Guidance for government science agencies and community stewardship groups to improve collaborations on environmental monitoring and research: lessons from the Pacific Science Enterprise Centre (PSEC) Community Stream Monitoring (CoSMo) project

Nicola C. Kroetsch[1], Stephen J. Healy[1], and David A. Patterson[1,2]

[1]Fisheries and Oceans Canada
Science Branch, Pacific Region
Ecosystem Sciences Division
Pacific Science Enterprise Centre
West Vancouver, British Columbia
V7V 1N6

[2]Fisheries and Oceans Canada
Science Branch, Pacific Region
Aquatic Research Cooperative Institute
Simon Fraser University,
Burnaby, British Columbia
V5A 4S8

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Nicola C. Kroetsch, Stephen J. Healy, and David A. Patterson

Science Branch
Pacific Region
Ecosystem Sciences Division
Fisheries and Oceans Canada
Pacific Science Enterprise Centre
4160 Marine Drive
West Vancouver, British Columbia
V7V 1N6

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Abstract

Kroetsch, N.C., Healy S.J., and Patterson D.A.. 2026. Guidance for government science agencies and community stewardship groups to improve collaborations on environmental monitoring and research: lessons from the Pacific Science Enterprise Centre (PSEC) Community Stream Monitoring (CoSMo) project. Can. Manuscr. Rep. Fish. Aquat. Sci. 3329: v + 57p. https://doi.org/10.60825/vy0h-wv17

Multi-year environmental monitoring and research can support effective resource management decisions. However, collecting long-term environmental data can be time consuming and expensive, which often limits a government's ability to collect this information at meaningful spatial and temporal scales. Collaborating with community stewardship groups on long-term environmental monitoring and research initiatives offers a potential means to address the limits of government science capacity. Moreover, previous case studies have shown that community-gathered environmental data can be comparable to professional data for certain parameters and with proper guidance. However, at present, there remains a paucity of guidance for government agencies and stewardship groups on how best to collaborate. Science staff at the Fisheries and Oceans Canada (DFO) Pacific Science Enterprise Centre (PSEC) piloted the Community Stream Monitoring (CoSMo) project by monitoring stream temperatures in 8 watersheds in collaboration with local stewardship groups in the Howe Sound and Burrard Inlet region, British Columbia. Initiated in 2019, the project has since evolved to include monitoring additional parameters, expanded geographically to include municipalities across the Greater Vancouver Area, and currently involves three universities, 15 stewardship groups, two municipalities, and one secondary school. The CoSMo data have been used for multiple research projects, to support resource management, and to aid in public engagement and education. In this report, we describe the CoSMo project and, based on our experiences, highlight 13 key elements of success when collaborating with stewardship groups on environmental monitoring initiatives, which relate to one of four major areas: (a) required resources, (b) relationships, communication, and working with stewardship groups, (c) logistics, planning, and project development, and (d) data management and quality assurance. By sharing this work and how it developed iteratively over time, we aim to contribute information to help facilitate future government science and citizen science collaborations, as well as provide some insight into approaches that can improve the quality of data for use in scientific research and monitoring. While the primary targeted audience for the present paper is government agencies and/or researchers, we also hope this guidance can be useful for community-based stewardship organizations trying to improve their engagements with government agencies.

Résumé

Kroetsch, N.C., Healy S.J., and Patterson D.A.. 2026. Guidance for government science agencies and community stewardship groups to improve collaborations on environmental monitoring and research: lessons from the Pacific Science Enterprise Centre (PSEC) Community Stream Monitoring (CoSMo) project. Can. Manuscr. Rep. Fish. Aquat. Sci. 3329: v + 57p. https://doi.org/10.60825/vy0h-wv17

La surveillance et la recherche environnementales pluriannuelles peuvent appuyer la prise de décisions efficaces en matière de gestion des ressources. Cependant, la collecte de données environnementales à long terme peut s'avérer longue et coûteuse, ce qui limite souvent la capacité d'un gouvernement à recueillir ces renseignements à des échelles spatiales et temporelles suffisamment significatives. La collaboration avec des groupes d'intendance communautaire dans le cadre d'initiatives de recherche et de surveillance environnementales à long terme peut permettre de pallier les limites des capacités scientifiques du gouvernement. De plus, des études de cas antérieures ont montré que les données environnementales recueillies par la communauté peuvent être comparables à des données professionnelles à certains égards, à condition de bénéficier d'un accompagnement adéquat. Toutefois, les organismes publics et les groupes de gestion reçoivent encore à l'heure actuelle très peu de directives sur la meilleure façon de collaborer. Le personnel scientifique du Centre d'entreprise scientifique du Pacifique (CESP) de Pêches et Océans Canada (MPO) a mené le Programme de surveillance communautaire des cours d'eau (CoSMo) en surveillant la température des cours d'eau dans huit bassins hydrographiques, en collaboration avec les groupes d'intendance locaux de la région de la baie Howe et de l'inlet Burrard, en Colombie-Britannique. Lancé en 2019, le projet a depuis évolué pour inclure le suivi de nouveaux paramètres. Il s'est étendu géographiquement pour englober des municipalités de la région du Grand Vancouver et compte actuellement trois universités, 15 groupes de gestion communautaire, deux municipalités et un établissement d'enseignement secondaire. Les données de CoSMo ont été utilisées dans le cadre de nombreux projets de recherche, pour soutenir la gestion des ressources, ainsi que pour favoriser la participation du public et la sensibilisation. Dans le présent rapport, nous décrivons le projet CoSMo et, forts de notre expérience, nous mettons en avant 13 éléments clés de la réussite de la collaboration avec des groupes d'intendance communautaire dans le cadre d'initiatives de surveillance environnementale, qui relèvent de l'un des quatre grands domaines suivants : (a) les ressources requises, (b) les relations, la communication et la collaboration avec les groupes d'intendance, (c) la logistique, la planification et l'élaboration de projets, et (d) la gestion des données et l'assurance qualité. En partageant ce travail et la manière dont il a évolué au fil du temps, nous souhaitons faciliter les futures collaborations entre la science au gouvernement et la science citoyenne, tout en donnant un aperçu des approches susceptibles d'améliorer la qualité des données utilisées dans la recherche scientifique et la surveillance. Bien que le présent document s'adresse en premier lieu aux organismes gouvernementaux et aux chercheurs, nous espérons également que ces recommandations pourront être utiles aux organisations d'intendance communautaires qui cherchent à nouer de meilleures relations avec les organismes gouvernementaux.

Introduction

Environmental monitoring and research is a critical component of resource management (Lovett, 2007; Aceves-Bueno et al., 2015). Without credible, long-term (multi-year) data, governments can be limited in their ability to identify ecosystem changes and trends and evaluate the efficacy of mitigation actions (e.g. restoration work), all of which increase the likelihood of making ineffective and potentially costly resource management decisions. However, generating long-term datasets can be time consuming and expensive (Braun et al., 2015; Blumstein, 2025). As a result, resource management agencies across different levels of government are often limited in their ability to collect data across the appropriate spatial and temporal scales to meet the management challenges and decisions they may face. Collaborating with community-based stewardship groups on environmental monitoring and research initiatives offers a potential means to address data collection capacity issues, and has become more common in recent years (e.g. Gouveia et al., 2004; Finn et al., 2010; Theobald et al., 2015; Pocock et al., 2017; B.C. Lake Stewardship and Monitoring Program, 2023).

Collaborations, whereby non-experts contribute to scientific research and monitoring, are often referred to as 'citizen science' or 'community-based monitoring'; both terms will be used interchangeably in this report. There are numerous examples of how citizen science projects across the world are helping address capacity issues, from animal census data (Amano et al., 2016) to water quality parameters (Loiselle et al., 2014). The wide range of citizen science projects can be categorized based on governance structure (e.g. Conrad & Hilchey, 2011) or level of participation of community members (e.g. Follett & Strezov, 2015). Broad categorizations that are commonly used to describe citizen science projects (e.g. Bonney et al., 2009; Follett & Strezov, 2015; Stratilová Urválková & Janoušková, 2019) include:

1. **Contributory:** projects are designed by scientists; volunteers contribute data, and occassionally help with data analysis;
2. **Collaborative:** projects are designed by scientists; volunteers contribute data, help with data analysis, and occassionally help inform study design;
3. **Co-created:** volunteers participate in every aspect of the project, from defining the research question and designing the project, through to data collection, analysis, and interpretation of results.

For environmentally focused citizen science projects, the vast majority are contributory (Pocock et al., 2017), in part because they provide a conduit for local and Indigenous knowledge (Aura et al., 2021; Tengö et al., 2021). This can help ensure scientific research and monitoring takes into account environmental factors that may be unknown to those unfamiliar with the ecosystems, such as historical species diversity or abundance, long-term changes in water quality, or infrastructure changes that may affect species distribution (e.g. culverts that impede fish passage).

Incorporation of citizen science data can be especially useful when the species and their habitat requiements span large spatial areas, such as spawning salmon. For example, on Canada's west coast, the most comprehensive source for salmon spawner abundance data is the New Salmon Escapement Database (NuSEDS), which is maintained by the federal department of Fisheries and Oceans Canada (DFO), but contains data from a variety of sources, including citizen science sources (i.e. not for-profit organizations and stewardship groups). These citizen science contributions help DFO adhere to conservation-related policies, such as those in the 2005 Wild Salmon Policy, which suggests the first step towards restoring wild Pacific salmon populations is to monitor and assess the current status of wild salmon populations (Strategy 1; Fisheries and Oceans Canada, 2005).

Despite a wide array of benefits, there are many potential challenges inherent with community-based monitoring. In order to produce datasets that are credible and useful, citizen science collaborations need to address challenges related to logistics, data quality control, data management, and overall communications. Many studies have critiqued the efficacy of community-based monitoring (primarily regarding data quality) and highlighted the main challenges associated with public participation in environmental monitoring (Fore et al., 2001; Conrad & Hilchey, 2011; Kosmala et al., 2016). Challenges related to citizen science can be categorized as either: organizational issues (e.g. lack of funding or access to information), data collection issues (e.g. lack of experimental design, data inaccuracy), or data use issues (i.e. lack of uptake of community-gathered data by researchers and decision-makers; Conrad & Hilchey, 2011). Such issues are not insignificant barriers that need to be overcome in order for community-based monitoring to produce datasets that are accurate and relevant to the key questions asked; however, studies show that trained volunteers can produce data comparable to professionals (Fore et al., 2001; Lefler, 2010; Jordon et al., 2012) and/or can be readily corrected prior to use (Bird et al., 2014).

Recommendations for addressing some of the challenges with the generation and uptake of citizen science data have been proposed, including examples where these strategies have been implemented successfully (e.g. Conrad & Hilchey, 2011). For example, securing funding prior to monitoring can address data fragmentation, and commmunicating how the community-generated data are contributing to planning and management can prevent loss of interest by volunteers (Whitelaw et al., 2003). Sharing expertise, equipment, and knowledge, maintaining communication, and publically acknowledging volunteers' effort are also important aspects of community-based monitoring projects that build capacity, trust, and long-term collaborations (Buckland-Nicks, 2015). For example, the Regional District of Nanaimo (RDN) in British Columbia (BC) implements many of these strategies through its Community Watershed Monitoring (CWM) program, which monitors water quality in 40 creeks in collaboration with community members. In partnership with the BC Ministry of Environment and Climate Change Strategy and Mosaic Forest Management, the RDN trains volunteers, loans equipment, covers laboratory cost, and shares annual reports summarizing results. These data help identify trends, inform land-use planning, and flag watersheds requiring additional monitoring or changes in watershed management (Community Watershed Monitoring, n.d., accessed June 27, 2025).

Citizen science can be a valuable tool for governments seeking to increase their environmental monitoring capacity (e.g. Atkinson et al., 2025), but guidance on how governments can incorporate community-based monitoring and addressing its inherent challenges remain limited. The purpose of this report is to provide guidance and lessons learned from a pilot citizen science project initiated by the DFO Pacific Science Enterprise Centre (PSEC). PSEC is a Government of Canada DFO research facility and science hub located in West Vancouver, British Columbia, whose overall vision includes community engagement and public education. Recognizing a scientific and regional need for improved stream monitoring and the potential of community-based monitoring to help address that need, PSEC staff piloted the collaborative Community Stream Monitoring (CoSMo) project in 2019. The original objectives of the CoSMo project were to: (1) conduct environmental research and improve monitoring of water temperatures in urban salmon-bearing streams with community groups, (2) conduct social science research to learn how to better work with stewardship groups and develop guidance for citizen science collaborations, and (3) engage with local universities and the general public. In this report, we share some of the key lessons learned from the CoSMo project implementation to date. By sharing how this work developed iteratively over time, we aim to facilitate future government-citizen science collaborations and identify approaches that can improve the quality of citizen science data. While the targeted audience for the present paper is various government agencies or researchers, we also hope this guidance can be useful for community science organizations trying to improve their engagements with government agencies.

Methods

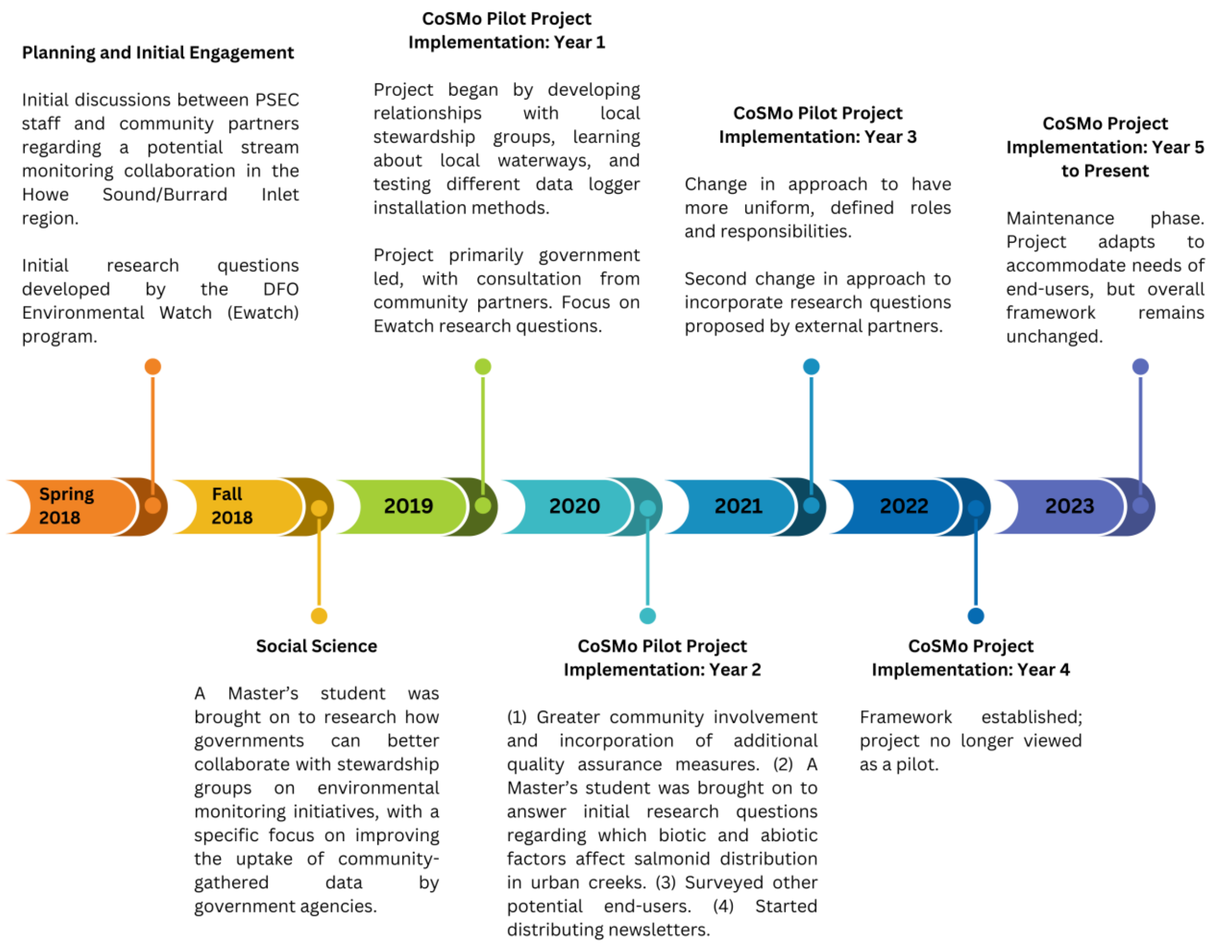

Figure 1: Timeline of key events of each phase of the CoSMo pilot project development, implementation, and evolution.

Background of the CoSMo project

Primary Community Partner Organizations: Streamkeepers

In this report, Streamkeepers refers to community stewardship groups in western Canada that steward streams and wetlands. They operate under the Pacific Streamkeepers Federation, which provides them with guidance, support, education, and resources (The Pacific Streamkeepers Federation, 2025). Streamkeeper groups vary in size and capacity, from a few dedicated individuals who steward a single stream, to hundreds working across multiple streams within a municipality. Activities also vary and may include salmon spawner surveys, water quality monitoring, habitat restoration, garbage cleanup, storm drain marking (identifying storm drains leading to fish habitat), and community outreach.

Many groups also operate community salmonid hatcheries, in an effort to enhance local streams with impacted salmon populations and offer opportunities for public engagement and education.

Planning and Initial Engagement

In 2018, initial discussions between PSEC science staff and community partners (e.g. stewardship groups) from Squamish, Bowen Island, North and West Vancouver, and Port Moody took place regarding a potential stream monitoring collaboration in the Howe Sound/Burrard Inlet region (see Figure 1 for project timeline). Planning for the CoSMo pilot project involved meetings with community partners, with the objectives of: (1) determining current monitoring efforts, (2) discussing stream criteria and stream selection, (3) identifying the main challenges associated with stream monitoring, and (4) beginning to co-create a research vision.

Initial discussions proposed monitoring multiple stream parameters (primarily temperature, dissolved oxygen, and flow) using automated data loggers. DFO would be responsible for purchasing equipment, training community partners how to install and use data loggers, and providing data loggers and equipment to Indigenous partners and community groups. Collaborators would conduct some of the installation and maintenance of data loggers and support site-selection, in conjunction with DFO staff. DFO-Science protocols would be used for collecting, recording, and reporting data. Data collected from data loggers would be shared in a central data location, and PSEC staff would collaborate to assist with data analysis. However, after initial meetings, there was not yet clarification as to what the sampling and reporting methods would be, what central platform would be used to share the data, or to what extent DFO staff would be involved in the analysis of the data.

Ultimately, the joint DFO-Stewardship group agreed to implement a pilot project focused on water temperature. Stream temperature was selected for the following reasons: it can be referred to as ‘the master factor’, as it controls most biological processes in aquatic systems (Caissie, 2006) and is vulnerable to both urban development and climate change (Wenger et al., 2011; Isaak et al., 2012; Somers et al., 2013). Water temperature can also be much easier and more affordable to collect than other parameters, such as dissolved oxygen, flow, and contaminants. Lastly, the main DFO-Science partner at PSEC, the DFO Environmental Watch (Ewatch) program, has extensive scientific expertise and an existing mandate to research and monitor water temperature in salmon habitat throughout the province (e.g. Fraser River Environmental Watch | Pacific Region | Fisheries and Oceans Canada); thus, the CoSMo project would help extend Ewatch’s network and research goals.

Four primary science questions were proposed by Ewatch staff following initial meetings, which influenced initial project implementation (primarily site selection and density of loggers):

1. What are the thermal profiles of the proposed salmonid-bearing (*Oncorhynchus spp.*) urbanized creeks (across stream gradient, year)?
2. Are there any instances of high or low temperatures that exceed thresholds for salmonids, and if so, when and where?

3. How do the thermal profiles, in addition to other factors (e.g. level of urbanization, stream substrate, habitat characteristics) influence distribution and presence of salmon in the proposed creeks?
4. Could Environmental DNA (eDNA[1]) methodologies be an appropriate alternative method for identifying salmonid presence/absence in urbanized watersheds (e.g. compared to trapping or electrofishing)?

Social Science Research

As part of the CoSMo project, we also wanted to study how government, especially resource management agencies, can better collaborate with stewardship groups on environmental monitoring initiatives, with a specific focus on improving the uptake of community-gathered data by government agencies. In 2018, a Master's student from the Simon Fraser University (SFU) School of Resource and Environmental Management was brought on for this social science aspect of the project, and was directly involved in piloting the CoSMo project. This research involved interviews with 42 people, including staff from federal (n=7), provincial (n=2), and municipal (n=12) government agencies and volunteers from 13 stewardship groups (n=21), to assess current environmental monitoring collaborations in the region, identify barriers to collaboration, and examine data management practices among stewardships groups, with the objective of providing guidance for successful collaborations (Kroetsch, 2021).

Interviews were semi-structured (i.e. a combination of structured and open-ended questions; Appendix 1), were conducted in-person or by phone, and took an average of 1.5 hours (ranging from 35 minutes to 3 hours). Questions focused on:

- Which parameters are most important to monitor and which are currently being monitored by stewardship groups. These questions sought to determine whether resource management agencies and stewardship groups had shared goals and objectives, and whether there was consensus regarding what should be monitored in urban streams.
- Data quality assurance, including training of volunteers, level of experience, and challenges experienced when monitoring (and how challenges were addressed, if applicable). These questions aimed to help identify steps in the data lifecycle that may currently lack sufficient quality assurance measures, for which incorporation of more stringent quality assurance protocols could help improve the quality and credibility of community-gathered data.
- Protocols and methods for data collection, storage, analysis, and sharing. These questions intended to facilitate comparison of data management by resource

[1] eDNA is DNA that organisms shed into their environment, such as skin cells, hair, and mucus, which can be collected via a water sample. The water sample is then filtered and processed in a laboratory to determine which species were present or not present around the time the water sample was collected (IUCN, 2024).

management agencies versus stewardship groups and to determine whether data were being shared effectively.

- Use of community-generated data by resource management agencies; specifically, whether resource management agencies use the data that are provided to them by stewardship groups, and if so, what they use them for.
- Questions about overall collaboration and communication, including what facilitates or hinders successful collaborations, and the main challenges encountered.

Outputs from the social science research project included a guidebook and data management plan template to facilitate collaborations by supporting governments and stewardship groups in developing collaborative data management plans (Kroetsch, 2021).

CoSMo Pilot Project Implementation

Pilot Project Implementation, Year 1: Government-led with consultation from stewardship groups

Field implementation of the CoSMo pilot project began in 2019. We started by developing relationships with local stewardship groups, learning about local waterways, and testing different data logger installation methods. In order to study fine-scale habitat use by juvenile coho salmon in relation to stream temperatures and other factors, we initially deployed 57 temperature data loggers (Onset HOBO Pendant MX2201 and Tidbit MX2203; Appendix 2) across eight watersheds between Bowen Island and the Indian River watershed (following: U.S. Environmental Protection Agency, 2014), as well as 10 loggers that record both water depth and temperature (Onset HOBO U20L). Loggers were placed at key regions identified with the help of community partners familiar with the systems, which helped us gain a better understanding of known fish distributions, barriers to migration, locations of significant tributaries, flow patterns, issues related to urbanization and contamination, and what level of foot-traffic is common at the site (i.e. the risk of potential vandalism given their urbanized nature). This local knowledge was critical in helping us select suitable sites for data loggers, trapping, and eDNA sampling. To explore the use of eDNA as a tool to determine fine-scale presence of salmonids in urban watersheds, we paired eDNA sampling with minnow trapping at select sites.

Stewardship group participation varied. Some wanted to help only with site selection, while others wanted to help download the data but not with installations. For the first year following community engagement and site selection, DFO staff did the majority of installations of equipment, maintaining sites, and downloading data from loggers. A CoSMo data download sheet was developed (modified from existing data sheets from within DFO) to ensure relevant metadata would be recorded at each site visit (Table 1). Initially, data were only stored on government servers, as a suitable centralized data platform had not yet been identified.

Table 1: Parameters included in CoSMo data sheets, which are filled out at time of logger data download, and the purpose of capturing each piece of information.

Parameter	Description	Purpose
Date	When the logger data were downloaded	To facilitate data processing and track logger maintenance/downloads
Personnel	Who downloaded the data	To ensure we knew who to contact if we had questions regarding logger or data sheet
Waterbody and Site Name	Name of creek and specific site within creek	To identify site
Purpose of deployment	To clarify whether data were being downloaded or logger was being replaced	To enable us to track loggers and when replacements occurred
Water depth	Depth of entire water column at logger site (manual measurement)	When compared to height above bottom, allowed us to know how close the logger was to the surface; also enabled comparison with logger depth readings (if applicable) to ensure logger accuracy
Height above bottom	Vertical distance from the creek bottom to the data logger (manual measurement)	When compared to water depth, allowed us to know how close the logger was to the surface and whether sedimentation may be an issue (e.g. logger getting buried)
Water temperature	Manual temperature reading taken at the time of download	Enabled comparison with logger temperature reading, to ensure accuracy
Thermometer ID	The thermometer that was used to take the manual temperature reading	If discrepancy between manual temperature reading and logger reading, allowed us to identify which thermometer was used so post-season bias corrections could potentially be applied
Installation Technique and Logger Placement	The method we used to install the data logger and where the logger is located within the creek	Helped us relocate the logger during subsequent site visits
Site information	GPS coordinates for logger site	Used with Waterbody and Site Name information to confirm location

Pilot Project Implementation, Year 2: Greater community involvement

The CoSMo pilot became more organized and structured in Year 2 (2020). A series of improvements that contributed to data quality assurance were added, including:

- Gear and installation method-troubleshooting, which helped us mitigate future data gaps due to equipment malfunctions;
- Creating a detailed instruction document for community partners who maintained loggers;
- Designing a data management plan (DMP), defined as: a full lifecycle document that outlines the purpose and methods for data collection; Quality Assurance/Quality Control (QAQC) protocols; procedures for data storage and use (e.g. analyses and outputs), as well as how the data and their synthesis/analyses might inform or support decision making (Kroetsch, 2021).

In 2020, a second SFU Master's student was brought on to lead the implementation, field work, and analyses of some of the initial science research questions. In order to better understand how various physical factors (e.g. water temperature, urbanization levels, habitat) relate to salmonid distribution, she conducted habitat assessments, monitored temperature and flow, and matched fish capture information with eDNA samples in select streams (Gemmell, 2023). Flow monitoring and eDNA sampling were conducted by SFU students and DFO staff, not volunteers.

To identify future opportunities for collaboration, potential data end-users (e.g. other government agencies, post-secondary institutions) were surveyed to assess current data gaps and whether the CoSMo project could help address them. Lastly, following results from surveys and other research on citizen science that identified good communication and keeping partners up-to-date as critical for maintaining volunteer interest and motivation, we began distributing quarterly newsletters to provide collaborators, stakeholders, and rightsholders (i.e. First Nations) with project updates and simple data summaries.

Pilot Project Implementation, Year 3: Shift in approach

In Year 3 (2021), roles and responsibilities were more clearly defined. For example, site selection for new data loggers was done in partnership with the stewardship groups. DFO was responsible for installing data loggers, training volunteers, providing field support, and managing the data, while collaborators were responsible for accessing and downloading logger data 3-4 times per year and sending the data files and data sheets to DFO. The shift in approach was done for several reasons:

- We wanted to expand the project cohesively, and we felt the previous approach, whereby community partners participated to varying degrees, was disorganized, difficult to manage, and compromised data integrity and project expansion;
- We wanted to further ensure data quality by applying lessons learned from the social science research, which recommended simple and straightforward volunteer protocols;

- We learned that experience is required for site selection and secure data logger installations. Most stewardship groups would only be maintaining one or a few data loggers, limiting opportunities to install gear across a variety of hydraulic and geomorphic conditions. Therefore, to avoid losing gear (due to flashy, rainfall-driven systems) and data gaps, we opted to do the installations on behalf of our partners;
- We wanted to maintain volunteer interest, engagement, and avoid volunteer-burnout. We applied additional lessons learned from the social science research and broader literature on citizen science, such as reducing the overall volunteer workload (i.e. by having volunteers be solely responsible for downloading the data from the loggers). Involving volunteers in site selection also ensured we chose creeks that were both relevant for them (e.g. creeks they already steward or have a connection to) as well as the DFO-Science research questions, and locations that were convenient for volunteers to access at later dates.

In 2021, DFO began exploring options for better sharing of CoSMo data publicly, recognizing the importance of transparency and data sharing (Kroetsch, 2021). This included internal options, such as working with the DFO Information Technology group to assess feasibility of developing an outward-facing platform, and external options, like hosting the data on an external platform. Lastly, in late 2020/early 2021, DFO was engaged by the Stoney Creek Environment Committee (a stewardship group in Burnaby, BC) and the BC Institute of Technology (BCIT), who were interested in investigating potential impacts of road salt on urban salmon populations. This led to monitoring conductivity (a proxy for road salt contamination), in partnership with two BCIT Master's students, as part of the Road Salt and Pacific Salmon Success Project (i.e. the 'Road Salt Project'). The overall objectives of this research were to study the extent and severity of potential road salt contamination in urban creeks in the Greater Vancouver Area, and to better understand what effects road salt contamination may be having on chum (*O. keta*) and coho (*O. kisutch*) salmon populations residing in urban creeks. This marked another shift in the CoSMo approach, whereby we began to select and/or augment sites and parameters to address research questions posed by external collaborators. The Road Salt Project expanded to involve faculty and graduate students at the University of British Columbia (UBC), SFU, and BCIT, as well as 13 stewardship groups in the Greater Vancouver Area. The research initiative used a combination of field and laboratory data, including stream conductivity and temperature data collected as part of the CoSMo project, juvenile fish trapping, invertebrate surveys, and spawner surveys conducted by the stewardship groups within the CoSMo network. In-kind contributions of data loggers from the Road Salt Project partners and an additional three municipalities (with the agreement that the loggers would be installed and data managed by DFO staff) allowed for pooling of resources to address budget constraints and partners' limited experience installing data loggers.

Data collection to support the Road Salt Project followed the same CoSMo process, whereby we installed automated data loggers in creeks on behalf of the stewardship groups, who would download the data from the loggers 3-4 times per year and send the data files and data sheets to us to process and manage. However, as monitoring conductivity required a new type of logger (Solinst Levelogger 5 LTC; Appendix 2), this shift required familiarizing ourselves with, creating protocols for, and learning new installation methods for these new loggers, which record water level, temperature, and conductivity.

CoSMo Project Expansion

Framework

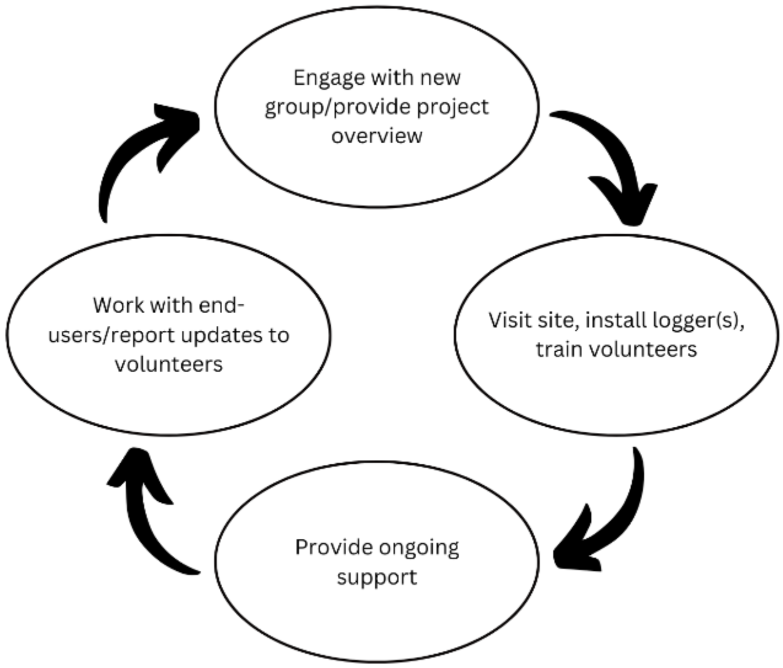

Figure 2: The CoSMo engagement framework that was developed iteratively from project initiation (2019) to present, which best describes how we collaborate with community partners and maintain long-term engagement.

By the end of 2021, we had established the engagement framework that we currently use (Figure 2). At this point, some of the initial research questions regarding salmonid distribution in urban creeks had been addressed, and collaborations with external partners had expanded to include long-term monitoring and baseline data collection to support current and emerging research initiatives and questions.

Following the new CoSMo framework, when we first engaged new potential partners, we provided them with a project overview, including project objectives, what we could offer, the role of partners, and criteria for site selection. If the group wanted to be involved and committed to maintaining the dataloggers, we would visit their watersheds of interest, select appropriate sites, install the data loggers, provide a demonstration to the volunteers how to download the data and calibrate the loggers (if applicable), and ensure volunteers had all necessary pieces of equipment and instruction documents. Afterwards, we would provide ongoing field support (primarily by phone) to volunteers, as well as periodic reminders to do the data downloads. DFO staff managed the CoSMo data, including application of quality assurance procedures (checks to verify data accuracy and flag inconsistencies, anomalies), and worked with potential data end-users to promote data uptake. Lastly, DFO staff were responsible for reporting back to volunteers how the data were being used (via email and regular newsletters). With this framework, we engaged several new stewardship groups (see Appendix 5 for a complete list of CoSMo collaborators) and expanded the CoSMo project geographically throughout the Greater Vancouver region (Figure 3).

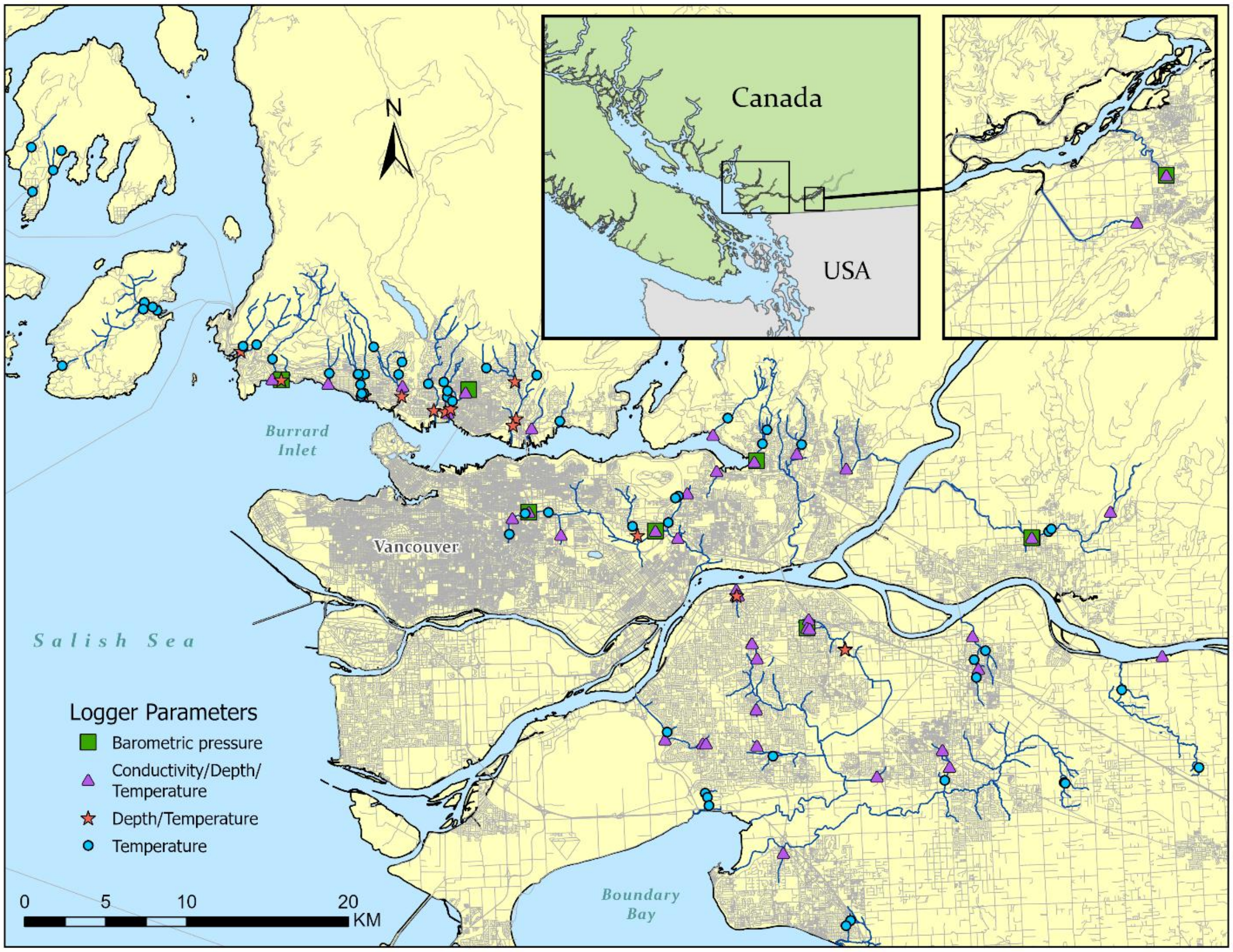

Figure 3: CoSMo data logger network following expansion across Greater Vancouver Area. The network includes a variety of logger types, which record temperature, depth, and/or conductivity data, as well as barometric pressure loggers, which record ambient pressure

Our engagement framework allowed us to provide guidance and leadership for stewardship groups who wanted to improve monitoring of the creeks they steward, while still allowing flexibility as far as which streams, locations, and parameters (among those of focus within the project) were monitored. This standardized nature of volunteer involvement allowed us to clearly state roles and responsibilities at the outset, and provide clear, step-by-step instructions and protocols. The framework also allowed for quality assurance measures to be incorporated at various stages in the data lifecycle, and eliminated nearly all administrative workload for volunteers. Use of automated data loggers also reduced volunteer workload and allowed a lot of flexibility for volunteers regarding when they chose to download the data.

Data Sharing

Making data publicly available so they can be used by a diverse array of end-users has been shown to be beneficial to collaborative partnerships (National Academies, 2007; USGS, n.d.). As such, in 2022 we partnered with DataStream, a not-for-profit organization that facilitates sharing of water quality data via their open-data platform, to make the CoSMo data publicly available (CoSMo DataStream, 2024). The CoSMo DataStream page is updated by DFO staff several times each year following QAQC of any new data. End-users, such as our academic partners participating in the Road Salt Project, can view and download the CoSMo data from the DataStream platform at their convenience, and with the confidence that the data have undergone QAQC procedures before being uploaded to DataStream.

Results and Project Adjustments

Conducting social science research in parallel to the development of the CoSMo project allowed us to better understand current barriers and successes in near real time, and thus enabled us to adjust the project to better align mutual priorities and hone protocols as we went. More specifically, the social science research project revealed that local resource management agencies experience data gaps for some of the parameters that local stewardship groups monitor, suggesting that data gaps can be the result of issues related to data uptake, rather than a lack of data (Kroetsch, 2021). Responses from interviewees suggested that limited uptake of stewardship group data stems in part from skepticism about data accuracy and precision (e.g. due to lack of or inconsistent quality assurance protocols, training), inadequate data management practices, and ineffective communication and data sharing (Kroetsch, 2021). Below are a few highlighted results of the social science surveys and how we addressed these identified challenges when piloting the CoSMo project. The social science research results are also summarized in the main deliverables from the social science project, which included a guidebook and data management plan template for resource managers and stewardship groups to use when initiating a collaboration (Kroetsch, 2021).

The following sections within the results have been structured to follow a similar pattern. First, there is an initial discussion of the key social science research survey results. Second, there is a description of key results we found by executing this study that relate to the survey results, noting similarities and differences between survey and execution in the key phases of the project.

Planning and Engagement

The social science survey reported past challenges that are consistent with the related literature, such as lack of experimental design (Conrad & Hilchey, 2011), limited capacity and resources (Mamun & Natcher, 2023), and concerns regarding data quality and consistency (Fore et al., 2001; Conrad & Hilchey, 2011; Kosmala et al., 2016). These are further explored below.

Initial discussions in 2018 between DFO staff and community partners highlighted several challenges related to current community-based stream monitoring, many of which related to capacity (including volunteer and government time and resources), communication (among and within groups), data quality control and assurance, and data management (including which data to collect and how to share them). Specific challenges identified from both government agencies and community groups during initial discussions included:

- Not having enough volunteers/staff to conduct the monitoring;
- Lack of clarity regarding roles/responsibilities (e.g. training and recruiting volunteers, what volunteers are required to do);
- Unclear protocols for sharing data and information with others (e.g. consultants, municipalities, Indigenous groups, citizen science organizations);
- Lack of project design, such as determining which and how many parameters to monitor;
- Lack of data use (e.g. linking monitoring with enhancement and restoration), and;
- Lack of consistent, standardized methods.

Data Quality

When asked about data collected by volunteer groups in general, responses from several government interviewees generally indicated skepticism toward 'community-gathered' data quality; however, there was no consensus on whether community-gathered data are of lesser quality than 'researcher-gathered' data (Kroetsch, 2021). For example, when asked if they viewed data collected by trained volunteers the same as data collected by professional scientists, government interviewee responses (n = 20) were divided between *Yes* (35 %; n = 7), *No* (30 %; n = 6), and *It depends* (e.g. on the type of data; 35 %; n = 7). Some government interviewees felt that water quality data are challenging to collect and therefore should be left to professionals. Others felt their confidence depended on the type of data, and one government interviewee elaborated to say that if volunteers are following defined protocols and collecting data regularly, their data may even be better than a researcher who is limited in the amount of data they can collect (and consequently the amount of experience they have).

Training of volunteers is one means of improving data quality. Government and stewardship group interviewees were all aware of the importance of training – specifically, in the case of CoSMo: in-person training that takes place in the field. Further, *training* and *proof of training* were identified by government interviewees when asked what would need to occur in order for community-gathered data to be viewed as comparable to researcher-gathered data. Nearly all volunteer interviewees had received some form of training prior to us engaging with them; however, for the stewardship groups in our case study (primarily Streamkeeper groups), training is not mandatory. While many of the volunteers had previously received training via the Pacific Streamkeepers Federation's (PSKF) standard two-day training course, others reported receiving training from different sources, highlighting lack of standardized training among community partners (Kroetsch, 2021).

To address the lack of standardization of training among volunteers, we directly trained participants when they joined the project. A training session for at least one or more of the group members was mandatory, and we encouraged community partners to invite all members who may be involved in downloading the data. The majority of training involved instruction on how to fill out a data sheet and use an app for automated data logger downloads that were already installed by PSEC staff, which offered confidence that data quality would not be compromised. Additional training sessions were provided as needed, and we empowered trained volunteers to supervise and train new recruits as needed.

To further address concerns around data quality, we elected to have the data be routed through our staff before being made publicly available (as opposed to individual groups uploading and sharing data they downloaded). As an additional quality assurance measure, all CoSMo data were then screened and processed by DFO staff prior to being uploaded to the CoSMo DataStream page. Data processing included manually reviewing the data, removal of erroneous data (such as times when the data logger was not in the water), and incorporation of relevant notes to help with data interpretation and analysis.

Data Management Practices

Data management protocols should cover the full lifecycle of the data, from initial planning and data collection through to data storage, analysis, sharing, and linking the data to action. The survey results indicated that in our case study, there was some level of standardization with regards to data collection (The Streamkeepers Handbook and Modules, n.d.), but results showed there was little to no standardization as far as data storage, analysis, or sharing (Kroetsch, 2021).

We recorded a variety of data storage methods employed by Streamkeepers. Some stored their water quality data as hard copies, others digitized their data (e.g. Excel spreadsheets) and stored them on personal computers, and some entered their data into the PSKF database (an online platform for volunteers to upload and share survey results publicly). Many stewardship group interviewees reported that their groups' data were rarely analyzed. When analyses did occur, they were typically conducted by volunteers and tended to consist of data summaries instead of more rigorous statistical analyses (Kroetsch, 2021).

To address the lack of standardized data management practices among stewardship groups, for the CoSMo project, we:

- Used automated data loggers recording at regular intervals, and provided clear and simple protocols for downloading the data, which helped standardize data collection;
- Required that volunteers fill out CoSMo data sheets when they downloaded the data from the loggers, to standardize metadata collection;
- Stored the data on our government servers and periodically backed the data up on an external hard drive, to standardize data storage and protect the data from loss. The dataset was also saved and made publicly available via the DataStream database (an online data portal), which added a layer of protection in the event of technical issues affecting government servers or shifts in government priorities affecting the CoSMo data availability in the future;
- DFO staff processed the raw data and formatted for upload to the CoSMo DataStream page, which standardized the data processing process.

Data Mobilization

The survey results indicated that most stream stewardship groups in our case study typically shared their data informally and in an *ad hoc* manner, with the exception of stewardship groups that participated in structured, organized, government-led data collection projects, such as the Regional District of Nanaimo's Community Watershed Monitoring Program (Kroetsch, 2021). Stewardship groups historically shared their data with potential end-users in a variety of ways, including emailing raw or summarized data (e.g. spreadsheets), reports, or by simply providing verbal updates. Some Streamkeepers took the time to enter their data into the PSKF database, resulting in some data that were digitized and publicly available; however, the PSKF database does not allow users to view or download data from multiple sites or dates, which makes data analysis challenging.

Conversely, when government interviewees were asked where they source freshwater habitat data, 35 of the 47 interviewee responses (74 %) cited federal government sources (21 %; n = 10), provincial government sources (26 %; n = 12), and local/municipal government sources (28 %; n = 13). Some government interviewee responses (21 %; n = 10) also cited Streamkeepers and/or others working in the area of interest when in need of data, but there was emphasis that it depends on the type of data and intended use of the data. For example, government employees were more likely to ask stewardship groups for data if they wanted to simply 'get a sense of the state of the ecosystem', but were less likely if they needed accurate quantitative data for use in analyses or decision-making. Stewardship group interviewees expressed frustration that the data they collect are not used to their full potential (i.e. not linked to action by government agencies and other decision-makers; Kroetsch, 2021).

Early on in the CoSMo project, one of our priorities was to share data externally to address concerns around data sharing outlined above, and echoed with our participating stewardship groups. However, data collection began before a data sharing platform was in place, and there was no suitable internal government system for accommodating our community-gathered data that fit our timelines or internal resources. Given survey results that suggested end-users prefer sourcing data from government databases, our first preference would have been to share the CoSMo data on a government database; however, given the lack of readily available internal infrastructure or resources available to develop such a platform, we sought external platforms. This led us to DataStream, an open-access hub for hosting and sharing standardized water quality data that met most of our needs.

To increase the likelihood of CoSMo data being used for research, and as information support for management actions, we implemented a variety of strategies:

- We made the data publicly available on our DataStream page for easy access. The project description included a note asking end-users to notify us if they used the data, so that we could keep our partners informed on data use;
- We worked with potential end-users to identify data needs and whether CoSMo could fill them. For example, we engaged with a research team from DFO, UBC, and SFU that conducts research on 6PPD-quinone (a chemical in car tire residue that has adverse effects on salmon; Tian et al., 2020) and learned that they required freshwater discharge data from creeks. We informed them of current logger locations (which influenced their site selection),

installed additional loggers at sites of interest, and provided training on developing stage-discharge relationships in streams. A similar approach was used for the Road Salt Project. Collaborative engagement ensured our data met user needs, and increased meaningful use of CoSMo data;

- We prioritized public engagement and utilized a wide variety of opportunities to spread the word about the CoSMo project though participating in community events, giving talks to secondary and post-secondary classes, and through facility tours at PSEC. These efforts raised awareness of the CoSMo dataset (and its access) for potential end-users.

Communication

When asked questions during the social science research interviews, interviewees were allowed to provide multiple responses to open-ended questions, and then each response was categorized. Interviewees often provided multiple responses to a question, thus potentially contributing to multiple categories. When asked what is needed for a successful collaboration and what hinders or challenges successful collaborations, 133 out of 270 total interviewee responses (49%) revolved around communication (Table 2). Specifically, responses focused on the need for effective communication, lack of direction from governments regarding how stewardship groups can improve their data collection and management practices, and the importance of relationships and challenges that arise from staff turnover. Several government interviewees also listed “volunteer fatigue/burnout” and “unrealistic demands/expectations of government” as collaboration barriers, and several volunteer interviewees responded with comments that fell under “politics and understanding of politics” (Table 2), reflecting the need for clearer communication about volunteer capacity and workload, and government capacity and jurisdiction, respectively.

Table 2: Number of categorized responses from Government Employee (Gov.) and Stewardship Group Volunteer (SG) interviewees to questions regarding what is necessary for a collaboration to succeed, what hinders collaborations (barriers), and challenges of collaborating. Interviewees often provided multiple responses to a question, thus potentially contributing to multiple categories.

Categories of Responses	**Necessary for successful collaboration**		**Hindering collaboration (barriers)**		**Challenges of collaborating**		**Total responses per category (% of total responses**
	Gov.	SG	Gov.	SG	Gov.	SG	
Relationships, people, and communication	32	29	25	24	16	7	133 (49%)
Human resources and capacity	10	4	15	13	11	5	58 (21%)
Tangible resources	1	0	2	0	2	0	5 (2%)
Logistics and planning	8	2	7	1	2	1	21 (8%)
Politics and understanding of politics	8	5	7	5	5	12	42 (16%)
Miscellaneous	5	2	0	0	2	2	11 (4%)
					Total number of responses:		**270**

To address communication concerns for the CoSMo project, and to help maintain volunteer interest and motivation, we implemented the following strategies. First, the DFO project lead maintained regular, open lines of communication with volunteers (primarily through email, but also phone). An annual survey was sent to volunteers, which provided an opportunity for volunteers to share feedback regarding project management, communication, or other thoughts they had. Additionally, volunteer partners were notified (via newsletter and/or email) what the CoSMo data were being used for. Lastly, staff hosted annual workshops for the Road Salt Project (which uses CoSMo data) that included presentations summarizing the data volunteers had collected and what had been learned from analyses of the data. For a full list of outputs from the CoSMo project to date, see Appendix 6.

Discussion

Lessons Learned During Project Implementation

Developing and expanding a new citizen science project over the past seven years, supported by a concurrent social science study aimed to investigate effective project design, has allowed us a unique opportunity to share a discussion about the opportunities and challenges of establishing an environmental research and monitoring collaboration with community-based stewardship groups and partners. From our experiences, we highlight 13 key elements of success that should provide helpful guidance for those initiating similar collaborations. While the primary target audience for this report is government science agencies, we hope the recommendations to follow will be useful for any stewardship group to consider when planning a collaborative research or monitoring project (Figure 5). Though not exhaustive, we have also framed these elements within the broader citizen science literature where possible. We have grouped these key elements into the following four categories, while acknowledging that there is substantial overlap, as many elements have aspects that apply to more than one category: (1) Required Resources, (2) Relationships, Communication, and Working with Stewardship Groups, (3) Logistics, Planning, and Project Development, and (4) Data Management and Quality Assurance.

Required Resources

Key Element #1: Sufficient government resources and appropriate people dedicated to coordinating the project and supporting volunteers

To be able to identify or study ecosystem changes, collaborative environmental monitoring or research projects often require consistent funding for operations and maintenance (including staff salaries), which can be challenging for both government and community groups to acquire or manage on their own (Sharpe & Conrad, 2006). Funding and commitments should be secured prior to initiating a monitoring project as a means to address such common constraints of community-based monitoring (Whitelaw et al., 2003). Co-funding a project or pooling resources with external partners or stakeholders is a common option to ensure the project is sustainable (Cunha et al., 2017).

For the government agency, having consistent, dedicated staff (e.g. a project coordinator) tasked with collaborating with and supporting partnering stewardship groups is equally important. The project coordinator should have sufficient time and resources in their core workplan to prioritize relationships and communication with stewardship groups, train and support volunteers, and help troubleshoot issues. Staff time requirements will change as the project transitions from planning stages to growth and then maintenance phases, and building a larger core team (as opposed to a single project coordinator) may be necessary for larger citizen science projects (i.e. thousands of volunteers; Locke et al., 2019).

Relationships, Communication, and Working with Stewardship Groups

Key Element #2: The government agency taking a leadership role and providing guidance to stewardship groups

Many community-based stewardship groups collect data for which governments and resource management agencies report gaps (Kroetsch, 2021). However, lack of standardization within and between groups (Conrad & Daoust, 2008), insufficient data management and sharing, and insufficient or undocumented quality assurance protocols hinder the uptake of community-gathered data (de Sherbinin et al., 2021; Kroetsch, 2021). This suggests a key role that government partners can play when collaborating with environmental stewardship groups: providing guidance on how to collect and maintain good-quality environmental data. In our social science survey, when community groups were asked what role they felt DFO and other government agencies could play to help improve environmental monitoring collaborations, many responses touched on the need for guidance and leadership (Kroetsch, 2021). Specifically, it was suggested that governments could provide training and address issues related to standardization, data storage, and data use. Moreover, community-generated data have the potential to be more influential to government decision-making if the government partner was involved and provided guidance and training through the entire process (Buckland-Nicks, 2015).

Key Element #3: Having a designated liaison within the government agency and each stewardship group to ensure effective, efficient communication

Effective communication is a crucial component of collaborative monitoring initiatives. Frequent communication helps build trust and understanding between government and stewardship groups and ensures all parties have up-to-date information on the project (McKay & Johnson, 2017). Providing rapid feedback has been shown to help with volunteer retention (Robinson et al., 2021); however, excessive or redundant communication can lead to frustration for both parties. Therefore, a balance is needed between relationship building and time efficiency, especially when multiple groups are involved. Working with volunteers also requires additional patience, as they are not paid for the work they do and are not obligated to do anything asked of them. Therefore, the project coordinator working with volunteers should ideally be personable, patient, an effective communicator, and enthusiastic about the project engagement.

To ensure efficient communication for the CoSMo project, we found it helpful to have a designated point of contact on both sides. Our project coordinator was responsible for communicating with and supporting partnering stewardship groups, acting as a point of contact for incoming and outgoing questions and communications. This ensured there was no confusion amongst volunteers who they should contact if they had a question. Similarly, we always identified who our point of contact should be when engaging with new groups.

Key Element #4: Prioritizing relationships and engaging frequently and purposefully with citizen science collaborators

The social relationship component is a critical piece to collaboration (Hecker & Taddicken, 2022), and can be a challenging aspect for government agencies or researchers to navigate. However, prioritizing positive relationships with community partners, such as through the provision of two-way learning, can help with volunteer retention (Robinson et al., 2021). High volunteer turnover, through feelings of alienation, can cost additional labour and resources (e.g. to recruit and train new volunteers) (West & Pateman, 2016).

Volunteer Retention:

There are different ways project coordinators can maintain volunteer interest and participation over the long term. Aceves-Bueno et al. (2015) reviewed 83 studies regarding citizen science and categorized five ways in which project coordinators engaged and motivated volunteers. The motivators, in order of most to least frequently mentioned in the studies, were: (1) potential for knowledge gain, (2) sense of place/social capital (i.e. when participation in the project makes people feel connected to their local community or environment), (3) action, such as helping participants feel their contributions are directly contributing to more effective management decisions, (4) tools and technology (e.g. innovative web platforms), and (5) economic incentives.

From our experience with the CoSMo project, we found there are three strategies that, when implemented consistently, seemed to help keep volunteers engaged long-term. They are:

1. *Prioritize the relationship*. This relates to Motivator 2: sense of place/social capital (Aceves-Bueno et al., 2015). Humans are more likely to remain engaged and committed to a project if we form social connections and feel valued, respected, and connected to those we work with (Measham & Barnett, 2007; West & Pateman, 2016). For example, we found that small acts of reciprocity (e.g. providing reference letters, and mentorship to volunteers) reminded our collaborators that they are valued and respected partners. This in turn helped keep volunteers engaged and interested in the project and the partnership. Direct interactions with scientists have also been shown to increase volunteers' sense of being valued partners (Evans et al., 2005). In our experience through CoSMo, prioritizing the relationships we formed with volunteers has also benefited our staff, who found enjoyment connecting with, conversing with, and learning from our stewardship group partners.
2. *Determine what participants hope to get from volunteering and (if possible) help attain it*. People volunteer in community-science projects for a variety of reasons; some witness environmental degradation and feel compelled to act, others want to learn new skills, and some volunteer as a social activity (West & Pateman, 2016; Sextus et al., 2024). When establishing relationships with volunteers, getting a sense of what motivates them (what they hope to gain from participation in the project) and then striving to fulfill their goals can result in increased long-term volunteer engagement and motivation (Locke et al., 2019). For a government agency or project coordinator with specific mandates, this can be a challenge to facilitate; however, volunteer 'wants' can often be fulfilled in small ways that don't overwhelm the project coordinator capacity. For example, while implementing the CoSMo project, we learned that volunteers were eager and enthusiastic about the 'boots on the ground' field work aspect of environmental monitoring projects (as further discussed in Key Element #8), and tended to be much less enthusiastic about administrative tasks (e.g. data entry). Consequently, we focused volunteer efforts primarily on field-based activities to maintain interest. Furthermore, for partners who wanted to learn new skills or information, we invited them to training workshops and virtual presentations that we hosted, and forwarded them invitations for workshops hosted by other partners.
3. *Link the data to action*. Using the data meaningfully and reporting back to volunteers can help sustain volunteer participation (de Vries et al., 2019). Accordingly, data from the CoSMo project have been directly used to support ongoing research initiatives that are intended to support resource management, the results of which are regularly communicated out to community partners. These include the initial research focus of CoSMo studying abiotic and biotic determinants of salmonid abundance in urbanized watersheds (Gemmell, 2023). Additional research has tracked contamination of urban streams by road salt (e.g. Kilgour et al., 2025),

which is intended to inform road salt regulations in Canada. Research on 6PPD-quinone (6PPD-Q, commonly referred to as the ‘toxic tire chemical’), seeks to improve understanding of 6PPD-Q dynamics and potentially help identify 6PPD-Q hotspots that could be prioritized when identifying restoration sites (King et al., 2025). Finally, research on thermal regimes, including studying stream responses to meteorological events (Déry et al., 2024) and how aquatic thermal sensitivities and acute heat events throughout the year can influence salmonids at various life stages (For a full list of outputs from the CoSMo project, see Appendix 6.

Two-Way Learning Opportunities:

Prioritizing relationships with community partners provides opportunities for two-way learning. For example, purposeful engagement and consultation between professionals and public can promote mutual learning and greater awareness of the limits of each groups’ expertise (Boivin et al., 2014). Close collaboration with community groups can also enable researchers to better understand their data by shedding light on nuanced details unknown to someone who lacks local knowledge (Gunnell et al., 2021).

Working with community groups means working with a diverse group of people with varying personalities, capacities, levels of experience, and motivations that can differ from the government researcher or project coordinator. However, such differences may further the potential for two-way learning opportunities. For instance, for the CoSMo project, many of our volunteer partners lived near the watersheds they stewarded for many years (often decades) and had valuable local knowledge about the site history, changes over time, and current conditions, which proved to be especially important for facilitating site selection. Local knowledge and collaboration with community partners was also the catalyst for the Road Salt Project, which was spearheaded by one of our partnering community groups and has led to greater understanding of the impacts road salt is having on urban freshwater ecosystems and the juvenile salmon residing in them (e.g. Kilgour et al., 2025; Winter et al., 2026).

Additional Societal Benefits:

Prioritizing relationships with community partners may provide additional societal benefits. We’ve found that prioritizing the relationships we’ve established with volunteers has helped build a strong rapport that leads to increased trust, and provided opportunities for volunteers to ask questions about the project and scientific processes more broadly. This involves small acts such as responding to emails in a timely fashion, attending community events hosted by partnering groups when possible, and providing thoughtful and helpful responses, even if the question asked is unrelated to the project. For the CoSMo project, one-on-one conversations about water quality have also provided opportunities for volunteers to ask questions regarding management of creeks and salmonids. Such conversations between community volunteers and researchers can lead to improvements in volunteer knowledge on focal species and/or scientific methodologies (Evans et al., 2005), government operations and legislations, and may empower community partners to educate the broader public and become more-informed environmental advocates in their communities (Whitelaw et al., 2003; Aceves-Bueno et al., 2015).

By establishing relationships and communicating regularly and effectively with stewardship partners, governments can help ensure the information those stewardship groups share externally is accurate and that the groups have credible data to support their public education and awareness initiatives. For example, for the Road Salt Project, we maintained close relationships and engaged frequently with partnering stewardship groups to ensure they had the most up-to-date data and information regarding road salt impacts, which ensured they could provide their communities with accurate information and guidance regarding salting practices.

Key Element #5: Clear communication with volunteers regarding data quality and data collection

Providing honest feedback to stewardship groups regarding data quality and collection practices is a critical step that many government agencies overlook (Kroetsch, 2021). Historically, environmental data provided by stewardship groups to governments (i.e. to inform resource management decisions) has not been viewed as high enough quality to be used in decision making (Underwood & Chapman, 2002; Carlson & Cohen, 2018), but those providing the data are not given direct feedback on how they can improve their data quality in most cases. For example, from our interviews, this lack of evaluation and failure to provide feedback was acknowledged by a DFO representative, who stated:

> *Often the groups provide information or data and it's just not valued, and instead of telling them why it wasn't used or how it can be improved … we seemingly every year are taking info and not using it to its full potential … instead of wasting people's time we should be very clear about what we can use and how we can improve things … we don't do a follow up or review process ... we don't do enough evaluation* (Kroetsch, 2021, p. 70).

This lack of communication can frustrate community members who want to contribute to science and/or decision-making that affects their local ecosystems and don't want to waste time collecting data that aren't useful.

Certain parameters or circumstances have complex data collection procedures, for which data will only be used for decision-making if collected by a professional. This further speaks to the importance of government agencies leading the project, or at the very least providing guidance and clear communication to partnering stewardship groups so that they know at the outset which types of community-gathered data are more or less likely to be utilized. Conversely, for parameters with relatively simple data collection procedures - where community-gathered data are likely to be comparable to professional data (e.g. water temperature from properly installed and QAQC'd automated data loggers) - data quality expectations should be clear. If the data are not of high enough quality to be useful, the government partner should communicate explicitly what is required for the data to be considered credible for decision making or analyses. Examples of quality assurance measures that can help improve the quality of community-gathered data are discussed in the *Data Management and Quality Assurance* section.

Logistics, Planning, and Project Development

Key Element #6: Clearly defined roles, responsibilities, and capacities

When co-developing a project with community-based stewardship groups, it's crucial to clarify roles, responsibilities, and capacity of both parties at the outset. Clear communication regarding volunteer time and effort ensures that potential new volunteers can make an informed decision whether participation in the project is feasible given their volunteer capacity. This helps reduce volunteer burnout – defined as a state of emotional, physical, and/or mental exhaustion resulting from prolonged or excessive volunteer activities (VCLA, 2025) – which can contribute to high volunteer turnover (West & Pateman, 2016; Sextus et al., 2024) and was identified by several government representatives in our interviews as a hindrance to collaboration (Kroetsch, 2021).

Project coordinators should be mindful of volunteer burnout and work to mitigate if possible, though this can be challenging given the wide variation in capacity between community-based stewardship groups. If volunteer burnout leads to high volunteer turnover, more time and resources must be allocated towards recruiting and training new volunteers, so prevention of burnout is beneficial for both parties. Our community surveys showed volunteer burnout was a challenge for many of the environmental stewardship groups (Kroetsch, 2021); thus, for the CoSMo project, we tried to mitigate volunteer burnout by clearly stating the expectations of volunteer commitment at the outset. We also encouraged new volunteers to start small (e.g. by starting with a single data logger) to gauge the workload and reminded them that it's a long-term project, meaning they'd have opportunities to take on additional data loggers in the future if they wanted. We felt that starting small and increasing workload gradually was better than taking on several tasks right away and having to scale back, should volunteers realize the workload wasn't manageable. Alternatively, "taster sessions" can be offered, which allow potential volunteers to try tasks before committing to joining the project (West & Pateman, 2016). We also reminded volunteers that participation in the project is meant to be a fun and enjoyable process, and that starting small would ensure that participation continued to be fun, rather than feeling like a burden or overwhelming obligation.

Depending on the type of project and parameters being monitored, it may prove beneficial to offer different levels of participation to volunteers. For example, the B.C. Lake Stewardship and Monitoring Program has clearly-stated, predefined roles for volunteers, but given the variety of tasks and parameters that they monitor, they have divided their program into five different levels of monitoring, with increasing number of parameters and time requirements for each level (B.C. Lake Stewardship and Monitoring Program, 2023). This approach ensures volunteers know exactly what they are committing to, and has the added benefit of providing options and accessibility for volunteers with varying capacities.

Clearly communicating the roles and responsibilities of government partners (e.g. jurisdiction, capacity, expertise, data use) may help prevent unrealistic expectations and misunderstandings about government capacities and political processes that government interviewees identified as hindering collaborations (Kroetsch, 2021). For example, during initial meetings with community partners regarding a potential stream monitoring collaboration, some participants stated or implied that DFO should be leading extensive contaminants monitoring in steams; a viewpoint that we have repeatedly heard since. However, the mandate and expertise of specific DFO researchers involved in the partnerships does not focus on contaminants. The monitoring of contaminants and other 'deleterious substances' is primarily the responsibility of Environment and Climate Change Canada (ECCC), who are responsible for enforcing Section 36 of the Fisheries Act, which focuses on harm or potential harm caused by 'deleterious substances' in fish-bearing habitat (Fisheries Act, 1985; Government of Canada, 2017). This misunderstanding of researcher expertise, jurisdiction, and regulatory roles initially led to some futile discussions, whereas subsequent meetings with community partners have provided opportunities for discussion and clarification regarding DFO's mandate and our specific expertise. Thus, we feel engaging in direct collaborations with community partners has allowed us to better communicate some of these jurisdictional nuances, which may help with transparency of government agency roles and capacities.

Key Element #7: Starting small to enable strategic project growth

When first initiating the CoSMo project, we had heard anecdotally that many volunteer-based environmental monitoring programs that have overly ambitious objectives at the outset fail (i.e. place unrealistic demands on staff and volunteers, leading to project failure due to burnout and lack of volunteer retention). Issues related to time management, as well as having too high expectations of volunteers, can be common causes for project failure (Westreicher et al., 2020). Ultimately, we found that this 'start slow, then expand gradually' approach (i.e. start with a single parameter and small geographic area, then slowly expand) facilitated successful project management, as it allowed for more adaptive expansion at a rate that didn't exceed our capacity (see: Locke et al., 2019; Sardo et al., 2025).

Volunteers participating in the CoSMo project were initially only offered the option to monitor stream temperature (for which the data loggers are very simple and require minimal maintenance). As the project expanded to include additional parameters (e.g. the Road Salt Project), a subset of the community partners were given the option to have conductivity/depth/temperature loggers installed, which require additional maintenance (e.g. regular calibration). Some community partners felt comfortable increasing their volunteer workload with the multi-parameter loggers, whereas others preferred to stick with their original temperature loggers.

Key Element #8: Match volunteer tasks with volunteer capacity and interests

When designing a collaborative monitoring project, we recommend planning so that the volunteer tasks match volunteer capacity, and interests when possible (West & Pateman, 2016). In our case, this meant that volunteers were mainly engaged in field work, and we, as the government agency, assumed as many of the 'office-based' data management responsibilities as possible (e.g. data processing, storage, analysis, and sharing). More specifically, for the CoSMo project, once at the site, much of the volunteer data collection steps could be performed with a smartphone and app. The data and metadata were subsequently screened, processed, and uploaded to the DataStream database by DFO staff. This recommendation is in line with some citizen science projects that ask volunteers to submit data and/or samples, which are then processed by professionals (e.g. the Province of B.C. Lake Stewardship and Monitoring Program; Florida Lakewatch), but is contrary to other volunteer-based programs that require volunteers to record data by hand in the field and then upload the data into a database from their computer when they return home.

Having volunteers upload their data to a database theoretically reduces the administrative burden for the project coordinator; however, we advise against this method for a few reasons. First, having many volunteers with varying levels of experience and expertise enter their own data reduces overall consistency and may increase the likelihood of error. Second, even if automated quality assurance mechanisms are in place (e.g. values outside a certain range are automatically flagged), the perception of data quality by end-users may be affected if the data are not screened by a professional prior to being shared publicly. Indeed, we have heard from end-users of the CoSMo data, including researchers and other government agencies, that they view the data as credible in part because the data are QAQC'd by government staff prior to being shared publicly. And third, we have heard that when volunteers are asked to upload their own data upon returning home from the field, sometimes data are not entered, instead stored as hand-written data sheets where they are inaccessible to others and unlikely to ever get used.

To address these issues and maintain quality assurance (and the perception of quality assurance by end-users), for the CoSMo project, we had volunteers send the data files and complete data sheets to the CoSMo project coordinator, who reviewed the data sheets promptly so they could follow up with any questions if necessary. The data were then processed and uploaded to the DataStream platform in a timely manner.

Key Element #9: Lead organization sharing the data and results of analyses with partners and the public

When community partners are involved in data collection, it is imperative that the data and/or results of data analyses (if completed) be shared back with them (Cooper et al., 2007; Locke et al., 2019). Providing volunteers with results of data collection contributes to better public understanding of project results (Cooper et al., 2007) and shows volunteers how their efforts are contributing to science, which can help maintain engagement and motivation (de Vries et al., 2019). Having data be made publicly accessible is the aim of the Government of Canada's directives and policy on most government collected data (Government of Canada, 2023), as there are recognized benefits of open data (National Academies, 2007; USGS, n.d.). Further, including visualizations of the data (e.g. on a project website) may facilitate public learning (de Vries et al., 2019). Discussions regarding how and with whom the data will be shared should occur before data are collected, as data sharing may present a challenge.

In addition to sharing data, we feel it's important to provide community partners with project updates, as well as summarized results from data collection that are written in lay language. Direct communication with scientists or project leads can improve engagement of community partners by involving them more thoroughly in the research process (Evans et al., 2005). We have heard from CoSMo volunteers that seeing the results of their work also helps maintain motivation and interest. We elected to provide high-level updates via regular newsletters (containing project updates, images, preliminary results, and figures), which we distribute to project partners as well as a wide array of internal and external stakeholders. Newsletters allowed us to reach a broad audience, and we regularly received positive feedback that indicated community partners found the newsletters to be engaging and interesting. However, newsletters shouldn't be the only means of communication, as they can lack fine details that many groups find interesting and are unlikely to achieve the "personal, sustained communication" that has been identified as a critical element of success for community-based monitoring projects (Evans et al., 2005). Conversely, direct email updates to a single community group liaison or small group of people may reach a much smaller audience, but can allow for a personal connection and sharing of finer details, such as information about particular sites in a creek, for which our community partners have expressed appreciation. There are pros and cons to each method of communication, and we feel the mixed-method approach (e.g. using a combination of newsletters, emails, workshops) has been well-received.

Key Element #10: Using the data and reporting on the scientific and/or management use of the data to stewardship groups to help maintain volunteer motivation

People participate in community-based monitoring projects for a variety of reasons, but a common motivator is the desire to influence local decision-making to improve the environment (Carlson & Cohen, 2018; Sextus et al., 2024). Responses from our interviewees suggest that historically, data collected by stream stewardship groups in the Lower Mainland, B.C. typically haven't been analyzed or used meaningfully (Kroetsch, 2021). Many Streamkeepers, during interviews and subsequent discussions, expressed frustration at the lack of use, given that they collect the data in hopes of contributing to decision-making and improved management of the watersheds in their areas.

There are many ways community-gathered data can be used, including: scientific research papers; identifying areas that would benefit most from restoration work (Rowe et al., 2021); filling in monitoring gaps in areas that are often overlooked or inaccessible to researchers (Cooper et al., 2007; Hadj-Hammou et al., 2017); and evaluating the efficacy of existing mitigation projects (Yardi et al., 2019). To avoid frustration, improve relationships with community partners, and maintain volunteer participation and motivation, we recommend where possible using the data collected by community partners and notifying them what the data are used for (e.g. via newsletter). However, this can be a challenge for government agencies, as there is often a lack of internal processes or frameworks for incorporating community-gathered data into decision-making processes (Conrad & Daoust, 2008). Jurisdiction, with varying levels or types of governments, can also hinder uptake of citizen science into management or policy. To address this, discussions about how the data can be incorporated into internal processes should occur before project implementation and data collection. Decision-makers should also clarify what data are needed to support management or policy decisions, and what protocols or methods much be followed for citizen science data to be incorporated in those processes (Watson, 2005; Turbé et al., 2019). Lastly, transparent and candid conversations with community partners about the potential limits and challenges of using data for management should occur up front, to help build trust.

Data Management and Quality Assurance

Key Element #11: Developing a data management plan before data collection begins

Data management plans (DMPs) help ensure all steps of the data life cycle – including data collection, storage, analyses, sharing, and use – are accounted for, standardized, and include quality assurance measures (for more info, see Kroetsch, 2021). Our social science research highlighted the importance of having a comprehensive DMP that covers the full life cycle of the data, and that DMPs by stewardship groups are typically lacking, which can hinder uptake of community gathered data by governments and other potential end-users (Kroetsch, 2021). Given the importance of standardized data collection for enabling comparative analysis, and the influence that effective data sharing has on data uptake, it is imperative that a DMP be developed before data collection begins.

In environmental monitoring collaborations with community-based stewardship groups, government leadership is important from initial project development and DMP design through project implementation and data management. For the CoSMo project, we found that creating the DMP helped clarify processes, roles, and responsibilities; helped remind us to implement best practices (e.g. backing up data and metadata files to ensure safe and redundant storage), and flagged challenges that we had not yet addressed, such as how to make the data publicly available. However, we learned something during our experience implementing the CoSMo project that contradicted initial research findings by Kroetsch (2021). Kroetsch highlighted the importance of establishing a DMP before collecting data and suggested that co-developing the plan with stewardship partners could be beneficial. This process of co-developing the plan could help improve transparency, trust, and provide opportunities for stewardship groups to gain a better understanding of jurisdictional boundaries. Involving volunteers in shaping research questions and project outputs can foster a sense of ownership and responsibility towards the project (Aceves-Bueno et al., 2015), and co-designing projects can facilitate a two-way flow of expertise (Clarke et al., 2023). However, when we first engaged groups for CoSMo, prior to having a structured framework and DMP, it became evident that stewardship groups expected us to have a plan in place before engaging them. Reflecting on this, whether or not the DMP should be developed by the government agency in advance of engaging with stewardship groups or co-developed with stewardship groups likely depends on the type of project and the number of groups that will be involved. For instance, project coordinators hoping to collaborate with 1-2 groups in a small geographical area may benefit from co-developing the DMP from start to finish. However, contrary to our initial research findings, when collaborating with many community-based groups with varying capacities, concerns, interests, and focus across a broad region, it may be more beneficial to have a plan in place before engaging. Allowing some flexibility and adjusting the plan based on feedback from groups is helpful and can show that the government agency values their input; however, developing a DMP from scratch with agreement from all groups could potentially be time consuming and frustrating for the groups, who may just want to proceed with data collection. Having a comprehensive DMP that is up-to-date may also be helpful for bringing new staff up to speed in the event of staff turnover. For more information regarding what we recommend be included in a DMP, please see Kroetsch (2021).

Key Element #12: Quality assurance protocols incorporated into every step of the data management process

To ensure data quality and facilitate the uptake of community-gathered data by intended end-users, it’s important to incorporate Quality Assurance and Quality Control (QAQC) protocols at every step in the data life cycle. This can be especially important for citizen science projects, given that community-gathered data tend to be subject to greater skepticism than professional data and are often assumed to be inaccurate or of poor quality (Carlson & Cohen, 2018), which can hinder uptake of data by resource managers and other potential end-users (Underwood & Chapman, 2002; Gouveia et al., 2004; Gillett et al., 2012; Burgess, 2017). CoSMo survey responses showed variation in how interviewees viewed data collected by trained volunteers compared to professional scientists. Although some government employees were less skeptical of community-gathered data, uptake would likely be improved if rigorous quality assurance protocols were incorporated and clearly communicated (König et al., 2021). Quality assurance measures can include, but are not limited to: (1) mandating training for volunteers, (2) keeping protocols as simple as possible, (3) conducting validation studies to ensure simplified volunteer protocols and professional protocols reach the same conclusions (e.g. Finn et al., 2010; Hoyer et al., 2012), (4) utilizing technology that can reduce opportunities for human error, and (5) having government staff screen the data before they are published (also see: Clark & Whitfield, 1993 and Freitag et al., 2016).

Training:

Mandated training has the potential to solve issues with standardization and inconsistencies in volunteer experience, and thus data credibility. This strategy is used by the Regional District of Nanaimo (RDN), who monitor a network of streams for five weeks, twice per year, in collaboration with their local stewardship groups, the Province of British Columbia, and other stakeholders (Community Watershed Monitoring, n.d.). In order to sign out the required data collection equipment, volunteers must have participated in the annual training that is offered before the spring sampling session. Mandating training for their program has increased their data credibility, and consequently the data are used meaningfully to support planning and decision-making processes (Community Watershed Monitoring, n.d.)

Research suggests that training is most effective when done in-person (in CoSMo case: in-the-field), as volunteers feel they obtain a better understanding when learning is place-based and experiential, rather than out of context, such as training that occurs in a classroom or online (Haywood et al., 2016; Kroetsch, 2021). When arranging the training sessions for the CoSMo project, we recommended that everyone who would be maintaining data loggers join for the training session. Having more volunteers who are officially trained reduces the need for refresher training sessions, because volunteers can help remind each other of key protocols. Additionally, when volunteers understand the purpose behind certain steps in a protocol, they are more likely to appreciate their importance and perform tasks diligently (Clark & Whitfield, 1993; Haywood et al., 2016). Therefore, during the training sessions for CoSMo, we also clearly explained the importance of each step. Lastly, any supplementary written instructions should be explicit. What we found most effective was to provide instructions that included a one-page procedural 'checklist' to act as a brief reminder of the steps involved, followed by a thorough set of instructions that covered each step in detail, including several photos and screenshots, for anyone needing a more detailed reminder of the protocols.

Simple Protocols:

Another way to improve data accuracy and potentially improve data uptake is to ensure volunteer tasks are simple. Volunteers can produce data comparable to professional data when tasks and protocols are kept simple; however, accuracy can decline for more complex tasks (Jordon et al., 2012). For the CoSMo project, we kept data collection protocols simple by utilizing automated in-stream data loggers from which data could be downloaded via Bluetooth using a smart phone, and asked volunteers to fill out a simple data sheet.

Validation Studies:

When designing the protocols and initiating a project, it can be helpful to validate the data collected following any simplified citizen science protocols to ensure data quality. For example, Quinlivan et al. (2020) compared water quality data collected by volunteers with laboratory results for five parameters and found that the community-gathered data were comparable for three of them. While no specific validation studies were performed for the CoSMo project (we opted to use automated data loggers that didn’t require simplified protocols), this study highlights the value of validating protocols during initial project development. Validation can flag whether protocols need to be adjusted to improve data accuracy or indicate which parameters may not be suitable for community involvement (i.e. because it is not possible to achieve an acceptable level of data accuracy with simplified protocols).

Use of Technology:

Community-based water quality monitoring often relies on simple, low-cost methods and equipment, such as visual assessments or colorimetric test strips; however, these methods often produce data that are imprecise, and consequently not very useful (Blanco Ramírez et al., 2023). Conversely, the use of more advanced technology, such as automated data loggers or properly calibrated hand-held multi-meters probes, can produce data that are more precise, and can streamline and simplify the data collection process, which can help improve data accuracy by reducing opportunities for human error.

Appropriate use of technology (automated data loggers) was one of the primary quality assurance methods applied for the CoSMo project. For example, we applied a water bath protocol to the majority of loggers prior to deployment in creeks to validate data logger accuracy. This entailed submerging the temperature loggers in an ice bath (0 °C) followed by a warm water bath and comparing logger readings with measurements taken by an accurate hand-held thermometer. By utilizing automated data loggers, that were QAQC’d, instead of asking volunteers to collect spot samples, we were able to achieve a simple data collection process without compromising the accuracy and precision of the data. Further, use of automated loggers allowed for standardization regarding when and at what frequency data were collected (i.e. the data loggers recorded at regular intervals that were unaffected by volunteer schedules), which produced a more useful and comparable dataset.

Data Screening:

As previously discussed, if the data are to be made publicly available, it is imperative that the government science agency screen and quality check the data before they are published, as opposed to having volunteers enter/upload their own data. All CoSMo data are screened by the DFO project coordinator before being uploaded to the CoSMo DataStream page, and we have heard from our data end-users that this process makes them feel confident that the data are accurate.

Key Element #13: Periodic evaluations of overall project management and collaboration by both parties

For citizen science projects, regular (e.g. annual) evaluation of the data management plan as well as the collaboration more broadly can help answer questions such as: *Are we achieving our objectives? Are there any redundancies or inefficiencies that could be addressed? Is everyone happy with how things are done? Is the volunteer workload reasonable?* There are a variety of different ways that citizen science projects can be evaluated, including: the number of publications that result from the data collection, monitoring how the data are used and trusted by end-users, and increased levels of public participation over time (Locke et al., 2019). Following evaluation, adjustments can be made to address any issues, and subsequent evaluations can then assess if the adjustments were successful, which allows for ongoing, iterative improvements.

We've found that periodic, informal evaluations are also helpful in ensuring the project objectives are met. For example, to ensure we remained on track to achieve our CoSMo project objectives, we had monthly meetings with the PSEC staff who run the project; to ensure that our community partners remained happy with the project and the role that they played, we had regular conversations with volunteers and incorporated their feedback whenever possible; and approximately once a year, we reached out to our partners via email to specifically ask for feedback on the project and if they had any suggestions for how we could improve things.

Conclusion

Environmental research and monitoring collaborations involving government agencies and community-based stewardship groups have the potential to improve resource management by increasing monitoring capacity and thus increasing the amount of credible information to help inform decision-making. In 2019, PSEC Science staff initiated a pilot Community Stream Monitoring (CoSMo) project in eight watersheds in the Howe Sound/Burrard Inlet region to improve research and monitoring related to water temperature in urban salmon-bearing streams, as well as to learn how to better collaborate with stewardship groups, and engage local universities and the general public. The project has since expanded to include 55 watersheds in the Greater Vancouver Area, added additional parameters, and broadened in scope to support several other freshwater-related research projects. Streams are monitored and data gathered in partnership with 15 stewardship groups, three universities, two municipalities, and one secondary school. Given the CoSMo project's successful expansion, longevity, and use of its data for multiple research initiatives, it provides a strong example of how collaborations with the proper support can enable community groups to produce credible, standardized datasets.

In this report, we shared our experiences and lessons learned from collaborating with community-based stewardship groups on environmental monitoring initiatives, including examples of how specific problems and challenges were addressed (Figure 4). Based on our experiences developing, implementing, and maintaining a collaborative, community-based stream-monitoring project, we offer what we feel are 13 key elements for success (Figure 5), which relate to: (1) required resources, (2) relationships, communication, and working with stewardship groups, (3) logistics, planning, and project development, and (4) data management and quality assurance. This paper contributes to the broader literature on how to improve citizen science initiatives, and aims to address the current paucity of guidance for government agencies on how best to collaborate with community-based stewardship groups on environmental monitoring and research initiatives. While the targeted audience for the present paper is different government agencies or researchers, we also hope this guidance can be useful for community-based stewardship organizations trying to improve their engagements with government agencies.

	Problem	Solution
Required Resources	Limited project budget	Resource pooling with external partners
Relationships, communication, and working with stewardship groups	Lack of clarity regarding roles & responsibilities	Standardized volunteer role/ involvement. Clearly communicated roles/commitments when first engaging with new potential partners.
	Need to maintain volunteer interest/engagement	Involved volunteers in site selection. Reported back to volunteers what data used for. Prioritized the relationships. Attempted to identify volunteer motivations and fulfill wants.
	Needed to maintain effective communication	Had clear points of contact. Maintained open lines of communication. Distributed newsletters. Surveys requesting feedback regarding project/communication.
	Need to mitigate volunteer burnout	Designed project to minimize volunteer workload and admin/computer work, and allow for flexible schedule. Clearly stated roles and responsibilities at the outset. Encouraged volunteers to start small and gradually increase workload.
Logistics, planning, and project development	Project management felt disorganized/not condusive to expansion	Established predefined roles/responsibilites.
	Risk of overwhelming staff capacity	Started with small pilot project, expanded gradually.
Data management and quality assurance	Lack of standardized data collection practices	Used automated loggers. Provided clear download instructions. Required that volunteers fill out data sheets.
	Lack of standardized data management practices	Created data management plan. DFO staff managed and shared data.
	Lacked ability to share community-gathered data externally	Partnered with DataStream.
	Quality assurance concerns/skepticism about community-gathered data quality	Incorporated multiple QAQC protocols. DFO staff processed and screened data before making publicly available.
	Lack of uptake of data	Prioritized communication and data sharing. Worked with potential end-users to determine data needs/whether we could meet those needs (maintained flexibility).
	Data gaps caused by equipment malfunctions or lost gear	Tested different loggers and installation methods before project expansion. DFO staff did all installations.

Figure 4: Examples of problems/challenges experienced when developing and implementing the CoSMo project, and how they were addressed.

Figure 5: Key Elements for success for collaborations between government agencies and community stewardship groups, which address issues related to (a) required resources (Element 1), (b) relationships, communication, and working with stewardship groups (Elements 2, 3, 4, 5), (c) logistics, planning, and project development (Elements 6, 7, 8, 9, 10), and (d) data management and quality assurance (Elements 11, 12, 13).

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References

Aceves-Bueno, E., Adeleye, A., Bradley, D., Brandt, W., Callery, P., Feraud, M., Garner, K.L., Gentry, R., Huang, Y., McCullough, I., Pearlman, I., Sutherland, S.A., Wilkinson, W., Yang, Y., Zink, T., Anderson, S.E., and Tague, C. 2015. Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-in in Adaptive Management: Criteria and Evidence. Ecosystems, 18, 493-506. doi:10.1007/s10021-015-9842-4

Amano, T., Lamming, J., and Sutherland, W. 2016. Spatial Gaps in Global Biodiversity Information and the Role of Citizen Science. BioScience, 66, 393-400. doi:10.1093/biosci/biw022

Atkinson, E., Carturan, B., Atkinson, C., Bateman, A., Connors, K., Hertz, E., and Peacock, S. 2025. Monitoring for fisheries or for fish? Declines in monitoring of salmon spawners continue despite a conservation crisis. Canadian Journal of Fisheries and Aquatic Sciences, 82, 1-18. Retrieved from http://dx.doi.org/10.1139/cjfas-2024-0387

Aura, C., Nyamweya, C., Owiti, H., Odoli, C., Musa, S., Njiru, J., Nyakeya, K., and Masese, F. 2021. Citizen Science for Bio-indication: Development of a Community-Based Index of Ecosystem Integrity for Assessing the Status of Afrotropical Riverine Ecosystems. Frontiers in Water, 2. doi:10.3389/frwa.2020.609215

B.C. Lake Stewardship and Monitoring Program. 2023. Retrieved from British Columbia: https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/lake-monitoring/bc-lake-stewardship-and-monitoring-program

Bird, T., Bates, A., Lefcheck, J., Hill, N., Thomson, R., Edgar, G., Stuart-Smith, R.D., Wotherspoon, S., Krkosek, M., Stuart-Smith, J.F., Pecl, G.T., Barrett, N., and Frusher, S. 2014. Statistical solutions for error and bias in global citizen science datasets. Biological Conservation, 173, 144-154. Retrieved from https://doi.org/10.1016/j.biocon.2013.07.037

Blanco Ramírez, S., van Meerveld, I., and Seibert, J. 2023. Citizen science approaches for water quality measurements. Science of the Total Environment, 897. Retrieved from http://dx.doi.org/10.1016/j.scitotenv.2023.165436

Blumstein, D.T. 2025. The end of long-term ecological data? PLoS Biology, 23(4). Retrieved from https://doi.org/10.1371/journal.pbio.3003102

Boivin, A., Lehoux, P., Burgers, J., and Grol, R. 2014. What Are the Key Ingredients for Effective Public Involvement in Health Care Improvement and Policy Decisions? A Randomized Trial Process Evaluation. Milbank Quarterly, 92, 319-350.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., and Wilderman, C. 2009. Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. Washington D.C.: Center for Advancement of Informal Science Education (CAISE). Retrieved from https://files.eric.ed.gov/fulltext/ED519688.pdf

Braun, D., Reynolds, J., and Patterson, D. 2015. Using watershed characteristics to inform cost-effective stream temperature monitoring. Aquatic Ecology, 49(3), 373-388. doi:10.1007/s10452-015-9531-6

Buckland-Nicks, A. 2015. Keys to Success: A Case Study Approach to Understanding Community-Based Water Monitoring Uptake in Governmental Decision-Making. Dalhousie University. Retrieved from https://dalspaceb.library.dal.ca/server/api/core/bitstreams/b7a9bffc-0bca-47a4-8572-57c7721e5fea/content

Burgess, H.D. 2017. The science of citizen science: Exploring barriers to use as a primary research tool. Biological Conservation, 208, 113-120. Retrieved from https://doi.org/10.1016/j.biocon.2016.05.014

Caissie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology, 51(8), 1389-1406. Retrieved from https://doi.org/10.1111/j.1365-2427.2006.01597.x

Carlson, T. and Cohen, A. 2018. Linking community-based monitoring to water policy: Perceptions of citizen scientists. Journal of Environmental Management, 219, 168-177. Retrieved from https://doi.org/10.1016/j.jenvman.2018.04.077

Clark, M. and Whitfield, P. 1993. A practical model for integrating quality assurance into environmental monitoring. Water Resources Bulletin, 29(1), 119-130. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.1993.tb01509.x

Clarke, S.J., Long, E., Biggs, J., Bruce, K., Weatherby, A., Harper, L.R., and Hails, R.S. 2023. Unlocking the potential of eDNA for volunteer freshwater monitoring. Ecological Solutions and Evidence, 4. Retrieved from https://doi.org/10.1002/2688-8319.12273

Community Watershed Monitoring. n.d. Retrieved from Regional District of Nanaimo: https://www.rdn.bc.ca/community-watershed-monitoring

Conrad, C. and Daoust, T. 2008. Community-Based Monitoring Frameworks: Increasing the Effectiveness of Environmental Stewardship. Environmental Management, 41, 358–366. doi:10.1007/s00267-007-9042-x

Conrad, C. and Hilchey, K. 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. Environmental Monitoring and Assessment, 273-291. doi:10.1007/s10661-010-1582-5

Cooper, C.B., Dickinson, J., Phillips, T., and Bonney, R. 2007. Citizen Science as a Tool for Conservation in Residential Ecosystems. Ecology and Society, 12(2). Retrieved from http://www.jstor.org/stable/26267884

CoSMo DataStream. 2024. Retrieved from https://doi.org/10.25976/0gvo-9d12

Cunha, D., Marques, J., De Resende, J., De Falco, P., De Souza, C., and Loiselle, S. 2017. Citizen science participation in research in the environmental sciences: key factors related to projects' success and longevity. Annals of the Brazilian Academy of Sciences, 89(3), 2229-2245. Retrieved from https://doi.org/10.1590/0001-3765201720160548

de Sherbinin, A., Bowser, A., Chuang, T.R., Cooper, C., Danielsen, F., Edmunds, R., Elias, P., Faustman, E., Hultquist, C., Mondardini, R., Popescu, I., Shonowo, A., and Sivakumar, K. 2021. The Critical Importance of Citizen Science Data. Frontiers in Climate, 3. doi:10.3389/fclim.2021.650760

de Vries, M., Land-Zandstra, A., and Smeets, I. 2019. Citizen Scientists' Preferences for Communication of Scientific Output: A Literature Review. Citizen Science: Theory and Practice, 4(1), 1-13. Retrieved from https://doi.org/10.5334/cstp.136

Déry, S., Martins, E., Owens, P., and Petticrew, E. 2024. Extreme hydrometeorological events induce abrupt and widespread freshwater temperature changes across the Pacific Northwest of North America. Communications Earth & Environment, 5. Retrieved from https://doi.org/10.1038/s43247-024-01407-6

Evans, C., Abrams, E., Reltsrna, R., Roux, K., Salmonsen, L., and Marra, P.P. 2005. The Neighborhood Nestwatch Program: Participant Outcomes of a Citizen-Science Ecological Research Project. Conservation Biology, 589–594. doi:10.1111/j.1523-1739.2005.00s01.x

Finn, P., Udy, N., Baltais, S., Price, K., and Coles, L. 2010. Assessing the quality of seagrass data collected by community volunteers in Moreton Bay Marine Park, Australia. Environmental Conservation, 37, 83-89. doi:10.1017/S0376892910000251

Fisheries Act. 1985. Retrieved from https://laws.justice.gc.ca/eng/acts/f-14/page-4.html#docCont

Fisheries and Oceans Canada. 2005. Canada's Policy for Conservation of Wild Pacific Salmon. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/315577.pdf

Follett, R. and Strezov, V. 2015. An Analysis of Citizen Science Based Research: Usage and Publication Patterns. PLoS ONE, 10(11). Retrieved from https://doi.org/10.1371/journal.pone.0143687

Fore, L., Paulsen, K., and O'Laughlin, K. 2001. Assessing the performance of volunteers in monitoring streams. Freshwater Biology, 46(1), 109-123. doi:10.1111/j.1365-2427.2001.00640.x

Freitag, A, Meyer, R. and Whiteman, L. 2016 Strategies Employed by Citizen Science Programs to Increase the Credibility of Their Data. Citizen Science: Theory and Practice, 1(1): 2, pp. 1–11, DOI: http://dx.doi.org/10.5334/cstp.6

Gemmell, C. 2023. Interconnected effects of water temperature and habitat on relative abundance of juvenile salmonids during the summer months in coastal urban streams. Simon Fraser University. Retrieved from https://summit.sfu.ca/item/38000

Gillett, D., Pondella II, D., Freiwald, J., Schiff, K., Caselle, J., and Shuman, C. 2012. Comparing volunteer and professionally collected monitoring data from the rocky subtidal reefs of Southern California, USA. Environmental Monitoring and Assessment, 184, 3239-3257. doi:10.1007/s10661-011-2185-5

Gouveia, C., Fonseca, A., Câmara, A., and Ferreira, F. 2004. Promoting the use of environmental data collected by concerned citizens through information and communication technologies. Journal of Environmental Management, 71, 135-154. doi:10.1016/j.jenvman.2004.01.009

Government of Canada. 2023. The Open Government Guidebook 2023 A guide to releasing open government data and information on open.canada.ca. Retrieved from https://publications.gc.ca/collections/collection_2024/sct-tbs/BT22-278-2023-eng.pdf

Government of Canada. 2017. Compliance and enforcement policy for habitat and pollution provisions of Fisheries Act: chapter 3, Jurisdiction and Responsibilities. Retrieved from https://www.canada.ca/en/environment-climate-change/services/environmental-enforcement/publications/compliance-enforcement-policy-fisheries-act/chapter-3.html

Gunnell, J., Golumbic, Y., Hayes, T., and Cooper, M. 2021. Co-created citizen science: challenging cultures and practice in scientific research. Journal of Science Communication, 20(5), 1-17. Retrieved from https://doi.org/10.22323/2.20050401

Hadj-Hammou, J., Loiselle, S., Ophof, D., and Thornhill, I. 2017. Getting the full picture: Assessing the complementarity of citizen science and agency monitoring data. PLoS ONE, 12(12). Retrieved from https://doi.org/10.1371/journal.pone.0188507

Haywood, B., Parrish, J., and Dolliver, J. 2016. Place-based and data-rich citizen science as a precursor for conservation action. Conservation Biology, 30(3), 476-486. doi:10.1111/cobi.12702

Hecker, S. and Taddicken, M. 2022. Deconstructing citizen science: a framework on communication and interaction using the concept of roles. Journal of Science Communication, 21(1). Retrieved from https://doi.org/10.22323/2.21010207

Hoyer, M., Wellendorf, N., Frydenborg, R., Bartlett, D., and Canfield, D.J. 2012. A comparison between professionally (Florida Department of Environmental Protection) and volunteer (Florida LAKEWATCH) collected trophic state chemistry data in Florida. Lake and Reservoir Management, 28, 277-281. doi:10.1080/07438141.2012.736016

Isaak, D., Wollrab, S., Horan, D., and Chandler, G. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. Climate Change, 113, 499-524. doi:10.1007/s10584-011-0326-z

IUCN. 2024. Issues Brief: Environmental DNA. Retrieved July 1, 2025, from IUCN: https://iucn.org/resources/issues-brief/environmental-dna

Jordon, R., Brooks, W., Howe, D., and Ehrenfeld, J. 2012. Evaluating the Performance of Volunteers in Mapping Invasive Plants in Public Conservation Lands. Environmental Management, 49, 425-434. doi:10.1007/s00267-011-9789-y

Kilgour, C., Winter, C., Brauner, C., Chará-Serna, A., James, A., Kroetsch, N., Schulte, P.M., and Wood, C. 2025. Tracking Road Salt Contamination Through Community Monitoring: Annual Surface Water Chloride Trends in Streams of a Major Urban Area, the Vancouver Lower Mainland, B.C., Canada. Archives of Environmental Contamination and Toxicology, 89, 221-238. Retrieved from https://doi.org/10.1007/s00244-025-01156-3

King, M., Rodgers, T., Sharma, G., Reger, S., Liao, X., Ross, A., Mueller, M., Drew, S., Scholes, R., and Brown, T. 2025. Tracking 6PPD-Quinone Dynamics in a Coho Salmon-Bearing Stream Following Rain Reveals Elevated Concentrations for Multihour Periods During High Flow. Environmental Science & Technology Letters, 12, 1026-1031. Retrieved from https://pubs.acs.org/doi/10.1021/acs.estlett.5c00477?ref=PDF

König, A., Pickar, K., Stankiewicz, J., and Hondrila, K. 2021. Can citizen science complement official data sources that serve as evidence-base for policies and practice to improve water quality? Statistical Journal of the IAOS, 37, 189-204. doi:10.3233/SJI-200737

Kosmala, M., Wiggins, A., Swanson, A., and Simmons, B. 2016. Assessing data quality in citizen science. Frontiers in Ecology and the Environment, 14(10), 551-560. Retrieved from https://doi.org/10.1002/fee.1436

Kroetsch, N. 2021. Improving the uptake of citizen science environmental monitoring data by resource management agencies through co-development of data management plans. School of Resource and Environmental Management. Burnaby: Simon Fraser University. Retrieved from https://summit.sfu.ca/item/34441

Lefler, T. 2010. Successful Community-based Monitoring in Canada: Three Case Studies. University of Guelph. Retrieved from https://d1wqtxts1xzle7.cloudfront.net/30298264/successful_community-based_monitoring_in_canada_final_mrp_%28tristan_lefler%29-libre.pdf?1390883470=&response-content-disposition=inline%3B+filename%3DSuccessful_Community_based_Monitoring_in.pdf&Expires=1715

Locke, C., Anhalt-Depies, C., Frett, S., Stenglein, J., Cameron, S., Malleshappa, V., Peltier, T., Zuckerberg, B., and Townsend, P. 2019. Managing a large citizen science project to monitor wildlife. Wildlife Society Bulletin, 43(1), 4-10. Retrieved from https://doi.org/10.1002/wsb.943

Loiselle, S., Bishop, I., Moorhouse, H., Pilat, C., Koelman, E., Nelson, R., Clymans, W., Pratt, J., and Lewis, V. 2014. Citizen scientists filling knowledge gaps of phosphate pollution dynamics in rural areas. Environmental Monitoring and Assessment, 196. Retrieved from https://doi.org/10.1007/s10661-024-12389-5

Lovett, G.B. 2007. Who needs environmental monitoring? Frontiers in Ecology and the Environment, 5, 253-260. Retrieved from https://doi.org/10.1890/1540-9295(2007)5[253:WNEM]2.0.CO;2

Mamun, A. and Natcher, D. 2023. The promise and pitfalls of community-based monitoring with a focus on Canadian examples. Environmental Monitoring and Assessment, 195. Retrieved from https://doi.org/10.1007/s10661-022-10841-y

McKay, A. and Johnson, C.J. 2017. Identifying Effective and Sustainable Measures for Community-Based Environmental Monitoring. Environmental Management, 60, 484–495. doi:10.1007/s00267-017-0887-3

Measham, T. and Barnett, G. 2007. Environmental Volunteering: Motivations, Modes and Outcomes. Australian Geographer, 39(4), 1-27. doi:10.1080/00049180802419237

National Academies. 2007. Environmental Data Management at NOAA: Archiving, Stewardship, and Access: Report. Retrieved from https://nap.nationalacademies.org/resource/12017/data_at_noaa_final.pdf

Pocock, M., Tweddle, J., Savage, J., Robinson, L., and Roy, H. 2017. The diversity and evolution of ecological and environmental citizen science. PLOS ONE, 12(4). Retrieved from https://doi.org/10.1371/journal.pone.0172579

Province of BC. n.d. B.C. Lake Stewardship and Monitoring Program. Retrieved January 4, 2024, from https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/lake-monitoring/bc-lake-stewardship-and-monitoring-program/about-the-program/volunteer-requirements

Quinlivan, L., Chapman, D., and Sullivan, T. 2020. Validating citizen science monitoring of ambient water quality for the United Nations sustainable development goals. Science of the Total Environment, 699, 1-9. Retrieved from https://doi.org/10.1016/j.scitotenv.2019.134255

Robinson, J., Kocman, D., Speyer, O., and Gerasopoulos, E. 2021. Meeting volunteer expectations — a review of volunteer motivations in citizen science and best practices for their retention through implementation of functional features in CS tools. Journal of Environmental Planning and Management, 64(12), 2089–2113. Retrieved from https://doi.org/10.1080/09640568.2020.1853507

Rowe, H., Gruber, D., and Fastiggi, M. 2021. Where to start? A new citizen science, remote sensing approach to map recreational disturbance and other degraded areas for restoration planning. Restoration Ecology, 29(6). Retrieved from https://doi.org/10.1111/rec.13454

Sardo, A., De Vito, L., Pringle, K., Hansen, M., Lamb-Riddell, K., Laggan, S., Cox, T., and Williams, B. 2025. Co-creation in citizen science: sharing learnings and good practice from an indoor, airborne microplastics project. Journal of Science Communication, 24(1). Retrieved from https://doi.org/10.22323/2.24010802

Sextus, C., Hytten, K., and Perry, P. 2024. A Systematic Review of Environmental Volunteer Motivations. Society & Natural Resources, 37(11), 1591–1608. Retrieved from https://doi.org/10.1080/08941920.2024.2381202

Sharpe, A. and Conrad, C. 2006. COMMUNITY BASED ECOLOGICAL MONITORING IN NOVA SCOTIA: CHALLENGES AND OPPORTUNITIES. Environmental Monitoring and Assessment, 113, 395–409. doi:10.1007/s10661-005-9091-7

Somers, K., Bernhardt, E., Grace, J., Hassett, B., Sudduth, E., Wang, S., and Urban, D. 2013. Streams in the urban heat island: spatial and temporal variability in temperature. Freshwater Science, 32(1), 309-326. doi:10.1899/12-046.1

Stratilová Urválková, E. and Janoušková, S. 2019. Citizen science – bridging the gap between scientists and amateurs. Chemistry Teacher International, 1. doi:10.1515/cti-2018-0032

Tengö, M., Austin, B., Danielsen, F., and Fernández-Llamazares, Á. 2021. Creating Synergies between Citizen Science and Indigenous and Local Knowledge. BioScience, 71(5), 503-518. Retrieved from https://doi.org/10.1093/biosci/biab023

The Pacific Streamkeepers Federation. 2025. Retrieved from https://www.pskf.ca/index.php

The Streamkeepers Handbook and Modules. n.d. Retrieved from The Pacific Streamkeepers Federation: https://pskf.org/publications/handbook.php#:~:text=A%20resource%20for%20getting%20involved%20in%20your%20local%20stream,%20with

Theobald, E., Ettinger, A., Burgess, H., DeBey, L., Schmidt, N., Froehlich, H., Wagner, C., HilleRisLambers, J., Tewksbury, J., Harsch, M.A., and Parrish, J. 2015. Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. Biological Conservation, 236-244. Retrieved from http://dx.doi.org/10.1016/j.biocon.2014.10.021

Tian, Z., Zhao, H., Peter, K., Gonzalez, M., Wetzel, J., Wu, C., Hu, X., Prat, J., Mudrock, E., Hettinger, R., Cortina, A.E., Biswas, R.G., Kock, F.V.C., Soong, R., Jenne, A., Du, B., Hou, F., He, H., Lundeen, R., Gilbreath, A., Sutton, R., Scholz, N.L., Davis, J.W., Dodd, M.C., Simpson, A., McIntyre, J.K., and Kolodziej, E. 2020. A ubiquitous tire rubber-derived chemical induces acute mortality in coho salmon. Science, 185-189. doi:10.1126/science.abd6951

Turbé, A., Barba, J., Pelacho, M., Mugdal, S., Robinson, L., Serrano-Sanz, F., Sanz, F., Tsinaraki, C., Rubio, J.M., and Schade, S. 2019. Understanding the Citizen Science Landscape for European Environmental Policy: An Assessment and Recommendations. Citizen Science: Theory and Practice, 4(1), 1-16. Retrieved from https://doi.org/10.5334/cstp.239

U.S. Environmental Protection Agency (EPA). 2014. Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams. Washington, D.C.: Global Change Research Program, National Center for Environmental Assessment. doi:EPA/600/R-13/170f. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncca

Underwood, A. and Chapman, M. 2002. Conservation of coastal organisms depends on scientific realism, not community “monitoring”. In D. Lunney, S. Burgin, & C. R. Dickman, A Clash of Paradigms: Community and Research-based Conservation (pp. 20-37). Sydney: Royal Zoological Society of New South Wales, 2002. Retrieved from https://doi.org/10.7882/FS.2002.019

USGS. n.d. Why Share Your Data. Retrieved from USGS: https://www.usgs.gov/data-management/why-share-your-data

VCLA. 2025. The Psychology Behind Volunteer Burnout: Recognition and Prevention. Retrieved August 26, 2025, from VCLA: https://vcla.net/the-psychology-behind-volunteer-burnout-recognition-

and-
prevention/#:~:text=Volunteer%20burnout%2C%20at%20its%20core%2C%20is%20a%20state,volunteer%20activities.%20It%E2%80%99s%20often%20intertwined%20with%20compassion%20fatigue.

Watson, R. 2005. Turning science into policy: challenges and experiences from the science–policy interface. Philosophical Transactions of the Royal Society B, 360, 471-477. doi:10.1098/rstb.2004.1601

Wenger, S., Isaak, D., Luce, C., Neville, H., Fausch, K., Dunham, J., Dauwalter, D., Young, M., Elsner, M., Rieman, B., Hamlet, A., and Williams, J. 2011. Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. PNAS, 108(34), 14175-14180. Retrieved from https://doi.org/10.1073/pnas.1103097108

West, S. and Pateman, R. 2016. Recruiting and Retaining Participants in Citizen Science: What Can Be Learned from the Volunteering Literature? Citizen Science: Theory and Practice, 1(2), 1-10. Retrieved from https://doi.org/10.5334/cstp.8

Westreicher, F., Cieslinski, M., Ernst, M., Frigerio, D., Heinisch, B., Hübner, T., and Rüdisser, J. 2020. Recognizing failures in citizen science projects: Lessons learned. Proceedings of Science. Retrieved from https://pos.sissa.it/393/007/pdf

Whitelaw, G., Vaughan, H., Craig, B., and Atkinson, D. 2003. ESTABLISHING THE CANADIAN COMMUNITY MONITORING NETWORK. Environmental Monitoring and Assessment, 88, 409-418. doi:10.1023/A:1025545813057

Winter, C., Kilgour, C., Brauner, C., Schulte, P., and Wood, C. 2026. The effects of pulse exposures to road salt at various stages of early development in rainbow trout (*Oncorhynchus mykiss*). Comparative Biochemistry and Physiology, Part C, 299. Retrieved from https://doi.org/10.1016/j.cbpc.2025.110334

Yardi, K., Bharucha, E., and Girade, S. 2019. Post-restoration monitoring of water quality and avifaunal diversity of Pashan Lake, Pune, India using a citizen science approach. Freshwater Science, 38(2), 231-433. Retrieved from https://doi.org/10.1086/703440

Appendix 1: Interview Questions

There were two sets of interview questions used for the social science research component of the CoSMo pilot project, one set for stewardship group volunteers and one set for resource management agency (i.e. government) employees. The questions included for each are shown below (please note that the first six questions are identical, with questions diverging at question 7).

Stewardship Group Volunteer Interview Questions

1. In your opinion, what is necessary for a collaboration between a community group and a resource management agency to succeed?
2. In your opinion, what prevents or hinders successful collaborations between community groups and resource management agencies (i.e. why do some collaborations fail?)
3. In your opinion, what are the main challenges when working with resource management agencies? (e.g. DFO, municipal governments, etc.)
4. A) Rank which freshwater habitat factors/parameters you feel are most important to monitor (1 = most important, 5 = least important).
    - Stream discharge/flow
    - Dissolved oxygen
    - Turbidity
    - Stream temperature
    - pH

   B) Why do you feel each of these is important to monitor?
5. Are there any additional factors/parameters you feel are important to monitor in freshwater habitats? If so, briefly include why you feel these are important.
6. In your opinion, what are the biggest threats to freshwater habitat in the Lower Mainland, British Columbia (or your region, if outside the Lower Mainland)?
7. Have you participated in stream monitoring (e.g. conducting spawner surveys, trapping juveniles, taking stream temperatures, measuring habitat characteristics, etc.) as part of a stream steward group? (Yes/No). If no, skip to question 24.
8. How often/long did you participate in stream monitoring with your stream steward group? (______ times per week/month/year for ______ weeks/months/years)
9. What does your stream steward group currently monitor?
10. Does your stream steward group have an official data management plan/protocol? (e.g. describing the purpose of data collection, mandate, process of data collection, etc.) (Select an option)
    - Yes, always
    - Yes, sometimes
    - No
11. How does your stream steward group typically record data? (Select an option)
    - By hand
    - Digital
    - Other (please explain)
12. How does your stream steward group store data that you have collected via fieldwork? (Select an option)
    - Personal computers or hard drives

- Online platform
- Other (please explain)

13. How does your stream steward group typically analyze data that you collect? (Select an option)
    - The data are not analyzed (i.e. the raw data are stored or entered into a database, but nothing more)
    - The data get summarized (e.g. some figures are produced, or values of data added), but no statistical analysis is conducted
    - The data are statistically analyzed
14. Who analyzes the data collected by your stream steward group? (Select an option)
    - Members of our stream steward group
    - An external group (e.g., consulting firm, grad student, etc.) (please specify)
15. Does your stream steward group share data with other people/groups? (Yes/No)
16. If data are shared, how does your stream steward group share data with other people/groups? (Select from options)
    - Raw data available online via a website
    - Raw data (e.g. hard/paper copies) are shared in person
    - Data are emailed to other people
    - Summarized data are available online via a website
    - Other (please explain)
17. A) Was fieldwork/data collection training provided to you? (Yes/No)
    B) If so, who trained you and how was training conducted? (In person, via email, etc.)
18. A) In your opinion, is this method of training adequate? (Select an option)
    - Not at all adequate
    - Somewhat adequate
    - Adequate

    B) What training method/s do you feel are the most effective? Do you have any thoughts on the training process (e.g. what is needed to improve training)?
19. A) Did you/your stream steward group encounter any challenges while monitoring local streams/collecting environmental data? (Yes/No)
    B) What were they? Were they mitigated/resolved? And if so, how?
20. A) Does your stream steward group collaborate with any federal, provincial, or municipal government agencies? (Yes/No)
    B) If so, which agency? Briefly describe the collaboration/roles of each party (e.g. what data/information or resources are exchanged, and what benefits are gained from the collaboration)
21. How frequently does communication with the agency take place? (______ times per week/month/year)
22. How long has the collaboration been maintained? (______ weeks/months/years)
23. A) Would you describe this collaboration as successful? (Yes/No)
    B) Why? What worked and what didn't work?
24. In your opinion, what role does (or should) DFO play in community stewardship collaborations?
25. A) Are you familiar with the 2005 Wild Salmon Policy and the 2018 Wild Salmon Policy Implementation Plan? (Yes/No)
    B) If yes, in your opinion, what role should community environmental steward groups play in activities mentioned in the Wild Salmon Policy Implementation Plan?
26. In your opinion, what needs to be done to improve freshwater habitat monitoring collaborations between DFO Science, DFO Management, and community environmental steward groups?

Resource Management Agency Employee Interview Questions

1. In your opinion, what is necessary for a collaboration between a community group and a resource management agency to succeed?
2. In your opinion, what prevents or hinders successful collaborations between community groups and resource management agencies (i.e. why do some collaborations fail?)
3. In your opinion, what are the main challenges when working with resource management agencies? (e.g. DFO, municipal governments, etc.)
4. A) Rank which freshwater habitat factors/parameters you feel are most important to monitor (1 = most important, 5 = least important).
    - Stream discharge/flow
    - Dissolved oxygen
    - Turbidity
    - Stream temperature
    - pH

   B) Why do you feel each of these is important to monitor?
5. Are there any additional factors/parameters you feel are important to monitor in freshwater habitats? If so, briefly include why you feel these are important.
6. In your opinion, what are the biggest threats to freshwater habitat in the Lower Mainland, British Columbia (or your region, if outside the Lower Mainland)?
7. If you need current data on freshwater habitat parameters, where do you typically go to collect or access these data? (e.g. if you need flow data prior to developing near a river bank)
8. A) Do you ever experience data gaps when searching for current freshwater ecosystem data? (Select an option)
    - Always
    - Often
    - Occasionally
    - Never

   B) Can you provide an example of a type of data or environmental factor that is often lacking/where you experience regular data gaps? (e.g. water flow data)
9. A) Have you worked/collaborated with a community environmental steward group before? (Yes/No)

   B) Briefly describe the collaboration/roles of each party (e.g. what data/information or resources are/were exchanged, and what benefits are/were gained from the collaboration)
10. How frequently did/does communication with the stream steward group take place? (_____ times per week/month/year)
11. How long has the collaboration been maintained? (_____ weeks/months/years)
12. A) Would you describe this collaboration as successful? (Yes/No)

    B) Why?
13. Do you/your resource management agency have an official data management plan/protocol? (e.g. describing the purpose of data collection, mandate, process of data collection, etc.) (Select an option)
    - Yes, always
    - Yes, sometimes
    - No

14. When you/your resource management agency conduct fieldwork, how do you record data? (Select an option)
    - By hand
    - Digital
    - Other (Please explain)
15. How does the community steward group you collaborate with record data? (Select an option)
    - By hand
    - Digital
    - Other (Please explain)
16. How do you/your resource management agency store data that you have collected via fieldwork? (Select from options)
    - Personal computers or hard drives
    - Online platform
    - Other (Please explain)
17. How does the community steward group you collaborate with store data they have collected via fieldwork? (Select from options)
    - Personal computer or hard drives
    - Online platform
    - Other (Please explain)
18. When you/your resource management agency conduct fieldwork, how do you typically analyze the data that you collect? (Select option)
    - The data are not analyzed (i.e. the raw data are stored or entered into a database, but nothing more)
    - The data get summarized (e.g. some figures are produced or values of data added), but not statistically analyzed
    - The data are statistically analyzed
19. How does the community steward group data typically get analyzed? (Select option)
    - The data are not analyzed (i.e. the raw data are stored or entered into a database, but nothing more)
    - The data get summarized (e.g. some figures are produced or values of data added), but not statistically analyzed
    - The data are statistically analyzed
20. If the data collected by community members whom you collaborated with are analyzed, who analyzes them? (Select option)
    - Members of the community steward group analyze the data they collect
    - I/my resource management agency analyze the data that the community members collect
21. Do you/your resource management agency share data that you collect with other people/groups? (Yes/No)
22. If yes, how do you/your resource management agency share data? (Select from options)
    - Raw data available online via a website
    - Raw data (e.g. hard/paper copies) are shared in person
    - Data are emailed to other people
    - Summarized data are available online via a website
    - The data are not shared
    - Other (Please explain)

23. Does the community steward group you collaborate with share data with other people/groups? (Yes/No)
24. If yes, how do they share data? (Select from options)
    - Raw data available online via a website
    - Raw data (e.g. hard/paper copies) are shared in person
    - Data are emailed to other people
    - Summarized data are available online via a website
    - The data are not shared
    - Other (Please explain)
25. Once you receive the data/information from the community steward group, what are they used for?
26. A) Was fieldwork/data collection training provided to the community steward volunteers? (Yes/No)
    B) If so, who trained the volunteers and how was training conducted? (In person, via email, etc.)
27. A) In your opinion, is this method of training adequate? (Select option)
    - Not at all adequate
    - Somewhat adequate
    - Adequate

    B) What training method(s) do you feel are the most effective? Do you have any thoughts on the training process (e.g. what is needed to improve training?)
28. A) Did you/the community steward group you collaborate with encounter any challenges while monitoring/collecting environmental data? (Yes/No)
    B) What were they? Were they mitigated/resolved? And if so, how?
29. A) Do you view data collected by trained volunteers the same as data collected by professional scientists? (Yes/No)
    B) If no, what would need to occur in order to have volunteer data be viewed as comparable to professional data?
30. In your opinion, what role does (or should) DFO play in community environmental stewardship collaborations?
31. A) Are you familiar with the 2005 Wild Salmon Policy and the 2018 Wild Salmon Policy Implementation Plan? (Yes/No)
    B) If yes, in your opinion, what role should community environmental groups play in activities mentioned in the Wild Salmon Policy Implementation Plan?
32. In your opinion, what needs to be done to improve freshwater habitat monitoring collaboration between DFO Science, DFO Management, and community environmental steward groups?

Appendix 2: Data loggers used as part of the CoSMo project

There are three parameters monitored consistently as part of the CoSMo project – water temperature, depth, and conductivity – for which we use four types of loggers (shown below). We refer to some of the loggers as “depth loggers” or “water level loggers”, but it is worth noting that the data loggers technically don’t record “depth”; rather, they record total pressure, which includes the pressure of the water column above the logger as well as the ambient atmospheric pressure. To obtain a water depth value, we use a Barologger to record ambient pressure, which is subtracted from the total pressure value, leaving only the pressure of the water column, which is then converted to water depth.

Onset HOBO Tidbit® MX2203 Temperature Data Logger

Range: -20 deg C to 50 deg C in water

Accuracy: +/- 0.25 deg C from -20 deg C to 0 deg C, +/- 0.2 deg C from 0 deg C to 50 deg C

Connects to Smartphone via Bluetooth

Memory: 96,000 measurements

Battery life: 2-3 years (user-replaceable battery)

Figure 6: HOBO Tidbit temperature logger. Image obtained from https://www.onsetcomp.com/products/data-loggers/mx2203

Onset HOBO® U20L Water Level and Temperature Data Logger

Non-vented

Range:

- Water level: 0-4 m
- Temperature: -20 deg C to 50 deg C

Accuracy:

- Water level: +/- 0.4 cm
- Temperature: +/- 0.44 deg C from 0-50 deg C

Connects to laptop via shuttle

Memory: ~21,700 measurements

Battery life: 5 years (factory replaceable; user cannot replace)

Figure 7: HOBO U20L-04 depth and temperature logger. Image obtained from https://www.onsetcomp.com/products/data-loggers/u20l-0x#specifications

Solinst Levelogger® 5 LTC Water Level, Temperature, and Conductivity Data Logger

Range:

- Water level: 0-5 m
- Temperature: -20 deg C to 80 deg C
- Conductivity: 0-100,000 uS/cm

Figure 8: Solinst Levelogger 5 LTC depth, temperature, and conductivity logger. Image obtained from https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/ltc-levelogger/datasheet.php

Accuracy:

- Water level: +/- 0.3 cm
- Temperature: +/- 0.05 deg C
- Conductivity: +/- 1%: 5,000 µS/cm – 80,000 µS/cm; greater of +/- 2% or 15 µS/cm: 50 µS/cm –5,000 µS/cm

Connects to Smartphone via Bluetooth

Memory: 100,000 measurements

Battery life: 8 years (factory replaceable; user cannot replace)

Solinst® Barologger 5

Range:

- Water level: N/A (air only)
- Temperature: -20 deg C to 80 deg C

Figure 9: Solinst Barologger 5, which measures ambient pressure and temperature. Image obtained from https://www.solinst.com/products/dataloggers-and-telemetry/3001-levelogger-series/operating-instructions/user-guide/1-introduction/1-1-2-barologger.php

Accuracy:

- Level: +/- 0.05 kPa
- Temperature: +/- 0.05 deg C

Memory: 150,000 measurements

Battery life: 10 years (factory replaceable; user cannot replace)

Appendix 3: Data Logger Download Sheets

Data logger download sheet: temperature and depth loggers

During Year 1, we developed the first version of the CoSMo data sheets to ensure relevant metadata would be recorded at each site visit (Table 1 and Figure 10):

- *Water depth* refers to the depth of the entire water column at the logger site, which is a manual measurement taken at the time of download. For the subset of data loggers that record depth*, the manual measurements were later compared to the depth values recorded by the data logger, to ensure any logger drift was accounted for when processing the data.
- *Height above bottom* refers to the vertical distance from the creek bottom to the data logger. This information helped keep us informed of potential sedimentation issues (e.g. the logger getting buried).
- *Water temperature* is a manual temperature reading taken at the time of download, which was compared to the reading taken by the data logger to ensure the data logger was reading accurately.
- *Thermometer ID* is the thermometer that was used to take the manual reading. If there was ever a discrepency between the manual temperature reading taken at the time of download and the reading recorded by the data logger, knowing which thermometer was used allowed us to track down the thermometer and determine whether it was the thermometer or data logger that was giving an inaccurate reading.
- *Installation technique* refers to the method we used to install the data logger (see Appendix 4 for installation methods).
- *Logger battery level* is recorded to help flag when batteries will soon need to be replaced.
- *Site information:* GPS coordinates were recorded at each site visit. The coordinates, in combination with the site name and logger serial number, helped PSEC staff ensure the data were linked to the correct site/metadata.
- *Notes*: this section provided space for volunteers to share extra information they felt that PSEC staff should know (e.g. issues related to sedimentation).

* The data loggers technically don't record "depth"; rather, they record total pressure, which includes the pressure of the water column above the logger as well as the ambient atmospheric pressure. To obtain a water depth value, the ambient pressure (which is recorded by a Barologger) is subtracted from

the total pressure value, leaving only the pressure of the water column, which is then converted to water depth (see Appendix 2 for details on the different types of data loggers that were utilized for the CoSMo project).

Community Stream Monitoring Project – Logger Data Download

Date:	**Weather:**	**Personnel:**
Waterbody:	**Site Name (e.g., CYPR04):**	
Purpose of deployment (circle one):	Data download	Redeployment (if logger missing)
LOGGER INFORMATION		
Serial number:	**Installation technique (for redeployment only):**	
Logger type:		
Water depth (m):		
Height above bottom (m):	**Logger placement (for redeployment only):**	
Deployment time:		
Water temperature (°C):		
Air temperature (°C):		
Thermometer ID:		
SITE INFORMATION		**Logger battery level:**
GPS ID (e.g., iPhone):	**Latitude:**	**Longitude:**
Notes:		

Figure 10: the CoSMo data download sheet for temperature and temperature/depth loggers

Data logger download sheet: conductivity/depth/temperature loggers

When we began using the Solinst Levelogger 5 LTC data loggers, we modified the original data sheets to include the following:

- *Time logger was removed from water* and *time logger was returned to water*: The Leveloggers were calibrated for conductivity when the data were downloaded, which required the logger to be out of the water for a period of time. Knowing when the logger was removed from and put back in the water told us which data points would need to be removed (i.e. the period when the logger was not in the water).
- *Was the logger calibrated?:* Occasionally, the calibration did not succeed or the person maintaining the logger chose not to calibrate the logger (e.g. they didn't have time, or were missing equipment). This cell asked whether the logger was calibrated, and the reason for not calibrating could be added to the notes section, if applicable, which helped us keep track of logger maintenance.
- *Was the logger turned back on after calibrating?*: The Solinst Leveloggers must be turned off in order to calibrate them, which means there's the risk that the person doing the download would

forget to turn the logger back on. To prevent this, we included this cell as a reminder for volunteers that they must turn the logger back on.

- *Was there sediment build-up in the pipe?:* The conductivity sensors are prone to getting clogged with sediment, which affects the data readings. We asked the volunteers to indicate whether there was sediment build-up in the pipe that houses the logger, which helped explain unusual data trends (e.g. repetitive zero-readings).

Community Stream Monitoring Project – Conductivity Logger Data Download			
Date:	Weather:		Personnel:
Waterbody:		Site Name (e.g., CYPR04):	
Purpose of deployment (circle one):	Data download	redeployment	
LOGGER INFORMATION			
Serial number:		Time logger removed from water:	
Logger type:		Was logger calibrated (Y/N)?	
Water depth (m):		Was logger turned back on	
Height above bottom (m):		after calibrating (Y/N)?	
Thermometer ID:		Time logger returned to water:	
Water temperature (°C):		Logger battery level:	
Air temperature (°C):		Was there sediment build-up in the pipe? (circle one)	
		No Yes, a little Yes, lots	
SITE INFORMATION			
GPS ID:	Latitude:	Longitude:	
Notes:			

Figure 11: The CoSMo data sheet used for the conductivity/depth/temperature data loggers

Appendix 4: Methods used to install data loggers

We used a variety of methods to install the data loggers, depending on the type of logger and the creek substrate/features. The most common methods, and the pros and cons of each method, are:

Epoxy and PVC end-cap

Our preferred method for installing the HOBO Tidbit temperature loggers was the “epoxy and endcap” method, whereby we secured the data logger inside a 2.5” PVC end-cap (which had holes drilled in it to allow water flow) and then used an underwater epoxy to adhere the base of the PVC end-cap to the downstream side of a large boulder, concrete culvert, or other structure that we were confident would not move during high flows.

Figure 12: A PVC end-cap housing a HOBO Tidbit temperature data logger, which has been epoxied to a large boulder.

Pros:

- Allows the logger to be easily accessed by twisting on/off the end-cap
- Quick and easy to install
- Suitable for flashy creeks
- Logger is typically not very visible, which reduces likelihood of vandalism or theft

Cons:

- Requires a boulder, culvert, or other solid structure, which may not always be available
- Logger is not very visible, meaning it may be difficult to locate the logger when attempting subsequent downloads
- Occasionally the epoxy will not adhere properly and the logger will get washed downstream

Figure 13: A HOBO Tidbit temperature logger secured inside a PVC end-cap

ABS pipe secured to boulder/culvert

For the HOBO U20L depth/temperature loggers and the Solinst Levelogger 5 LTC loggers, we housed the loggers inside pieces of 2" ABS pipe, which had holes drilled in them to allow water flow and were fitted with locking caps. We used a hammer drill to secure the pipe to a large boulder, concrete culvert, or other structure that we were confident would not move during periods of high flow.

Figure 14: An ABS pipe housing a Solinst Levelogger 5 LTC logger, which is bolted to a culvert

Pros:

- Very secure, unlikely to get washed downstream
- Easily visible, which makes locating the logger for subsequent downloads easy
- Suitable for flashy creeks

Cons:

- Requires a boulder, culvert, or other solid structure, which may not always be available
- Logger is typically very visible, which means increased risk of vandalism or theft
- Potential for sedimentation issues (e.g. sediment building up around base of pipe and/or clogging logger sensors)

Cinder block and cable

For slower moving creeks that lacked large boulders or other structures that the loggers could be epoxied to, the HOBO Tidbit temperature loggers could be secured inside a small (3”) piece of ABS pipe (to protect the logger from debris and direct sunlight), which was then secured inside a cinder block. The cinder block was then cabled to a tree or other solid feature on the shore.

Figure 15: A cinder block housing a HOBO Tidbit temperature logger

Pros:

- Quick and easy to install
- The cable is typically very visible, which makes locating the logger for subsequent downloads easy
- Logger can often be accessed without having to go in the water

Cons:

- Not suitable for flashy creeks. During periods of high flow, the cable can get snagged by debris (e.g. sticks, logs) that flows downstream, which can pull the cinder block out of the water, or even snap the cable
- The cable is typically very visible, which increases the risk of vandalism or theft

Zap-strap/cable-tie

Another method we used for deploying HOBO Tidbit temperature loggers in slower moving creeks that lacked large boulders or concrete structures was to secure the logger in a small (3”) piece of ABS pipe (to protect the logger from debris and direct sunlight) and then to use zap-straps/cable-ties to secure the ABS pipe to a solid tree root or other feature in the water that was unlikely to move.

Figure 16: A piece of ABS pipe housing a temperature data logger, which is then zap-strapped to a tree root

Pros:

- Very quick and easy to install
- Logger is typically not very visible, which reduces the likelihood of vandalism or theft

Cons:

- Not suitable for flashy creeks or creeks with high flow
- Logger is typically not very visible, which can make locating the logger for subsequent downloads difficult
- Not very secure, logger can easily get ripped off if snagged by debris

Appendix 5: List of groups and direct collaborators that have been involved in the CoSMo project

Stewardship groups:
Alouette River Management Society
Bowen Island Fish & Wildlife Club
Burrard Inlet Marine Enhancement Society (Mossom Creek Streamkeepers)
Capilano Golf & Country Club
Caribou Heights Forest Preservation Society
Carlson Creek volunteers
Cougar Creek Streamkeepers
Friends of McNally Creek
Howe Sound Biosphere Region Initiative Society
Hoy-Scott Watershed Society
Hyde Creek Watershed Society
Nicomekl Enhancement Society
North Shore Streamkeepers
Seymour Salmonid Society
Still Moon Arts Society (Still Creek Streamkeepers)
Stoney Creek Environment Committee
Water Wealth Project
West Creek Awareness Group
West Vancouver Streamkeepers
Willband Creek volunteers
Yorkson Watershed Enhancement Society

First Nations
Tsleil-Waututh Nation

Municipal partners:
City of Surrey
City of Port Moody

Academic partners:
UBC 6PPD-Q group
SFU 6PPD-Q group
SFU – Moore Lab
Johnston Heights Secondary

Appendix 6: List of outputs that have used the CoSMo project data to date

Published Peer-Reviewed Papers:

Winter, C.E., Kilgour, C., Brauner, C.J., Schulte, P., and Wood, C.M. 2026. Effects of pulse exposures to road salt at various stages of early development in rainbow trout (*Oncorhynchus mykiss*). Comp. Biochem. Physiol. C. 299: 110334. https://doi.org/10.1016/j.cbpc.2025.110334

Winter, C.E., Kilgour, C.L., Brauner, C.J., Wood, C.M., and Schulte, P.M. 2026. Road salt creates a slippery slope for Pacific salmon: environmentally realistic salt pulses have lethal and sublethal effects on developing coho salmon (*Oncorhynchus kisutch*). Aquatic Toxicology 292, 107737. https://doi.org/10.1016/j.aquatox.2026.107737

Kilgour, C.L., Winter, C.E., Brauner, C.J., Charà-Serna, A.M., James, A.C., Kroetsch, N.C., Schulte, P.M., and Wood, C.M. 2025. Tracking road salt contamination through community monitoring: Surface water chloride trends in streams of a major urban area, Vancouver's Lower Mainland. Archives Environ. Contam. Toxicol. 89: 221–238. https://doi.org/10.1007/s00244-025-01156-3

King, M.D., Rodgers, T.F.M., Sharma, G., Reger, S., Liao, X., Ross, A.R.S., Mueller, M., Drew, S., Scholes, R.C., and Brown, T. 2025. Tracking 6PPD-Quinone Dynamics in a Coho Salmon-Bearing Stream Following Rain Reveals Elevated Concentrations for Multihour Periods During High Flow. Environmental Science & Technology Letters, 12, 1026-1031. Retrieved from https://pubs.acs.org/doi/10.1021/acs.estlett.5c00477?ref=PDF

Déry, S.J., Martins, E.G., Owens, P.N., and Petticrew, E.L. 2024. Extreme hydrometeorological events induce abrupt and widespread freshwater temperature changes across the Pacific Northwest of North America. Communications Earth & Environment, 5(1), 228.

Student Theses Completed:

Kroetsch, N.C. 2021. Improving the uptake of citizen science environmental monitoring data by resource management agencies through co-development of data management plans. School of Resource and Environmental Management. Burnaby: Simon Fraser University. Retrieved from https://summit.sfu.ca/item/34441

Gemmell, C. 2023. Interconnected effects of water temperature and habitat on relative abundance of juvenile salmonids during the summer months in coastal urban streams. Simon Fraser University. Retrieved from https://summit.sfu.ca/item/38000

Glavas, M.S. 2023. Quantifying road salt contamination in salmon-bearing streams within Metro Vancouver, BC. British Columbia Institute of Technology, Dec. 2023.

Gosling, J.D. 2024. Melting away habitat: exploring road salt impact on stream life. M.Sc. Thesis. British Columbia Institute of Technology, June 2024.

Guo, Z.K. 2025. Influence of temperature and episodic exposure scenarios on the toxicity of road salt to *Chironomus dilutus* and *Hyalella azteca*. MET (Master of Environmental Toxicology) thesis, Simon Fraser University, June 2025.

Kilgour, C.E. 2025. Tracking road salt contamination in the Vancouver Lower Mainland through community monitoring: toxicological implications and predicted risk for local coho salmon species. M.Sc. to Ph.D. Transfer Report, University of British Columbia, Dec. 2025.

Winter, C.E. 2025. The effects of road salt contamination on the development and physiology of rainbow trout (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). M.Sc. Thesis. University of British Columbia, Sept. 2025.

Other:

CoSMo DataStream database. 2026. Retrieved from https://doi.org/10.25976/0gvo-9d12