# Improving Environmental Monitoring Collaborations Through Co-development of Data Management Plans

*A guide for Resource Management Agencies and Environmental Stewardship Groups*

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*This guidebook was written by Nicola Kroetsch as a functional deliverable for her Masters research. It is intended to help Resource Management Agencies and Stewardship Groups initiate new environmental monitoring collaborations, or improve existing ones, for which the primary purpose is to collect environmental data for use in decision-making, research, and stewardship.*

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# Introduction

> *Inadequate monitoring can be both misleading and dangerous not only because of their inability to detect ecologically significant changes, but also because they create the illusion that something useful has been done*[1, p. 194]

Environmental monitoring is essential to identify and understand natural and anthropogenic changes to ecosystems[2,3,4,5,6]. Climate change coupled with industrialized human activities are accelerating the impact that people are having on the health and functionality of ecosystems[2,3]. Many governments recognize the need to identify and mitigate these ecosystem impacts, but can be hindered in their efforts by lack of sufficient environmental data. For example, in order to document a change in water quality parameters or a biodiversity metric over time, reliable preimpact data is needed. Changes in water quality, hydrodynamics, air quality, and biodiversity are observed; however, without baseline data that indicates what the "unimpacted" ecosystems looked like, there is no way of quantifying how much change has occurred. Accumulation of verifiable environmental data that can be used to quantify impacts is critical for Resource Management Agencies (RMAs) to make informed decisions that can prevent or mitigate some of the adverse impacts to humans and ecosystems and to manage natural resources so that these resources can continue to provide for future generations.

This compilation and analysis of high quality environmental data requires diligent environmental monitoring that is time consuming and expensive. Consequently, monitoring required by RMAs is often hindered by lack of resources, which results in persistent environmental monitoring gaps [7,8,9,10]. There is a growing need for environmental monitoring, but it is not clear that RMAs have the best institutions, resources, and methods to keep up with the accelerating demand for quality environmental data. This has led to an increased call to maximize the utility of citizen science, to assist in comprehensive environmental monitoring.

Citizen science, defined herein as the participation of the public – whom are not explicitly trained science professionals – in scientific research, has grown rapidly in popularity in recent decades; in particular with respect to environmental monitoring[11,12,13,14,15]. The term "citizen science" is used interchangeably in the literature and in this Guidebook with "community-based

science" and the resulting data are referred to in this Guidebook as "community-gathered data" and/or "volunteer-gathered data".

Public participation in resource management, such as via citizen science, is essential for sustainable development and has been described as "one of the most significant developments in resource management since the environmental movement itself" [16, p. 26]. Stewardship Groups can facilitate improved resource management by contributing to activities related to environmental conservation, monitoring, restoration, public education, and/or enforcement. The reported benefits of public participation in resource management are manifold, and include:

- *Economic benefits*: Stewardship Groups provide economic benefits to RMAs by providing volunteer labour and can help provide a cost-effective means to collect data[12,17], which allow RMAs to make more informed, effective decisions. Stewardship Groups also tend to have local knowledge and can contribute to more effective decision-making, policy-making, and project-planning; all of which provide economic benefits to RMAs by improving the efficiency and efficacy of management decisions. Further, Stewardship Groups can apply for grants that RMAs are not able to apply for, which allows for cost-sharing for environmental monitoring or restoration projects. In return, RMAs can provide economic benefits to Stewardship Groups directly by providing funding or indirectly by providing guidance, training, expertise, and in-kind support that increases the efficiency and efficacy of volunteer operations.

- *Relationship-building*: Collaborations between RMAs and Stewardship Groups have the potential to improve relationships and foster trust and understanding between both parties, which may mitigate conflicts and reduce adversarial energy between RMAs and Stewardship Groups. For example, provincial government employees interviewed by Buckland-Nicks reportedly "noticed that they received less angry phone calls when they took a collaborative approach with watershed groups ... pointing towards increased trust in the community"[3, p. 87]. Similarly, a volunteer who was interviewed for the author's research[18] commented that they have only ever had positive experiences with their Fisheries and Oceans Canada (DFO) Community Advisor (who regularly works with their Stewardship Group), which improved their overall perception of DFO. Improved

relationships mitigate challenges related to RMA public-relations, contribute to social capital, and foster a more cohesive, informed community.

- *Public engagement and education*: Community members who become engaged and educated about their local ecosystems often feel empowered to share what they learn and many develop a stewardship mentality[13,19]. As such, RMA investment in Stewardship Groups often results in a proliferation of positive impacts[11]. As Stewardship Groups often focus on public engagement and education, collaboration with RMAs benefits (1) Stewardship Groups, by helping them build capacity and acquire resources to better engage and educate the public; (2) RMAs, by ensuring Stewardship Groups are sharing relevant, accurate information with the public; and (3) the broader public, by providing them with a trustworthy source (i.e., the Stewardship Group) from which to acquire information about their local ecosystems.
- *Enforcement of environmental regulations*: Collectively, Stewardship Groups form an army of dedicated individuals; they are the 'boots on the ground', the 'watchdogs', the 'early warning system' for RMAs. Stewardship Groups spend more time monitoring their local ecosystems than any RMA has the capacity to do, which puts them in an ideal position to notify RMAs of any acute or ongoing environmental issues and/or infractions of laws/regulations.

Despite the potential benefits of citizen science to volunteers, RMAs, and the broader public, there are challenges that still need to be overcome in order to realize the full potential of citizen science collaborations between RMAs and Stewardship Groups. Challenges of citizen science have been categorized as organizational issues, data collection issues, and data use issues[13]. Organizational issues include lack of access to information (for Stewardship Groups and RMAs). Lack of access to information can refer to Stewardship Groups lacking access to resources such as scientific methods and protocols or it can refer to RMAs lacking access to data collected by Stewardship Groups (often because they are unaware that said groups exist and are collecting relevant data). Data collection issues include lack of proper experimental design, data fragmentation, and data quality[13]. Data use issues can stem from data collection issues. Fragmented data that do not follow a proper experimental design are often noncomparable, which makes analysis challenging or impossible and reduces the functionality of citizen science data. Issues of

flawed experimental design and insufficient data quality lead to skepticism of the credibility of citizen science data, which hinders uptake of citizen science data by RMAs. The abovementioned challenges continue to hinder collaborations between Stewardship Groups and RMAs, which results in RMAs facing persistent gaps in environmental monitoring – thus having to make management decisions with limited data – and Stewardship Groups left frustrated that their time and effort go unheeded; however, this needn't be the case.

This Guidebook discusses how co-development of data management plans may address several challenges currently hindering environmental monitoring collaborations between RMAs and Stewardship Groups by improving collaboration, communication, and data management. Addressing the abovementioned challenges is no small feat; however, the benefits of collaborations between RMAs and Stewardship Groups – which extend far beyond the actual collection of data; permeating through social networks and contributing to social capital – promise to outweigh the costs. This first half of the Guidebook consists of a high-level discussion of the importance of data management, the core components of data management, and the missing component of conventional data management plans. The latter half of the Guidebook consists of 'operational level' discussion and suggestions and 'action item' examples that RMAs and Stewardship Groups can implement to improve their environmental monitoring collaborations. The discussions and suggestions are intended to be accompanied by the *RMA-Stewardship Group Environmental Monitoring Data Management Plan Template*, henceforth referred to as 'the DMP Template'.

## The Importance of Data Management and the Planning Process

Data management is a critical, but often overlooked, factor of environmental monitoring collaborations. Comprehensive data management planning (1) ensures both parties are in agreement of, and understand, the purpose, goals, and objectives of the collaboration; (2) ensures efficiency of operations is maximised, which mitigates capacity issues (i.e., by reducing extraneous use of time, money, or other resources); (3) ensures the chosen parameters and data collection methods are appropriate for the research question(s) at hand; and (4) provides a foundation on which formal project evaluations can take place, thus allowing for ongoing, incremental improvements to the project and the collaboration as a whole.

Data management is laid out via a data management plan, which is defined herein as *a document that states the purpose and process of data collection; data collection and Quality Assurance/Quality Control (QA/QC) protocols and methods; protocols for data transfer, storage, and sharing; methods of data analysis; and how the data will be linked to action*. A data management plan should cover the full life cycle of the data and should clearly state the protocols and methods for each part of the process. Adherence to such a plan mitigates issues related to logistics and project implementation and is likely to address several issues identified in the literature that hinder citizen science collaborations, such as lack of standardized experimental design, data fragmentation[13], and incompatible methods of sharing data[20]. Further, in the event of volunteer- or RMA staff-turnover, a data management plan can also help maintain continuity of operations and streamline the process of bringing new volunteers or staff members up to speed.

A data management plan is a useful tool for addressing challenges related to data management; however, for collaborations between RMAs and Stewardship Groups, equally as important is the *process* of co-developing the data management plan. Said process – which involves (ideally) face-to-face meetings, discussions, and methodically forming each section of the plan – can help address certain social and sociopolitical challenges (e.g., public misunderstanding of RMA regulatory processes and/or jurisdiction) and allows for any potential barriers or hurtles (such as capacity issues or conflicting goals or priorities) to be identified and addressed well before they impact the collaboration and/or dataset. The desire to implement the 'fun part' of an environmental monitoring collaboration – i.e., the fieldwork – may result in the planning stage of a collaboration being rushed. However, given the importance of a comprehensive data management plan to the efficiency and efficacy of an environmental monitoring collaboration and the quality (and therefore usability) of the resulting dataset, it is recommended that sufficient time and effort be dedicated to the planning process. That being said, the DMP Template can help guide conversations and streamline the planning process, whilst ensuring no important steps are overlooked.

## Core Components of Data Management for Environmental Monitoring

### *Component 1: Purpose/goal and objectives of data collection*

One of the common pitfalls of community-based environmental monitoring is "monitoring for the sake of monitoring"[13, p. 281]. Not all environmental data are suitable for answering every environmental question. Environmental monitoring should be designed with purpose[21]. The purpose, or goal, and objectives of monitoring will determine which indicators or parameters to monitor, the spatial and temporal scale necessary to identify specific impacts or trends, the appropriate protocols and methods that will ensure the project meets its objectives, how long the project should run for, and how and with whom the data should be presented or shared. Further, designing a monitoring project that is "fit for purpose" ensures there is sufficient quality and quantity of data to achieve the stated objectives and that the data collection process will be as efficient and effective as possible[21]. In contrast, "undirected monitoring" – monitoring that lacks clearly stated goals and a data management plan – "can use up considerable resources and time yet achieve very little, resulting in inadequate datasets that fail to inform decisions"[22, p. 135-136].

### *Component 2: Metadata and documentation*

Data must be accompanied by all necessary metadata. Metadata – which are essentially data that describe the data – provide context, allow for data records to be maintained, and enable future end-users to evaluate the appropriateness of the dataset for their intended purposes. Examples include the date and time, GPS coordinates of the sample site, weather, ambient air temperature, and person who collected the data. Recording the maintenance of equipment as well as any changes to protocols or methods, including QA/QC protocols, is also an important part of documentation.

The importance of accurate documentation – such as recording of metadata and/or any deviations from protocols – cannot be understated, as said information can help explain potential anomalies or unexpected readings, which is critical for analysis of the data. For example, when analyzing temperature data for climatological research, researchers found that the data were affected by "changes in instrumentation, local site conditions, site relocations, [and] changes in observing practices"[21, p. 27]. If the necessary information was not documented, those performing

the analysis could not have known if abnormalities in the data were the result of changing environmental conditions or deviations from the monitoring procedures.

### *Component 3: Statistical power*

It is important to consider statistical power when designing an environmental monitoring project. Statistical power – which is the probability that a statistical test will detect an effect that is not due to chance – is determined by "effect size, error, variance, sample size and the Type 1 error rate"[1, p. 196]. Larger effects are easier to detect than more subtle effects; however, because "the size of the effect is usually unknown" during the planning stage of environmental monitoring projects, "the limits of acceptable change should be fixed at the planning stage and the monitoring designed so that a change of that magnitude will be detected if it occurs" [1, p. 196]. Larger sample sizes increase the statistical power of monitoring data, but are subject to the law of diminishing returns; i.e., once an optimal sample size has been reached, additional sampling effort will not provide any new information or meaningfully affect the results.

### *Component 4: Quality Assurance/Quality Control (QA/QC)*

QA/QC consists of methods or tasks that reduce the likelihood of measurement error, sample contamination, or other occurrences that compromise the quality of the data. QA/QC procedures provide the end-user of the data with a level of confidence (e.g., precision, accuracy) in the data being collected. In order to create useable data the QA/QC protocols should be included in each step of the environmental monitoring process[23]. The QA/QC protocols can also prevent wasting time and materials by allowing for errors to be identified and corrected before they adversely affect the quality of the data[23]. Data collected in nature lack the conventional controlled, repeatable experimental conditions common to scientific experiments, which means that careful planning of methods and documentation of any deviation from said methods must occur[23]. Clark and Whitfield propose a 14-step iterative model for environmental monitoring that involves: design, plan, protocols, preparation, field liaison, sample collection, sample handling, laboratory analysis, data transmission, data validation, data approval, data provision, statistical analysis, and reporting[23, p. 120]. Clark and Whitfield stress that "data are no better than the weakest link" and given that changes to each step are likely to occur over time, as knowledge and technology advance, it is important to have quality assurance strategies for each step in order to monitor and account for changes or improvements that occur[23, p. 120]. As an example, for the 'laboratory

analysis' step, Clark and Whitfield recommend to request a copy of the laboratory's QA/QC protocols and request to be informed of any changes to their protocols or methods of analysis.

### *Component 5: Protocols and methods*

The protocols (sets or lists of methods) and methods (specific instructions on how to complete a task) consist of step-by-step instructions that clearly state what a person must do before, during, and after data collection. Including explicit protocols and methods in the data management plan is important to ensure there is no confusion regarding what steps must be taken, which in turn ensures the data are comparable and the dataset is usable. In contrast, if two groups do not follow the same protocols/methods, the resulting datasets may be challenging – if not impossible – to comparatively analyze, thus limiting the usefulness of the data.

### *Component 6: Data transfer, storage, organization, and protection*

Data collection is just one part of the data management process. Equally as important are the subsequent steps, including data transfer, storage, organization, and protection[24]. Though arguably the most mundane part of an environmental monitoring project, addressing Component 6 ensures the data are organized and accompanied by the necessary metadata and are therefore accessible, useful, and in a state where they can be analyzed and/or shared and subsequently linked to action.

### *Component 7: Data analysis*

Data analysis is the process of extracting information from the data by means of processing, modeling, and/or applying statistical tests to the data. Data analyses should be done properly, as the results of analyses may be used to justify management action or inaction. Different statistical tests are intended for different types of data; therefore, it is important that an appropriate test be used. For example, a Chi-square test may be used for categorical data, whereas an Analysis of Variance (ANOVA) may be used for continuous data[25].

### *Component 8: Data sharing*

The method which data are shared, how they are presented (e.g., hard copies versus Excel spreadsheets), whom they are shared with, where they are made available, and when they are shared all influence the likelihood of the data being used in resource management processes. *Open data* – defined as data that are freely available to the public, "machine readable and non-

proprietary", and easy to access using "freely available software tools"[26] – are becoming increasingly popular. Sharing data reduces redundancy of data collection, thus allowing for increased collective efficiency, increased opportunities for learning, and more resources available to facilitate informed decision-making.

### *Component 9: Linking data collection to action*

Data collection and analysis should be clearly linked to management action(s) that were identified during the planning stages of the project. *Action* may mean different things depending on the goals and objectives of the project or the capacity or jurisdiction of the organizations involved, but may include implementation of restoration work, prosecution of polluters, public education initiatives, or modification of policies or legislation.

## The Missing Component (Component 10): Overall Collaboration and Communication

Collaborations exist within a social landscape. RMAs and Stewardship Groups consist of diverse groups of individuals with varying backgrounds, perspectives, values, and ways of thinking. This diversity offers immense potential, as diverse individuals also bring to the table a variety of thoughts, ideas, experiences, skills, and expertise; the interface at which truly innovative ideas are formed. However, this same diversity can cause challenges if steps are not taken to understand the other party (e.g., their perspective, expectations, reasoning for decisions, and roles and responsibilities within their organization or agency) and efforts are not made to achieve efficient, effective communication.

Misunderstanding, miscommunication, and misinformation lead to frustrations and distrust, which can quickly derail a collaboration. For multi-institutional collaborations, such as collaborations between RMAs and Stewardship Groups, miscommunication not only hinders a collaboration, but can exacerbate social and sociopolitical challenges. For example, lack of information regarding why a RMA made, or did not make, a certain management decision may result in frustration and adversely (and unfairly) affect public perception of the RMA. Similarly, community members reportedly often do not know who to contact if they have questions, concerns, or want to report environmental problems; or do not receive follow-up after they report an environmental problem to the appropriate RMA hotline. Collectively, these communication

failures result in pent-up frustrations that are occasionally released on government representatives when the opportunity arises (e.g., during a panel discussion at a meeting/conference). When observing the pros and cons of these encounters, the only 'pro' is that community members have the opportunity to release a bit of the pent up frustration they have. The 'cons', on the other hand, are plentiful. Community members unleashing their frustrations on RMA representatives results in a missed opportunity for a meaningful discussion and discourages RMA representatives from wanting to engage or collaborate with Stewardship Groups in the future; which in turn maintains the status quo in which Stewardship Group and RMA relationships are perceived to be adversarial rather than collaborative. However, these situations can be avoided if regular, effective communication is maintained. As such, in order to achieve the benefits of collaboration, it is important that RMAs and Stewardship Groups establish and maintain an ongoing relationship and effective two-way communication.

Effective communication also contributes to efficiency. Addressing issues related to limited resources and capacity is one of the potential benefits of collaborations between RMAs and Stewardship Groups, as collaboration allows for the pooling of resources, which in turn allows for more than can be achieved by working independently. However, disorganized collaboration and inefficient communication waste the most valuable resource of all: Time. Wasted time is not only economically inefficient, but can also exacerbate capacity issues and contribute to volunteer burnout. In contrast, effective communication from the outset of a collaboration can help flag potential challenges, such as lack of capacity or time management issues, and allow for the project to be planned and scoped to mitigate said issues. Effective, ongoing communication can also help flag any redundancies or inefficiencies so that the project may be tweaked and adapted accordingly.

Indeed, Component 10: *Overall collaboration and communication* is a critical part of collaboration that can directly or indirectly affect all other components of data management; yet is not addressed by conventional data management plans. Therefore, the DMP Template addresses this 'missing component' by including a *Communication Plan* section to help ensure this critical component of data management is not overlooked when RMAs and Stewardship Groups are planning an environmental monitoring collaboration.

## Operational Level: Discussion, Suggestions, and Action Item Examples

### Preliminary Planning to Facilitate Efficient Communication

When a Stewardship Group or RMA decides that they would like to initiate a collaboration with the other party, it can often be challenging to know where to start. Questions may arise about how, when, and with whom to engage, as well as what can be done prior to engagement to set the collaboration up for success. Having a plan prior to engagement is beneficial, but a final plan for a collaboration should contain input from both parties, meaning any preliminary plans or ideas should be flexible.

When a collaboration is first initiated, during initial discussions and prior to delegation of roles and responsibilities, the RMA and Stewardship Group should determine their respective capacities and priorities. By determining in advance what each individual person and party hopes to achieve and is willing and able to contribute (e.g., how many hours per week, how much in-kind support) and then communicating this at the first formal meeting(s), the collective group can better design and structure the project so that it is within the means of those involved. Further, if the RMA and Stewardship Group identify their respective top priorities in advance of discussions with the other party, then – should capacity be a limiting factor – the collective group can design the project so that it addresses the most important priorities first. Also, an arguably very important caveat: each individual/party *must* respect the stated capacity of the other individuals/party. For example, if a person responds that they can only dedicate two hours per week to the collaboration, other individuals must accept that response. Pushing someone to commit to more than they think they can reasonably achieve is a recipe for failure; either the person will push themselves too hard and 'burn out' or will fail to achieve what they agreed to do, which is likely to adversely affect the project and/or collaboration.

**Action Items:**

- Use a framework, such as the Functional Community Based Monitoring (CBM) Framework provided by Conrad and Daoust[27], that outlines the steps that should be taken – and importantly, the order in which steps should be taken – when initiating a collaborative environmental monitoring project.

- Research similar case studies, which often provide valuable, nuanced information that can help one learn from others' experiences.
- RMA: Before engaging in formal meetings, the RMA employee who is interested in collaborating should first ask themself:
    - What do I hope to achieve by collaborating with the Stewardship Group(s)?
    - What are my top priorities?
    - How much time (e.g., per week/month) can I reasonably dedicate to engaging and collaborating?
    - What other resources (e.g., tools, equipment) can I contribute to the collaborative project?
    - Am I willing to occasionally meet with groups during non-working hours, recognizing that many volunteers also have full-time jobs?
    - Are there others in my agency who may be interested in the potential collaboration?
    - Are other RMAs engaging in similar collaborations? And if so, can I contact them and ask for advice prior to meeting with the Stewardship Group(s)?
- Stewardship Group: Before engaging in formal meetings, the Stewardship Group members who are interested in collaborating should first:
    - Contact other group members to determine if others are also interested in the proposed collaboration;
    - Establish a board;
    - Designate a liaison and create a group email list for disseminating information;
    - Determine the priorities, goals (i.e., what does the group hope to achieve by collaborating with the RMA), and capacity of each group member and the group as a whole. Questions group members should ask themselves include:
        - How much time (e.g., per week/month) can I reasonably dedicate to engaging and collaborating?
        - What skills and/or resources am I able and willing to contribute?

## Data Management Plan

A comprehensive data management plan should cover the 10 core components of data management: (1) Purpose/goal and objectives of data collection; (2) Metadata and documentation; (3) Statistical power; (4) Quality Assurance/Quality Control; (5) Protocols and methods; (6) Data transfer, storage, organization, and protection; (7) Data analysis; (8) Data sharing; (9) Linking data collection to action; and (10) Overall collaboration and communication[18]. The following subsections correspond to the headings of the DMP Template and are meant to provide explanation of the importance of each section of the DMP Template.

**Action Items:**

- Host one or more meetings involving the RMA and Stewardship Group collaborators to co-develop a data management plan. Use the DMP Template to guide discussions and structure the plan.
- Ensure all participants understand and agree to the data management plan prior to project implementation.

### Participants, Roles, and Responsibilities

Including a section in the data management plan that states which RMA(s) and Stewardship Group(s) are involved in the collaboration, provides contact information for designated liaisons, and summarizes each party's roles and responsibilities provides a helpful reference for participants and also helps bring new participants up to speed (which may be helpful in the event of volunteer or staff turnover). This section can also include relevant information about each party's expectations and limitations, such as a summary of the jurisdiction and/or mandate(s) of each party; what each party hopes to gain from participation in the collaboration; and a summary of the resources each party has agreed to provide. Collectively, this information may help manage expectations and facilitate annual evaluation, in particular when determining if each party's expectations have been met.

### Code of Conduct

In order for positive relationships to form and good communication to occur, individuals must feel respected, valued, heard, and understood; and must feel comfortable voicing concerns without fear of unfair repercussions. Therefore, before jumping into the project details, it is

worthwhile to co-develop a Code of Conduct. Co-developing a Code of Conduct allows each participant to help shape the collaborative space into one they will feel most comfortable in; and including the Code of Conduct in the data management plan allows for easy reference for current and new participants. Examples of productive rules that can be included in a Code of Conduct include: (1) Allow each person to speak, uninterrupted; (2) No foul language or malicious comments; (3) Make an effort to understand the other party's reasoning/to 'walk in their shoes'; (4) Leave your ego at the door/work as a team; and/or (5) 'Call in, don't call out' (i.e., if someone says something that you find upsetting or offensive, instead of calling them out in front of the group – which can trigger a defensive response that hinders learning and growth – mention to the person afterwards/in private why you found their comment to be upsetting, which is more likely to result in the person listening, processing the feedback, and learning from the experience).

**Action Items:**

- During one of the initial meetings regarding a proposed collaboration, co-develop a Code of Conduct. For example, have the person(s) chairing the meeting ask participants what they would like included in the Code of Conduct; record responses so that they can be viewed by the group (e.g., on a flipchart of whiteboard); ensure all are in agreement with the final product; and then include the Code of Conduct in the data management plan.

### Project Description, Goals, and Objectives

Including a brief project description and proposed timeline in a data management plan provides a concise summary for new or potential participants and allows for ease of reference for current participants. The proposed timeline can be divided into various components of the environmental monitoring project – such as 'procurement of equipment' and/or 'installation of equipment' – to help keep each component on track. Depending on the complexity of the project, a Gantt Chart may be a useful tool.

A successful collaboration requires both parties to be in agreement on the goals and objectives of the project. Clearly stating the goals and objectives of the monitoring initiative in the data management plan ensures all current and future participants understand why the data are being collected. This section is particularly important, as discussions of shared goals and specific

objectives – including which metrics will be used to evaluate progress – lay the foundation for the rest of the data management plan as well as future evaluations.

Given that Stewardship Groups are typically more interested in the actions that will be taken in response to the results of data analyses, as opposed to the data themselves, clarifying the goals, objectives, and how the data will be linked to action (Component 9) is especially important. As such, when creating a data management plan it is important that (1) those involved are in agreement as to *why* the data are being collected; (2) there is discussion of how the results of data collection can be linked to action (Component 9); and (3) that those involved are aware of the jurisdictional mandate and limitations of the RMA. If achievement of the Stewardship Group's goal(s) requires actions that are outside the jurisdiction of the RMA collaborator, it is worth considering whether a RMA that is able to implement the desired actions should be included in the collaboration. If it is agreed that an additional agency or agencies should be involved, then engagement and involvement of said agency/ies should occur before proceeding any further with the data management plan, to ensure that all parties are on the same page throughout the entire planning process.

### Metadata and Documentation

Data must be accompanied by the necessary metadata in order to be useful. As such, when planning an environmental monitoring project, it is critical that both parties agree on what should be documented at the time of data collection prior to any data being collected. A data management plan should clearly indicate what information should be recorded when data are collected. Agreeing on the format the metadata should be in – e.g., 24-hour time or decimal degree GPS coordinates – can also save time when transcribing and/or uploading the metadata.

Equipment and Maintenance Records and QA/QC Records are also critical pieces of documentation[23]. Having scheduled equipment maintenance and documenting when and by whom equipment maintenance occurs ensures that equipment is maintained properly and on time, thus prolonging the life and functionality of the equipment; which, for equipment such as data loggers, can directly affect the accuracy of the data. A QA/QC Record documents any changes to protocols or methods, including when and why the change occurred. Further, as consistency and standardization of protocols are crucial if the data are to be viewed as credible, the QA/QC Record may also include requirements, such as an approval process, that must occur in order for any

protocols or methods to be changed[23]. Collectively, these records provide valuable information that may help analysts explain any unexpected or abnormal readings or measurements. Given that training is an important component of quality assurance, a QA/QC Record may also summarize training requirements that are relevant to ensuring data quality.

**Action Items:**

- Establish and maintain an 'Equipment and Maintenance Record' and a 'QA/QC Record'.
- Explain to those collecting the data *why* the metadata and records are important, so that they may understand the value in diligently recording the information.

## Protocols, Methods, and Materials/Equipment

### *Selection of Parameters*

When selecting which parameters to monitor, it is important to first identify the data needs of the intended end-user(s), so that the project as a whole, and more specifically the protocols and methods, can be tailored to meet those needs. The intended end-user may be the RMA collaborator, or may be a third-party who is consulted to determine their data needs but is not an active participant in the collaborative monitoring project. Once the intended end-user has identified which parameters would be beneficial to have data, the RMA and Stewardship Group can determine which parameters have data collection methods suitable for volunteers (i.e., that do not require extensive training) and are feasible to include in the environmental monitoring collaboration (e.g., that do not require large quantities of expensive equipment).

When selecting parameters, it is also important to prioritize efficiency in order to achieve the stated objectives whilst avoiding volunteer burnout. It is arguably better to monitor fewer, carefully-selected indicator parameters effectively and consistently for a longer period of time than to attempt to monitor many parameters, only to find the workload to be too much of a burden to maintain. As such, research should be done or a specialist consulted to identify which parameters provide the most information about the ecosystem health or research question(s) at hand – the 'best bang for your buck' – prior to finalizing parameter selection and purchasing equipment. Once the parameters have been selected, the next step is to determine which metric will be used and the

appropriate target range and limit of acceptable change for each metric, which will indicate the level of precision required[6].

Collectively deciding which parameters, metrics, and targets are appropriate for the environmental monitoring project (which may involve consulting a specialist during the planning process), and documenting the results of this decision-making process in the data management plan, provides a beneficial learning experience for current and future participants and ensures that all participants understand the reasons for selecting the chosen parameters. This is important for several reasons: (1) it ensures all participants understand and are in agreement on the monitoring that is to take place; (2) volunteers who understand and appreciate the value of the data they are collecting are more likely to remain engaged and interested in the project, and thus to continue participating; (3) the knowledge gained empowers Stewardship Group members, who can then educate the broader public about the importance of the environmental monitoring project; and (4) documenting the chosen parameters, metrics, targets, and the justifications for the choices that were made provides valuable information for future data end-users, so that they may determine the suitability of the data for their respective uses.

**Action Items:**

- Consult the intended data end-user(s) to determine their data needs, then work backwards to determine which of their needs can be filled via the collaborative monitoring project.
- Consult a specialist to determine which parameters will provide the most information about the ecosystem of interest for the least effort and cost.

### *Protocols for Before, During, and After Data Collection (including QA/QC)*

For each parameter, the data management plan should clearly state the method of data collection/sampling, the metric of choice, how data are to be recorded, the spatial and temporal frequency of monitoring, who is responsible for each task, and provide easy-to-follow, step-by-step instructions on how to complete each task. The protocols and methods must be appropriate for the purpose of the monitoring; specifically, there must be a means to "distinguish changes that are of no particular consequence, from changes that can be attributed to the impact or management treatment of interest" [1, p. 198]. The protocols and methods should cover each step that must occur

prior to data collection, during data collection, and after data collection, including the QA/QC- and equipment maintenance-protocols. Steps that occur prior to data collection may include sterilizing equipment, recording serial numbers, and/or calibrating equipment. Steps that occur after data collection may involve double-checking that datasheets are filled out and/or keeping samples on ice while transporting them to a laboratory (if applicable).

When determining which methods should be used to collect data, it is arguably best to opt for the simplest methods that still achieve the level of precision needed to meet the objectives. Simple methods are more accessible to volunteers with a variety of skillsets and reduce room for human error; however, simplifying protocols should not adversely affect the results of the data. To ensure data collected following simplified protocols are comparable to more complicated sampling techniques, "volunteer monitoring protocols must be analyzed in detail and compared with appropriate statistical techniques to confirm that they reach the same conclusions as the professional protocols"[8, p. 175]. Such a comparison of protocols and results for volunteer-gathered data is essential to assure RMAs and other end-users that the volunteer-gathered data are credible and comparable to professional data.

Depending on the parameter and the available funding, it is not always possible to achieve high precision data using simplified methods, whilst maintaining an acceptable level of accuracy. For example, accurate invertebrate sampling can be conducted at relatively low cost if the results need not be precise (e.g., organisms do not need to be identified down to species level); however, if precision is necessary and samples must be sent to a lab to be identified by an entomologist, monitoring costs increase substantially. For monitoring collaborations between Stewardship Groups and RMAs, when forced to choose between accuracy and precision, it is best to prioritize accuracy. The reason for this is that data that are precise, but inaccurate, are less likely to be viewed as credible by end-users; whereas, less precise, highly accurate data are more likely to be trusted by end-users and can help flag 'problem areas' that warrant additional, more-precise investigation by professionals. For example, if volunteers conducting invertebrate surveys consistently achieve a 90 percent accuracy rate when categorizing organisms down to the taxonomic order or family, this may prove to be more useful than achieving an averaged 65 or 70 percent accuracy rate whilst attempting to categorize invertebrates down to genus or species level.

For methods that involve manual data collection, time management and data continuity should be considered early on in the planning process. Scheduling data collection and arranging for backup volunteers to be 'on-call' and able to collect data in the event the original volunteer is unable is an effective way to ensure continuity of data collection and reduce gaps in the dataset. However, if it is not feasible to have scheduled data collection days and backup volunteers available, the collective group may decide that (1) they are satisfied with their dataset having potential gaps due to issues related to volunteer availability; and if so, must decide the maximum frequency of gaps that is acceptable before it renders the dataset unusable; or (2) it is best to choose a parameter that does not require as frequent monitoring or a parameter for which automated loggers are affordable, such as stream temperature. Regardless of which option the group decides, what is important is that the data collected by volunteers are useful and usable and that the contribution volunteers agree to is one that is reasonable and achievable and does not risk overburdening volunteers and/or causing volunteer burnout.

QA/QC protocols are especially important to clearly document, as the data are unlikely to be used by the intended end-user(s) if there is reason to believe the QA/QC protocols are inadequate or not being adhered to. Indeed, concerns about data quality are one of the most widely cited barriers to uptake of community-gathered data by RMAs[19,28,29,30]. Given that data collection is arguably pointless if the data are not used, there is considerable incentive to incorporate thorough QA/QC protocols into data collection and data management plans, to assure the data end-users that the data are credible. There are plenty of resources available to help address skepticism of data quality. For example, Clark and Whitfield[23] provide QA/QC examples for each of the 14 steps in their iterative model and Freitag et al.[31] provide 12 credibility strategies that Stewardship Groups can use to improve the credibility of their data. It is not necessary to incorporate all strategies in order for citizen science data to be deemed credible; however, QA/QC procedures should be incorporated into each stage of the process[31]; i.e., before, during, and after data collection. The QA/QC suggestions made by Clark and Whitfield and credibility strategies suggested by Freitag et al. are summarized in the Appendix. It is recommended that as many strategies be incorporated into the before, during, and after stages of data collection as are needed to provide enough assurance to the RMA collaborator or other end-users to guarantee uptake of the community-gathered data (i.e., to ensure they will link the data to action).

Each QA/QC protocol should be recorded in the data management plan and accompanied by reasons why each step is important, so that current and future participants understand the value that comes from diligently following the stated protocols. In the DMP Template, QA/QC subsections are nested within the *Protocols, Methods, and Materials/Equipment* section, for convenient reference by volunteers and data end-users. A copy of the laboratory's protocols and QA/QC procedures should also be included in the data management plan, to ensure completeness of documentation and records.

**Action Item:**

- Simplify protocols, but conduct a thorough comparative analysis of the simplified protocols versus professional protocols, to ensure the results of each are comparable.
- During initial meetings, discuss potential challenges related to time management and create a plan to ensure data continuity.
- Meet with the intended end-users of the data and discuss any concerns about data quality. Present the QA/QC methods and credibility strategies in in the Appendix (or other recommended methods) to the intended end-users and discuss which – and how many – strategies would sufficiently eliminate skepticism regarding data quality; then incorporate the selected strategies into the data management plan and communicate the importance of said strategies to all participants.
- Request a copy of the laboratory's protocols (including QA/QC protocols), if applicable, and request to be notified and provided with an updated copy should any changes to protocols or methods occur (including a record of what changes were made and the dates changes occurred)[23].

### *Materials and Equipment*

The equipment required to implement a collaborative environmental monitoring project will depend on the parameters selected, the level of precision needed, and the corresponding protocols and methods. Including detailed information in a data management plan about the equipment required, accessories required to calibrate and maintain said equipment, and where the equipment is procured ensures there is no confusion regarding what equipment is needed to continue the monitoring project (which may be helpful in the event of volunteer or RMA staff

turnover). Further, information regarding how long it takes to receive equipment from a distributor may help avoid mid-project issues and corresponding gaps in the dataset by flagging the need to purchase extra/backup equipment in advance, in case any equipment failures occur.

### *Maintenance of Equipment*

The data management plan should clearly outline what is required to maintain equipment; the timeline or frequency that maintenance must occur (e.g., annually, after every use); who is responsible for maintenance; and what must be recorded in the Equipment and Maintenance Record at the time of maintenance. Having clear, step-by-step instructions ensures equipment is maintained properly and accurate maintenance records are kept.

## Data Transfer, Storage, Organization, and Protection

A data management plan should clearly state what is to occur with the data after they are collected, from the time they are in the hands of volunteers or lab technicians to the time they reach their final storage destination; including who is responsible for each part of the process. This process will vary depending on how the data are recorded (e.g., digitally versus manually), whether there are samples that must be sent to a lab for analysis, who is responsible for storing the data, and where the data are to be stored.

A data management plan should also clearly state where the data and metadata will be stored, how they will be organized (e.g., organized in digital folders labeled by site name), and how they will be protected from loss. Digital data storage allows for ease of analysis and sharing of data, but maintaining hard copies in addition to digital copies provides extra assurance in case of a technical disaster. Further, this section of the data management plan should cover which mechanisms are in place to protect the data and the project in the event of a shift in political climate that dwindles or outright eliminates support for environmental monitoring collaborations.

Without a structured data management plan, this stage of data management is often where community-monitoring falls short, as volunteers collect data which then remain in various locations with limited accessibility, such as filing cabinets or Excel spreadsheets on personal computers. Who should be responsible for data storage and organization will likely be context dependent, but there are several reasons why the RMA collaborator may be best suited to store and organize the data, including: (1) many volunteers enjoy being the ‘boots on the ground’ but are

understandably less motivated to do the subsequent office-based components of data management, meaning delegating this responsibility to a RMA employee or other paid person ensures this component of data management is not overlooked; (2) the RMA typically has a larger region of interest and can act as a data hub by partnering with multiple Stewardship Groups (Figure 1), facilitating standardized data collection across the region, and then compiling the Stewardship Groups' data into a master dataset; and (3) RMAs often have greater storage capacity and server space on which to store the data. Further, given that the RMA is likely to be the primary end-user of the data, it makes sense for the agency to have easy access to the data and metadata for ease of analysis.

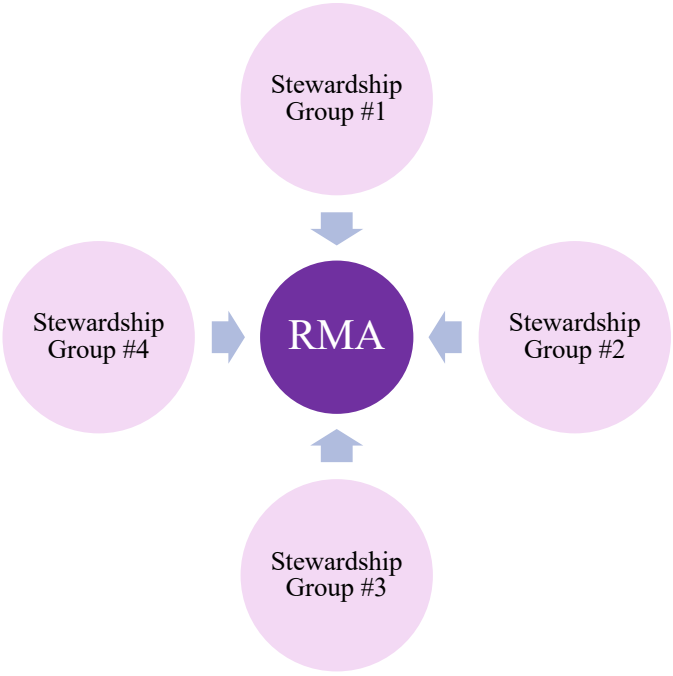


*Figure 1: A Resource Management Agency (RMA) collaborating with multiple Stewardship Groups, who each focus on a subregion of the RMA's jurisdiction, can act as a data hub and facilitate data sharing and comparative analyses that benefit the RMA and the Stewardship Groups.*

### Data Analysis/Statistical Power

How the community-gathered data will be analyzed should be determined prior to collecting said data, to ensure the data collection plan and methods are appropriate and will achieve adequate statistical power to address the research question(s) at hand (Component 3); and step-by-

step instructions for analyses should be documented in the data management plan. This may include instructions and formulas for how to conduct an analysis using Excel; or it may include code and/or script for conducting an analysis in R, R Studio, or other statistical software. Whatever program is used to conduct the analysis, it is crucial that explicit instructions be provided so that, in the event of staff or volunteer turnover, a new person is able to maintain consistency of analyses.

As monitoring is time consuming and expensive, it is important that calculations be made in the planning stages of an environmental monitoring project to determine the sample size needed to draw meaningful conclusions and achieve the goals of the project, whilst avoiding collection of extra, unnecessary data. Due to time and financial constraints, there is often a tradeoff that must be made between collecting fewer, high-precision samples and many, less precise samples. Finally, the type I error rate is important to consider when designing an environmental monitoring project.

A type I error rate is the probability of rejecting a true null hypothesis (i.e., getting a false positive), which contrasts to a type II error, which is the probability of failing to reject a false null hypothesis (i.e., getting a false negative). For example, if one were monitoring salt concentration in an urban stream to determine if road-salting was contaminating the stream – using the null hypothesis "road-salting does not affect the stream" – a type I error would incorrectly indicate that contamination was occurring (when it was not) and a type II error would incorrectly indicate that contamination was not occurring (when it was). The type I error rate is typically set at $\alpha = 0.05$, but there is substantial potential risk in using the conventional, arbitrary 0.05 value for environmental monitoring[1,32]. As such, Legg and Nagy[1] and Field et al.[32] suggest that the type I error rate be increased, which also increases statistical power. The reason for this recommendation is explained in the following quote by Field et al.[32, p. 670]:

> The reason is that failing to detect an environmental effect (a Type II error) may result in serious damage to the environment that is long-term and/or irreversible, such as the collapse of fish stocks ... the extinction of threatened species ... or the pollution of water supplies ... On the other hand, mistakenly concluding there is an effect (a Type I error) will usually cause relatively minor short-term economic impacts.

The implications of this management preference should not be understated and highlight the importance of data analysis being matched to management objectives. The restoration of a depleted

or deteriorated natural resource – if it is even possible – is much more challenging and the depletion of an economically valuable resource results in increased costs in the long run that are often overlooked[32]. For example, Field et al.[32] showcased that when comparing the economic implications of varying type I error rates, "there is always a greater penalty for choosing a [type I error rate] that is too low, as opposed to one that is too high", and recommend "favouring a low [type II error rate] over a low [type 1 error rate]"[32, p. 673]. Further, mismanagement of a natural resource is typically accompanied by other negative externalities, such as indirect impacts to predator or prey species, alterations to habitat, and/or shifts in community structure in an ecosystem. For the aforementioned reasons, it is imperative that statistical power be considered when creating a data management plan. Indeed, Legg and Nagy stress that if managers do not intend to "give scientists sufficient funds and time to carry out a high power test of the null hypothesis", then the monitoring efforts are a waste of time and there is no point in funding them at all[1, p. 198].

Stewardship Groups often partner with RMAs in hopes that the RMA will help them analyze and draw conclusions from the data they collect. As such, data analysis is best addressed by the RMA collaborator, who typically has the in-house expertise to conduct (or the ability to contract out) analyses on community-gathered data. For environmental monitoring collaborations between RMAs and Stewardship Groups, the data should be analyzed frequently – ideally more than once per year – so that results can be shared with those who collected the data in a timely manner. Doing so provides ongoing motivation for volunteers, as they are able to regularly see the fruits of their labour, and maintains the overall momentum of the monitoring project.

**Action Items:**

- Consult a statistician when planning an environmental monitoring project.
- Conduct a power analysis prior to collecting data.

### Data Sharing

A data management plan should indicate how, when, and with whom the data and results of analyses are to be shared; which platform the data will be made available (if applicable); who is responsible for disseminating the data, results of analyses, and/or uploading the data to the

platform; and how frequently information is to be shared and/or data are to be uploaded to the platform.

Publicizing data may not always be deemed beneficial; however, for environmental monitoring collaborations between RMAs and Stewardship Groups, there is an ethical obligation to share the data and the results of any analyses with the Stewardship Group(s) who collected the data. The RMA and Stewardship Group should collectively decide on the best means of sharing data collected by volunteers. Regardless of whether the collective group decides to make the data available to the broader public, what remains important is that data sharing is discussed in the planning stages of the monitoring project and agreed on before data collection occurs.

It is also important to consult the intended end-users of the data to determine how they would like the data to be presented to them (e.g., raw data, summarized data, as a report) and when they need the data and/or results of analyses, so that the data may be incorporated into resource management processes. This approach – in which end-users are involved in the planning process – is described as "collaborative monitoring", which contrasts with "advocacy monitoring". Advocacy monitoring involves the independent collection of data (i.e., without consulting the intended data end-users), which are then delivered to RMAs in hopes that the data will provide enough evidence of a need for action that decision-makers will be swayed into taking said action[27]. Advocacy monitoring is necessary at times, such as when a RMA refuses to collaborate with a Stewardship Group; however, collaborative monitoring has the potential to produce positive externalities that advocacy monitoring does not, such as increased levels of trust, relationship-building, and pooling of resources.

**Action Items:**

- During one of the initial meetings, discuss whether or not the data should be made publicly available. If it is agreed that the data should not be publicly available, clarify what must occur (e.g., an approval process) in order for the data to be shared with external parties.
- Consult the intended data end-users to determine how and when they would like the data and/or results of analyses presented to them, so that they may be incorporated in resource management and decision-making processes.

## Linking the Data to Action

A data management plan should clearly state how the data will be linked to management action. For environmental monitoring collaborations between RMAs and Stewardship Groups, this is arguably the most important component of data management, because this is the part that volunteers are most interested in. Effectively linking the data to action is what is most likely to build trust, improve the working relationship, and keep volunteers engaged and wanting to participate in the environmental monitoring project. This section of the data management plan may include a description of the resource management processes the data will contribute to, the actions that will be taken by each data end-user, and/or how the results of analyses can be linked to public engagement/education activities.

It is important to discuss how the data can be linked to action during the planning process, because it highlights the jurisdictional or regulatory limitations of the RMA, which in turn ensures that volunteers do not have unrealistic expectations of what will become of their monitoring efforts. As previously mentioned, if the desired actions of the Stewardship Group are outside the jurisdiction of the RMA, it is worth considering whether another RMA that is able to implement the desired actions should be included in the collaboration. Involving all relevant agencies will allow for more actions to be taken, which in turn will strengthen the monitoring initiative.

**Action Items:**

- Involve data end-users in the planning process early on. Work together to identify specific resource management processes that the community-gathered data can contribute to; or actions that can be taken if monitoring indicates that parameters are outside the acceptable range.

## Communication Plan

Including a communication plan as part of a data management plan can facilitate structured, efficient, and effective communication. As previously discussed, *Collaboration and Communication* is a critical component of data management that can affect every other component; yet it is missing from conventional data management plans. Both parties should discuss and agree on the best means of communication and agree on a plan to ensure effective communication is maintained. The *Communication Plan* section of a data management plan should clarify the

processes and points of contact for all potential situations. For example, the communication plan should specify when and how frequently meetings should take place, as well as who is responsible for organizing and chairing said meetings; how Stewardship Groups will be notified if/when their data are used by RMAs; who individuals should contact if they cannot fulfill the tasks they previously committed to; who volunteers can contact for support if they run into issues; how communication with the public will occur; and how communication with other stakeholders will occur.

**Action Items:**

- Schedule regular (e.g., monthly or bimonthly), in-person meetings to discuss the collaboration and facilitate ongoing communication. This method is utilized by the District of West Vancouver, British Columbia and the West Vancouver Streamkeepers, who report it being an effective way to foster a positive relationship and maintain communication. Said meetings reportedly allow for positive interactions in which each party can share thoughts and ideas and can inform the other party of any concerns, progress, or challenges related to the collaboration (as opposed to only meeting when problems arise), which facilitates positive relationship-building.
- Designate a liaison within the RMA and Stewardship Group. A liaison is a primary point of contact who is responsible for disseminating information provided by their collaborators to their group members and for providing information from their group to their collaborators (Figure 2). Designating a liaison (1) eliminates confusion as to whom someone should speak with, (2) reduces redundancy and therefore increases efficiency of communication (e.g., reduces multiple group members emailing the other party asking the same questions), and (3) ensures that all group members receive the same information.

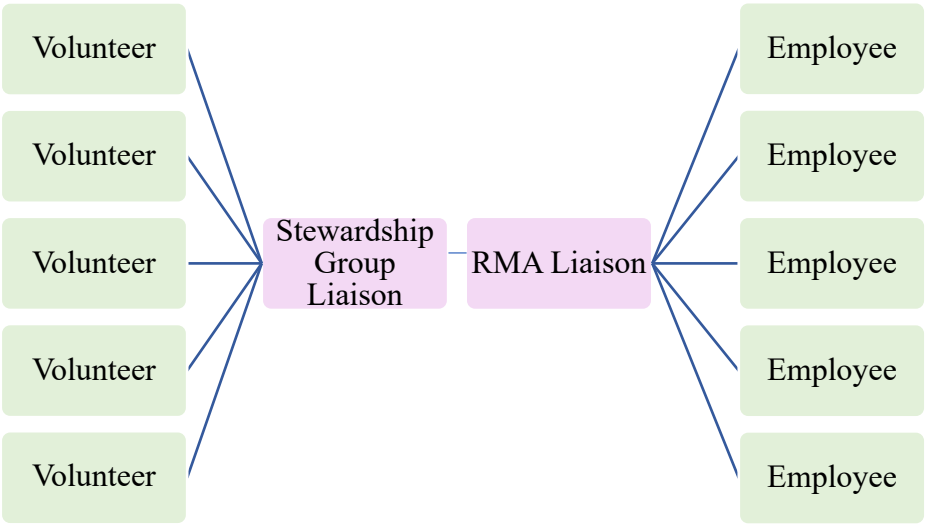


*Figure 2: A recommended communication structure for collaborations between Resource Management Agencies (RMAs) and Stewardship Groups.*

## Training

The *Training* section of a data management plan should clarify what training entails, including how and when training will occur (e.g., annual, in-the-field training), what skills or methods are taught, how frequently training will be available (e.g., for new volunteers), and how often refresher training will be required (if applicable). Further, for environmental monitoring collaborations between RMAs and Stewardship Groups, training should emphasize *why* each component of a protocol or step of a method is important, as well as the importance of standardizing data collection processes and diligently recording metadata.

Providing training is an effective means of ensuring data quality; however, training often focuses on the data collection tasks, while neglecting the rest of the data management process. Biasing volunteer knowledge towards data collection tasks is counterproductive, as volunteers are more likely to be diligent about following protocols if they understand the purpose of certain steps and the value said steps have for subsequent parts of the data management process. For example, even if volunteers are not responsible for data storage and organization, analysis, and/or sharing, if they have an understanding of what occurs during those stages of data management, they may better understand the importance of certain tasks, such as meticulously recording metadata, and therefore may take extra care in ensuring their datasheets are filled out completely and accurately.

As such, volunteers would likely benefit from training that covers the full data management process, rather than the fieldwork stage alone.

As training is important for assuring data end-users that the data are credible, training protocols should be clearly outlined in the data management plan and the Stewardship Group and RMA (or other end-user, if different from the collaborating parties) should critique the proposed data collection methods and corresponding training methods prior to implementing training. All parties must agree that – if volunteers undergo the training and adhere to the data collection and QA/QC protocols – the data will be fit for use by the intended end-user(s). Any skepticism about training should be addressed prior to training and data collection, to avoid wasted time and corresponding frustrations that occur when volunteers collect data that do not meet the RMA's standards and are therefore not used to their full potential.

**Action Items:**

- Mandate training: Research has shown that mandating training prior to participation in a project, as well as mandating refresher training courses, are effective QA/QC methods that ensure volunteers are consistently following data collection methods and assure data end-users that the data are credible. Indeed, the Regional District of Nanaimo, British Columbia utilizes this method, and attributes the success of their Community Watershed Monitoring program in part to the data credibility that is achieved by mandating annual training of volunteers.
- Offer hands-on, in-person, in-the-field training: Training that is hands-on allows volunteers to gain practical experience; in-person training allows for questions to be asked immediately and for protocols to be clarified if any of the instructions are unclear; and place-based, in-the-field training has been shown to be more effective, as volunteers associate their training with a connection to place[33].
- Train volunteers about the full data management process, not just fieldwork.
- Provide field-handbooks: A handbook cannot replace quality, in-person training; however, providing a hard-copy handbook or 'cheat-sheet' that volunteers can use in the field is a simple, effective method of solidifying the training volunteers previously received.

## Budget and Funding

Insufficient funding can stop a project in its tracks, so it is important to secure funding prior to project implementation. Each party can contribute to fundraising, thus reducing the financial burden that would exist, had the RMA and Stewardship Group chosen to work independently rather than collaborate on the environmental monitoring initiative. The planning process should involve preparation of a draft budget followed by exploration of funding options, to determine if the draft budget is feasible. Co-development of the budget helps ensure all potential options for funding are explored, as each individual has the opportunity to offer in-kind resources or support. For example, a RMA may be able to provide equipment; or if a RMA collaborator or member of the Stewardship Group has a strong background in statistics, there may be no need to contract a statistician during the project planning and data analysis stages.

A detailed copy of the project's budget should be included in the data management plan, including initial and ongoing costs and which sources of funding will cover which costs. The most obvious costs to account for are the costs of purchasing and maintaining equipment and materials needed for data collection (e.g., automated loggers, zap straps, rebar, calibration reagents). However, it is important to also account for additional costs related to data storage, analysis, and sharing of data (i.e., to account for the full life cycle of the data) when creating the budget.

**Action Items:**

- Co-develop a budget.
- Explore funding options:
    - Stewardship Group (grants): Non-profit organizations (NPOs) and non-governmental organizations (NGOs) have access to grants that RMAs do not have access to. Grants are often offered by governments (e.g., the Natural Sciences and Engineering Research Council (NSERC) of Canada) and larger NPOs (e.g., the Pacific Salmon Foundation), and are occasionally offered by industry or academia (which can be accessed if a Stewardship Group member is also a student).
    - Stewardship Group (direct fundraising): Stewardship Groups can also explore direct fundraising options. This can include approaching local industries or

businesses to ask for monetary or in-kind support; using a crowdsourcing platform (e.g., GoFundMe); or can involve more conventional, fun ways of fundraising, such as hosting – and selling tickets to – a community event (which can incorporate live music performances, silent auctions, 50/50 draws, etc.).

- RMA: The RMA may be able to contribute direct funding or in-kind labour or equipment. Alternatively, the RMA can facilitate the Stewardship Group's fundraising by helping write grant applications, providing or sourcing letters of support, and/or promoting the Stewardship Group and the proposed monitoring project to industry partners who may be interested in supporting the project.

### Evaluation

Evaluation is a valuable component of data management; yet it is also one that is often overlooked or omitted. Evaluation refers to evaluation of the project/collaboration as a whole; evaluation of the training volunteers receive; and evaluation of the data management plan. Regularly evaluating the collaboration as a whole – and then using the feedback to improve operations or address problems – helps ensure each party is satisfied with the collaborative effort, including progress made and delegation of roles and responsibilities; that participants are not feeling overburdened by their commitments; and that positive working relationships are fostered and maintained. Evaluation of the collaboration can include questions such as:

- *Are you happy with the current delegation of roles and responsibilities?*
- *Do you feel as though project operations, including the distribution of effort, are fair?*
- *Is the project being implemented as you expected? Is there anything you would like to see changed?*

Evaluation of the project can ask questions such as:

- *Do you feel as though the stated objectives are being met?*
- *Are you satisfied with the actions that have been taken as a result of the project?*
- *Do you feel as though any part of the project is redundant or could be made more efficient?*

Evaluation of the training process ensures training remains effective; that volunteers understand what they are being taught; and, importantly, that volunteers enjoy the educational experience.

Finally, the data management plan should be reviewed, evaluated, and revised regularly (e.g., annually) to ensure project operations, protocols, and methods remain appropriate; that inefficiencies are identified and addressed; and that the stated objectives and contact information remain relevant.

The evaluation process for the overall project, training, and the data management plan should allow for all participants to provide feedback, which can then be incorporated into the revised data management plan. The results of the evaluation and any changes made to the data management plan should be recorded, so that future evaluations can assess the effectiveness of any changes that were made. This ongoing tracking of progress will ensure the project is continuously evolving and improving, which will increase economic efficiency and ensure that participants are satisfied with the project's evolution.

In addition to formal evaluations, participants should be encouraged to speak openly about any concerns or challenges as they arise and well before they cause problems. Voicing concerns and/or challenges early on allows for the collective group to work together to address issues before they adversely affect the working relationship or impact the project and/or the resulting dataset.

**Action Items:**

- During initial planning stages, discuss the best means for evaluating the collaboration and the project (e.g., at an Annual General Meeting [AGM] or via an annual survey). If evaluation is to occur in-person, such as during an AGM, determine how participants who are not able to attend the in-person meeting can still contribute to the evaluation.
- Determine what the evaluation will entail and what metrics will be used to measure progress/success.
- Periodically (e.g., every 3 years) assess the state of the ecosystem being monitored to quantify the positive effects (if any) that have occurred as a result of the environmental monitoring project and corresponding actions taken (this may also be helpful for generating ongoing funding).
- Regularly check in with participants, especially if there are any signs that someone is feeling displeased, overburdened, or is otherwise unhappy with project operations.

- During each meeting, ask attendees if there are any challenges or concerns that they would like to discuss, so that the group can work together to devise a solution.

### Appendices

Additional information that may provide a useful reference and/or help bring new participants up to speed can be kept in the appendices of the data management plan. For example, a more thorough description of the RMA collaborator's jurisdiction, mandates, and limitations may be included to solidify volunteers' understanding of RMA limitations and in turn better manage expectations. Background information about the ecosystem being monitored may also be helpful, including results of previous research; documentation of historical restoration projects; historic, ongoing, or future development projects, etc.

**Action Item:**

- Host an in-person meeting to discuss the potential for collaboration and dedicate part of said meeting to educating community members about the RMA collaborator's jurisdictional mandates and limitations. Some volunteers may already have a solid understanding of the regulatory frameworks that RMA employees must work within, but others may not and would therefore benefit from the learning opportunity.
- Create a summary document that explains the jurisdictional mandates and limitations of the RMA collaborator(s) and include this document as an appendix in the finalized data management plan so that community members may refer to it if in need of a reminder, or use it to educate new volunteers.
- Some background information will likely be brought up immediately by knowledgeable participants, but other, more-detailed information may require more extensive research. If this is the case, the initial meeting can be used to identify what information would be beneficial to have, and then participants can independently conduct research and provide the additional information and sources to the group at the following meeting.

# Conclusion

Environmental monitoring collaborations between RMAs and Stewardship groups offer a potential cost-effective means to collect data across a greater spatial and temporal scale than RMAs alone are cable of. Said collaborations have the potential to address data gaps, which can enable RMAs to make informed resource management decisions, contribute to scientific research, and allow for more effective stewardship of ecosystems. Further, collaborations may simultaneously address social and sociopolitical issues by helping to establish positive, ongoing working-relationships between RMA employees and community members. Collaborations also benefit Stewardship Groups by providing them with the resources needed to more effectively engage and educate the broader public about the ecosystem of interest.

To maximize the benefits of environmental monitoring collaborations and address issues related to data management, RMAs and Stewardship Groups should co-develop a data management plan that addresses the core components of data management; including the missing component, *Collaboration and Communication*. A data management plan will help address issues stemming from lack of standardization, data fragmentation, ineffective data sharing, and failure to link data to action, among other logistical challenges. Additionally, the process of co-developing the data management plan – which involves (ideally) face-to-face discussions about goals, priorities, expectations and limitations, capacity, and jurisdiction and mandates, among other things – may help address some of the social and sociopolitical challenges that stem from miscommunication, misinformation, and misunderstanding.

## Primary Recommendations

To realize the benefits of improved data management and collaboration between RMAs and Stewardship Groups, the primary recommendations are proposed:

1. RMAs and Stewardship Groups should co-develop a data management plan that covers all core components of data management and annually evaluate said plan to ensure information and protocols remain relevant;

2. RMAs and Stewardship Groups should involve the intended data end-users early on to identify their needs and which processes the Stewardship Group data can contribute to;

3. RMAs and Stewardship Groups should choose simple protocols and prioritize accuracy of results over precision;

4. QA/QC strategies should be incorporated into the co-developed data management plan to increase credibility of Stewardship Group data and intended end-users should be consulted to ensure the QA/QC strategies are sufficient;

5. RMAs should provide ongoing training (and proof of training) to volunteers on the full life cycle of data management, from data collection and QA/QC procedures, to data storage, organization, protection, and analysis; including *why* each step of a protocol is important;

6. Stewardship Groups should mandate training prior to volunteer participation in the project, as well as regular (e.g., annual) refresher training;

7. RMAs and Stewardship Groups should consult scientists and statisticians when designing the data management plan;

8. RMAs and Stewardship Groups should regularly (e.g., annually) evaluate the collaboration/project as a whole, the data collection protocols and methods, and the training process.

9. A 'communication plan' should be included as part of the co-developed data management plan; and

10. When the Stewardship Group data are used, RMAs should provide feedback to the Stewardship Group(s) regarding what their data were used for.

## Glossary

*Citizen science*: The participation of the public – whom are not explicitly trained science professionals – in scientific research.

*Community-gathered data*: Data collected by members of a Stewardship Group (synonymous with *volunteer-gathered data*)

*Data management plan*: A document that states the purpose and process of data collection; data collection and Quality Assurance/Quality Control (QA/QC) protocols and methods; protocols for data transfer, storage, and sharing; methods of data analysis; and how the data will be linked to action.

*Open data*: Data that are freely available to the public, "machine readable and non-proprietary", and easy to access using "freely available software tools"[26].

*RMA collaborator*: The staff member(s) of a Resource Management Agency (RMA) that have chosen to collaborate with the Stewardship Group(s).

*Volunteer-gathered data*: Data collected by members of a Stewardship Group (synonymous with *community-gathered data*)

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## Appendix: QA/QC Methods and Credibility Strategies

Clark and Whitfield's QA/QC Methods

The following are methods of incorporating QA/QC into each step of the environmental monitoring process, as per Clark and Whitfield[23]. For additional methods and further explanation of the following methods, see the full article.

1. *Design*: Describe specific goals and identify the study area, then ensure the data collection methods are appropriate and sufficient to meet the stated goals.
2. *Plan*: Create a comprehensive plan that outlines all the details of the environmental monitoring project and incorporate measures to ensure good communication takes place between participants.
3. *Protocols*: Include in the protocols regular reporting of "quality assurance results" (p. 122). Protocols should ensure data are protected from loss; and ensure thorough reporting of all "exceptions-to-the-rule or nonconforming events" or modifications or updates to methodologies. Requiring formal authorization to modify protocols is another option to ensure proper documentation of changes is maintained.
4. *Preparation*: When preparing equipment, sampling kits, reagents, or anything else required for data collection, maintenance logs and calibration records should be kept for each instrument. Purchasing equipment well in advance of needing it, or purchasing extra equipment in case of equipment failure, is also a means of mitigating fieldwork interruptions.
5. *Field liaison*: Ensure effective two-way communication (e.g., by maintaining communication records and training records) between those doing fieldwork and those in headquarters (which, for environmental monitoring collaboration involving RMAs and Stewardship Groups, translates to communication between volunteers and RMA collaborators).
6. *Sample collection*: Care must be taken immediately before, during, and after collecting samples, to ensure protocols are followed precisely; and any deviations from the protocols or methods should be recorded.
7. *Sample handling*: Care must be taken not to contaminate any samples with foreign objects. For example, at no point should anything (e.g., a thermometer) be put into a sample bottle

except the sample and a "preservation reagent" (if applicable). QA/QC for *sample handling* also involves maintaining ambient conditions conducive of sample preservation when transporting samples, such as maintaining cool temperatures by transporting samples on ice.

8. *Laboratory analysis*: Request that the laboratory provide a summary of their QA/QC protocols and regularly report their QA/QC results, as well as any changes to their in-house protocols and methods of analysis.
9. *Data transmission*: Maintain a complete record of what "algorithms and code were used in flagging, checking, calculating, validating, censoring, or otherwise processing the data" (p. 125).
10. *Data validation*: Protocols should clarify exactly what steps must occur to "ensure the data on record are valid" and that any errors are identified and addressed (p. 125).
11. *Data approval*: Incorporating formal data approval assures data end-users that the data have undergone some established approval process. QA/QC for this step ensures "there is a clear distinction made between validated and nonvalidated data" (p. 126).
12. *Data provision*: Complete and accurate data records and QA/QC results should be provided to end-users in a timely manner, in a format they will understand that is appropriate for their needs and intended uses.
13. *Statistical analysis*: Consult a statistician during project planning and during analysis; make note of statistical assumptions (and record when assumptions are violated).
14. *Reporting*: Data summaries should be reported clearly, concisely, in a timely manner, and in a way that non-scientists can understand; and should be accompanied by the QA/QC results.

Freitag et al.'s (2016) Credibility Strategies

Strategies Stewardship Groups can use to increase the credibility of their data, as per Freitag et al. (2016), include:

Early actions:

1. *Prior expertise*: Require that volunteers have a certain level of expertise in order to participate in the project.
2. *Training*: Offer or mandate training of volunteers on project protocols.

3. *Science advising*: Consult a scientist when developing the project.

In the field:

1. *Ranking system*: Volunteers begin at different 'levels' and move up in ranks; becoming designated 'experts' after they have proven that they have a certain level of skill and experience.
2. *In-person oversight*: Have 'staff, science partners, or "expert" volunteers ... directly oversee data collection' (p. 6).
3. *Retraining*: Offer or mandate ongoing training of volunteers.
4. *Technological aids*: Use technology to simplify data collection methods.

In the office:

1. *Validation of observations*: Regularly check for human error, including completeness of data and metadata recording; and answer questions volunteers may have (e.g., regarding species identification).
2. *Cross-comparison*: Directly compare community-gathered data with professional data.
3. *Publication*: Publish results of citizen science research in peer-reviewed journals.
4. *Management use*: When managers use community-gathered data, it indicates they trust the data.
5. *Quality assurance protocols*: Require QA/QC protocols be followed by volunteers.