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FISHGLOB: A collaborative infrastructure to bridge the gap between scientific monitoring and marine biodiversity conservation

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Abstract
Large-scale biodiversity assessments and conservation applications require integrated and up-to-date datasets across regions. In the oceans, monitoring is fragmented, which affects knowledge exchange and usage. Among existing monitoring programs, scientific bottom-trawl surveys (SBTS) are long-term,

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rich, and well-maintained data sources at the scale of each sampled region, but these data are under-utilized in biodiversity applications, especially across regions. This is hampered by the lack of an international community and database maintained through time. To address this, we created FISHGLOB, an infrastructure gathering SBTS and experts. In 5 years, we developed an integrated database of SBTS and a consortium gathering more than 100 experts and users. Here, we are sharing the project history, achievements, challenges, and outlooks. In particular, we reflect on the infrastructure-building social and technical processes which will guide the development of similar infrastructures. The FISHGLOB project takes ocean monitoring one step forward in working as a unified community across disciplines and regions of the world.

KEYWORDS
biodiversity monitoring, bottom trawl surveys, community-building, dataset integration, global change, knowledge transfer, marine fish, species conservation

1 | INTRODUCTION

The United Nations (UN) Decade of Ocean Science for Sustainable Development seeks to mobilize existing data to understand global change impacts on marine ecosystems and conserve biodiversity (Franke et al., 2023). The UN Decade of Ocean Science complements and supports international ocean-related goals from the Sustainable Development Goals (SDGs) and the Kunming-Montreal Global Biodiversity Framework. Goals such as the SDG 14 "Life below water" and the SDG target 17.16 "Enhance the global partnership for sustainable development" require available and easily accessible syntheses of biodiversity information to assess evidence of ocean change and recovery, plan conservation actions, and track progress towards conservation targets worldwide.

Scientific ecological surveys, which use consistent and well-documented sampling methods through time, are vital to this effort (Edwards et al., 2010). However, there are only a few initiatives that exist to compile and harmonize the metadata and data collected by marine scientific surveys at larger spatial scales. This is mostly because of disparities in visibility, availability, and capacity across regions of the world, making such coordinated efforts particularly challenging. Limited availability of funding for maintenance of partnerships and data products for long-term continuity adds to the difficulty in establishing successful integrated datasets (Kühl et al., 2020). As a consequence, applications of these survey data in informing conservation and management in relation to international goals–such as biodiversity conservation across borders, species conservation status, climate change adaptation, and biodiversity indicators for reporting conservation targets–remain limited. This is especially problematic because data usage increases with time and effort spent updating datasets and growing a trained community of users.

To try to fill this gap, we initiated a project called FISHGLOB (originally the biodiversity working group "fish biodiversity under global change" https://www.fondationbiodiversite.fr/en/the-frb-in-action/programs-and-projects/le-cesab/fishglob/) to identify and integrate monitoring datasets from scientific bottom trawl surveys (SBTS) supporting ocean biodiversity monitoring. FISHGLOB's overarching goal is to support the translation of biodiversity knowledge into conservation actions and informed decision-making in an era of profound change. This goal is supported by a social infrastructure enhancing cross-regional collaborations (FISHGLOB consortium) and a technical infrastructure developing analytical tools for integrating datasets (FISHGLOB technical infrastructure). Calls to accelerate research to solve global issues have included both enhanced collaboration and technical infrastructure as key elements (Heberling et al., 2021; Lowndes et al., 2024; Malekpour et al., 2023). FISHGLOB's strategy relies on stronger cooperation across marine regions, enhanced data availability, and the creation of a user community to lead expanded use of SBTS in favor of a healthier ocean. Here, we present progress, lessons learned, and opportunities with FISHGLOB to increase awareness of challenges and solutions in creating global collaborative infrastructures around biodiversity monitoring datasets to enhance knowledge coordination for conservation purposes.

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2 | THE PROCESS TOWARDS THE SOCIO-TECHNICAL FISHGLOB INFRASTRUCTURE

2.1 | Mobilizing scientific/biodiversity surveys

In 2019, three early career scientists organized a meeting at the International Council for the Exploration of the Sea (ICES) Annual Scientific Conference to discuss collaborations around SBTS which sample continental shelves (Figure 1), some of the most diverse and productive marine ecosystems. The first SBTS started as early as the 1900s to collect demersal marine species (living over and on the sea bottom) and provide data for fisheries management and ecosystem monitoring independently from the fishing industry.

The 2019 initiative led to the first global inventory of SBTS metadata, revealing 95 recurring and ongoing surveys across all continents and covering more than 283,000 sampling events across 2.5 million km^2 of seafloor since 2000 (Maureaud et al., 2021). Over 40% of the survey data were publicly available in the inventory, while the rest had varying levels of accessibility (Figure 2). Focusing initially on an inventory of metadata allowed us to build a comprehensive catalog of existing surveys and an international consortium. One of our contributions to the global marine biodiversity community is that no other biodiversity data repository encompasses such a comprehensive SBTS metadata compilation (Table S1). Sharing our experience in consortium-building and inventorying is broadly valuable, as cross-regional data accessibility is a challenge for many other types of marine monitoring surveys (Figure 2).

Survey data accessed via public repositories or collaborations have been integrated for the first time into a technical infrastructure by the FISHGLOB biodiversity synthesis working group. Procedures were developed for data quality control and standardization that allow for cross-continental integration of SBTS (Maureaud et al., 2024). The public data products are version-controlled with openly available code on GitHub to facilitate the standardized use of 29 surveys (Maureaud et al., 2023, https://github.com/AquaAuma/FishGlob_data). This dataset fills a critical gap since existing data repositories do not allow for such a comprehensive SBTS compilation. Specifically, not all 29 publicly available SBTS are compiled in a single global repository, abundance/biomass data are not necessarily reported within already existing biodiversity data repositories, and

FIGURE 1 Monitoring demersal communities with scientific bottom-trawl surveys (SBTS). Sampling steps with SBTS: Trawling operation (a) and (b), bringing the trawl back onboard (c), catches from the haul (d), individual specimen identification and measurements (e). Survey photo credits: Elitsa Petrova from the Institute of Fish Resources in Bulgaria (Western Black Sea survey in [a] and [e]), Svanhildur Egilsdóttir from the Marine and Freshwater Research Institute in Iceland (Icelandic survey in [c]), and George Tserpes from the Hellenic Center for Marine Research in Greece (Mediterranean Survey via the MEDITS program in [b] and [d]).

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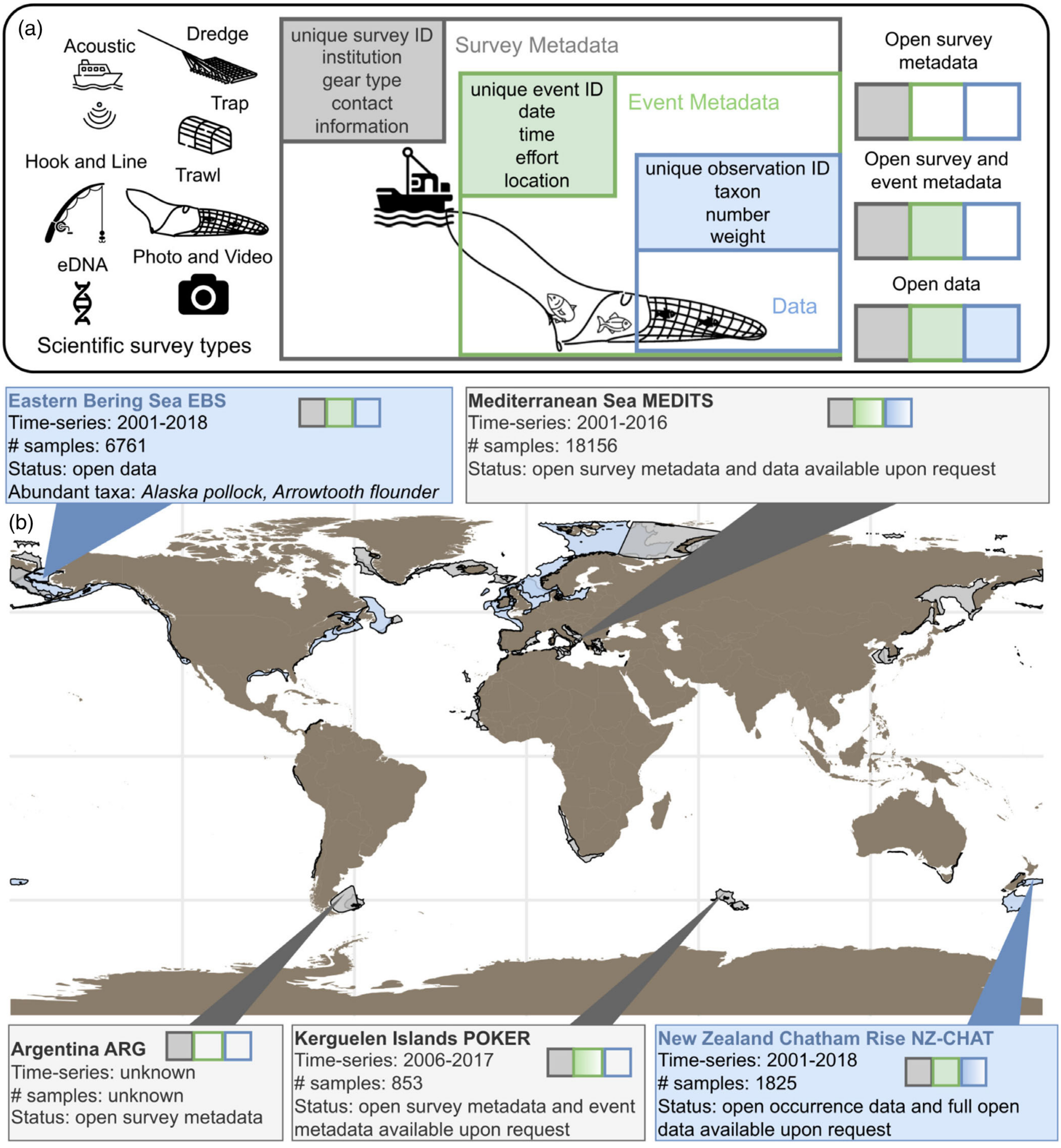

FIGURE 2 SBTS data structure and availability around the demersal seas of the world. Scientific survey datasets in the oceans can be performed with a wide range of designs and sampling methods ([a] on the left). Within scientific surveys, SBTS in FISHGLOB ([a] on the right) are structured around the integration of the survey metadata (gray) with individual sampling event metadata (green) and biological observations (blue). The FISHGLOB technical infrastructure supports a range of data privacy, from fully open survey data to surveys with only survey-level metadata that are public. SBTS regions sampled since 2001 and their range of data accessibility adapted from Maureaud et al., 2021 (b). When the metadata or data are available upon request, the corresponding legend box was filled with a color gradient. The availability status of five example surveys is detailed at the top and bottom of the world map. The map additionally displays a land layer from the Natural Earth Data (https://www.naturalearthdata.com). Icon credits in (a): https://www.flaticon.com.

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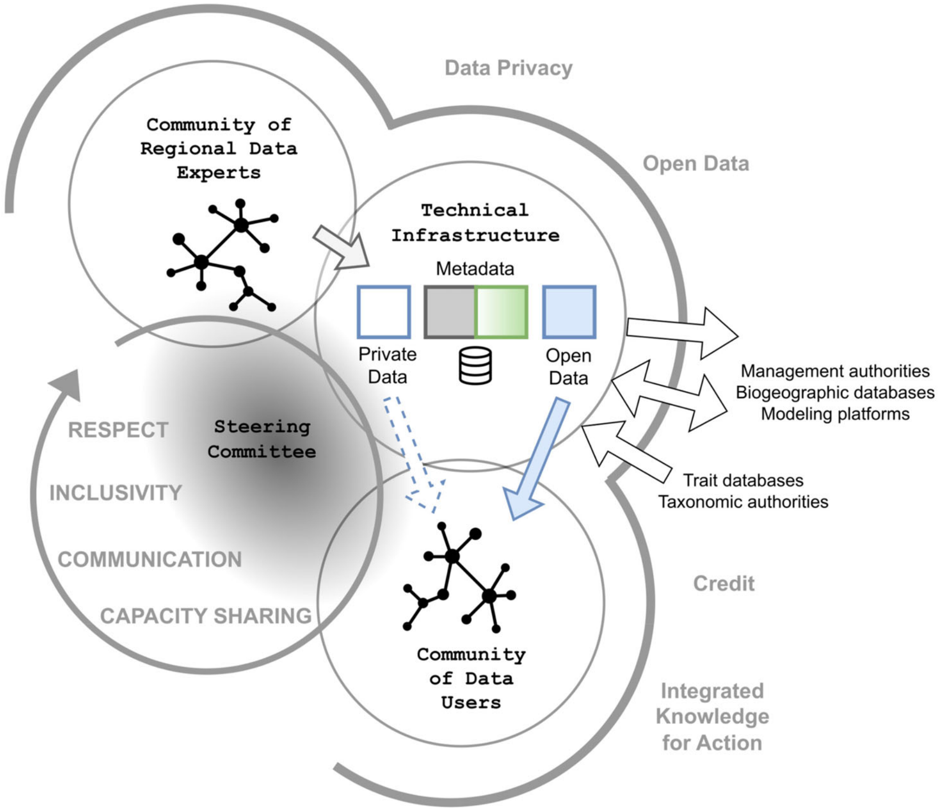

FIGURE 3 The FISHGLOB socio-technical infrastructure. The FISHGLOB infrastructure is centered around shared values, two primary communities, and a technical data integration process and datastore, coordinated by a steering committee. The FISHGLOB infrastructure specifically recognizes and includes a range of data privacy for the metadata and survey data (Maureaud et al., 2021), following both open science and FAIR principles (Wilkinson et al., 2016). FISHGLOB needs to further develop its connections within the landscape of other data platforms to ensure interoperability of SBTS. The philosophy behind the infrastructure supports both credit to experts and contributors, as well as the use of integrated knowledge for action in an era of global change.

regional repositories compiling subsets of SBTS are not easily combined with each other (see details in Table S1). FISHGLOB's technical infrastructure includes several levels of information, ranging from survey metadata and event-based metadata to species occurrence and abundance data, thereby optimizing visibility and transparency under different levels of accessibility (Figure 3).

An important opportunity for FISHGLOB moving forward will be to ensure regular updates of the SBTS metadata and data. The current infrastructure on Github allows the broader community to identify issues, opportunities, and solutions, which the steering committee can then moderate and incorporate (Figure 3). Quarterly meetings of this committee facilitate the process. In addition, SBTS surveys continue to operate, and new data can therefore be incorporated in regular updates. Based on previous experience, new data also bring changes in the format of data delivery or protocols for at least one survey. It requires matching changes in data processing, cleaning for integration, and coordination. Such updates need support from dedicated funding and capacity.

2.2 | Linking the data infrastructure

The development of the data infrastructure led to considering its integration in the larger landscape of biodiversity databases. FISHGLOB currently reconciles taxonomy from the World Register of Marine Species (WoRMS, https://www.marinespecies.org/, Figure 3). This already enables connecting SBTS to trait databases (e.g., FishLife https://github.com/James-Thorson-NOAA/FishLife, FishBase https://www.fishbase.se/). This direct integration of SBTS with other data sources enables research applications, for instance, related to trait-based ecology (Beukhof et al., 2019; Thorson et al., 2023).

Several other existing databases and data infrastructures can be considered to be connected with the FISHGLOB database. These were identified when new consortium members shared ideas for new applications of SBTS, or during the synthesis group meeting that took place in spring 2023 that gathered 10 of us. SBTS applications can be enhanced via linking the FISHGLOB dataset with biogeography data repositories (e.g., the Ocean Biodiversity Information System https://obis.org/, the Global Biodiversity Information Facility https://www.gbif.org/, Aquamaps https://www.aquamaps.org/), species modeling tools (Grüss et al., 2024; Thorson, 2019; Thorson et al., 2024), species and biodiversity conservation platforms (e.g., the IUCN Red List https://www.iucnredlist.org/, the Group of Earth Observations Biodiversity Observation Network https://geobon.org/), ecosystem modeling platforms (e.g., the Fisheries and Marine Ecosystem Model Intercomparison Project https://www.isimip.org/

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about/marine-ecosystems-fisheries/), fisheries data platforms (e.g., RAM legacy database https://www.re3data.org/repository/r3d100012095, the Sea Around Us project https://www.seaaroundus.org/), and institutional data servers (e.g., ICES-DATRAS https://www.ices.dk/) and visualization tools (e.g., NOAA DisMAP https://apps-st.fisheries.noaa.gov/dismap/DisMAP.html).

Further development of metadata standards is needed to better connect the above-mentioned initiatives. For example, Darwin Core (Wieczorek et al., 2012) is a well-used data and metadata format for species occurrences that cannot fully capture central information from monitoring scientific surveys. Linking to nascent inventory metadata standards, such as the Humboldt Extension to the Darwin Core (Guralnick et al., 2018), may provide an elegant solution for FISHGLOB's technical infrastructure and alike initiatives. Establishing operational links between primary data sources and data aggregators are crucial to develop downstream biodiversity data products such as species distribution maps and biodiversity indicators (Jetz et al., 2019; Sandall et al., 2023). These, in turn, can inform the conservation and management status of species and ecosystems, in line with international policies.

2.3 | Values to bring people together

While SBTS are similar in their sampling design, most surveys are conducted locally or regionally. This is true for most scientific monitoring programs, often leading to fragmented scientific communities with regional disparities in survey visibility, capacity, and availability (Chapman et al., 2024; Maureaud et al., 2021), resulting in biased spatial representation of biodiversity sampling worldwide (Hughes et al., 2021; Lenoir et al., 2020). As such, larger scale integration is dependent on the success of cross-regional partnerships to allow for scientific knowledge exchange that less specialized platforms often cannot tackle.

At the beginning of the project, consortium members were identified as survey data holders in most countries of the world through wide searches in existing networks and known fisheries institutes from all continents (Maureaud et al., 2021). Representation of most surveyed regions has been a central aspect when searching for new international collaborations. We also welcomed experts who led us to make successful connections to SBTS data holders. Our community continued to grow as we started developing data products and encouraged reaching out to us. We tried to maintain engagement via scientific contributions such as this one, as well as frequent communications asking for feedback, ideas, and scoping interest. For instance, we produced SBTS summaries for each region and used the technical infrastructure as a way to engage with experts, and ask for feedback on the data integration and interpretations of our findings early on (see for instance https://github.com/AquaAuma/FishGlob_data/blob/main/summary/ebs.pdf to access the Bering Sea SBTS summary). This procedure was repeated for each individual survey accessed. We found that this step allowed for open communication, reaffirmed that expertise is necessary and appreciated, and helped in building more trust in the generated data products.

This is why in the FISHGLOB consortium we considered people, relationships, and trust among partners to be fundamental for understanding demersal biodiversity and ecosystem dynamics across regions. In 2022, a series of webinars resulted in recognition of shared interests in data and knowledge exchange among consortium members, while also revealing substantial diversity in goals (e.g., providing, using, or coordinating technical and social infrastructures) and capacity. Maintaining long-term participation requires shared values, ethos, and frameworks for data sharing that offer tangible benefits to participants. In this context, we identified key values for the consortium (Figure 3) aligned with the United Nations Educational, Scientific and Cultural Organization's recommendations on open science (UNESCO,https://www.unesco.org/en/open-science), including:

- Open data and open science as guiding principles to enable wide societal benefits.
- Data sovereignty and a recognition that data originators may place limits on visibility, access, and on how data are used, such as through licensing, data use agreements, and prior and informed consent approaches, all of which follow the FAIR principles (Findable, Accessible, Interoperable, Reusable; Wilkinson et al., 2016).
- Capacity sharing to grow an international community that addresses historical, linguistic (Amano et al., 2023), cultural, financial, political, technical, and structural barriers to participation. Capacity is essential because sharing data can perpetuate rather than overcome inequities by benefiting users from countries that already have the most financial capacity (MacFadyen et al., 2022; Trisos et al., 2021).
- Credit and visibility for consortium members, including documented methods for citing data products and inclusive models for authorship.

At the core of the infrastructure, these values facilitate participation while respecting sovereignty and credit for contributions by experts. They are transferable to

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other cross-regional monitoring schemes and can serve as a foundation for more equitable, representative, and transparent infrastructures that sustain long-term partnerships (Ross-Hellauer et al., 2022).

The FISHGLOB consortium currently includes more than 100 contributors from 36 countries (see the full list on the FISHGLOB website https://fishglob.sites.ucsc.edu/fishglob-consortium-join-us/), which is a great achievement in 4 years. Since 2023, FISHGLOB has been endorsed by the UN Decade of Ocean Science SUPREME Programme (https://oceandecade.org/actions/fish-biodiversity-facing-global-change-fishglob/), demonstrating broad participation and recognition. As part of the UN Decade of Ocean Science, a longer-term priority is the further development of collaborations between regions with different levels of capacity and that do not currently operate under open science policies. These collaborations will be essential in establishing a global inclusive and equitable community conscious of the western-biased and colonial history of ecology, now and in the past, and the need of actively practicing decoloniality (Trisos et al., 2021; Woodall et al., 2021). Such opportunities need support from international organizations and funding agencies and are key in meeting conservation and sustainable international goals in all demersal seas of the world.

3 | FUTURE CHALLENGES AND APPLICATIONS

3.1 | Monitoring and infrastructure sustainability

Ensuring consistent regional and global monitoring is challenging because of survey and funding disruptions. This can impact scientific capacity to monitor the impacts of climate change on demersal seas in the case of SBTS (Berg et al., 2021), or inform the conservation status of sensitive species over time. Since FISHGLOB is already in a place to connect regional experts together across SBTS regions of the world, the socio-technical infrastructure could be used to monitor changes in SBTS, including temporal and spatial trends in data coverage, as well as alerting the broader community to the importance of SBTS monitoring for conservation science and practice.

Maintenance of infrastructure for continuity of FISHGLOB is a common limit in infrastructure development (Kühl et al., 2020). Building long-term partnerships that are beneficial for all partners takes a long time and requires financial and human resources that are often scarce. In FISHGLOB, we have identified priorities to maintain the infrastructure and consortium given current limited capacity. For instance, the steering committee was established to divide responsibilities to maintain the consortium, the database, the development of research applications, and the link with stakeholders, regardless of personnel turnover. Efforts are targeted towards maintaining and updating the list of consortium members, and especially the list of regional SBTS experts, which is rapidly changing and expanding. The steering committee also serves as a way of centralizing information and opportunities for growth and collaborations with other projects (as described in Section 2.2). Identifying new applications and filling knowledge gaps are central to developing a socio-technical infrastructure that will be useful and likely picked up by the community in the short- to long-term.

3.2 | Co-development of new conservation applications

Infrastructure building relies on a social process of identifying needs and solutions that maximize community participation and thus requires consultation for its development (Chapman et al., 2024; Montana, 2019). A survey distributed to data providers and regional experts in the FISHGLOB consortium allowed gathering interests of experts from 14 regions where SBTS are ongoing but not public. This study allowed identifying that standardized sets of visual summaries, including biodiversity change indicators and maps of species distributions, would be a useful, value-added product for the consortium, both at the scale of single regions or multiple regions. Our survey complemented existing work on public SBTS that has already led to broadly disseminated knowledge and data products. As a future outlook, sharing survey data deliverables on an online platform aims to lower the barrier of using SBTS data for management and education purposes, much as similar maps from OceanAdapt (https://oceanadapt.rutgers.edu/) enabled widespread use by journalists, students, and teachers, textbook authors (Cardinale et al., 2020), fisheries management councils, environmental agencies, and conservation non-profits. Partnerships with conservation and societal initiatives strengthen efforts to co-develop products responding to the needs of the consortium and larger audiences.

The FISHGLOB consortium has identified priority applications that can uniquely be enhanced by the infrastructure, and its scientific community of experts and users have started to demonstrate its potential in recent publications. One important theme is marine communities' response to climate change and adaptation of management responses (Fredston et al., 2023; Maureaud

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et al., 2021). This theme can be tackled with empirical or predictive modeling methods to understand climate change impacts and anticipate future changes, and test management scenarios. A second application is the contribution of SBTS surveys to indicators described in Essential Biodiversity Variables and Essential Ocean Variables to measure cross-taxa biodiversity change (Johnson et al., 2024; Miloslavich et al., 2018; Muller-Karger et al., 2018). A third important application is the inclusion of SBTS in population IUCN Red List assessments where fish taxa are currently misrepresented (Cazalis et al., 2022; Miqueleiz et al., 2020). By combining the FISHGLOB dataset with a new modeling method (Grüss et al., 2024), robust and up-to-date IUCN Red List assessments can better inform marine fish population and species conservation status. While previously neglected in conservation applications, SBTS are data-rich sources of information that can allow for robust, continuous, and representative monitoring of populations and species.

4 | CONCLUSION

Our example in establishing FISHGLOB as a socio-technical infrastructure shows how to enhance coordinated and representative biodiversity assessments for better conservation. The FISHGLOB infrastructure facilitates innovation by integrating SBTS across regions in a time when scientific evidence is needed to inform conservation and tackle unprecedented ocean change. FISHGLOB creates an opportunity for all those who wish to be involved to collectively provide evidence for how humans changed the ocean, and to act for the ocean we want (to join the consortium, readers can sign up at https://fishglob.sites.ucsc.edu). We encourage similar collaborative projects to embrace the representation of diverse perspectives by connecting communities who generate and use marine datasets. Only then can we better assess and disseminate knowledge of ocean change and recovery to practitioners and policy-makers across regions of the world.

AUTHOR CONTRIBUTIONS

In this article, there are 63 authors. Ten of us met for a working group in person in 2023 and led the primary draft of the manuscript (Aurore A. Maureaud, Zoë Kitchel, Alexa Fredston, Robert Guralnick, Juliano Palacios-Abrantes, Maria L. D. Palomares, Malin L. Pinsky, Nancy L. Shackell, James T. Thorson, and Bastien Mérigot). Then, the draft was shared with every person from the consortium, and the whole group had the opportunity to read, edit, and comment on the text. Persons who were invited as authors have contributed to the activities of our project (e.g., working groups, webinars, data processing, data sharing, infrastructure development, data usage, project strategy) which have shaped the experience and vision described, and contributed to the writing. We are an international consortium, so taking into account the perspectives of each regional expert has been critical in developing our work.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

All data described in this article are public. Bottom trawl survey metadata are taken from a previous publication (https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.15404). Descriptions of bottom trawl survey data are based on a previous publication (https://www.nature.com/articles/s41597-023-02866-w). The availability assessment of trawl surveys is based on public repositories, and all links are provided in the supplementary information table.

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