Salmon Data Mobilization

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Abstract: Despite substantial research and conservation efforts, many salmon populations are in decline. Globally, salmon research is not delivering effective decision support products to help managers apply research insights as informed management actions. Data Mobilization (DM) is a key step towards building the wider evidence base required to deliver accountable, reliable, and usable scientific advice to managers. Best practices for DM are being adopted throughout the scientific community but have not permeated deeply into the culture of salmon research and conservation. To address this, we present a strategy for Salmon Data Mobilization (SDM). This strategy defines three spheres of agencies and practitioners that must interact to advance SDM: (1) authoritative bodies that can create policies to support SDM uptake; (2) agencies that can promote, fund, and implement those policies; and (3) the broad salmon community of practice that can support uptake of SDM within focused interest groups. We sketch a future for SDM and propose functional changes required to improve it throughout the community.

Keywords: salmon, data mobilization, research community, FAIR, research culture

INTRODUCTION

The abundance of fishes within the subfamily Salmoninae (Cuvier 1816) (hereafter referred to as salmon) are declining across most of their natural range (Dorner et al. 2008; Crozier et al. 2019; NASCO 2020; COSEWIC 2021). Understanding the causes and predicting these collapses in time to intervene effectively are urgent ecological and socio-

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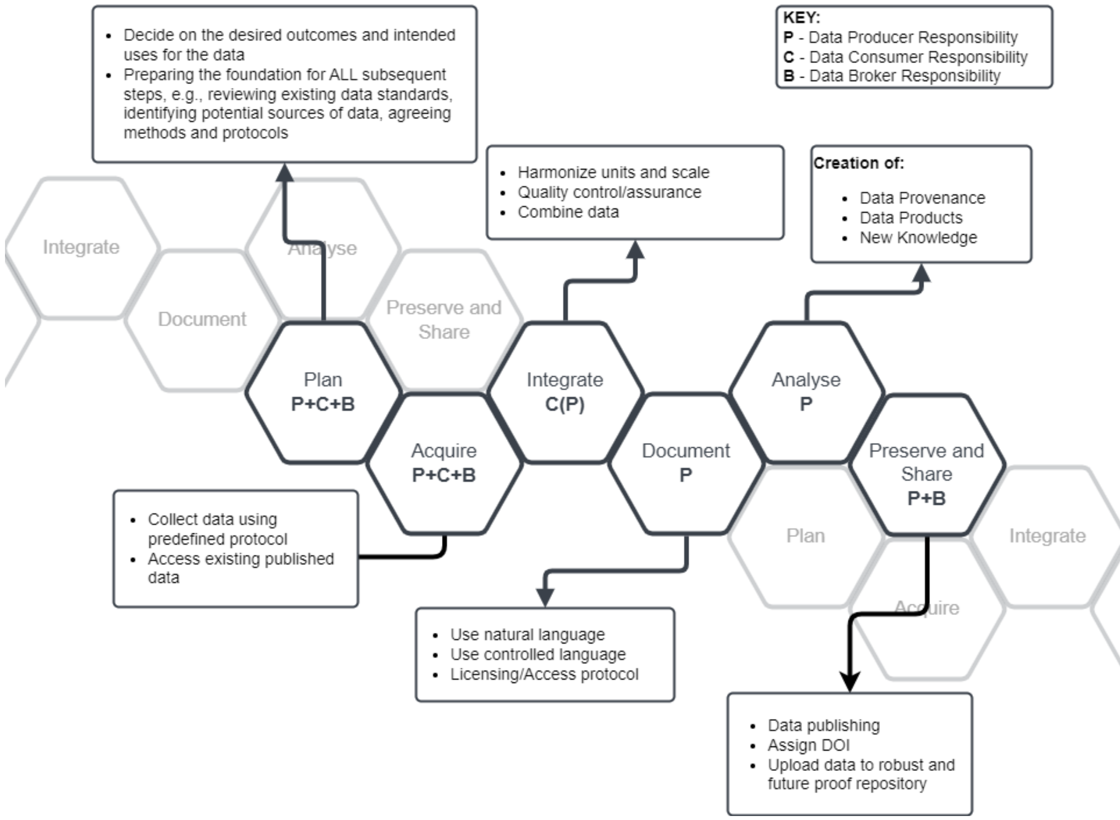

Fig. 1. The Data Mobilization Pathways. Research data life cycles (e.g., Humphrey 2006; Strasser et al. 2011) should be considered as a continual pathway through multiple projects. Information and data products flow between adjacent hexagon faces. P (Data Producer), C (Data Consumer), and B (Data Broker) are core roles with responsibilities within the step. In this context, Consumers transition into Producers at the Integrate step.

economic priorities. Despite widespread data collection, research and conservation efforts, the global salmon research and conservation community has so far struggled to understand fully or reverse this severe trend.

These widespread declines have provoked reviews of salmon ecology in terms of management of fisheries, salmon habitat condition, and human cultural impacts. Research in recent decades has identified marine survival as one of the main drivers of decline (Chaput 2012; Olmos et al. 2019; ICES 2021; Welch et al. 2020). Many causal agents have been suggested including climate change, salmon farming, salmon stocking, habitat condition, food availability at sea, or marine predators—none of which have led to convincing, testable, mechanistic explanations (Dadswell et al. 2022).

The reasons for this lack of actionable hypotheses are as simple as the solutions seem intractable; salmon management and science are complicated by the dual marine and freshwater components of the salmon life cycle, and the resulting direct and indirect human impacts, interests, and responsibilities that intersect with them. Conservation of existing salmon populations is inextricably linked to human-induced stressors such as climate change and freshwater habitat degradation (Nicola et al. 2018; Bernthal et al. 2022), each of which represents a complex suite of problems. Additionally, salmon have important societal significance to many groups across their range, making it important that any management actions are the outcome of collaboration between these stakeholders. Hence, salmon conservation requires not only stewardship informed by traditional knowledge and local insights but also action at multiple scales. Given this, research efforts will only be effective if they are able to support:

- developing a deeper understanding of processes affecting salmon survival, and from that, hypothesizing interventions likely to improve survival;
- building an evidence base to inform necessary social, economic, restoration and other interventions; and
- coordinating triage and alignment of immediate and future actions intended to reverse declines.

Despite salmon being among the most widely studied of fish (e.g., O'Maoiléidigh et al. 2018; Birnie-Gauvin et al. 2019), we are currently failing to leverage these existing data into solutions that can halt salmon declines. Central to this failure is the fact that salmon data are heterogeneous, geographically dispersed (e.g., ICES 2020), and typically focused on localized insights. With a clearly defined problem space it would perhaps be simple to rally around a few key data types and indicators that could inform management actions. But as described already, salmon ecology is complex, with many interacting known and unknown factors. Thus, it is challenging to compile salmon datasets into broadly useful resources and new perspectives that could drive effective management actions. Instead, most datasets tend to remain inaccessible to the broader research community. This fragmentation of salmon data sources constrains opportunities for researchers to work collaboratively, hampering broad-scale insights and solutions.

Improving salmon population health and reversing population declines therefore requires better data management within salmon research (Gillis et al. 2023). The term *Data Mobilization* (DM) refers to the effort required to create a digital environment in which datasets can be effectively shared, understood, and reused. This concept has become a priority for development in many branches of science, including ecology (Michener and Jones 2012; Michener 2015). The aim of this paper is to define what this concept means in the context of salmon research and conservation, and to propose a course of action for the global salmon community.

SALMON DATA MOBILIZATION

Data Mobilization—Definition

Successful DM requires individuals and organizations to take data management actions that make their data Findable, Accessible, Interoperable and Reusable—or FAIR (Wilkinson et al. 2016). Building on the concept of research data life cycles (e.g., Humphrey 2006; Strasser et al. 2011), we define DM as the Planning, Acquisition, Integration, Documentation, Analysis and Preservation steps of the data life cycle (Fig. 1). However, the concept of mobilization extends beyond data management as it invokes data moving from one place to another and achieving some purpose, engaging a broader suite of stakeholders than data managers alone. We therefore clarify how data life cycle steps fall to data stakeholders, including data producers (those creating data products) and consumers (those finding and using data products), to ensure datasets are available for broad use by a community of practice. We also formalize the role of data brokers as those who mediate the collection, curation and distribution of data. Where previous discussion of data life cycles focus on a linear path within a research effort, our representation of DM highlights how these life cycle concepts should propagate across interconnected research streams in support of enhanced research outcomes. While this creation of advanced insights is the eventual purpose of Data Mobilization, we leave out (for now) discussion of knowledge creation processes that follow from DM (Humphrey 2006).

What Slows Data Mobilization?

The barriers to DM are well documented in the context of the wider research community (e.g., Perrier et al. 2020; Hrynaszkiewicz et al. 2021; Digital Science et al. 2022), and relate to working practices of data stakeholders. Broadly speaking, these barriers can be categorized as sociocultural, technical, and organizational/institutional in origin, with these barriers often being synergistic or compounding in nature (Diack et al. 2022).

From a sociocultural perspective, problems with effective data sharing have been attributed to a lack of incentives, concerns of data misuse, scooping, and unclear citation practices—as well as a perceived risk of discredit if data management or analysis does not attain a high enough standard. Technical barriers—such as skills available for data curation, data and metadata standardization, and knowledge of available technical infrastructure and data management—highlight that specific skills are not being catered for in research projects with inadequate data management resources. Finally, at an organizational level, poor funding and staffing for DM means it gets insufficient attention, or is an added burden to those collecting data. There may also be legal or ethical constraints to sharing data due to varying approaches to copyright, collection of sensitive or restricted data, complexity of intellectual rights and confidentiality issues.

Additionally, within DM, it is vital to highlight the ethical component to responsible data management and mobilization—especially where data and knowledge about salmon are created and held across so many diverse stakeholders, rights holders, and knowledge systems. For example, principles around First Nations data ownership and control show how effective ecosystem management will rely on trust between stakeholders, and adherence to principles such as OCAP[1] (Ownership, Control, Access, Possession; all endnotes listed in Appendix Table 1) and CARE[2] (Collective Benefit, Authority to Control, Responsibility, Ethics), supporting communities' data sovereignty and stewardship. Efforts should not merely aim to minimize harm at the local scale, but actively strive to benefit local communities and partnerships across many scales. Such efforts require building of trusted relationships that, in many cases, take years or decades to develop (e.g., Johnsen and Søreng 2018).

What Data Mobilization Needs Does the Salmon Crisis Demand?

Salmon research and management requires a transdisciplinary approach bringing together a wide variety of data resources to better understand responses to past conditions, more accurate forecasting, and effective decision support. For example, timely and accurate predictions of the effects of climate change on salmon production requires a better understanding of the mechanisms underlying salmon survival. In ecological fields this will mean mobilizing information from a diversity of methods to re-analyze, update, or integrate information with those derived from new techniques—all within a framework that ensures the quality, traceability, and ethical nature of the data. Making this interoperability will require a transformation of the current salmon research data culture into one focused on sharing, collaboration, and data reuse; a transformation we call Salmon Data Mobilization (SDM).

Characterizing Salmon Data Mobilization

SDM helps salmon scientists to innovate by ensuring that data of relevance to their field are discoverable, accessible, understandable, and usable across the diverse data formats, disciplines, and languages where they may exist. But the multiple spatiotemporal scales at which salmon population declines are unfolding mean that SDM requires that we view salmon populations as if through:

1. **A telescope**—to support analysis of population dynamics in relation to climate change and variability, habitat changes, behavior, life history strategies, and genomics (stress, disease, starvation).
2. **A microscope**—to support detailed mechanistic models to understand the genetics of physiology and behavior underlying population dynamics and trends therein, and the reactions of individual salmon to the habitats they encounter throughout their life, the basis for comprehensive models of salmon ecology.

Integrating across these scales to understand how micro- and macro-scale impacts cumulatively result in population-scale declines is at the core of Salmon Data Mobilization. The challenges of SDM are characterized by the:

1. **Range** of species, geography, habitats, governments, and agencies.
2. **Breadth** of information types: from physiology to fisheries, from lab results to decision support products, from targeted observation campaigns to indigenous knowledge systems.
3. **Depth** (detail) of information: the contrasting behavior of large versus small spawners, the genetics of populations and the genomics of individuals, acoustic and archival tags that track individual salmon through migrations of thousands of kilometers.
4. **Uncertainty** about many observations (precision, reliability, method).
5. **Volume:** Fisheries and Oceans Canada (DFO) Pacific region records about 20,000 spawning locations for commercial salmon; extrapolating to all salmon everywhere might exceed 200,000 spawning sites, each possibly representing a subpopulation to be protected.

From a 20th century perspective, mobilizing resources at this scale would have been technically and logistically impossible. In the 21st century, digital and technological advances, despite creating their own unique challenges, mean that SDM is feasible—so long as it is orchestrated with suitable technology and supported culturally.

Three Spheres of the SDM Socio-technical System

The vision of SDM requires a social system that uses technology to enact and coordinate policies, implementation, and practice (Fig. 2). This system involves three spheres of organizations: (1) *Policy Leaders* that set priorities and define rules through policy and governance; (2) *Enabling Agencies* that distribute the required resources, capacity, training, and infrastructure via research, funding and public or private advocacy agencies; and (3) *Community Leaders*, or the data producers, brokers, and consumers, who operationalize a community of practice. As in any social system, each level has roles and responsibilities to effect SDM, and each is motivated by derived benefits. By acknowledging these roles and motivations at different levels, we hope to illustrate how they can work in a more coordinated manner.

1. Policy Leaders

At the policy and governance levels, societal and cultural values are formalized into policies so that they may be implemented. In the context of salmon, policies from multiple branches perspectives can affect the uptake of SDM. For example, in Canada the Wild Salmon Policy of 2018 provides an implementation plan for the conservation of salmon (DFO 2005; DFO 2018) and implicates SDM efforts. Whereas high-level open data policies (e.g., Canada Treasury Board 2014; United States Government 2017; European Parliament 2019), which provide guidance on the kinds of information that should be made available and lay the foundations for government-wide data strategies, directly influence SDM efforts in parallel with general DM. From a policy perspective, SDM can provide insight into the effectiveness of salmon policy objectives, both internally and to the public. To illustrate, a policy objective can open funding opportunities for new data collection activity. New data that are managed with SDM values will create persistent identifiers that track usage over time. The data will develop a timeline of usage through data citation that can be linked to the original policy objective via project and funding documentation.

2. Enabling Agencies

Enabling Agencies, such as funding agencies, scientific journals, and research and education institutions, can provide the means to enact policy and sustain SDM over the long term by focusing sustainable and predictable re-

Fig. 2. Three spheres of SDM with the capacity to govern, implement, and operationalize Salmon Data Mobilization. Community Leaders are directly engaged with the steps of the DM pathways. This group requires resources from Enabling Agencies to exist and function (e.g., employment, funding, training). Enabling Agencies are therefore those who have the power to directly motivate good DM practices in the community. Policy Leaders include those involved in creating policies and directives. Policy Leaders create the high level goals of DM (e.g., certain types of data must be made available within certain timescales, and can create the policy framework which Enabling Agencies can base their compliance procedures upon, both reward and penalization).

sources on research and logistical efforts, and reward structures for good practice. By helping to aggregate and focus expertise and effort, Enabling Agencies can benefit from SDM by increased efficiency of resource use and better progress toward desired outcomes. This progress will increase their overall impact and profile through broad distribution of data to the community, and by corroboration of policy success to Policy Leaders.

3. Community Leaders

Data Community Leaders are those involved directly in the SDM pathways, and as the core SDM practitioners need to be recognized in more detail (Fig. 3). As recipients of policy and resources, Community Leaders directly face the barriers to implementation of SDM, and ideally, foresee suitable rewards both personally and for their agencies. Additionally, Community Leaders work in multiple roles in SDM, including as data producers, consumers, or brokers. While individuals and organizations may participate in all of these roles, we define them separately for clarity.

Data Producers create or acquire new datasets and their responsibilities to SDM are largely around recording and publicizing sufficient and appropriate information around this creation so datasets can be efficiently understood and reused. Producers work with a Data Broker to archive their datasets and make them persistently available, easy to find, and available for appropriate reuse. This includes tracking provenance and a chain of custody, the use of standard data

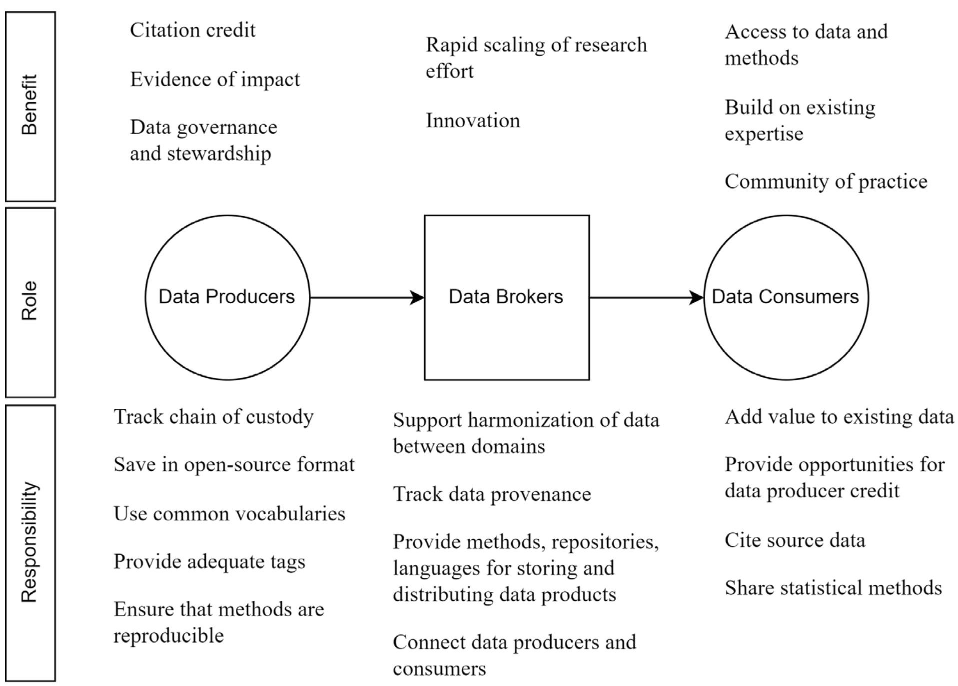

Fig. 3. The Community Leaders of salmon data mobilization are defined as data producers, brokers, and consumers. Three roles with varying responsibilities for, and derive varying benefits from, adherence to SDM policies and practices.

vocabularies, non-proprietary data formats, open code, and open-source tools. Additionally, scripted data transformations and analyses should be done reproducibly. By mobilizing their data, Data Producers will extend the reach and impact of their data assets through new research, citations, collaborations and co-authorship. This impact relies on Data Consumers doing their part to provide appropriate attribution, and on Data Brokers to provide infrastructure that supports this attribution, discovery and distribution process.

Data Consumers search for and reuse data assets. It is typically Data Consumers who are thought of as the beneficiaries of DM, with increased access to expertise and rapid learning of methods via existing standards and methods. In acknowledgement of this benefit, Data Consumers should provide credit to the Data Producers and where possible track the provenance of any sources used. Since data reuse frequently results in new data products, analyses or synthesis, Data Consumers often become Data Producers (Fig. 1) and should therefore include best data production practices as part of the publication process.

SDM processes require a place to put the data, and a common set of governance guidelines and processes for making data discoverable and accessible. We define the Data Brokers as those who provide the necessary infrastructure and environment that aggregates and serves data products. Such repositories aggregate aspects of human knowledge and understanding, but also build on data and knowledge in foreseen and unforeseen ways. The effort and responsibility of setting up a data repository is significant, and much hinges on being able to identify a common purpose for supporting data sharing. For example, oceanographic data repositories such as the Environmental Research Division Data Access Program (ERDDAP)[3], Ocean Biodiversity Information System (OBIS)[4] or the Global Ocean Observing System (GOOS)[5] framework, share a common purpose of scaling research efforts across that community of Data Producers and Consumers. Interdisciplinary research, such as salmon ecology, may not warrant a salmon-domain-specific repository (BECI 2022). Data Brokers for SDM are instead required to utilize existing repositories for the producers and consumers, and consider where gaps and linkages may be present. The importance of SDM repositories is often overlooked or under-rated and stable funding is therefore critical to keeping Data Brokers empowered to keep and maintain the highest quality data services.

LOOKING FORWARD TO SDM

Recommendations, Risks, and Benefits

The simplest pathway to achieving SDM is for the international salmon community to adopt existing, well-established research data management practices and tools. This change requires a new environment that aligns research communities and rewards data curation and sharing in support of the research insights and informed management actions needed to address declining salmon populations. For each of the spheres in the community outlined above we identify some approaches to successful implementation, highlighting existing initiatives, risks, and barriers to uptake, and how members of the community can support one another.

1. Policy Leaders

Continued improvement and harmonization of open data policies can ensure Data Mobilization is integral to salmon data efforts. This includes regulation to incorporate Data Mobilization requirements into data management practices, as well as compliance monitoring, enforcement and rewards. An effective system would work across the multiple scales at which salmon need intervention and connect with other appropriate policies on challenges such as climate change, biodiversity and more. To achieve adoption and uptake more rapidly, Policy Leaders can work to synchronize their efforts and leverage existing open data policies.

Policy leadership in the area of SDM would help ensure that Enabling Agencies and Community Leaders know what is expected of them as they work with data, and can help justify resources to meet policy objectives. Ideally, this leadership would be applied at multiple levels, including international and national directives and legislation, employers, and funders.

In the case of salmon data, many publicly funded datasets are collected and/or maintained by organizations within the public sector, but are not publicly accessible. While keeping in mind constraints around ethics and security, these situations can provide a leading example by enforcing government policy to make these data a public resource. Policy leadership in this area within state agencies is apparent (e.g., EU 2019; OSTP 2022). The mandate becomes even stronger when such data are designated official government statistics, which then leads to a suite of data quality controls and binding commitments to publish by specific dates (e.g., Scottish Government 2023).

Policy only works if it is adopted by the relevant entities. Compliance involves monitoring, motivating and/or enforcing. For example, the European Union (EU) can issue infringement procedures to member states for failing to adequately provide evidence of directives being transposed into national law. Non-compliance with the Canadian Open Data Directive leads to institutional and/or individual consequences ranging from additional training of individuals (motivation) to the placing of institutions into receivership or dismissal of individuals (enforcement) (Canada Treasury Board 2010).

National and international coordination of policies around data sharing will make it easier for organizations

Table 1. Examples of policy and leadership currently in effect.

Country or Agency	Policy
USA	Office of Science and Technology Policy (OSTP) launches Year of Open Science to advance national open science policies across the federal government in 2023.
USA	All federal agencies have been instructed to update their public access policies "...to make publications and their supporting data resulting from federally funded research publicly accessible without an embargo on their free and public release" (OSTP 2022).
EU	The Open Data Directive (EU 2019) sets out the requirement that all public sector bodies provide access to data which "...allows citizens and legal entities to find new ways to use them and create new, innovative products and services." This directive has been enshrined into national laws of member states across the EU, mandating the timely release of public sector data in free and open formats.
USA	Foundations for Evidence-Based Policymaking Act of 2018, Pub. L. No. 115-435, 132 Stat. 5529 (2019) —also called the OPEN Government Data Act (United States Government 2018).
EU	Reporting requirements under the EU's Data Collection Framework (EU 2017), once adopted by a state agency, requires data to be reported in a timely, coordinated fashion, for use by international scientific agencies.
Scotland (UK)	All public services are required to adopt the Open Data Strategy (Scottish Government 2015) whereby those holding public data should (by default) make it open and available for others to reuse, and those collecting new data should make sure that releasing these data for reuse is built into the collection process.
Canada	The Directive on Open Government (Canada Treasurey Board 2014) requires "...all government departments and agencies to make their information resources that are eligible for release to be more easily discoverable and reusable."
EU	Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) (EU 2007).
USA	How to get your Open Data on Data.gov (https://resources.data.gov/resources/data-gov-open-data-howto/).
United Nations	https://en.unesco.org/science-sustainable-future/open-science/recommendation
European Research Area (EU)	"Open Science in Europe" as a means for improving the quality of research for transparency and reproducibility, and their use by the industry and society as a growth mechanism. The European Research Area (ERA) is a unified research area open to the world based on the Internal market, in which researchers, scientific knowledge and technology circulate freely (https://www.openaire.eu/open-science-europe-overview).
UK	UK Government Open Science commitment through the National Data Strategy (NDS) Mission. This is a wider initiative than science, but it shares many of the points discussed.

and research funders to implement within their own areas (Table 1). Policy Leaders stand to win from improved DM, as policy initiatives require an evidence base from which to develop and adapt. Interestingly, the complexity of the salmon challenge and the methods being developed to deal with the multiple scales and solutions involved mean that SDM can play an important role supporting the development, implementation, and adaptation of policy. Issues such as climate change highlight the complex interplay between societal issues and the inherent tradeoffs that occur at the intersection between policies. Policy Leaders therefore need support in being able to identify and negotiate these intersections. Thus, a SDM community has a role to play by providing an evidence base for informed policy in complex problem spaces. For example, the intersection between climate change and policies protecting endangered or at-risk stocks mean that massive resource may be used to support stocks that have little hope of recovery. Therefore, salmon experts will need to bring their expertise to bear on these complex tradeoffs. Similarly, Enabling Agencies, as aggregators of significant intelligence on the outcomes of policy, have a responsibility to signal back to policymakers when that policy and governance fails to hit the mark or drifts from its intended outcomes.

Policy coordination is also challenged by the diversity of societal needs; intertwined and conflicting policies rarely focus on investments in DM, as the process of DM requires working-level tools and functionality for each component of the data management cycle that cannot be easily tied to specific policies. For example, processes of defining and sharing methodological information or formalizing language models between differing systems of research are essential components of supporting interoperability. Fortunately, examples exist already of Community Leaders identifying these sorts of functional constraints and developing resources that will support implementation and coordination of policy outcomes:

- Pacific Northwest Aquatic Monitoring Partnership (PNAMP) have developed the Monitoring Resources[6] web application, a suite of tools for the community to capture, share, and re-use information about their project's methods and protocols.
- The International Council for the Exploration of the Sea (ICES) Working Group on North Atlantic Salmon (WGNAS) are developing a new Life Cycle Model (Rivot et al. 2021) which is driven by community data (SALMOGLOB[7]; Hernvann et al.

Table 2. Examples of resources for the salmon data community.

Resource Type	Resource
Online DM Resource	Monitoring Resources http://monitoringresources.org/
Online DM Resource	Salmon Ontology https://bioportal.bioontology.org/ontologies/SALMON/?p=summary
Online DM Resource	Salmon Ecosystem Data Hub https://shiny.missingsalmonalliance.org/salhub/
Open Community Tools	Knowledge Network for Biocomplexity Publishing Tools https://knb.ecoinformatics.org/tools
Online DM Resource	State of Alaska Salmon and People (SASAP) https://knb.ecoinformatics.org/portals/SASAP/Data
DM Peer based Incentive	Global Biodiversity Information Facility Data Call https://www.gbif.org/news/2Z7fge80XcPXfdas6iysh7/call-for-data-papers-to-fill-gaps-on-freshwater-species
DM Monetary Incentive	Biennial monetary prize for FAIR research data https://researchdata.nl/en/services/de-nederlandse-dataprijs/
Community Data Solution	The WGNAS-SalmoGlob ToolBox http://sirs.agrocampus-ouest.fr/discardless_app/WGNAS-ToolBox/
Community Data Solution	Online Collection of Fish Samples https://www.colisa.fr/
Community Data Solution	Freshwater Information Platform http://www.freshwaterplatform.eu/
Online DM Resource	ICES Data Centre Tool https://www.ices.dk/data/tools/Pages/Data-profiler.aspx
Online DM Resource	ICES Data Management Best Practices Handbook https://ices-library.figshare.com/articles/report/ICES_User_Handbook_Best_Practice_for_Data_ Management/18700580
Open Community Tools	ICES GitHub presence https://github.com/ices-tools-prod
Open Community Tools	Institute of Marine Research, Norway. GitHub presence https://github.com/IMRpelagic
Open Community Tools	Irish Marine Institute creating a map between two large vocab servers https://github.com/IrishMarineInstitute/ICES2NVS_semantic_map
Community Data Solution	International Year of the Salmon Data Catalogue and GitHub data solution https://data.npafc.org/ and https://github.com/international-year-of-the-salmon
Online DM Resource	Pacific Salmon Foundation Salmon Watersheds Program Data Library and Explorer https://data.salmonwatersheds.ca/data-library/default.aspx https://salmonwatersheds.ca/pacific-salmon-explorer

2021). Data custodians upload yearly data through a template, creating a standardized and well described data resource leveraged by the model.

- The Hakai Institute developed a data federation model for the International Year of the Salmon (IYS) (Johnson and van der Stap 2023) that leverages existing technologies, CKAN[8] and Github[9], to create a transparent data journey from data collection during research cruises through to synthesis and analysis.
- The Salmon Ecosystem Data Hub (SalHub[10]; Diack et al. 2022) is a tool that prioritizes simplified yet interoperable metadata to help users in identifying, describing, and sharing salmon-related datasets.
- The National Centre for Ecological Analysis and Synthesis (NCEAS) has developed and released a community-driven salmon specific ontology (BioPortal SALMON[11]). This ontology provides metadata authors with rich descriptions from salmon research and management, enabling easier linking between related datasets.
- The Atlantic Salmon Research Joint Venture (ASRJV) is developing a 'Data Mobilization Plan' that will facilitate the mobilization of salmon data through a collaborative partnership of over 20 academic, government, non-government, and indigenous organizations in eastern Canada.

These efforts and more (Table 2) show that innovation and drive exist for better SDM within the salmon science community, and these Community Leaders work to extend support to smaller data holders through training and workshops. How these same salmon ecologists and managers can leverage efforts like the UN Decade for Ocean Science, or the USA's "Desirable Characteristics of Data Repositories For Federally Funded Research" (OSTP 2022) remains an important configuration, coordination, and implementation challenge. The answer again lies in improving the connection between these policies and the Community Leaders as pro-SDM sentiment and an appropriate level of understanding is yet to reach a critical mass in the community. Achieving this critical mass will require commitment from Enabling Agencies.

2. Enabling Agencies

Salmon science should be supported by greater adoption of data planning, literacy, and life cycle support through the efforts of data expert roles. Enabling Agencies have the power to provide the resourcing required to enable SDM and create the linkages to policy that supports the growth of these roles. This includes incentives and education around the importance of SDM, funding for full time data expert roles, or where talent pools are limited resources, training and funding are needed to ensure salmon experts have the capacity to carry out SDM tasks properly. In return, Enabling Agencies need evidence of their impact via appropriate attribution of funding and support.

To achieve best effect, DM needs to be included throughout a research plan and involve both researchers and data experts in complementary roles. To achieve this, salmon scientists need sufficient data literacy to understand and engage with DM in their work, as well as support to plan, execute and maintain data processes throughout a project. These investments will ultimately reduce the overall burden on salmon experts during data collation stages of the project, allowing for long-term high quality and harmonized data, and avoiding costly 'Data Rescue' scenarios. Early data planning and coordination amongst partners and stakeholders will also lead to greater repeatability and comparability of the data between sites and years, thus leading to greater scalability and impact of the work. However, data experts alone cannot create an appropriate project-level data management regime, as the origins, use-cases and limitations of salmon data will vary significantly. Multi-disciplinary teams with both data and salmon knowledge are therefore essential, particularly in long-term monitoring projects where legacy data products may need integrating with modern data processes.

This level of integration of data services will require significant effort, starting with suitable data literacy, through training and relevant reference materials to ensure that the knowledge is up-to-date and can be easily recalled. Also, time is required to understand the needs, objectives, and constraints of each subject matter expert. Multi-disciplinary collaborations between people with different backgrounds and motivations require careful consideration to address diverse data needs—but can also create stronger allies and opportunities among collaborators (Poisot et al. 2019). Furthermore, the correct balance of roles and responsibilities needs to be set out from the beginning. A salmon ecology expert should not be expected to fulfill the role of a data expert, and vice-versa, but must be able to carry out everyday data management tasks within an existing framework of guiding principles.

The knowledge and coordination described above requires significant investment, which is where Enabling Agencies can play an outsized role, yet it can be unclear to these agencies how they should make those investments. To support broader awareness and education around data sharing, the Transparency and Openness Promotion guidelines (TOP[12]; Nosek et al. 2015) is a concise framework for funders and publishers to help promote open data throughout their audiences, but also serves as a useful guide for core SDM roles to appraise journals and funding agencies (e.g., https://topfactor.org/). Establishing centers of excellence such as NCEAS and formalized inter-agency working groups such as the IYS, furthers the legitimacy of this expertise by focusing innovation and networking energy on building and maintaining the lasting professional careers and relationships that will carry the DM community forward. Finally, these agencies can invest in large-scale projects aimed at functions such as data rescue, curation, and exposure.

Both funding agencies and publishers are becoming proactive in incentivizing DM, particularly when the funds are coming from a public purse. This leadership encourages future cohorts of scientific researchers to share data by default (e.g., National Science Foundation 2021; Horizon Europe 2022). Some funders have moved directly to enforcement by withholding funds to researchers who fail to comply (van Noorden 2014). Where funding is linked with open access data, data producers are often concerned about scooping or inappropriate use of data. Effective tracking of data provenance can help mitigate these risks and show how open science is positively correlated with increases in citations, media attention, potential collaborators, job opportunities and funding opportunities (McKiernan et al. 2016; Gomes et al. 2022).

As funding agencies and project coordinators gain a deeper understanding of the resource requirements of SDM, data management can be justified in the planning and budgeting phase of research activities. An additional barrier to DM uptake is the availability of sufficient expertise and knowledge resources. To build a pool of expertise, Enabling Agencies can also support training and education programs aimed at the various roles within the core SDM community (Table 3). For instance, salmon experts need time and support to learn the rationale, benefits and application of DM and data management best practices, and an appreciation of the expected project time costs. Universities can help ensure that undergraduate and postgraduate salmon scientists are taught DM and data management best practices as a core part

Table 3. Examples of resource allocation and training opportunities

Example of:	Resource
Dedicated Data Experts	Many agencies now have an online presence dedicated to their data responsibilities, e.g., https://data.cefas.co.uk/, http://data.marine.ie/, http://metadata.nmdc.no/, https://data.marine.gov.scot/ which suggests that they have dedicated Data Expert resource. Specific project level examples are difficult to uncover.
Gamified Online Training	https://community.data.4tu.nl/games/
Short Course Training	https://community.data.4tu.nl/2022/01/27/essentials-4-data-support-registration-now-open/
Short Course Training	https://www.nceas.ucsb.edu/learning-hub/
Short Course Training	https://ukdataservice.ac.uk/learning-hub/
Degree Based Program	https://www.ubishops.ca/bishops-university-launches-new-graduate-certificate-on-knowledge-mobilization/ Teaching DM in universities. Bishop's University (QC, Canada) offering a graduate level certification in Knowledge Mobilization.
Degree Based Program	(Data Science in Biology) program within the biology department of the University of Hamburg (UHH). https://www.biologie.uni-hamburg.de/en.html https://github.com/uham-bio/DSBswirl/
Degree Based Program	Bren's Master of Environmental Data Science degree for students with a background in environmental science, environmental studies, or similar disciplines with exposure to data science and mathematics. https://bren.ucsb.edu/masters-programs/master-environmental-data-science/
Fund Requirements	The data management rules for applications to the Horizon Europe Marie-Curie Doctoral network make it very clear that FAIR data handling is a prerequisite of any successful grant (Horizon Europe 2022). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561563110433&uri=CELEX:32019L1024
Fund Requirements	In the USA, the NSF (National Science Foundation) requires investigators to "*share with other researchers, at no more than incremental cost and within a reasonable time, the primary data, samples, physical collections and other supporting materials created or gathered in the course of work under NSF grants. Grantees are expected to encourage and facilitate such sharing*" (NSF 2021).
Fund Requirements	UK Research and Innovation awards have open data policies requiring funded research to implement data management plans that promote transparency and ease of reuse.
Journal Requirements	Ecology and Evolution (Wiley) requires, as a condition for publication, that data supporting the results in the paper should be archived in an appropriate […] long-term and stable public repositories.
Journal Requirements	Computational Biology (PLOS) The data availability statement must give details of both the data and code that supports the results presented in the article.
Journal Requirements	Peer journals require that all authors are responsible for making materials, code, raw data and associated protocols relevant to the submission available without delay.

of degree programs in ecology and environmental sciences. Similarly, data-experts-in-training should be offered specialization within the ecological/biological informatics realm as a part of data management/informatics degree programs. To ensure that these opportunities are part of a core vision, educating heads of institutions and funding agencies on the benefits of mobilized data as an outcome of good data management (and the costs of data mismanagement) can help put assistance, motivation and correction where needed.

While such large-scale initiatives are certainly desirable, it is also important to account for the time needed to find, hire, and train the people who will undertake this work rather than expecting an existing cadre of researchers and biologists to take on these roles. This time and resourcing for administrative tasks such as hiring or training the right people is an urgently needed missing link that often makes it infeasible for Community Leaders to adopt SDM practice. For this reason, it is vital that guiding policy and governance support is available to underpin the long-term efforts needed.

As primary providers of such background support, Enabling Agencies have much to risk and much to gain from their investment. Implementation of SDM will foster unique skill sets around information management that will easily apply to other problem spaces. By extension, education institutions can leverage this research innovation into unique and attractive education programs that help bolster student recruitment or attract top talent. Publishers can gain increased traffic and influence metrics through additional data citations, and funders can better target their money to address specific or multiple policy objectives. It is therefore a core responsibility of SDM practitioners to acknowledge and advertise the support they receive from resourcing agencies. Salmon management agencies that benefit from increased efficiency in the implementation of programs and potential to better manage tradeoffs must similarly demonstrate the positive impact that SDM has on their work. Policy makers have a responsibility to reliably signal continued support and investment, but also to provide the governance framework that facilitates success in this realm.

3. *Community Leaders*

Establishing a Salmon Data Mobilization Community could serve as an Interest Group of the Research Data

Alliance. This peer network would build social incentives, promote good practice via examples, and engage in a socially active, pro-SDM community to enhance visibility of research activity and data, and foster confidence in appropriate data reuse. This network may also sustain open-source collaborative development of toolkits such as methods libraries, open-source software, controlled vocabularies and web applications.

A peer-support network for SDM would enable active engagement, transparent communication, and inclusive processes. Through such a network, a Salmon Data Mobilization Community (SDMC) can connect subject matter experts and facilitate the sharing of salmon relevant data. To support broader inclusion of data and knowledge types that challenge rigidly held research and management views, SDMC should actively engage with indigenous communities in an environment that promotes knowledge sharing, whilst respecting and supporting the ethical considerations around data sovereignty and stewardship.

The SDMC can establish the practice of SDM by connecting data providers and managers to data repositories and resources, including links to the various community-developed biological or geochemical data standards initiatives and repositories, such as Darwin Core (DwC), or the Climate Forecast Conventions, and international metadata standards such as ISO-19115 and Ecological Metadata Language (EML; Jones et al. 2019). The SDMC can promote resources that help navigate the selection of these standards (i.e., ESIP Biological Observation Data Primer; Benson et al. 2022). Rather than developing salmon-specific standards for the sharing of information, the SDMC can actively avoid reinvention by leveraging existing robust and interoperable knowledge systems, reusing standards, tools, taxonomic authorities, and documentation relevant to the salmon (data) community. The community can promote the latest developments in salmon bioinformatics, semantics, relevant repositories and catalogs, and (controlled) vocabularies, to ensure uptake of existing or newly created toolkits, knowledge, and data standards. The SDMC can enable transparent data outcomes essential for taking on an advisory role for a variety of actors and agencies (e.g., organizations, policy makers, scientists) and to enable timely access and cross-disciplinary data integration of salmon data.

By bringing together early career scientists, data managers, and experienced scientists, participation can be motivated through social incentives, such as the ability to contribute to the development of persistent vocabularies and standards used in salmon science, and career incentives, such as increased citations, scientific community recognition, and opportunities to generate synthesis or collaborative datasets (Gomes et al. 2022).

Tools, best practices, and resources identified within the SDMC can be used to populate project-specific data policies around data management. Well-defined policies outlining data management, data storage, roles and responsibilities and sharing have proven to be successful in both local and larger international collaborative initiatives (e.g., Atlantic Salmon Research Joint Venture,[13] Coordinated Assessments Partnership,[14] International Year of the Salmon,[15] State of Alaska Salmon and People,[16] and Sámi Fisheries Research Network[17]). It will be in the self-interest of data providers to have active participation in the SDMC to ensure that the best practices they will reference from the SDMC in data policies will be the most accurate.

The success and relevance of the SDMC would be contingent upon: (1) participation of the data community; (2) a sustained, unique and attractive open access platform to provide tools to identify relevant data standards and metadata standards; (3) capacity to stay abreast of the latest developments in data and metadata standards; and (4) social incentives to reward adoption of best practices.

As a peer-supported network, the SDMC can be a vehicle for salmon scientists, data managers, funders, and policy makers to implement the requirements for Data Mobilization and reap the rewards and value it offers. It can provide the necessary connections between these groups to better communicate support received from resourcing agencies, demonstrate the positive impact that SDM has on their work, and signal their successes and needs back up the spheres. The SDMC can provide the conduit by which these communications can occur seamlessly. Therefore, following the footsteps of other Data Mobilization efforts, formally establishing a SDMC as an 'Interest Group' under the auspices of the Research Data Alliance which, if effective, could transition to a 'Community of Practice.'

CONCLUSION

Generations of salmon researchers and biologists have collected datasets, often in arduous conditions such as snorkeling down turbulent, nearly freezing rivers to count spawners, not just for the value of immediate applications, but with faith that future analysts will derive ongoing and increasing value from their collections. In the same way that those collecting scale samples in the 1920s could not imagine DNA analysis of the same scales in the 2020s, the present generation cannot imagine the value of their datasets and physical samples in the 2120s. Our call for SDM reflects both the immediacy of alarming salmon declines and the long-term value, an investment with unknowable payoffs, of simply not losing datasets and samples, or the metadata necessary to understand them.

SDM can improve research quality and quantity, optimize logistics of producing, managing, and accessing data, and develop a healthier culture around salmon data. Each of these elements has a part to play in helping us use data more effectively towards salmon conservation (Table 4).

- Research and knowledge, leading to management outcomes, are among the most obvious benefits of Data Mobilization. The 21st century paradigm of

Table 4. Benefits anticipated from SDM.

Area	Benefits	Future State
Research	*We can do better science with mobilized data*	
	Similar datasets can be more easily joined to expand the scope of inference	Increased spatial/temporal coverage
	Enrichment and proxy data can add value to existing datasets	Enhanced analytic tools including machine learning opportunities
	Hypotheses can be revisited and expanded in new contexts	Increased learning and understanding
Logistics	*We work more efficiently, effectively, and collaboratively*	
	It is easier to tell what kinds of information exist or are needed	Better understanding of data gaps and opportunities
	Data and analyses can be re-applied in new contexts	Repeatability gives greater return on investment per dataset
	Synergies and conflicts between analyses can be easily identified	More efficient allocation of effort across projects
Culture	*Our work better reflects core research values*	
	Credit and acknowledgement is given for sharing quality data and metadata. Discourages sharing where ethical or legal considerations do not allow it	Data sharing becomes a valued activity and proper attribution is followed. Avoid negative outcomes for indigenous cultures, aim to benefit those communities in tangible ways (e.g., SASAP)
	Datasets are given greater exposure and peer review, discouraging misuse	Overall data quality increases and misuse is more likely to be highlighted
	New data efforts build on previous works	Data is created that provide deeper insight into the global nature of the problem
	New users of old data provide new context by tracking provenance	The relevance of data expands with each reuse

'data as a product' means that data and knowledge producers have increasing incentives to create data specifically for the purpose of re-use. Research and knowledge outcomes that tap into the concepts of scalability and repeatability will tend to have greater opportunity for funding and promotion.

- Logistical elements such as the management and administration of data efforts can be improved through new tools for implementing data life cycle processes, and dedicated resources for planning and coordination. These elements will in turn influence the data gathering processes, potentially re-writing how data are planned and collected in the first place.
- Cultural outcomes are the social contracts that surround how we create, manage and share data towards common or conflicting goals. Cultural outcomes can be achieved through good relationship-building practices such as defining terms of reference, project charters, and data management plans which detail ethical considerations around data ownership, stewardship, and accessibility where applicable. Such outcomes will help ensure greater equity in terms of what data and knowledge are valued and diversity in terms of how we consider the shared problem of salmon declines.

We expect near-future uses of salmon datasets to address difficult problems, such as how salmon populations evolve life history strategies that tolerate the trends in climate change and variability, and how management actions might affect that. Future SDM provisions to support increasingly high-resolution models of salmon ecology include estimation of salmon marine habitat conditions from, for example, the Atlantis models in wide use (Caracappa 2022), and tracking salmon via eDNA and increasingly sophisticated acoustic and archival tags. The question of what kills more marine salmon now than in the 1980s, and why, will involve attention to a suite of pressures, their active locations and domains, and how human interventions exacerbate or alleviate them; the answers are data hungry. Implementing SDM tools and practices today lays the foundation for SDM processes that will deliver to future data demands.

Progressive thought centered on improving DM in the ecological sciences has been ongoing for decades (e.g., Michener et al. 1994; Cook et al. 2001; Michener and Jones 2012; Wicquart et al. 2022). Within the current technologically rich and socially connected culture and environment, the lack of widespread, default data sharing practices has moved from the realm of an impossibility and cultural aberration to one which is desirable and technically achievable for many but somehow just out of reach. It is clear that the availability of online tools and guides to enable DM has exploded in recent years (e.g., repositories and standards listed in re3data.org), and numerous studies have been published on improving accessibility to DM best practices. Today, it has never been easier to upload data to an online repository with guided metadata authoring tools, provenance tracking, and even licensing and time-based restricted access controls (e.g., Knowledge Network for Biocomplexity[18]). The gulf between the ability to do it, the time to do it, and the desire to do it, needs to be directly tackled. For this, a concerted effort needs to come from all three spheres of agencies and practitioners identified within the SDM socio-technical system.

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Appendix Table 1. A List of online resources (with URLs) referenced in the manuscript.

	Online resource
1	The First Nations Principles of OCAP; fnigc.ca/ocap-training/
2	CARE Principles for Indigenous Data Governance; gida-global.org/care
3	Environmental Research Division Data Access Program; ncei.noaa.gov/erddap
4	Ocean Biodiversity Information System; obis.org/
5	Global Ocean Observing System; goosocean.org/
6	monitoringresources.org
7	sirs.agrocampus-ouest.fr/discardless_app/WGNAS-ToolBox/
8	https://data.npafc.org
9	github.com/international-year-of-the-salmon/
10	missingsalmonalliance.org/salmon-ecosystem-data-hub
11	bioportal.bioontology.org/ontologies/SALMON
12	cos.io/initiatives/top-guidelines
13	ASRJV; dfo-mpo.gc.ca/science/publications/asrjv/plan/index-eng.html
14	CAP; streamnet.org/cap/about-cap/
15	IYS; yearofthesalmon.org
16	SASAP; alaskasalmonandpeople.org/
17	Fávllis; site.uit.no/favllis/
18	knb.ecoinformatics.org/