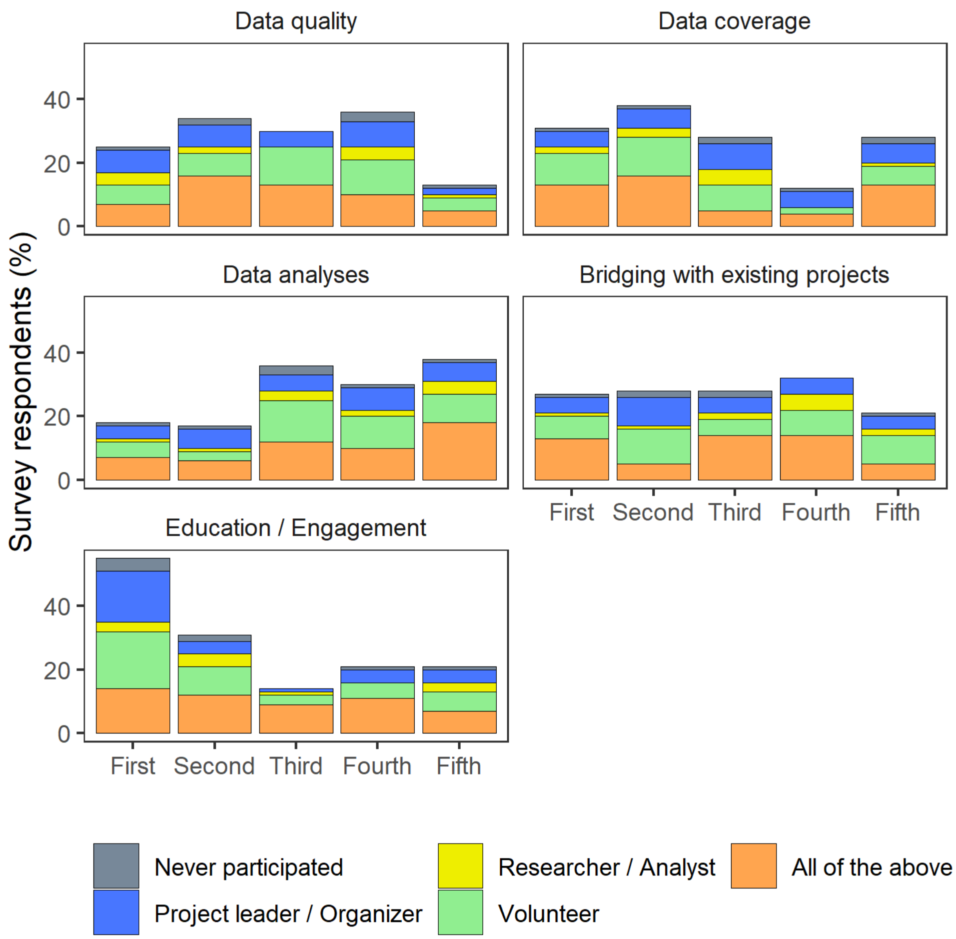



**Figure 4.** Priorities for the future of community science in B.C. as reported by survey respondents (n = 126) with various levels of experience and engagement in community science. Survey respondents were asked to rank i) Data quality, ii) Data coverage, iii) Data analysis, iv) Bridging with existing projects, and iv) Education and/or engagement as their first, second, third, fourth or fifth priority for the future of provincial community science efforts.

research objectives and the CS platform being used. For instance, contributory CS data can be improved by adding photos whenever possible, and most data can be enhanced by adopting standardized protocols and developing a more structured project style (see Recommendations for more details).

While conducting interviews, we regularly heard comments from both perspectives, and no single method will increase the quality of CS data for all wildlife researchers in the Province. Understanding project-specific data needs will likely help CS groups improve the quality and relevance of the collected data. The analysis of these data, however, was the least prioritized objective for the future of provincial CS, even among project leaders and data analysts. These observations may indicate a bottleneck occurring with the quality and quantity of CS data and that analytical processes or training are not the limiting factors.


Hoary Marmot (*Marmota caligata*)
Photo by Braden Judson (link)

# Opportunities and initiatives for community science in B.C.

## Digital platforms

In B.C., several Contributory CS platforms continually contribute to acquiring and distributing Provincewide ecological data (Table 2, Figure 3). Many of these data are vetted and publicly accessible so individuals can use them in various sectors and disciplines to answer ecologically relevant questions. However, the composition and quality of contributory CS data depends on the platform or application used, ranging from highly generalized (e.g., iNaturalist) to relatively specialized (e.g., WhaleReport). Accessible and easy-to-use contributory CS platforms have become extremely popular, with large amounts of data continuously uploaded worldwide. iNaturalist, for example, has documented more species than any other CS platform (Waller 2019) and has contributed at least 58% of records for 58% of all described species on GBIF since 2019 (Loarie 2023). Similarly, eBird has experienced continued and rapid growth, with data from millions of checklists contributing to more than 160 peer-reviewed publications for research and management in 2022 alone (Team eBird 2023). However, there are other research topics (and species groups) that cannot be addressed using these data sources, and thus, volunteers may be encouraged to use other, more targeted applications or participate in more structured CS projects.

Several provincial (e.g., Report Invasives B.C.) and more taxonomically specialized (e.g., Bumble Bee Watch) CS platforms are used in B.C. (Table 2). While these apps tend to have lower Provincewide uptake (Table 2, Figure 3), they have the potential to contribute data not produced by other applications, such as absence data through submissions of checklists. For instance, apps contributing checklists that imply species absences are the only data source suitable for distribution modelling (Elith and Leathwick 2009), despite other applications also recording the presence of the same species (Table 2a). Some applications enable users to explore global data and interact with users and experts worldwide, whereas others are more localized. Several CS platforms, such as eTick (Table 2) and eButterfly, were developed and maintained in Canada. Though relatively accessible platforms with support systems such as phone applications and AI assistance are widely used, data users and analysts interested in specific areas or data types may wish to use data from specific applications only. While a small number of applications tend to dominate the CS landscape in B.C. (Figure 3), the use of multiple applications by different contributors will undoubtedly better our understanding of provincial biodiversity.

**Table 2a.** Overview of commonly used digital community science platforms in B.C. This table summarizes popular applications; other less-frequently used applications are also used within the Province. Global GBIF uploads represent the total number of uploads since the project's inception. iNaturalist uploads to GBIF only include Research Grade (RG) observations, and eBird checklists only include complete checklists. Uploads in B.C. are specified as observations (o) or checklists (c).

| Platform | Taxonomic coverage | Geographic coverage | Data format | Uploads in B.C. | Global GBIF uploads | Year of creation | Country |
|---|---|---|---|---|---|---|---|
| B.C. Moose Tracker | Moose | B.C. only | Checklist | > 11,000 | NA | 2016 | Canada |
| BugGuide | Invertebrates | U.S. and Canada | Presence-only | > 29,000 (o) | > 500,000 | 2003 | USA |
| Bumble Bee Watch | Bumblebees | North America | Checklists | > 3,000 (o) | > 16,000 | 2014 | Canada |
| eBird | Birds | Global | Checklists | > 1,300,000 (c) | > 1,000,000,000 | 2002 | USA (.org) Canada (.ca) |
| eButterfly | Butterflies | Global | Checklists | > 20,000 (c) | > 480,000 | 2012 | Canada |
| eTick | Ticks | Canada | Presence-only | > 1,200 (o) | NA | 2014 | Canada |
| FrogWatch | Frogs | Canada | Checklist | 245 | NA | Late 1990s | Canada |
| iNaturalist | All species groups | Global | Presence-only | > 2,500,000 (o) | > 55,000,000 (RG) | 2008 | USA (.org) Canada (.ca) |
| Report Invasives B.C. | Invasive species | B.C. only | Presence-only | < 500 (o) | NA | NA | Canada |
| WSI-SPI | Most terrestrial wildlife and plant species | B.C. only | Various formats | Many | NA | 1996 | Canada |
| WhaleReport | Cetaceans and sea turtles | B.C. only | Presence-only | Unknown | NA | 1999 | Canada |

**Table 2b.** Summary of digital community science platforms commonly used in B.C. This table outlines some of the features of each application relevant to data contributors. The required expertise level is based on taxonomic specialization, the application's ease of use, and the availability of support (e.g., AI-assisted identification). The presence or absence of application-specific community events in B.C. was assessed in April of 2023; thus, these applications may still be used in future community events.

| Platform | Minimum level of expertise required | Community events in B.C. (e.g., Bioblitzes) | Mobile app availability | Discussion forums and group events | Identification assistance by AI |
|---|---|---|---|---|---|
| B.C. Moose Tracker | Low | N | iOS and Android | N | N |
| BugGuide | Medium | N | N | Y | N |
| Bumble Bee Watch | Medium | N | N | N | N |
| eBird | Medium | Y | iOS and Android | Y | Y (Merlin) |
| eButterfly | Low | N | iOS and Android * | Y | Y (eButterflAI) |
| eTick | Low | N | iOS and Android | N | N |
| FrogWatch | Medium | N | N | N | N |
| iNaturalist | Low | Y | iOS and Android | Y | Y (Seek) |
| Report Invasives B.C. | Medium | N | iOS and Android | N | N |
| WSI-SPI | Low | NA | N | N | N |
| WhaleReport | Medium | N | Y | N | N |

* Note that the eButterfly mobile app will be available in Fall 2023.

**Table 2c.** A subset of digital community science platforms in B.C. and how they can contribute data to various analyses. All platforms have the potential to detect newly invasive species, although we omit WhaleReport as there are no known invasive cetaceans. All apps recording the locations of threatened, unique or protected species have the potential to identify ecologically important habitats, although the combined data from multiple applications is likely necessary to identify important habitats confidently.

| Platform | Data verification method | Vouchers required (r) or optional (o) | Abundance monitoring | Migration and movement pattern identification | Species distribution modeling | Early warning system for invasive species | Identifying important habitats |
|---|---|---|---|---|---|---|---|
| B.C. Moose Tracker | Experts | None | Y | N | N | N | N |
| BugGuide | Community | Photos (r) | N | N | N | Y | Y |
| Bumble Bee Watch | Experts | Photos (o) | N | N | N | Y | Y |
| eBird | Select volunteers and experts | Photos, audio, or video (o) | Y | Y | Y | Y | Y |
| eButterfly | Community | Photos (o) | Y | Y | Y | Y | Y |
| eTick | Experts | Photos (r) | N | N | N | N | N |
| FrogWatch | Experts | Photos (o) | Y | N | N | Y | Y |
| iNaturalist | Community | Photos or audio (r) | N | N | N | Y | Y |
| Report Invasives B.C. | Select experts | Photos (o) | N | N | N | Y | N |
| WSI-SPI | Experts | Optional | Y | Y | Y | Y | Y |
| WhaleReport | Unknown (not public) | Photos (o) | N | N | N | N | Y |

Dedicated CS platforms are not the only places where biodiversity observations are shared and identified. Social media sites like Facebook and Twitter have also been cited as valuable resources for identifying certain species groups. For example, Facebook groups, such as Field Naturalists of Vancouver Island, are often active, with participants posting images of species they have encountered while in nature with others suggesting identifications. Survey participants even mentioned that observations of at-risk species have been reported on Facebook groups but not through other applications, representing a loss of potentially valuable data. Such groups could be a source of engagement and recruitment in CS efforts in some areas, and identifying critical social media sites and undertaking periodic monitoring and community engagement might prove to be an essential resource (e.g., government biologists suggesting contributing data to CS platforms).

## Bioblitzes

Due to the rapid advances of urban development and climate change, the need for swift and reliable data to guide informed conservation action is greater than ever. Surveys conducted by taxonomic experts are often the gold standard for data quality, but bioblitzes can also contribute significant data. While CS cannot replace traditional survey methods directly, in some cases, CS data can provide a less expensive and faster alternative. The collection of these data can be further accelerated by facilitating targeted bioblitzes. The bioblitz is typically a rapid (one day to one week) biodiversity inventory field survey conducted by volunteers and researchers to document as many species as possible in a predefined location; some bioblitzes are specific species groups (e.g., lichens; McMullin et al., 2018). Bioblitzes, therefore, present an excellent opportunity to rapidly acquire biodiversity data, such as occurrences of rare, threatened, or flagship species or species not previously known from a given location. Furthermore, bioblitzes present excellent public engagement and outreach opportunities and rare opportunities for experts and the public to work collaboratively. In 2022 alone, British Columbians from various naturalist groups organized more than 30 bioblitzes throughout the Province, bringing together thousands of participants to collect nearly 75,000 biodiversity observations (Appendix 1). Many of these bioblitzes are held annually (e.g., the City Nature Challenge) and can attract as many as 400 volunteers. Hosting bioblitzes in

Red Fox (*Vulpes vulpes*)
Photo by John Reynolds

B.C. appears to be an effective strategy for rapid data collection while providing an excellent opportunity for public engagement.

Bioblitzes can be simple and held in accessible locations or targeted and conducted in remote areas. Publicly accessible bioblitzes are great for community engagement, facilitating a connection to nature and offering an opportunity for scientific engagement for people of all abilities. Accessible survey locations can be diverse while enabling broader audience engagement. For example, Uplands Park (Victoria, B.C.) is an accessible park home to the highest density of endangered plant species in an urban park in Canada (Thomas 2019). While bioblitz organizers should be aware and mindful of susceptible areas and habitats that should not have wide public access (e.g., some areas of Uplands Park are restricted to the public at certain times of the year as they are susceptible to trampling), unique habitats like Uplands Park can provide a rich opportunity for learning, engagement, and research.

In contrast, remote locations generally have low public visitation, and thus, surveys in these areas often provide valuable baseline information in inaccessible ecosystems. Remote surveys, however, typically require more funding, planning and collaboration but can be very rewarding and informative when these resources are available. Bioblitzes can yield noteworthy observations and critical biodiversity data in urban, rural, and remote locales while offering varying engagement opportunities for the public and enthusiasts alike.

American Dipper (*Cinclus mexicanus*)
Photo by Blair Dudeck (link)

## Participatory volunteer opportunities

Participating in CS does not always directly involve data collection in the field but may also rely on volunteers for data digitization and curation. These remote or digital options also provide inclusive opportunities for volunteers with less mobility to engage in conservation science. For instance, numerous herbaria (e.g., the University of Victoria's Herbarium), museums (e.g., Beaty Biodiversity Museum) and research facilities (e.g., Agriculture and Agri-Foods Canada) rely on volunteer participation for processing samples and transforming them into online, digital submissions (Johnson and Owens, 2023). Furthermore, some organizations have digital CS portals that enable volunteers to contribute to real-time conservation research. Ocean Networks Canada, for example, has several options that allow volunteers to monitor high-resolution deep-sea videos and assist with fish identification and biodiversity monitoring. Participants contributing to these projects are also advancing the development of large-scale and complex data processing algorithms (e.g., computer vision or artificial intelligence) that can be used to expedite future data analyses in many life sciences (e.g., Sullivan et al., 2018; Langenkämper et al., 2019). Given these successes, organizations with a surplus of data may use community scientists to facilitate data processing while engaging with the public.

Mobile applications and easy web access allow volunteers to contribute to online CS platforms from home. These options do not rely on physically being in the field, which can be a barrier to some, and thus provide excellent opportunities for people with disabilities and mobility issues to engage in CS. One of the most popular online ecology-focused CS projects is Wildlife Cameras for Adaptive Management (WildCAM), in which wildlife

### Box 1: Early detection of invasive species

There are numerous examples where community science data have discovered potentially invasive species outside of their native range (e.g., Pawson et al., 2020). Pinzon et al., (2021) discuss the utility of iNaturalist in documenting the recent expansion of *Pholcus opilionoides,* a European cellar spider, throughout BC and the rest of Canada. Similarly, Cannings and Gibson (2019) highlight the community science platform BugGuide in detecting the first North American occurrence of the pallopterid fly, *Toxonevra muliebris*. This observation was instrumental in collecting voucher specimens to confirm the sighting, which have now been corroborated by numerous sightings throughout southern B.C.

*Toxonevra muliebris*; photographed by Thomas Barbin (2018).

*Pholcus opilionoides*; photographed by Braden Judson (2022).

surveys are conducted with remote camera traps. Numerous wildlife camera projects in western Canada contribute to wildlife management efforts, offering just one way rural residents can become involved in CS. Identifying observations at the appropriate taxonomic level on several CS platforms is crucial for data quality management. For several platforms, data quality is determined by the community of users (e.g., by suggesting identifications) (Table 2). However, most users do not contribute identifications, posing a bottleneck where there is a surplus of uploaded data but a paucity of identifiers with adequate expertise to suggest informed identifications (e.g., iNaturalist; Callaghan et al., 2022). Given the lack of contributions from taxonomic specialists, CS platforms would undoubtedly benefit from further recruiting experts, aspiring naturalists, and academics. Callaghan et al. (2022) highlight the need for identifiers and indicate that contributing identifications advances biodiversity and conservation research, encourages engagement with other naturalists, and is personally rewarding.

Oak Ferns (*Gymnocarpium sp.*)
Photo by Robby Deans (link)

## Specialized data collection

In B.C., numerous opportunities for CS engagement entail a higher level of commitment and responsibility for participants interested in more specialized tasks. For example, users can contribute detailed checklist data to apps such as eBird or eButterfly that include data on weather or search effort (i.e. time spent on gathering the data reported) to enable better researchers to study relative abundances of species distributions. Individuals can also join structured organizations with existing volunteer networks (e.g., Rocky Point Bird Observatory) to collaboratively contribute to further specialized research goals. These opportunities are as diverse as the organizations and vary from uniquely banding migratory birds to participating in long-term ecological monitoring projects. In these latter examples, volunteers can develop new skills and learn from other participants and collaborating scientists. Enabling volunteers to advance their skills or pursue their interests encourages long-term engagement while increasing the project's scientific value. Organizations are therefore encouraged to identify and create volunteer opportunities for participants while facilitating opportunities for learning and engagement whenever possible.

## Data from recreational harvests

The hunting, fishing, and trapping communities in B.C. also offer a rich and often underutilized source of wildlife data. Several programs already capitalize on these activities, such as the Internet Recreational Effort and Catch reporting program, which collects effort and catch data from recreational fisheries. Big game hunters can also contribute data via surveys, which collect hunt effort and harvest data from participants. However, data submission is voluntary, and compliance rates are not reported publicly and were not successfully acquired at the time of this report (and they can be low in other jurisdictions (Sexton 2018)). Similarly, licenced trappers submit annual summaries to the government which outline harvest statistics, such as animal sex and trapping effort and location. In compliance with the provincial Wildlife Act, some harvested species (e.g., Mountain goats, *Oreamnos americanus*) are subject to mandatory inspections, in which professional biologists collect detailed biometric data on the harvested animal.

Photo by Braden Judson (link)
Spruce Grouse (*Canachites canadensis*)

In some cases, submission of animal harvest data is incentivized, such as the Salmon Head Recovery Program, which offers prizes to anglers who submit salmon heads containing uniquely identifiable coded-wire tags. This program provides precious information on salmonid ecology in the ocean and relies heavily on data submitted by recreational and commercial anglers. These examples demonstrate that incentivizing voluntary data submissions and communicating data needs may increase engagement and provide additional opportunities for data collection (e.g., tissue samples for genetic analyses) from wildlife harvests throughout the Province.

## Abiotic data sources

Understanding wildlife habitats and their abiotic components often provides an essential context for wildlife management. For example, many abiotic data can be used to increase our understanding of species distributions or identify pollutants, habitat degradation and the effects of climate change. Consequently, there are numerous CS organizations dedicated to monitoring environmental parameters such as rainfall (e.g., CoCoRaHS), litter (e.g., Litterati) and atmospheric conditions (e.g., IQAir). These programs can help characterize environmental changes affecting wildlife and their habitats. Furthermore, high-resolution bioclimatic data from weather stations are available freely online from WorldClim. In conjunction with CS biodiversity data, these data provide a robust and inexpensive framework for understanding species distributions across space and time. Additionally, these platforms offer opportunities for volunteers to engage in relevant and meaningful environmental data. It should also be noted that many of these data are available in various forms through structured collection sites with climate data (e.g., Government of Canada data) and can be used to support modelling exercises with CS data.

### Box 2: Biodiversity inventories

Developing a comprehensive species checklist for a given area is often a labor-intensive endeavor that is unlikely to identify every species present. Community science data can therefore be used to bolster traditional inventory projects by providing opportunistically collected data over a greater time span. For example, Simon et al. (2022) developed a novel biodiversity informatics pipeline that integrated data from both professional and amateur naturalists to characterize the marine biodiversity associated with Galiano Island, B.C. Of the 20,000 data points representing more than 650 unique species groups, community science data from iNaturalist and the BC Cetacean Sightings Network accounted for almost one fifth of the novel recordings. Volunteer divers and naturalists from the Pacific Marine Life Surveys (PMLS) contributed more than 60% of the novel data used for this project. This project demonstrates the joint utility of expert surveys in addition to opportunistic (e.g., iNaturalist) and specialized (e.g., PMLS) community science data in understanding biological diversity in a typically under-sampled marine environment.

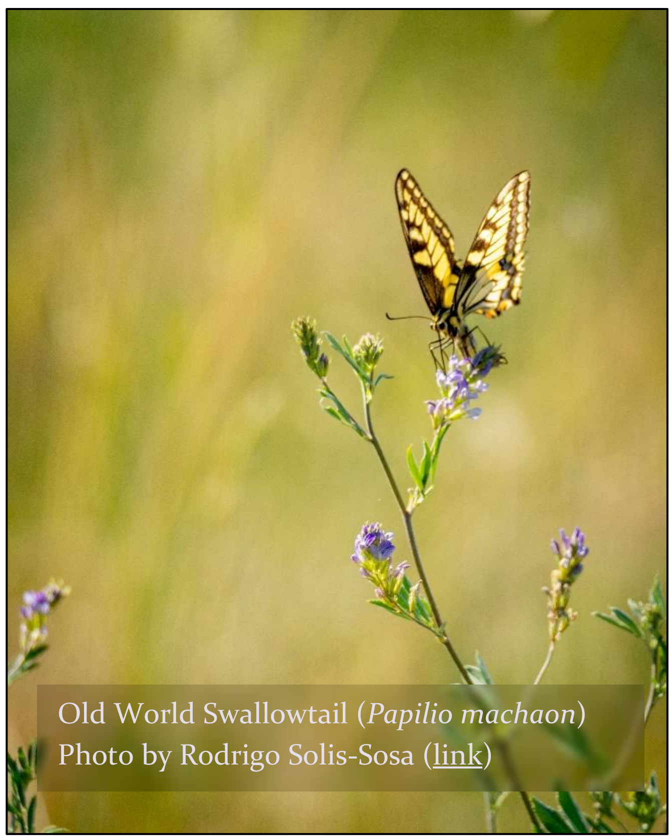
Octopus rubescens (East Pacific Red Octopus); photographed by Karolle Wall.

# Engagement

Public engagement is at the core of CS. After developing research goals, CS projects typically need to engage the public and build a community, often involving localized networking and potentially advertising to attract participants for collaborative CS projects. There may also be a role for government funding of initiatives, and government-supported programs can have field staff who collect high-quality data towards specific goals while demonstrating exemplary data collection techniques. Contributory projects may benefit from advertising via social media, email, newsletters, and other outlets since they sometimes lack the localized community engagement of collaborative CS projects. However, contributory and collaborative projects would likely benefit from localized and non-localized networking and promotion. Regardless of the promotional avenues taken, it is clear that science benefits from a more extensive and diverse community (Cooper et al., 2021; Pateman et al., 2021). Increased participation can be achieved by hosting workshops, meetings, and celebrations and acknowledging participant contributions (Fraisl et al., 2022). Using social media to promote events and volunteer opportunities has also successfully engaged community members (Oliveira et al., 2021).

## Recruitment

Studies show that exposure to nature as a child and a young person is often correlated with a lifelong interest in the environment (Chawla, 2020; Sachs et al., 2020), and an increased connection to nature helps to promote pro-environmental behaviours (Martin et al., 2020). By encouraging harmony with nature, there is an incentive to partake in CS. For example, developing partnerships with school districts and nature-based organizations and promoting rural and urban ecology has been well-received by students, teachers, and communities (Vieira et al., 2022; Knowlton Cockett et al., 2016). Organizations such as NatureKids B.C. and Nanaimo Science provide programming, workshops, and events to this effect for youth and schools, respectively. Bioblitz events, such as the City Nature Challenge (international) and the False Creek Bioblitz (Vancouver, B.C.), encourage the public to engage with nature by contributing observations in urban settings, whereas initiatives such as WildCAM may be more suitable for those living in more rural locations. Survey respondents who had not engaged in CS previously cited a lack of direction and not knowing where they could meaningfully contribute as reasons why they had not contributed to CS efforts. Therefore, recruitment of new volunteers for CS initiatives may benefit from clear communication of the goals and rationale of CS projects. Supporting programs that foster curiosity and connections with the environment is foundational to supporting continued engagement with CS and developing the next generation of naturalists.



Old World Swallowtail (*Papilio machaon*)
Photo by Rodrigo Solis-Sosa (link)

## Volunteer patterns

Retaining volunteers is often one of the significant challenges for any CS project (West and Pateman 2016). Communication is often the most essential factor for keeping volunteers engaged, and thus, it is vital that project goals and progress are frequently and effectively communicated to their volunteer base (Frigerio et al., 2018). For example, many participants who drop out of CS projects attribute their decision to feelings that their contributions were not valued or that they were not contributing to anything meaningful (Eveleigh et al., 2014). It’s common for people to participate in a one-time CS event and then discontinue their involvement because they don't feel the need to participate again (Fischer et al., 2021). Understanding the individual motives of volunteers and using these motives to increase engagement can help retain participants. For example, participants often contribute to wildlife-focused CS as they feel they are helping the environment (Geoghegan et al., 2016), as supported by responses to our survey in which a desire to contribute to science and conservation was cited as the most common rationale behind engaging with CS. Many volunteers are also encouraged by the social aspects of CS, and often, volunteers who have had positive experiences will invite others to CS initiatives, reducing the cost and efforts in recruitment for the organization (Andow et al., 2016).

Moreover, Andow et al. (2016) found that volunteers who recruit others do not cite it as a cost to themselves but rather as a benefit of sharing the experience with someone else. Therefore, CS projects may benefit from encouraging volunteers to work together or directing data collection for particular species groups and locations while communicating *why* these data are being collected. Creating recurring opportunities to keep participants engaged over one-time events would also help retain and re-recruit volunteers. Furthermore, aiming to make CS events fun and engaging and encouraging participants to invite friends and others interested in participating would help recruit and retain volunteers while reducing the effort required by organizers.

Lustrous Copper (*Lycaena cupreus*)
Photo by Julia Carr (link)

However, certain volunteer behaviours and engagement patterns are common to most CS projects. For example, most CS projects note that individual contributions vary considerably, with a small number of highly active participants and a significant number of *dabblers* who contribute periodically (Eveleigh et al., 2014). Highly active and specialized users are often a valuable asset to a CS project, and project managers would be wise to recognize these individuals and acknowledge their contributions (Di Cecco et al., 2021). Alternatively, many projects observe the gradual decline of dabblers, with occasional spikes of activity associated with particular outreach or engagement events (Sauermanna and Franzonib, 2015). Managers of CS projects are thereby often tasked with the challenge of keeping participants engaged after they have been recruited. Opportunities for training and learning often increase individual investment and mutually benefit the project and the participants.

# Community science data

## Open and accessible data

One core tenet of the Together for Wildlife initiative is scientific transparency regarding biodiversity data and wildlife management. As public trust in the government to manage wildlife and the environment has declined in recent decades (Citrin and Stoker, 2018), establishing open science frameworks suggests an opportunity to regain the public's trust (Anhalt-Depies et al., 2019). In 2011, building on the early successes of providing open data, the Province developed the Open Information and Open Data Policy. This policy prioritizes the public sharing of government data whenever possible while empowering collaboration between various government and public sectors—the B.C. Open Government Licence allows the public to use any data published under an open data licence as long as attribution is included and the licence terms are followed. Although the most commonly recognized source is the B.C. Data Catalogue, data posted to government websites can also be licenced open data. Data should be findable, accessible, interoperable, and reusable (Go FAIR) to optimize open data principles. As discussed above, while being mindful of data privacy concerns and the potential sensitivity of specific data, these objectives can often be met by uploading data to the appropriate location and making sure that analyses are reproducible by uploading the corresponding code to an accessible repository (e.g., by using GitHub). Roche et al. (2022) identify that adopting an open science framework is central to reducing data redundancy, improving public trust, and more effectively sharing information to make rapid and informed decisions. The B.C. government's open data policy and associated data repositories seek to achieve this structure.

Satinflower (*Olsynium douglasii*)
Photo by Brian Starzomski (link)

Many digital platforms contribute open and accessible biodiversity data to extensive, global networks for storing and distributing these data. For example, the provincial Conservation Data Centre (CDC) data that is uploaded to NatureServe, in addition to many data from digital platforms, are both uploaded to the Global Biodiversity Information Facility (GBIF) (Table 2).

Funded by governments around the globe, GBIF is the world's largest biodiversity information repository and data network designed for searching, downloading, and storing biodiversity data. Notably, most digital platforms only upload data passing certain quality thresholds to GBIF, and thus, users are advised to check these criteria before submitting data (e.g., only iNaturalist observations with CC0, CC, BY, or CC-BY NC licensing are imported to GBIF). Ensuring that biodiversity data meet requirements to be imported to GBIF guarantees the data are genuinely open, free, secure and accessible to the public. For researchers interested in more specific questions, much of the data from digital platforms can be downloaded directly from their websites or indirectly through various external software packages such as the eBird R package 'auk' (Strimas-Mackey et al., 2018). Knowing where and how to access data from these platforms can be a valuable tool for acquiring biodiversity data across large spatial scales, which can be used independently or in conjunction with data from more structured projects.

## Existing tools

Throughout the Province, considerable work has been done to ensure that biodiversity data are accurate, centralized, and accessible. Presently, wildlife survey, harvest, and observation data are available from several sources, including harvest and allocation data from the Wildlife Information and Licensing Data (WILD) system and observation and inventory data from the Wildlife Species Inventory (WSI-SPI) database in addition to numerous map and document libraries (e.g., EcoCat). Notably, the WSI-SPI database houses a variety of data that can be tailored to develop specialty data sources to which the public can contribute data. These data follow a standardized data submission process for inventory surveys, projects, and incidental observations. Volunteers and members of the public can also submit incidental observations in a structured way so they can be quickly brought into corporate data systems. Bulk submissions can also be made via email submission to the SPI-mailbox.

Cougar (*Puma concolor*)

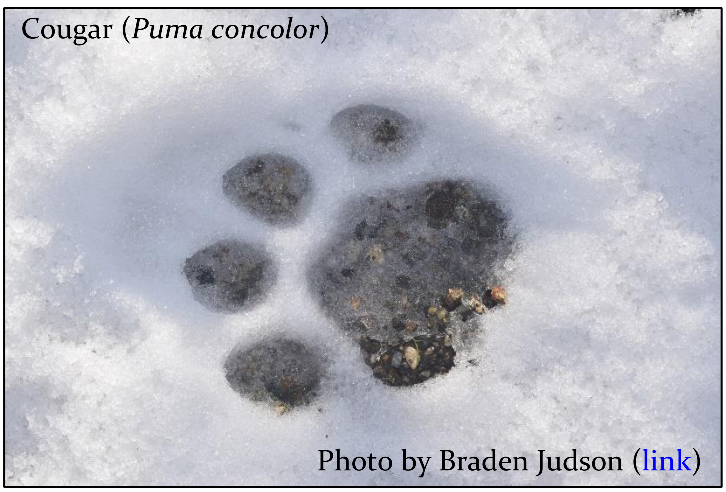


Photo by Braden Judson (link)

Most data submitted to the WSI-SPI database is publicly accessible. The four exceptions are species and ecosystems susceptible to harm, proprietary data, statutory constraints and government interest (Government of British Columbia, n.d.). Where sensitive data is secured and not made publicly available, most restricted datasets can still be accessed by request when an appropriate rationale is provided, data security training requirements are complete, and where a requestor has a signed confidentiality and non-reproduction agreement. Ultimately, releasing sensitive data hosted on the WSI-SPI database is determined case-by-case.

The WSI submission site is the primary conduit for wildlife inventory data submissions. Data undergoes quality control and quality assurance by provincial staff and is assessed to ensure no personal information is included and to determine whether any data must be restricted based on the data security categories outlined above. Wildlife datasets are then loaded to the SPI database and made available to data users.

Non-sensitive and publicly accessible data can be downloaded from DataBC or via spatial tools such as iMap B.C. or Habitat Wizard. Through DataBC, individuals can download multiple data formats, including those compatible with Google Earth or ESRI geographic information systems. Habitat Wizard has preloaded layers for viewing provincial data, and users are restricted from adding data layers. In contrast, the iMapBC portal enables users to add layers of their choice (pulled from DataBC) to create custom maps. In the coming months, the B.C. Conservation Data Center's B.C. iMap tool and Habitat Wizard will be merged into a single spatial access tool called EcoAtlas, meant to enhance data access, improve features, and provide a more user-friendly single point of access to B.C.'s species at risk and species inventory datasets.

By standardizing wildlife data at the provincial scale, provincial repositories such as the SPI database and WILD system then support various provincial business lines. An example is the linkage between WSI-SPI and the Province's CDC. The B.C. CDC is one of several CDCs in Canada that compile, map, assess and distribute high-quality species and ecosystem data. These sources act under the umbrella of NatureServe, a network of more than 60 organizations that collaboratively manage and synthesize biodiversity data throughout North America. The B.C. CDC pulls data from the SPI database and other sources and maps known element occurrences (an area of land and water where a species or ecosystem is known to occur) of red-listed and blue-listed species and ecosystems, meaning that incidental observations provided by the public may be incorporated into the CDC system only when they meet the necessary data standards.

## Tools in development

There is ongoing work in the Province to modernize current data systems with the development of Biodiversity Hub B.C., or BioHub. BioHub will provide an overarching framework that integrates multiple subsystems and enables the new systems to communicate with each other streamlined and efficiently. These multiple standalone subsystems will be designed with reusable components that use similar technology and are integrated through shared services and Application Programming Interfaces (APIs). One element of the BioHub tool is the Species Information Management System (SIMS), which is being developed to capture, store, and manage all terrestrial and aquatic species and habitat inventory data. Key functional components of SIMS will address the need to manage project metadata, survey information, inventory standards, data security, user mobility, data access, data analysis and reporting.

One attractive aspect of BioHub is the integration of standardized data formats, such as Darwin Core, which implements a standardized vocabulary for communicating biodiversity information (Wieczorek et al., 2012). Such a standardization level would help resolve issues associated with using multiple data sources (e.g., inconsistent taxonomic treatments of hybrids or subspecies).

Implementing a standardized data formatting system would address many of our interviewees' challenges about using CS data from multiple sources. In the future, CS projects should prioritize uploading their data to the appropriate system(s) to ensure that researchers from other institutions and locations can more easily access and use these data to benefit wildlife within the Province and abroad. For CS projects submitting data to government platforms, data contributors need to know that their data will be repackaged and reformatted to meet the needs of some of the data distribution tools mentioned above.


Photo by Brian Starzomski (link)
Glasswort Feather-moss
(*Scleropodium touretii*)

## Data privacy

Data privacy is essential for CS, as the data's management, expectations, and uses vary between organizations and providers. Regarding CS, Bowser et al. (2014) define privacy as "*the right to manage access to voluntarily submitted personal data*." Here, personal data can take a variety of meanings, including the names of volunteers, photos of recognizable places, or upload patterns that inadvertently reveal where users live or work (Bowser et al., 2014; Sandbrook et al., 2018; Anhalt-Depies et al., 2019). While data submitted to government databases are first cleared of personal information, digital CS platforms, external to the government, rely on the user to determine which data are open and which are withheld. However, data privacy often extends beyond the application as time-stamped and geotagged observations map biological patterns and those of the observer(s) (Bowser et al., 2014).

Furthermore, uploaded images may include recognizable people or places (e.g., privately owned land), potentially subject to privacy infringement concerns, primarily if the observation was not legally obtained (Sandbrook et al., 2018; Anhalt-Depies et al., 2019). iNaturalist, for example, allows users to circumvent some of these issues by setting *Private* (i.e., observation coordinates are inaccessible to other users) or *Obscured* (i.e., observations are set within a 0.2 x 0.2-degree rectangular cell encompassing the hidden true coordinates) observation coordinates. As a result of the potential issues associated with data privacy, many platforms suggest that users are over 18 years of age and read a privacy statement before agreeing to their terms. Users should always check platform-specific privacy settings and only upload data they are comfortable uploading.

The privacy of the observation subject is also crucial as many species groups are sensitive to disturbance and may be actively sought if their location is displayed to the public (Fox et al., 2019). On many platforms, the locations of sensitive species groups are automatically obscured or privatized (e.g., many owls on eBird). In most cases, however, it is up to the observer to choose when to limit data availability. Withheld observation coordinates can restrict the availability of the data to researchers and data users, who use element occurrences to assess the conservation status of certain species and habitats in B.C. (Government of British Columbia, n.d.). However, using Canadian versions of platforms (e.g., eBird.ca instead of eBird.org; Table 2) increases the accessibility of these data to Canadian researchers, such as provincial CDCs, while ensuring that sensitive data are not openly accessible to the public. While projects may often strive for complete data openness, exceptions regarding individual privacy, the protection of wildlife and resources, and government assets must be considered before distributing potentially sensitive data to the public.

## Data ownership, sovereignty, and acknowledgement

Clear data ownership and sharing protocols ensure trust and openness between data collectors and users. During our interviews, developing and respecting data ownership clauses was repeatedly identified as a significant priority for volunteer organizations. For instance, most volunteer groups want their data to be shared but not publicly available since members of other groups (e.g., industry) may use the information in an unexpected way. In addition, the public is increasingly asking for industry-collected wildlife data to be made publicly available, and when data is withheld from the industry, they may unwittingly proceed with an activity because they are unaware of the presence of a sensitive species. Consequently, some groups may be averse to sharing their data with the public or government agencies. Project-specific sharing policies can significantly impede the sharing of CS data, whereas projects that adopt existing sharing protocols enable the most effective sharing. Developing an agreement between independent CS projects/platforms and the government (or other agencies) may be a way to manage data ownership complexities and data sharing expectations. One approach the Province has used has been to develop Data and Information Sharing Agreements with different organizations and agencies interested in sharing data with the Province.

For CS data to be optimally shareable and open to the government and other collaborators, CS projects should strive to have their data as open as possible and with the fewest sharing restrictions. The most effective tool for sharing data in this way is to publish the data under an open data or creative licence. These approaches enable others to access and use the data without data providers having to relinquish authorship, copyright or ownership.

Partners must also be mindful of data ownership, control, access, and possession (OCAP[1]) in CS projects. The principles of OCAP maintain that decisions around data collection, ownership, usage, storage, sharing and distribution are controlled by the Indigenous communities within the research (First Nations Information Governance Centre [FNIGC] 2023). As a framework, OCAP exists to support First Nation sovereignty and empower Nations to incorporate the principles related to their protocols and worldviews (FNIGC 2023). To uphold these principles, the B.C. First Nations Data Governance Initiative was developed to provide guidance and policies for ensuring that Nations have the capacity and support to govern data and information concerning First Nations' people, lands and organizations. For example, the Environmental Stewardship Initiative was established in 2014 to support the collaborative assessment of environmental conditions in numerous traditional territories throughout the Province. Consequently, there are existing tools for collaborative stewardship of provincial and First Nations lands and ecosystems and the subsequent management of these data that builds towards respectful collaboration and reconciliation.

Acknowledgement of data contributors and contributing members of CS projects is essential. Data sources must be acknowledged and attributed adequately in CS projects. Indeed, acknowledging authorship is a fundamental criterion of the provincial open data licence. Since volunteers are the backbone of CS, their contributions must be acknowledged by the scientists and coordinators leading the project. Acknowledgement can take several forms, from including volunteers as authors on a publication to writing a formal acknowledgement section highlighting specific volunteers. Acknowledgements can often include recognizing where the project occurs and the local stewards of the land, including First Nations governments and territories and private landowners. While conducting interviews with CS volunteers, many voiced their concerns about scientists simply "using" their data without respecting and acknowledging the individuals who collected it. It is critical to give credit where it is due to promote strong, longstanding, and collaborative relationships between volunteer groups, land stewards and data users, ensuring that contributors are acknowledged in a way that suits their interests.

[1] OCAP® is a registered trademark of the First Nations Information Governance Centre (FNIGC). See https://fnigc.ca/ocap-training/ for more details.

Columbian Black-tailed Deer
(*Odocoileus hemionus columbianus*)
Photo by John Reynolds (link)

## Data standards

Individuals using CS data and managers of CS initiatives who were interviewed repeatedly stressed the need to collect *structured* data. Following defined protocols can mitigate many biases common to contributory CS projects. For instance, the Resources Information Standards Committee (RISC) has developed and distributed numerous standards for collecting ecological data types, including those focusing on soil, terrain, water and wildlife.

To facilitate the collection of structured and standardized wildlife data, the Province has also developed a Species Inventory Fundamentals document to guide the collection of wildlife data. A series of standardized protocols for inventorying ecology, biodiversity, vegetation and more complement these inventory standards. Furthermore, numerous provincially standardized wildlife data submission templates are available for many species groups (e.g., bats, plants and lichens, ungulates, and incidental observations). These documents guide collecting many types of wildlife data, including almost all major species groups and ranges in survey intensity and scope. These protocols can be used by various developing CS projects, which can use these documents to plan their study design to optimize data quality and comparability. For CS projects with non-inventory goals that do not align well with the preexisting government protocols (e.g., studies of animal behaviour), platforms such as CitSci enable projects to build custom, smartphone transferable datasheets to encourage the standardized collection of field data. Together, there are several government and non-government support tools accessible to CS projects that were designed to promote the standardized collection of wildlife data.

## Contributory community science data: Potential biases

One of the primary challenges associated with the post hoc analysis of contributory CS data is quality control and accounting for potential biases (Vantieghem et al., 2017; Dickinson et al., 2018; Adler et al., 2020). Quality control measures vary considerably between platforms (Table 2), and thus, researchers using data from these platforms must be cognizant of the potential limitations of the data.

Understanding the structure and limitations of the data is a crucial step in determining which inferences can be accurately made and which procedures can be used to increase the power and precision of the conclusions drawn (Van Eupen et al., 2021). For example, checklist-oriented platforms (Table 2) often use implicit zero-counts to indicate the absence of a species (e.g., Snäll et al., 2011). While it is crucial to account for varying and imperfect detection probabilities (Kéry et al., 2010), the presence and absence data retrieved from checklists can be used in a variety of applications, such as measuring relative abundances or fitting species distribution models (e.g., Johnston et al., 2021) if these are the topics of interest. Furthermore, checklists allow users to quantify the effort behind their checklist by recording the distance and duration of the list while also enabling users to record important metadata, such as the time surveyed or the weather. Alternatively, while presence-only data are helpful for various purposes (Table 2), there are challenges associated with estimating population abundances and species distributions.

### Box 3: Community Science in Action

Engaging volunteers to effectively collect widespread and long-term data on threatened species presents opportunities for community engagement and applied ecological research. Volunteers for the Nicola Naturalist Society, under the guidance of professional herpetologists, have contributed to amphibian conservation by conducting an extensive and long-term mapping project to identify priority areas for amphibians, including at-risk species such as the Great Basin Spadefoot (*Spea intermontana*) and Western Toads (*Anaxyrus boreas*). Structured field surveys by volunteers and autonomous recording units (ARUs) have improved our understanding of these amphibian distributions over space and time. These data have been used to monitor population dynamics and to identify areas susceptible to roadkill, which has been greatly mitigated by the installation of drift fences. Data collected from surveys are uploaded to the provincial SIMS database, and wildlife counts and observations are uploaded and publicly available on eBird and iNaturalist. By collaborating with landowners, professionals and naturalists, the Nicola Naturalists Society has modelled excellence in applied, long-term community science to the mutual benefit of the people and wildlife of the Nicola Valley.

*Spea intermontana* (Great Basin Spadefoot); photographed by Andrew Nydham (2021).

However, a variety of statistical tools, such as accounting for pseudo-absences (i.e. artificially created data points representing locations where a species is assumed to be absent), can use presence-only data to estimate how biodiversity is distributed throughout space and time (Mateo et al., 2010; Tulloch et al., 2013; Ver Hoef et al., 2021). Together, presence-only and checklist-oriented data have their limitations and strengths and researchers would benefit from carefully selecting which data they use and collaborating with statisticians to maximize the potential power of CS data (reviewed by Bird et al., 2014).

Some CS platforms benefit from photo-based identifications, which enable users in the community to corroborate or correct species identifications to control for the misidentification of particular species groups (Table 2). Specimen photos coupled with time stamps and geographic coordinates are invaluable for detecting potentially spurious observations (e.g., species groups out of their typical range or season) and correcting misidentifications (Vantieghem et al., 2017). However, photo-based identifications often bias observations towards charismatic, large, and easy-to-photograph species groups (e.g., plants) and away from cryptic, small and difficult-to-photograph species groups (e.g., nocturnal mammals). However, some CS platforms utilize audio files and sonograms (e.g., Xeno-canto; Table 2), which has increased our understanding of visually cryptic and audibly conspicuous groups. Smartphone applications such as Echo Meter Touch 2 (Wildlife Acoustics) allow users to record bat vocalizations by attaching a special microphone directly to the phone and identifying the species based on the spectrogram produced. The user can then upload the spectrogram to the relevant platform.

Furthermore, some species groups cannot be identified from photographs alone (e.g., many fungi) and are underrepresented and, potentially, misrepresented on digital CS platforms. Other platforms rely on selected experts or volunteers to vet data according to local and prior knowledge, ensuring that only trained or experienced individuals can verify observations. Depending on the project objectives, researchers may use data from certain platforms based on the platform's data vetting methods.

The structure of contributory CS data not only reflects ecological conditions but also the behaviours of the observers. For example, people tend to become more skilled at identifying and observing certain species groups because they focus on them more frequently and in greater detail than others, as evidenced by Di Cecco et al., 2021. Some behavioural patterns scale to populations, too; for instance, iNaturalist observations are more frequent and diverse on weekends and during the spring and less so during the week and in inclement weather (reviewed by Di Cecco et al., 2021). However, spatial biases are perhaps the most significant limitation regarding CS data. On a broad scale, there is uneven coverage within and between countries, in addition to fine-scale patterns such as data aggregation near roadways and other urban infrastructure (Di Cecco et al., 2021; Geurts et al., in press.). These observations corroborate feedback from our interviewees and survey respondents, who identified a lack of data coverage in relevant areas as a significant inhibitor to using CS data. These patterns are particularly relevant in B.C., where CS data are commonly centred around population centres despite most conservation work occurring outside urban or densely populated areas.

# Applications and potential limitations of CS

In light of the many aspects of CS we have discussed thus far, CS has many potential applications in addressing current and future scientific and management issues. Primarily, the CS framework enables researchers to collect data over a larger scale than would otherwise be possible, and there are valuable insights to be gained from these extensive datasets. With active contributors around the globe, CS data provide a powerful tool when monitoring invasive species (Pawson et al., 2020; Box 1), making important discoveries (Jain et al., 2019; Roberts et al., 2022) and developing a baseline understanding of existing biodiversity. The vast and rapidly growing body of contributory CS data has only begun to be explored, and these data can potentially shape many future decisions regarding wildlife conservation (Callaghan et al., 2021). Respectively, presence-only and checklist-oriented CS data have proven valuable in assessing localized species richnesses (Box 2) and understanding many species groups' movement and distribution patterns (Hurlbert and Liang, 2012; Soroye et al., 2018). CS can also further engage participants by allowing them to contribute to data processing tasks, such as verifying data on online platforms (Callaghan et al., 2022) or identifying wildlife photos collected from trail cameras (Lasky et al., 2021). Volunteers can also be central to conducting a wide array of field tasks, including conducting surveys (Box 3), sample collection (Ryan et al., 2019) and habitat restoration (Justice, 2007). Through recruiting volunteers, CS better enables project leaders and researchers to understand and conserve biodiversity than ever before.

Together, many of the above applications have the potential to shape the decisions being made by government agencies, conservationists and landowners. For example, individuals uploading potentially dangerous and distressed wildlife observations to the provincial Wildlife Alert Reporting Program (WARP) can inform management decisions about preventing human-wildlife conflicts in urban environments. Furthermore, CS observations of wildlife have been used to inform various status assessments and are now a regular component of the workflow assessing species conservation statuses by organizations such as COSEWIC (J.D Reynolds, former Chair or COSEWIC, *personal communications*). The 2021 status reassessment of the Sharp-tailed Snake (*Contia tenuis*), for example, was influenced by a single observation uploaded to iNaturalist, which substantially increased this species' known range on Vancouver Island. Furthermore, CS data regarding protected species groups can directly (i.e., uploaded observations) or indirectly (i.e., using patch-occupancy or species distribution models) identify locations where at-risk species potentially occur. By identifying sites and habitats where at-risk species groups potentially occur, managers can make better-informed decisions when conducting environmental assessments or deciding how lands are protected or developed.

Some provincial organizations, such as B.C. Parks have already integrated CS data into their land-use frameworks, where observations of specific species groups are used to inform management decisions about land protection and use. Given the predicted climate changes throughout the Province (e.g., Mahoney 2019), it will be necessary for managers to predict anticipated climatic conditions to make informed stewardship decisions accurately. As most of the Province will experience novel climates by 2050 (Mahoney 2019), there is potential for biotic communities to change and for species that cannot adjust to become extirpated or extinct (Urban

2015). Understanding how communities respond to climate change first requires we know what is there currently, highlighting the value of opportunistic CS data throughout the Province. As such, CS data have the potential to inform land stewardship decisions in a changing climate. Collectively, the CS databases in the Province form a relatively inexpensive resource that can expedite and inform various decisions affecting wildlife and habitat conservation. Furthermore, B.C. Parks has suggested that a high-priority CS project could collect data within Parks and other land ownership types throughout the Province to assess how well B.C. parks lands support provincial biodiversity.

Despite the vast utility of CS, there are some limitations to engaging volunteers, and thus, wildlife conservation will always rely on the joint efforts of paid professionals and volunteers. For example, moderate changes in wildlife population sizes are generally only detectable with repeated, non-random surveys, whereas surveys collected by volunteers often fail to detect these changes, especially for uncommon species (Ottvall et al., 2009). Professionals conducting targeted research may be better suited for assessing some population characteristics, such as changes in abundance, age composition or behaviour (Table 2). Furthermore, technical and financial limitations often prevent community scientists from studying specific species groups (e.g., bat surveys requiring expensive acoustic monitors) or locations (e.g., highly sensitive or remote areas). Data collections that require extensive safety or methodological training are also sometimes ill-suited for CS work (e.g., live animal trapping), although there are successful projects where volunteers assist professionals in conducting more complex tasks. These challenges are not exclusive to CS projects; however, if CS projects are not supported, and volunteers are not trained, they would likely be more hindered than professionals in overcoming these challenges. As such, research programs and professionals are encouraged to assess the suitability of their project for integrating volunteer efforts and may use online platforms (e.g., the Canadian Citizen Science Portal) or local networking to integrate volunteers into their work model wherever appropriate.

Townsend's Big-eared Bat
(*Corynorhinus townsendii*)
Photo by Jeremy Gatten
(link)

# Examples from other jurisdictions

While CS has a strong presence in B.C., there are opportunities to take inspiration from other countries and provinces and to innovate and advance existing CS efforts. Primarily, there are opportunities to capitalize on the community of volunteers throughout the Province and integrate these data into research and decision-making frameworks. For instance, the Norwegian University of Science and Technology (NTNU) has assembled a team of analysts and academics to identify avenues for optimizing Norwegian CS, including developing statistical models to identify knowledge gaps and using CS observations to bolster remote sensing data (NTNU 2019). Similarly, the Swedish ARCS (Arenas for Cooperation through Citizen Science) project facilitates cooperation between community scientists and academics to localize and enhance CS efforts within Sweden. Instances of programs with infrastructure bridging CS, academia, and the government are much rarer in North America. Consider, however, the Alberta Biodiversity Monitoring Institute (ABMI), a Canadian biodiversity survey program (perhaps the country's most comprehensive and best) with a complex infrastructure that uses biodiversity data to inform land management, conservation, and education while facilitating collaboration between industry, academia, Indigenous nations and the government. While the ABMI primarily relies on data collected by paid professionals, its organizational infrastructure may lend itself to incorporating CS efforts both provincially and beyond. Regions looking to support CS best may wish to incorporate some of these elements into their existing framework for monitoring biodiversity.

# Recommendations

After receiving feedback from British Columbians and exploring the topics discussed thus far, we have developed a set of recommendations that can be grouped into six main categories. We present these recommendations in the approximate order they were prioritized by our respondents, with higher-priority topics discussed first. However, potentially conflicting financial and logistical concerns may mean the Province may wish to prioritize these recommendations differently. Future work will be required to understand better how these recommendations can be implemented and in what order these deliveries should be addressed. *Overall, we recommend hosting conversations with provincial biologists and project managers to better i) the priorities of government staff, potentially different from those of our survey respondents, and ii) the strategies and priorities for recommendation implementation while considering existing projects, tools, and support systems.*

## Implementation

There is currently a gap in the provincial government for the coordination and leadership of CS, which could be addressed with a dedicated position. To initiate the delivery of the objectives described above, the Province would benefit from at least one dedicated position through a 27-level engagement specialist or research officer job profile. This position would facilitate the collection of CS data, promote provincial CS priorities, and summarize and analyze CS data for provincial use. Some of the primary responsibilities of this position would be:

1) Liaise with various governments, non-government organizations, and First Nations throughout the Province to identify data needs and work to meet these needs.

2) Identify knowledge gaps (e.g., taxonomic, biogeographic) and support CS solutions to fill these gaps.

3) Liaise between data sources and provincial biologists aiming to use CS data.

4) Report and effectively communicate CS results to decision-makers and conservation practitioners.

5) Take part in public engagement and scientific communication efforts to ensure that biodiversity in B.C. is an active part of the public's lives.

## Enhancing provincial community science engagement

The existing CS scientific literature and our survey results emphasized the significance of public engagement. Project leaders, volunteers and analysts alike indicated that the Province should prioritize enhancing and expanding CS efforts via improved engagement with the public. These data strongly suggest that provincial wildlife projects should prioritize public engagement in some way, which can vary from direct collaboration with volunteers to accessible public reporting of project progress. To improve CS engagement, we make the following recommendations:

1) Provide training and support options for project leaders to promote their project(s) on various platforms, including the Canadian Citizen Portal, SciStarter, and Zooniverse, which have proven effective recruiting volunteers. Contacting local ENGOs and distributing project information over social media and other communications channels may also effectively recruit and engage volunteers. Additionally, advertising broadly on social media and other public outlets may be an effective strategy to engage potential volunteers.

2) Communicating provincial CS efforts is a potential avenue for strengthening the relationship between the public and various government agencies. To accomplish this, the Province should support and develop a Together for Wildlife Community Science channel to highlight CS projects and their successes throughout the Province (inspired by the B.C. Parks Blog) such as blog and social media posts, newsletters, and emails distributing provincial CS information about as events and project highlights. Various government agencies already do this well and could promote community science information and opportunities with some support.

3) Support projects that develop an interest in nature and science among young British Columbians, thereby contributing to the next generation of community scientists (e.g., CS programs collaborating with schools or extracurricular programs that engage youth in nature).

4) Support initiatives and events contributing to meaningful data collection and volunteer involvement. A combination of groups in collaboration, including First Nations organizations, government bodies, ENGOs, and academics, may support these events. We suggest government groups support and implement the following tasks to promote informed data collection and public-government collaboration.

    a) Develop workshops and webinars to disseminate information and skills to a broad audience. Groups needing specific data would benefit from hosting these information sessions, which may focus on how to contribute data to particular platforms or how to identify organisms of interest.

    b) Support field activities to rapidly collect data while engaging with the public and partnering organizations. Planning and supporting regular bioblitzes in both accessible and more remote locations, using a variety of community science applications, is a recommended method for simultaneously engaging volunteers, collecting data, and communicating data needs.

    c) Provide inclusive opportunities for engagement that can be accessed remotely, such as helping to identify animals from camera trap photos. By allowing volunteers to contribute to CS efforts remotely, individuals in rural locations or those with disabilities and mobility issues can more easily engage in wildlife conservation work.

    d) Allocate resources to incentivize data (or sample) submissions and volunteerism for priority projects with specific data requirements. Incentivization can take various forms, including awarding prizes to bioblitz participants or rewarding individuals contributing data (or samples) from recreationally harvested wildlife.

## Building community

To promote strong working relationships and networking among organizations throughout the Province, strengthening several key partnerships should be prioritized:

1) First Nations groups throughout B.C. are the original holders of ecological knowledge, and CS efforts can only benefit from their guidance and collaboration. Many Indigenous territories are underrepresented, posing an opportunity for collaborative bioblitzes and other CS projects. For example, future CS efforts could synergize with and support First Nations' Guardian programs, and traditional ecological knowledge could also help identify priority areas for future CS work. Building these relationships would benefit from communications training and support to make and maintain these connections.

2) Academic institutions can support provincial CS efforts in several ways. By supporting research and the analysis of CS data, academics have the potential to provide insights that can guide the future of CS within B.C. and abroad. Universities may also consider hosting courses or workshops on CS methods and analyses. For CS projects with needs potentially

met by academic programs, infrastructure (e.g., data-sharing protocols) must be developed and maintained to allow seamless collaboration between academics, government biologists and volunteers.

3) A regular CS conference and field trips hosted within B.C. would facilitate knowledge sharing and collaboration among organizations around the Province. Project leaders could use this conference to communicate successes, challenges, and data needs. By providing a space for individuals and organizations to discuss their CS efforts, linkages between projects, data users and contributors can be developed and maintained over time.

4) A regional gear library where organizations could sign out and borrow technical gear for CS projects that would otherwise be financially burdensome would be a great way to support CS initiatives and foster community between projects and organizations. By lending out gear (e.g., wildlife cameras, entomological nets) that aren't currently in use, research organizations could increase the amount of data they collect at a minimal cost to themselves. Government support could take the form of purchasing or lending equipment. To prevent the aggregation of gear around urban hubs with universities and government buildings, local ENGOs or community libraries may be suitable candidate hosts for this program.

## Data quality, quantity, and coverage

Among CS projects, like all other scientific projects, data quality is of paramount importance. To ensure that the data collected by volunteers is of the highest quality possible, we provide a brief overview of improving data quality for structured and contributory CS projects. Our interviewees and survey respondents emphasized the need for structured data that were collected in a standardized fashion. To facilitate and improve the collection of structured CS data, we suggest the following:

1) Provincial biologists collaborating with CS projects should communicate data quality standards and requirements. Principally, using standard data collection protocols (e.g., RISC standards) whenever relevant increases the likelihood that CS data will be incorporated into government decision-making frameworks. Identifying and meeting government data standards and minimums will also guide data collection while promoting comparability over time and between projects. For projects without provincially standardized protocols, other platforms (e.g., CitSci.org) allow users to develop consistent data sheets and methods. Following these protocols would ensure that data are comparable within and between projects, and data comparability is essential to understanding many spatial and temporal ecological patterns.

2) Government staff and projects should aim to offer support to CS projects with overlapping interests. It is likely in the best interests of specific projects to provide some guidance in data collection protocols and experimental design, such that the highest quality results are achieved from a relatively small amount of professional oversight and a larger contribution of volunteer time and effort.

3) Existing data on contributory CS platforms offer a massive and untapped wealth of ecological information. To maximize the quality of these data, we suggest that the provincial government develop resources outlining best practices for data contributors using various CS platforms. This resource should emphasize the following points:

   a) Include media (i.e., audio, photos, or video) whenever possible. Media greatly expedites the data vetting process and often offers maximum confidence in the accuracy of the data. Subsequent government policies and procedures would need to be developed to address retention and storage, or deletion, of submitted media.

   b) Use Canadian portals to popular contributory CS platforms whenever relevant (see Table 2), enabling the government data users to access the coordinates of observations even when they are obscured by the platform or the observer (e.g. if it is a sensitive species).

   c) Record and contribute any relevant metadata. Particularly for checklist-oriented platforms, potentially informative covariates such as the weather and survey effort (e.g., time, distance, area) are essential to interpret the data accurately. For observations, this may include recording the abundance, age, sex, habitat, or phenology of the observed species.

   d) Georeference data accurately when appropriate and uploading data on time.

4) Many of our survey respondents and interviewees communicated that while CS data are relevant to their work, there is a paucity of relevant CS data in their work area, which, given that much of the Province is sparsely populated and, consequently, with low data coverage, is particularly relevant. To fill data gaps and increase the coverage of provincial CS data, the Province may also consider funding a B.C. Biodiversity Team to contribute data throughout the Province while promoting community engagement. This proposed project could be modelled after the success of the B.C. Parks Biodiversity Program (McKeown et al., 2022), wherein a team of naturalists are trained to collect biodiversity data throughout the Province while targeting priority areas (e.g., those most vulnerable to climate change) and species groups while engaging with community members. This project may also partner with other organizations or groups, such as First Nations, conducting bioblitzes within the Province and could present an opportunity where organizations could apply for funds to support priority species inventories, bioblitzes and CS engagement. Many of these data are essential for establishing biodiversity baselines that will become increasingly important as climate change alters communities and ecosystems throughout the Province. This program could also collect data toward priority questions regarding how well biodiversity is being protected within parks in B.C. relative to the rest of the Province.

## Accessible data and open science

The data collected by volunteers is most valuable when appropriately shared or communicated. There are several options to make sure that CS data are widely accessible:

1) The Province would benefit from developing resources that would guide and support CS groups to ensure their data are openly shared and uploaded to the appropriate platform under the most open licensing agreement possible. Guidance about determining if project data are suitable for open access would be needed, as well as encouraging users of contributory platforms to check their platform-specific settings and ensure their data are accessible to other organizations (e.g., GBIF). Making sure that data are accessible and shared hierarchically among multiple organizations increases the availability of these data to researchers and managers in B.C. and abroad.

2) Providing government staff training and orientation on the data management policy, tools and resources while encouraging the use of CS data will help to use CS data to make management decisions more effectively. Furthermore, data should strive to adopt an open science framework while hosting data, methods, and code on online and accessible repositories (e.g., GitHub).

3) Many survey respondents and interviewees identified not knowing how to access or use CS data as a significant impediment to using these potential resources. Within the Province, work is underway to develop tools that facilitate searching across multiple databases so researchers can more readily use data from various sources. Integrating CS data from numerous sources into this framework would better enable researchers to incorporate CS data into their current work model. Given the potential value of these data, we suggest that support is allocated to i) incorporate CS data into provincial data systems, ii) train researchers to effectively access and use these data while contributing to open science, and iii) integrate CS data into traditional decision-making workflows, such as determining land protection measures or assessing the conservation status of a particular species. A dedicated Provincial CS Biologist could facilitate this.

## Priorities for project leaders

Before developing ecological or methodological questions, project leaders should prioritize ensuring their project adheres to provincial policies protecting wildlife and their habitats. To enhance CS efforts within B.C., the Province could develop guidelines and best practices that ensure potential projects adhere to the following:

1) Following the Species at Risk Act, CS projects may aim to bridge existing efforts to improve the conservation and status of threatened species groups and habitats when possible. We note that some conservation efforts may be reserved for trained professionals due to the sensitivity of some threatened species groups.

2) CS groups should familiarize themselves with the laws relevant to their project, and professionals should be consulted to acquire appropriate training and permitting whenever applicable. Projects should also diligently report their activities and outcomes to all relevant reporting agencies.

3) Volunteers have the potential to disturb sensitive species groups and their habitats unintentionally. Project leaders should proactively identify potential risks and implement precautions necessary to avoid damage or disruption, such as restricting some locations to the exclusive focus of trained professionals.

## Next steps

Additional work is required to assess financial, logistical, legal, and ecological priorities throughout the Province to prioritize the recommendations above. Follow-up work will be necessary to detail which organizations would be best suited to address these recommendations and identify potential delivery avenues. We recommend that this work include liaising with government biologists and project managers to understand better how to prioritize, delegate and deliver the recommendations outlined here effectively. Furthermore, coordination with project managers throughout the Province will be required to determine how the CS position described above will be implemented, such as deciding the hosting organization and the initial duration of the position.


Photo by Julia Carr

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