frontiers | Frontiers in Remote Sensing

TYPE Original Research
PUBLISHED 07 January 2025
DOI 10.3389/frsen.2024.1484283

OPEN ACCESS

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RECEIVED 21 August 2024
ACCEPTED 11 December 2024
PUBLISHED 07 January 2025

CITATION
Lecours V, Misiuk B, Butschek F, Blondel P, Montereale-Gavazzi G, Lucieer VL and McGonigle C (2025) Identifying community-driven priority questions in acoustic backscatter research.
Front. Remote Sens. 5:1484283.
doi: 10.3389/frsen.2024.1484283

Identifying community-driven priority questions in acoustic backscatter research

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Introduction: Remotely-sensed acoustic backscatter is an indispensable tool for seabed mapping, among other disciplines. Almost a decade after the GeoHab Backscatter Working Group published its guidelines and recommendations report, new technologies, new challenges and new questions have emerged. Given the range of potential backscatter research avenues, it can be difficult to align research programs with the priorities of the community of practice. Prioritization of backscatter research topics is thus necessary to establish a roadmap for acoustic backscatter research efforts.

Methods: We asked the international community working with acoustic backscatter to submit their priority research questions over a 5- to 10-year horizon. We analyzed and curated a total of 177 research questions from 73 contributors, and the resulting 104 questions were grouped into eight broad recurring themes: "Technologies", "Calibration", "Data acquisition and ground-truthing", "Data processing", "Post-processing, quality control, data handling, and curation", "Data analysis", "Data interpretation", and "Applications and end uses". A follow-up survey based on the final list of questions was distributed to characterize the community working with backscatter and to identify key research priorities.

Results: A total of 120 responses originating from 23 countries were used for the analyses. Most respondents were researchers (68%), while others were technicians (25%) or department or program managers (11%), among other roles. Affiliations of respondents included academia (43%), governmental agencies (37%), and industry/private sector (18%). After scaling the responses, the most commonly selected theme was "Post-processing, quality control, data handling, and curation", followed by "Calibration" and "Data analysis". Respondents consistently ranked several research questions as priorities. The two questions that were identified as priorities by over 25% of respondents were "How can we move towards absolute calibration of different systems to allow interregional comparisons?", and "How can we quantify seafloor backscatter quality and develop standards similar to what exists with bathymetry?".

Discussion: All eight themes are represented in the top 10 priority questions, underscoring the need for contributions to backscatter research from multiple perspectives to advance the field. The ranking of priority questions encourages collaboration within the community and will serve as a roadmap for backscatter research programs over the next decade.

KEYWORDS

acoustic remote sensing, backscatter, geomorphology, mapping, marine habitats, seabed, seafloor, sonar

1 Introduction

Acoustic backscatter has been used for decades to characterize physical and biological properties of the water column and seafloor, improving our understanding of these environments for disciplines such as fisheries and geophysics. In recent years, improving how acoustic backscatter from multibeam and sidescan sonar can be used in disciplines like seafloor habitat mapping has become a new research focus for many (Misiuk and Brown, 2024). This trend is likely to endure with new developments including multi-frequency echosounder systems (Brown et al., 2019; Mopin et al., 2022) and interferometric synthetic aperture sidescan sonars (Zhang et al., 2023). Despite its relatively widespread use, much remains to be established in terms of our theoretical understanding of acoustic backscatter signals at different frequencies and how they interact with the environment, particularly in terms of practical and technological exploitation (*e.g.*, field sampling, calibration protocols). Improvements in acoustic backscatter utilization are aligned with the United Nations Sustainable Development Goal (SDG)-14 "Life below water", which is central to addressing other SDGs, namely, "Hunger" (SDG-2), the key link to "Climate" (SDG-13) and to "Water" (SDG-6), "Energy" (SDG-7), and "Ecosystems" (SDG-15) (Dawes, 2020).

In 2013, members of the GeoHab community (Marine Geological and Biological Habitat Mapping: https://geohab.org/) founded the Backscatter Working Group (BSWG: https://geohab.org/backscatter-working-group/). Within 2 years, the BSWG produced a report detailing guidelines and recommendations for backscatter measurements by seafloor mapping sonars (Lurton and Lamarche, 2015). The report was followed by a special issue in *Marine Geophysical Research* (Lamarche and Lurton, 2018a), which included a study about user expectations for multibeam backscatter (Lucieer et al., 2018). These were the first community-driven efforts towards establishing a documented guide for "best practices" related to employing acoustic backscatter data for seabed mapping. The report—which included topics such as data collection and processing, analysis, and interpretation—and the manuscripts in the special issue have become essential reference material for those working with acoustic backscatter. Now, 10 years later, the BSWG has reorganized itself into branches focusing on specific components of backscatter research (*e.g.*, data acquisition, data processing, data analysis and interpretation, multispectral, water column backscatter; Brown et al., 2022). A workshop was organized by the BSWG in October 2022 to identify ways in which to advance the scientific research on acoustic backscatter (see Brown et al., 2022 for more details). In order to determine how the field had progressed since 2013, it was necessary to map the current trajectory of the research themes initially included in the report and permit the inclusion of contemporary research avenues enabled through technological advances (*e.g.*, water column data), and changes in the ways backscatter data are used. This paper presents new and outstanding research questions from the backscatter community of practice, in order to identify knowledge gaps. The aim was to establish a consensus about prioritizing these research questions in order to advance the field over the coming decade.

Though methods such as literature and metadata reviews may be used to identify themes in the published backscatter literature (*e.g.*, Misiuk and Brown, 2024), this does not permit an open discussion amongst the community of practice. When attempting to distill a set of key research questions that involve confounding factors or incomplete data, the Delphi technique (Dey et al., 2020) recommends the use of strategically designed surveys to obtain reliable information from certified experts (*e.g.*, Hallowell and Gambatese, 2010). With this approach, survey respondents are selected according to predefined guidelines, and are queried via rounds of structured surveys. After each round, the facilitating team provides an anonymous summary of all previous answers for review by the respondents, aiming to decrease the variability of responses and achieve some form of consensus. This approach has been

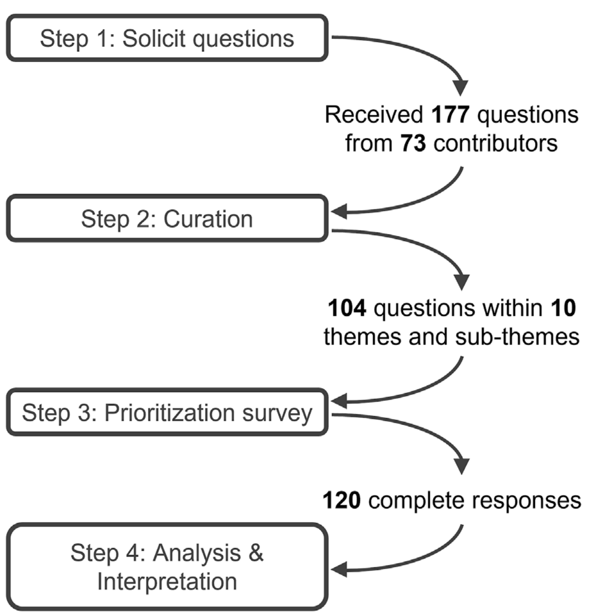

FIGURE 1
General workflow guiding this study.

successfully applied across different domains from construction engineering and management (Hallowell and Gambatese, 2010) to seascape ecology (Pittman et al., 2021) and seagrass conservation (Nordlund et al., 2024). We have drawn on these studies to adapt this approach to acoustic backscatter research. We first invited acoustic backscatter experts from different user groups to present the research questions they believed should be prioritized within the next five to 10 years. We then curated the questions and grouped them under broad themes. The final list of categorized questions was distributed among the wider community of practice, including users who self-identified as non-expert, who were tasked with a) selecting the questions they deemed most important, and b) ranking their top priorities.

2 Methods

The general workflow is presented in Figure 1 and was inspired by similar efforts conducted in recent years for other disciplines (*e.g.*, Pittman et al., 2021; Nordlund et al., 2024). In short, we solicited research questions from acoustic backscatter experts that they consider important to answer in a five-to ten-year horizon. We curated the questions and built a survey to facilitate their prioritization. The survey was distributed to the wider community of backscatter data users, and the results were interpreted.

2.1 Collection of research questions

In September 2022, potential expert participants were invited to submit a maximum of three questions they considered to be acoustic backscatter research priorities for the next five to 10 years. The criteria provided to developing a question were: i) to be of broad relevance (*e.g.*, not related to a specific study site); ii) to be answerable through a scientific research design; iii) to not be answerable by a simple "Yes" or "No"; and iv) to produce factual, objective answers associated with a measurable and repeatable outcome.

Being Specific, Measurable, Assignable, Realistic and Time-bound, these questions followed the traditional SMART criteria. Experts were encouraged to include a short justification (50–100 words) for each question that they provided. The invitation was first distributed through the BSWG mailing list, with other contacts appended by the authors, resulting in a list of 350 potential participants. Recipients were asked to forward the invitation to colleagues in academia, government, non-governmental organizations, or industry with the appropriate expertise in acoustic backscatter, expanding this to a network of potentially hundreds of researchers worldwide.

2.2 Curation of research questions

The authors of this project have a diversity of experience related to acoustic backscatter research. This diversity is represented by various disciplinary expertise across a range of backscatter research topics, and a cumulative a total of 106 years of experience working with backscatter at the end of 2024 (mean of 15 years). The group was therefore well-qualified to review proposed research questions to ensure compliance with the established criteria. When a question did not meet one or more criteria, the group collaboratively modified it for compliance, whilst retaining the original meaning and intent. This process was facilitated through the justifications provided for each question. The group also divided some questions into many to simplify them, and combined or eliminated others to eliminate redundancy. In some cases, additional questions were detected within the short justifications provided by experts. These were extracted and integrated into the final list of questions. Finally, the group qualitatively analyzed the questions and identified broad recurring themes, and each question was collaboratively assigned to one of these themes. Community feedback on the definition of the broad themes was sought at the October 2022 workshop of the BSWG held in Halifax, Canada (Brown et al., 2022), and additional themes were explored via word clouds from the questions.

2.3 Survey distribution

A survey based on the final list of questions was built using the Qualtrics™ platform (Snow and Mann, 2013). An introduction was provided to describe the motivation for the survey. Then, to characterize the community of practice, personal information was solicited, including whether participants contributed questions in the first phase, their location and country of work, primary expertise, primary fields of application, sector, and primary role in their organization. Participants were then presented with each theme, one at a time, and its associated questions. The participants were asked to select all questions within each theme that they considered a priority question to address in the next decade; they could select none, some or all of them. Survey respondents were also asked to self-evaluate their expertise in each theme on a scale from zero (no expertise at all) to five (very high expertise). Having completed all themes, survey respondents were presented with all questions they had selected, independent of themes, and were asked to select only seven of them as their top priority questions. Finally, they were presented with these seven questions and asked to rank them from the highest priority to the lowest priority.

The survey was distributed to the contributors of questions and through the initial list of 350 potential participants described in Section 2.1. The survey was also distributed through the GeoHab mailing list in May 2023 (over 1,300 potential participants, with some duplicates from the initial list). Again, recipients were invited to forward the invitation to colleagues in academia, government, non-governmental organizations, industry, or others who might be interested in prioritizing questions in acoustic backscatter research, expanding the total list of potential participants to thousands.

2.4 Analyses

Several analyses were performed to characterize survey respondents and their response patterns. First, we characterized the community of practice. Descriptive statistics, exploratory data plots, and maps were produced to illustrate the relative proportions of respondents per sector of activity (*e.g.*, academia, governments,

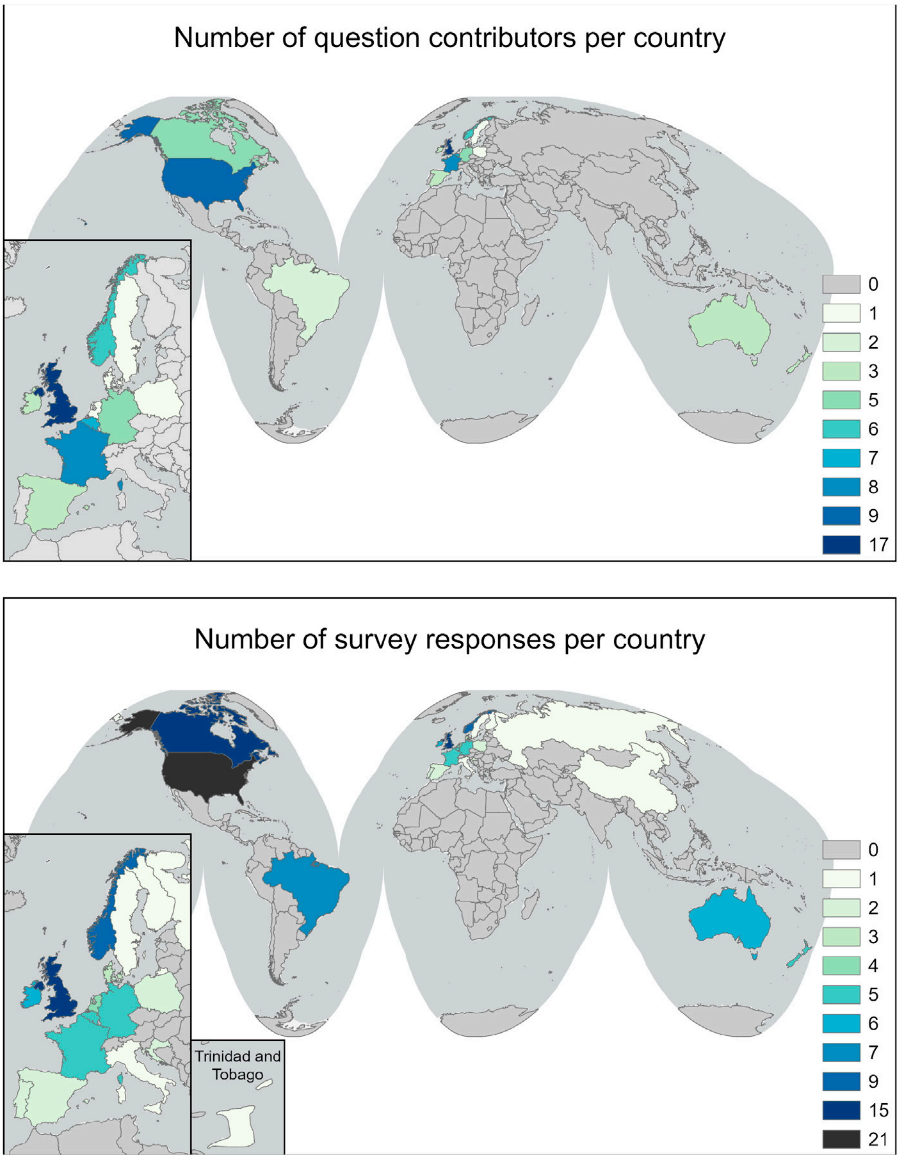

FIGURE 2
Countries in which contributors of questions work (top, N = 73), and countries in which survey respondents work (bottom, N = 120).

industry), geographic distribution, self-identified expertise levels per theme, expertise, fields of applications, and roles within their organization.

We then evaluated the priority themes through a scaled cumulative count (scc_i; equation below) of questions selected by theme, which was calculated by dividing the number of times a question from a given theme made it in the top seven selection (f_i) by the total number of questions in that theme (n_i), then multiplying by the average number of questions per theme ($\bar{x}$) (equation below); this effectively scales the selection frequency by the number of questions in a theme, then adjusts to the range of the average number of questions in all themes. This allowed for more direct comparisons among themes with differing numbers of questions. We performed a regression to test whether respondents with more expertise tended to select greater or fewer questions per theme using linear mixed-effects modeling.

$$scc_i = \frac{f_i}{n_i}(\bar{x})$$

Next, we investigated the priority questions using a frequency distribution analysis and the overall priorities using the rankings provided by respondents. This resulted in three tabulated rankings based on: (1) the number of times each question was identified as important, (2) the number of times each question was selected among the top seven, and (3) a relative importance score (*ImSc*, equation below), equal to the sum of inverted ranks (x_{pl}); the inversion of the priority ranking entered by respondents was necessary to ensure that summed scores reflected greater priority within the community of practice. For example, a ranking of seven became the most important instead of a ranking of 1, while unselected questions retained a 'no data' value. This ensured that the higher relative importance scores were in fact higher priority.

TABLE 1 Broad themes defined by the authors, number of questions included within them, average level of expertise of respondents associated with each theme, and statistics for theme ranking (1 being the highest).

	Themes		Number of questions from initial list	Average and standard deviation of self-reported expertise of respondents	Number of times a question from the theme made it in the top 7 selection	Scaled cumulative counts (scc_i)	Ranking in terms of priority themes (standardized selection)
1	Technologies		15 (14.4%)	2.73 (1.28)	119 (14.2%)	82.51	7
2	Calibration		10 (9.6%)	2.38 (1.29)	89 (10.6%)	92.56	2
3	Backscatter data acquisition and ground-truthing		11 (10.6%)	2.86 (1.25)	91 (10.8%)	86.04	5
4	Backscatter data processing		9 (8.7%)	2.78 (1.27)	77 (9.1%)	88.98	4
5	Post-processing, quality control, data handling and curation		9 (8.7%)	2.70 (1.28)	89 (10.6%)	102.84	1
6	Backscatter data analysis		12 (11.5%)	2.83 (1.37)	106 (12.6%)	91.87	3
7	Backscatter data interpretation		12 (11.5%)	2.72 (1.34)	89 (10.6%)	77.13	8
8.1	Applications and end uses	Backscatter for monitoring and change detection	7 (6.7%)	2.53 (1.40)	46 (5.5%)	68.34	9
8.2		Backscatter discrimination for physical and biological targets	9 (8.7%)	2.44 (1.30)	73 (8.7%)	84.36	6
8.3		Backscatter beyond the scientific community	10 (9.6%)	2.34 (1.31)	61 (7.3%)	63.44	10
All themes combined			104 ($\bar{x}$ = 10.4)	2.63 (1.32)	838 ($\bar{x}$ = 84)		

$$\boldsymbol{ImSc} = \sum \boldsymbol{x}_{pl}$$

Finally, multivariate tests were conducted on a data matrix coding selection of research questions as binary variables ('0' or '1') and respondents as observations in order to test for the effect of respondent expertise and sectoral affiliation on the overall survey results. These tests aimed to identify clustering or bias within the community of practice. Jaccard and Ochiai dissimilarity matrices were derived from the response data in order to perform distance-based multivariate statistical analyses including permutational multivariate analysis of variance (PERMANOVA) by redundancy analysis (RDA) and agglomerative hierarchical clustering with complete linkage. These tests were conducted in the R programming environment (R Core Team, 2023) using the *vegan* package for diversity analysis (Oksanen et al., 2022).

3 Results

3.1 Research questions and broad themes

A total of 177 research questions with 144 short justifications were received from 73 contributors. Most contributors (57) provided questions by themselves, but some provided questions pooled for a team of two to five members each. About 47% of contributors worked in academia, 43% in a governmental agency, and 12% in industry or the private sector, at the time of submission. The majority of contributors worked in Europe (71%) and North America (19%), with some contributions from Oceania (8%) and South America (3%) (Figure 2, top panel). A map included in the Supplementary Material shows the question providers per sector, per country (Supplementary Figure 1). We note that some contributors worked in more than one sector at the time of contribution (*e.g.*, academia and industry) and in some cases, with affiliations in more than one country, which is reflected in proportions that may exceed 100%.

After curation by the authors, 104 questions remained. Qualitative analysis revealed eight broad themes, listed in Table 1. Theme eight on applications and end uses was further subdivided into three categories to maintain a relatively similar number of questions per class in the survey. The informal feedback gathered from the expert community at the 2022 BSWG workshop was that these themes were representative of the questions received, and text mining and word clouds based on the questions did not identify additional themes.

3.2 Survey responses

A total of 254 responses to our survey were recorded by Qualtrics™. However, not all records were used for the analysis. 103 survey participants only answered the mandatory questions and

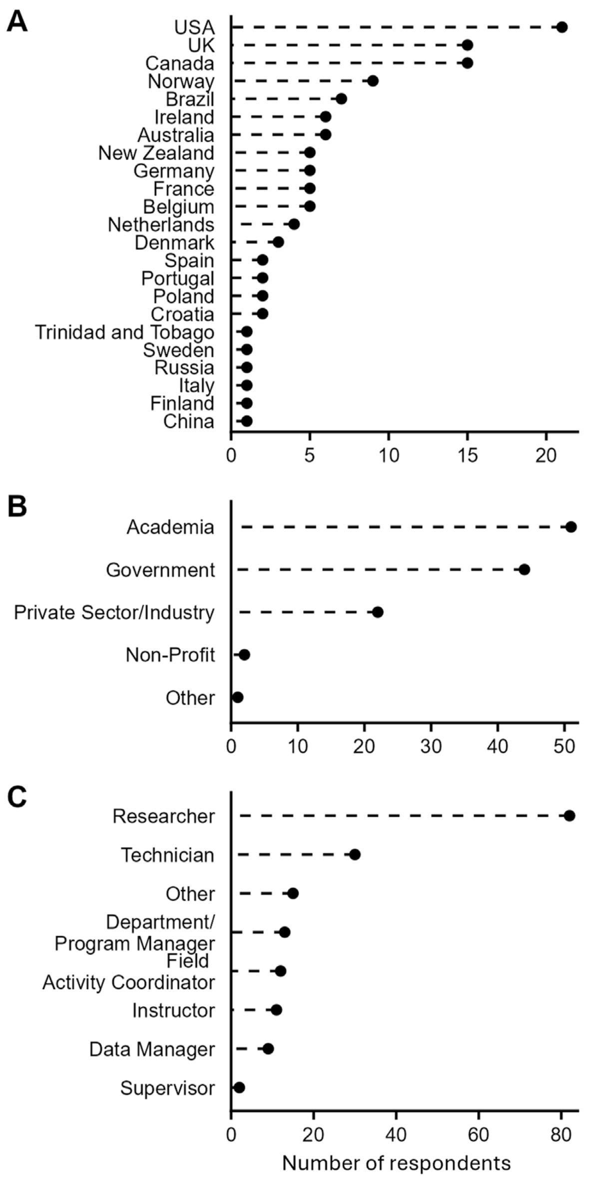

FIGURE 3
Number of respondents (*x*-axes) by **(A)** countries, **(B)** employment sector, and **(C)** occupational role.

then clicked through the themes without choosing a single priority question. Thus, to be included in our analysis, respondents had to have selected questions from at least 6 of the 10 research themes or sub-themes and select their top seven questions. In practice, this included all respondents who reached the end of the survey, while recognizing that some experts would either find no priority questions or hold no expertise in specific themes. In the end, 120 records were used for the analyses.

3.3 Portrait of the community of practice

The 120 records retained for the analyses corresponded to individuals from 23 different countries (Figure 2, bottom panel). The most common countries of affiliation were the United States (21 respondents; 17.5%) and Canada and the United Kingdom with 15 respondents (12.5%) (Figures 2, 3A). A map included in the Supplementary Material shows the respondents' sectors per country (Supplementary Figure 2). Most respondents (51; 42.5%) identified as members of academia, followed by governmental agencies (44; 36.7%), and the private sector (22; 18.3%) (Figure 3B). Finally, the majority of respondents identified themselves as researchers (82; 68.3%), followed by technicians (30; 25%) and department or program managers (13; 10.8%) (Figure 3C). We additionally note a substantial number of individuals who fulfilled "other" roles (15; 12.5%), suggesting that the full diversity of respondent roles was not captured in the questionnaire, or that respondents had more complex job descriptions than could be addressed simply (international differences in role description and perception may not be represented).

Respondents self-reported their expertise related to each theme (Figure 4). Each theme had both experts and non-experts. Most themes exhibited expertise conforming roughly to a normal distribution, which might be expected. However, themes 2 ("Calibration") and each of 8.1–8.3 ("Applications and end uses") appeared to be skewed towards lower levels of expertise, indicating a greater number of respondents who are not confident in their knowledge of these subjects. Theme 3 ("Data acquisition and ground-truthing") appeared to be skewed towards higher levels of expertise. Regression of the number of questions selected as priorities within each theme against self-reported expertise indicated a weak but significant relationship. Controlling for the individual respondent as a random effect (intercept), we found that the number of questions selected within a theme increased by 0.59 ± 0.06 per ordinal "level" of expertise ($p < 0.001$). Thus, we expect themes with more self-identified experts to contain slightly more questions voted as priorities.

3.4 Priority themes and questions

The theme with the highest number of selections in the top seven most important questions is "Technologies", followed by "Backscatter data analysis" (Table 1; Figure 5). When corrected for the number of questions within each theme - under the assumption that if a theme has more questions, the likelihood of one of its questions being included in the top seven was higher - the highest priority theme is "Post-processing, quality control, data handling and curation", followed by "Calibration" and "Backscatter data analysis" (Table 1; Figure 5).

The top 11 questions that were most often selected as a top seven priority are listed in Table 2; each of them was selected as a top seven priority by at least one in eight respondents. The questions "How can we move towards absolute calibration of different systems to allow interregional comparisons?" and "How can we quantify seafloor backscatter quality and develop standards similar to what exists with bathymetry?" were chosen by about one in four participants. These were followed by "How can we achieve open source and transparent backscatter data processing software and pipelines?" and "How can the data acquisition settings of multifrequency sonar systems be optimized to collect multifrequency backscatter data for habitat and seabed substrate mapping, while still performing at the highest standard for the

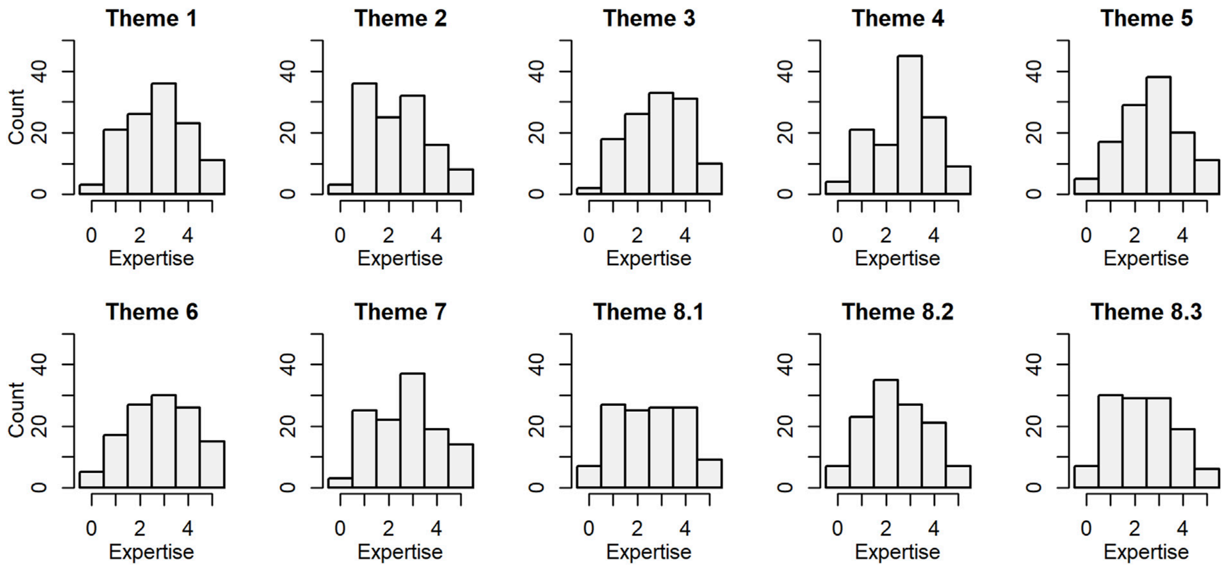

FIGURE 4
Self-reported expertise level per theme, from 0 (no expertise) to 5 (expert).

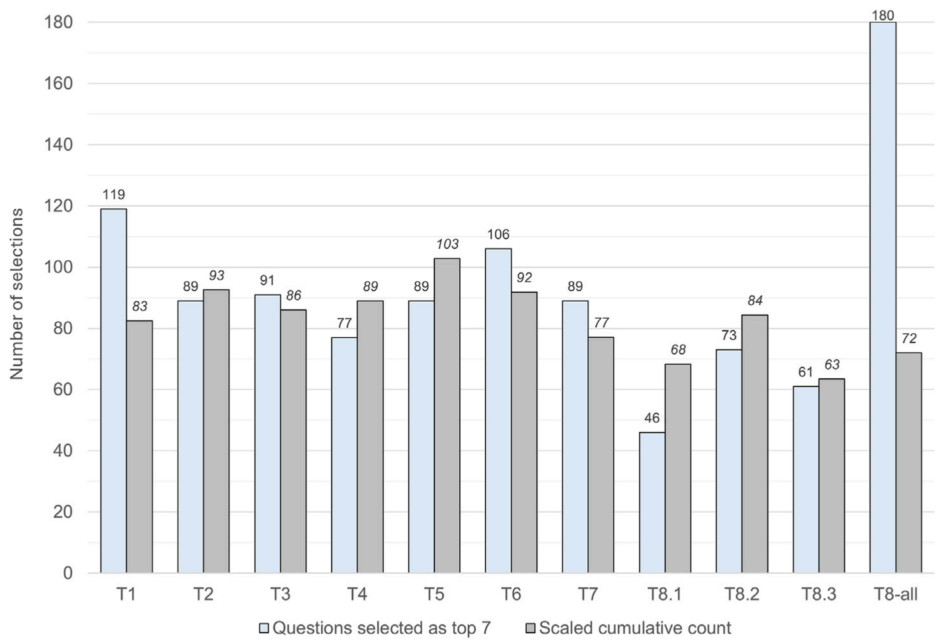

FIGURE 5
Selection frequency in the top seven by theme in raw counts (in blue with romanized labels) and scaled to the number of questions per theme (in gray with italicized labels).

collection of bathymetric data, for example, for hydrographic surveys?“. The ranking of the latter two questions inverted when taking into account only the frequency selection and not the rankings (Table 2), implying that although fewer participants selected these questions, the ones who did select them assigned them a high priority. The selection frequency is provided along with the relative importance rankings in Table 2 for the ten top questions. The complete rankings (both based on selection frequency and corrected for relative importance) for all questions can be found in the Supplementary Table 1, together with the differences between the two rankings. The raw data including the number of times each question was selected as important and the number of times each

TABLE 2 Top 11 questions (*i.e.*, those selected by at least one in eight respondents), according to the relative importance score, for all respondents (global ranking) and by primary sectors for academia (Acad.), governmental agencies (Govt.), and the industry sector (Ind.). The frequency count ranking is provided between parentheses. A full ranking (Supplementary Table 1) and raw counts (Supplementary Table 2) are available in the Supplementary Material.

Global ranking (N = 120)	Acad. (N = 51)	Govt (N = 44)	Ind. (N = 22)	Question	Theme
1 (1)	2 (2)	2 (3)	23 (11)	How can we move towards absolute calibration of different systems (from different manufacturers, with different engineering design) for example, to allow interregional comparisons?	Technologies
2 (2)	1 (1)	4 (3)	7 (3)	How can we quantify seafloor backscatter quality (*i.e.*, sensitivity and repeatability) and develop standards similar to what exists with bathymetry?	Post-processing, quality control, data handling and curation
3 (4)	8 (5)	1 (3)	8 (24)	How can we achieve open source and transparent backscatter data processing software and pipelines?	Backscatter data processing
4 (3)	9 (5)	6 (2)	5 (3)	How can the data acquisition settings of multifrequency sonar systems be optimised to collect multifrequency backscatter data for habitat and seabed substrate mapping, while still performing at the highest standard for the collection of bathymetric data, for example, for hydrographic surveys?	Backscatter data acquisition and ground-truthing
5 (5)	5 (3)	2 (6)	30 (3)	How can backscatter data collection and analysis be optimized for habitat mapping and modeling?	Applications and end uses - Backscatter discrimination for physical and biological targets
6 (6)	10 (11)	4 (1)	15 (11)	How can we establish acoustic signatures for biological (*e.g.*, taxa, biomass, community composition) and physical (*e.g.*, grain size, roughness) information from backscatter?	Backscatter data interpretation
7 (10)	4 (5)	18 (20)	11 (24)	How can we move towards standardization of processing algorithms?	Backscatter data processing
8 (8)	25 (27)	7 (10)	1 (1)	How can we best combine different data types (*e.g.*, seafloor backscatter, bathymetry, water column backscatter, and/or their respective derivatives) for the characterization of different environments?	Backscatter data analysis
9 (6)	11 (11)	12 (10)	2 (2)	How can uncalibrated backscatter measurements be calibrated a posteriori, post data acquisition?	Calibration
10 (10)	3 (3)	24 (29)	27 (24)	What is required to establish absolute calibration standards?	Calibration
11 (12)	7 (8)	9 (16)	18 (11)	What are the best practices for transparent acoustic backscatter calibration from multibeam sonars?	Calibration

question was selected in the top seven are included in the Supplementary Table 2.

Table 2 and Supplementary Table 1 also show the rankings of questions when considering only respondents from academia, respondents from government, and respondents from the private sector/industry. This highlights the differences among ranking depending on the sector of activity, and shows that while all questions were selected at least once in the top 7 by the respondents, 12 questions were not selected at least once by members of academia, 14 were not selected by members of government agencies, and 31 were not selected as top priorities by members of the private sector. The ranking by members of the private sector seems to differ the most from the two others, setting the question "How can we best combine different data types (*e.g.*, seafloor backscatter, bathymetry, water column backscatter, and/or their respective derivatives) for the characterization of different environments?" as the top priority, followed by "How can uncalibrated backscatter measurements be calibrated *a posteriori*, post data acquisition?".

3.5 Multivariate analyses

Analysis of a Jaccard dissimilarity matrix showed that respondents naturally clustered into broad groups at large heights in the dendrogram (Supplementary Figure 3); the significant height of terminal clades indicates a high degree of difference between most respondents, with nearly all leaves (>94% of respondents) having a height greater than 0.6. The permutational tests performed on the data confirmed that very little of the variation in question selection by respondents could be explained by the self-assigned expertise level (residual $R^2 > 0.90$, 9999 permutations), with only Theme 8.1 ("Backscatter for monitoring and change detection") significant at an α-level of 0.01, explaining 1.4% of the overall variation. While there was a significant effect of the respondents from academia on an Ochiai dissimilarity matrix based on a permutational analysis of variance ($p = 0.002$, $R^2 = 0.014$, 9999 permutations), the small effect size shows that it only explains <1.4% in multivariate variation. Thus, we found little to no evidence of confirmation bias skewing the research community's overall prioritization.

4 Discussion

Our questionnaires and their analyses build on previous efforts to set the research landscape in acoustic backscatter research. Lucieer et al. (2018) explored the adoption of backscatter into key areas of research, based on a survey of user expectations from 2014 (see also Lucieer et al., 2015). This survey revealed the necessary advancements for better adoption of multibeam echosounder backscatter data for various fields of marine research. A few years later, Montereale-Gavazzi and Roche (2020) conducted the Variability and Monitoring (VARIMONIT) survey to investigate backscatter users' methodologies and interest in monitoring applications. These surveys had different objectives and methodologies, and we use them in this section to set our results in context and evaluate how the discipline and stakeholder expectations have evolved in the last decade.

4.1 Community of practice

We consider the size and diversity of the respondent pool adequate to broadly represent global priorities in acoustic backscatter research. The participant sample size (N = 120) and number of countries represented here (23) are large compared to other studies of similar scope (*e.g.*, Pittman et al., 2021; Nordlund et al., 2024). The 2014 survey (Lucieer et al., 2015; Lucieer et al., 2018) indicated a growing appreciation for the potential utility of multibeam backscatter. Our relatively larger sample size may also be a reflection of that. The robustness of these metadata are corroborated by exploratory statistical analysis that failed to indicate any significant biases in responses according to the sector and self-identified expertise level.

The responses suggest a relative lack of geographic diversity among survey participants, with most respondents being from North America and Europe - though Brazil, Australia and New Zealand were also relatively well represented. Notwithstanding the recent growth in Asia, the bias observed in survey respondents is possibly representative of the research community, as it appears to match well the geographical distribution of sonar users worldwide at the time the first questionnaire was sent (*e.g.*, Fortune Business Insights, 2023). The same trends were observed from the group of question providers. Individuals from academia and governmental agencies provided the majority of questions and also comprised the majority of survey respondents, with a relatively even split. This represents a different composition compared to the 2014 survey, which had more respondents from governmental agencies (41%) than from academia (24%). Lucieer et al. (2018) additionally surveyed more respondents from the industry sector (31%) than from academia. Here, stakeholders in the industry sector and from non-governmental organizations are underrepresented, possibly resulting from the lower number of users within this sector (*e.g.*, Fortune Business Insights, 2023). More than two-thirds of our respondents primarily identified as "researchers", to whom the biggest part of the responsibility of addressing the prioritized research questions will fall. The remaining 32% of respondents who are not researchers provided valuable perspective as users of the data and developers of tools and equipment. This diversity in responses was essential for gaining a comprehensive understanding of the needs and challenges in the field. However, the relative imbalance in the number of responses from different sectors of activity and roles may indicate that not everyone's perspectives were captured by our prioritization, or that not all users thought that there was a need for questions.

The self-assessed expertise level reported by survey respondents potentially tells us about the relative maturity of the discipline and its constituents (*e.g.*, acquisition, processing, analysis, interpretation, end uses), and perhaps even about the amount of imposter syndrome amongst the community as data shows no Dunning-Kruger effect. The themes with the highest average expertise (Table 1; Figure 4) are related to data acquisition ($\bar{x}$ = 2.86), analysis ($\bar{x}$ = 2.83), and processing ($\bar{x}$ = 2.78) - three subjects for which there are generally well-established protocols. The theme on backscatter data processing shows a higher peak than a normal distribution would (Figure 4). A possible reason for this may be that most people do some amount of data processing, but few focus on it as a specific research topic. It may also highlight a certain confidence across the community in our collective ability to process data, and that perhaps future developments in processing are of lower priority compared to issues such as data standardization (*cf.* next section). Themes with the lowest average expertise scores are the "Applications and end uses" and "Calibration" themes. It is unsurprising that the "Applications and end uses" sub-themes contain fewer experts, since few participants are expected to hold expertise in multiple specific applications. The theme "backscatter beyond the scientific community" had the lowest average expertise level ($\bar{x}$ = 2.34), which indicates a potential gap in the understanding of how backscatter may be utilized outside of science. This potentially has impacts for backscatter research funding, as sponsors will often request that clear broader impacts be identified for a project. If our own community struggles to identify how backscatter is relevant beyond fundamental scientific advancements, it may impact how much funding is injected into acoustic backscatter research, and output transferability into applications and end-uses. The expertise level for the theme "Calibration" ($\bar{x}$ = 2.38) strongly suggests a gap in our collective capacity to address issues related to interoperability and the acquisition of absolute backscatter measurements that may be used to characterize the seafloor (Lamarche et al., 2011). This is critical because data calibration may impact other steps of the data processing pipeline (*i.e.*, acquisition, processing, quality control, analysis, interpretation, applications and end uses). The need for greater expertise related to calibration is corroborated by its perceived importance as the most pressing research priority.

Ultimately, the composition of the survey participants was influenced by the means of survey distribution, which, to align with our objectives, targeted individuals connected primarily and secondarily to GeoHab and the BSWG. The portrait of the community is also reflected in the questions that were submitted, with more of the provided questions being related to technologies, analysis and interpretation of backscatter data. Based on the questions that were submitted, our community is made of people working mainly with backscatter data from multibeam echosounders, with fewer with fisheries echosounders and sidescan sonars.

4.2 Priority themes

The themes identified by our team, based on the questions received and validated by the community and text mining and word clouds, span the entire life cycle of backscatter data—from data collection to end uses. Notably, all eight primary themes were represented among the top nine questions. This underscores the significant work that remains to advance the discipline towards maturity, in addition to the need for research across a very wide range of backscatter-related topics and for collaboration and communication among manufacturers, software developers, scientists, and end users. This also supports the 2022 reorganization of the BSWG into thematic branches, each dealing with a specific topic within backscatter (*e.g.*, backscatter data processing, multibeam water column data).

An interpretation of the difference between the relative importance score and selection frequency (Table 2; Supplementary Table 1) for questions within each theme highlights some interesting trends. For example, calibration has the greatest mean difference between frequency of selection and importance score, suggesting that in general, fewer respondents identified questions from this theme as important, but those that did think it is critical. Alternatively, some themes had a relatively large negative difference between the importance score and selection frequency, indicating that a high number of respondents identified questions within these themes as important, but ultimately ranked them towards the bottom of the top 7. This was particularly noteworthy for the "Applications and end uses" sub-theme, "Backscatter beyond the scientific community". This is interesting as it suggests that the community identifies the importance of backscatter in contexts such as resource management and conservation, but that before focusing on using backscatter in these contexts, it is necessary to address more pressing issues at other stages of the data life cycle. Other themes that had a relatively large negative difference in rankings (*i.e.*, frequent selection but low rank) are "Technologies" and the two other "Applications and end uses" sub-themes. Again, this suggests that before developing new technologies, perhaps we must better understand how to work with those that are already available.

4.3 Priority questions

All submitted questions were selected at least once as a top seven priority question, highlighting that all 104 questions can be considered priorities. Indeed, a low ranking does not suggest that a question is not important but rather, that it is only of lower priority at this time. After all, if a question made it into the survey, it means that it was considered important by members of the community. Consistent with the findings related to the research themes, the highest priority questions identified span the entire lifecycle of backscatter data. These questions address a broad range of issues, from initial data collection and processing methods to the final applications and implications of the data, highlighting the interconnected nature of the challenges and opportunities within this field.

Lucieer et al. (2018) identified three categories of backscatter surveys, each in need of different levels of stability and accuracy: one-time exploration surveys, habitat mapping and seabed classification, and monitoring programs. Monitoring programs require the most stable and accurate datasets. The survey presented here enabled not only the identification of the importance of calibration, like the 2014 survey, but also identified it as the primary priority among all others. This may indicate that the community is moving towards a greater need for monitoring, perhaps in response to programs such as the United Nations Sustainable Development Goals. This was captured by the VARIMONIT survey (*cf.* Montereale-Gavazzi and Roche, 2020), which indicated a significant interest in repeated multibeam echosounder backscatter surveys for various applications. Over half of the respondents of the VARIMONIT survey were active users, primarily focused on environmental monitoring of diverse targets such as benthic habitats, substrate types, and anthropogenic impacts (Montereale-Gavazzi and Roche, 2020). These users often conducted repeated surveys to detect changes over medium (seasonal) to long timescales (years to decades) within the contexts of scientific research and legal requirements, such as supporting monitoring assessments to meet environmental policies. Respondents not currently conducting serial multibeam echosounder backscatter surveys expressed a desire to adopt such practices in the future.

Additionally, standardization and transparency throughout the workflow emerged as clear trends characterizing the priority questions in our effort. Standardization too was highlighted as a challenge by survey respondents in 2014 (Lucieer et al., 2015; Lucieer et al., 2018), in particular as it relates to using backscatter for seabed monitoring. Despite calls to standardize hardware, software, and processing algorithms (*e.g.*, Schimel et al., 2018; Malik et al., 2019), there are still no standards guiding backscatter data uses. Through VARIMONIT (Montereale-Gavazzi and Roche, 2020), the user community demonstrated a clear willingness to engage in participatory exercises to process common datasets, underscoring the necessity for developing standardized approaches to detect seafloor changes.

The difference between the two types of rankings (*i.e.*, relative importance score and frequency selection; Table 2; Supplementary Table 1) highlights some interesting trends. For example, a number of questions moved much higher in the importance score ranking compared to their frequency selection ranking. This can be interpreted as fewer respondents thinking that these questions are important, but those who do think so believe that they are critical. The questions listed at the top of Table 3 showed the greatest positive differences in rankings. The same exercise can be done in the opposite way, to identify those questions that a lot of respondents identified as important, but when it was time to rank them, they would be assigned a low priority (bottom of Table 3). A deeper analysis could also look into the raw data (Supplementary Table 2), specifically into the differences between the number of times a question was selected as important and the number of times it was selected as a top seven priority.

The pool of respondents indicated that priority backscatter research questions are distributed across a range of themes, but that several specific questions should be prioritized immediately in order to advance the field. It is evident that both developing universal calibration methods and protocols (question rank 1) and establishing backscatter quality control standards (question

TABLE 3 Questions with the largest positive and negative differences between the relative importance score and the frequency selection rankings (ΔRank = selection frequency ranking - relative importance score ranking).

ΔRank	Question	Theme
+14	What is required from the research community and manufacturers to jointly establish calibration protocols, for example, to allow repeat surveys of sites with variable angle and penetration depth or to combine different surveys from different operators and platforms?	Calibration
+11	How can we best use angular range analysis to produce high-resolution, easy-to-understand interpretation products (*e.g.*, geotiff, vector file, sediment boundaries)?	Backscatter data analysis
+11	How can we provide best practice guidelines for acoustic seafloor characterization (*e.g.*, predictive modeling algorithm) in different depth ranges?	Backscatter data analysis
+10	How can backscatter be applied to understand responses of mobile animals to varying conditions of the oceans (*e.g.*, variations in temperature, new shipping routes, development, more food), to understand ecosystem function?	Applications and end uses - Backscatter discrimination for physical and biological targets
+10	What are the bottom characteristics that are influencing multispectral responses, and how can we use that information for interpretation?	Backscatter data interpretation
+10	What do we need to develop and deploy an accessible, portable, standardized calibration kit with targets of different sizes and natures that can be used with any system?	Calibration
+9	How can we disentangle environmental variability in space and time from backscatter signal variability to use the latter as an interpretive tool?	Backscatter data interpretation
+9	How can we use multibeam backscatter data to inform change detection across benthic habitats?	Applications and end uses - Backscatter for monitoring and change detection
−21	To what extent do water column properties and targets (*e.g.*, marine life, anthropogenic objects) affect water column backscatter and its variability?	Backscatter data acquisition and ground-truthing
−22	Which instrument characteristics and settings are best to optimize water column backscatter data collection and reduce measurement uncertainty and influence from the seabed?	Backscatter data acquisition and ground-truthing
−25	How can volume scattering be used quantitatively to accurately map the shallow and complex subsurface to better predict future seabed dynamics and habitat suitability?	Applications and end uses - Backscatter for monitoring and change detection
−25	How can backscatter data be used to study gas presence, release, circulation patterns, and interactions with the biotic environment?	Applications and end uses - Backscatter discrimination for physical and biological targets
−25	If relevant, what are the steps needed to have multibeam backscatter data become a mandatory dataset in surveys that have to be certified in view of risk management, or to become a requirement of licensing for development (*e.g.*, resource extraction, renewable energy sites)?	Applications and end uses - Backscatter beyond the scientific community
−28	How can we use backscatter frequency ratios (*i.e.*, differences between the signal from different frequencies) as a function of water depth for sound velocity estimation?	Technologies

rank 2) are urgent research priorities. In fact, other high-priority research questions stand to benefit considerably through advances in these topics. For example, questions ranked 2, 4 and 5 relate to optimizing backscatter data quality, yet this begs the question of how backscatter quality is to be assessed in the first place (*i.e.*, question rank 1). Questions ranked 5 and 6 indicate the importance of establishing acoustic backscatter signatures for specific biological and geological features; however, lacking some form of absolute calibration (*i.e.*, question rank 1), this may be a generally intractable task at the moment.

The rankings by sector of activity (Table 2; Supplementary Table 1) highlight interesting differences in priorities among sectors. For example, the question "How can we move towards absolute calibration of different systems (from different manufacturers, with different engineering design) for example, to allow interregional comparisons?" was ranked second overall by both members of academia and government agencies, but 23rd by members of the private sector/industry. On the other hand, the question "How can we develop guidelines for multibeam water column backscatter sediment plume detection and monitoring (*e.g.*, grain size and volume estimation) for various applications (*e.g.*, mining, dredging, trawling monitoring)?" was ranked third overall by members of the private sector/industry, but in 22nd position by government employees and in 60th place by academics. In some cases, these results show disagreement on what the community should be focusing on in the next decade.

As noted previously (*cf.* Sections 3.3, 4.1), this survey effort highlighted a general lack of representation of individuals working in developing countries. It is difficult to determine whether this is caused by a lack of connectivity between the BSWG membership and those individuals, or a lack of acoustic backscatter research (different from acoustic backscatter use) in those geographic areas. Only one question, ranked 58th overall, addressed this: "How can backscatter research attract and retain a diverse and inclusive next-generation of scientists, and serve societal needs of diverse stakeholders and the Global South?". We thus highlight an additional qualitative research priority: to better engage additional geographies in the BSWG and global backscatter community of practice - particularly, developing nations that are not represented amongst our respondents.

4.4 Looking back to the last decade and setting the research landscape for the next decade

4.4.1 What has changed in recent years?

The results of this survey provide a roadmap to inform a research agenda for acoustic backscatter research within and beyond the BSWG, and we anticipate that it will encourage international collaboration to address the most challenging problems that the community currently faces. Both our results and those of the 2014 survey revealed varied and complex applications across a range of disciplines, indicating that acoustic backscatter data has become a key data source for biological and geological seafloor mapping and monitoring. The progressive uptake of backscatter data usage over the last 15 years could in part be attributed to multibeam technological advancements, including improvements in transducer design, digital electronics, and signal processing that led to enhancements in resolution and dynamic range of multibeam echosounders, yielding improved seafloor characterization.

In 2014, users identified expectations such as improvements in calibration procedures, standardization, ability to use processing methods to discriminate between different seafloors substrates and habitats at specific spatial resolutions, classification accuracy, stability and accuracy of backscatter data and its derived products, data storage, and processing speeds (Lucieer et al., 2015; Lucieer et al., 2018). They also highlighted the diversity of skills and expertise required to acquire, process, and analyze the data, in a context where "scientists using backscatter data may not be trained in acoustics and may lack a full understanding of the factors that affect backscatter data or how to optimize the data for subsequent analysis" (Lucieer et al., 2018, p. 25). Finally, users called attention to the importance of scale - in particular in terms of the spatial resolution of backscatter data products, a lack of software to handle specific needs for information extraction from backscatter data and processing limitations either by software or computation limitations within their organization.

So what has changed in the last decade? The community has grown and with it the general skill level, although this is difficult to evaluate other than through this study's self-reporting (Table 1), our own experience and anecdotal evidence. That said, the average skill level for each theme was below 3.00 (Table 1; Figure 4), and it would be an interesting exercise to keep tracking this metric in the future as a proxy of the maturity of the discipline and the experience of the workforce. While the statement from [Lucieer et al. (2018), p. 25] quoted in the previous paragraph probably remains true as it pertains to the lack of training in acoustics, we believe that users now have a better understanding of the factors that affect backscatter data. However, there is still a lot of room for growth, as evidenced by priority questions such as "How much of the backscatter response comes from the seafloor surface (surface backscattering) and the buried sediments (volume backscattering) for a given frequency and incidence angle?" (rank 17) and "What are the bottom characteristics that are influencing multispectral responses, and how can we use that information for interpretation?" (rank 19).

Another element that was important in the 2014 survey and that has changed since is the concept of spatial scale. While questions associated with the spatial resolution of backscatter products and their ability to capture the relevant information about the seafloor were identified as key in 2014, only a few questions about this topic were provided for our survey (*e.g.*, "Through which experimental design can we identify the causes of backscatter variations at different temporal and spatial scales to facilitate interpretation of backscatter time-series?" (rank 65); "To what extent can roughness spectrum models differentiate between terrain variability at multiple spatial scales (*e.g.*, broad-scale bathymetry, local instantaneous insonified area, random scatterers)?" (rank 82)), and they did not rank very high. In addition, the scale component of these questions was often secondary, coming as a complementary element to the main part of a question (*e.g.*, "How can we measure and monitor patterns in acoustic backscatter without ground-truthing, similar to calibrated satellite measurements for earth observation? Also, what scales should we use for this characterization and monitoring?", (rank 42)). This reduction in importance for the concept of spatial scale may stem from the large amount of work that has been done in the last decade in fields associated with backscatter, such as marine habitat mapping (*e.g.*, Porskamp et al., 2018) and seafloor characterization (*e.g.*, Shang et al., 2021), to raise awareness about scale (*e.g.*, Lecours et al., 2015) and develop workflows to facilitate multiscale analyses (*e.g.*, Misiuk et al., 2018).

Some things have changed significantly since 2014 but remain ongoing challenges. For example, data storage and computing capabilities have increased, but so has data volume, in particular with the growing interest in multifrequency backscatter data and water column backscatter data. Data storage and computing capabilities thus remain primary concerns, as highlighted by the high rank (13) of the question "As backscatter datasets become increasingly large, how should processing of raw and processed data storage be handled (*e.g.*, file format, licensing, automated workflows, computing load, back-ups)?". With the different types of acoustic backscatter data (*i.e.*, seafloor, water column, multifrequency) that are increasingly being used and combined, we can expect the arrival of data cubes into the discipline in the near future. Data cubes are already used for remote sensing data, in particular for optical backscatter data (*e.g.*, Kopp et al., 2019; Truckenbrodt et al., 2019), and they are an integral part of observations in modern astrophysics (*e.g.*, Vogt et al., 2016).

Lucieer et al. (2018) identified a strong need for the development of improved backscatter data software solutions. It is also notable that here, the question "How can we achieve open source and transparent backscatter data processing software and pipelines" was ranked as the third greatest backscatter research priority. These results indicate that the development of suitable backscatter processing software is a persistent and critical challenge to the field. It also appears, though, that specifics of this challenge have evolved. In 2014, users highlighted a lack of software solutions for specific backscatter applications, a lack of platform-independent (*i.e.*, general-purpose) backscatter processing solutions, and a lack of adequate software documentation. Here, participants have clearly identified the need for transparent and open software solutions such as *MB-System* (https://www.mbari.org/technology/mb-system/). This may partly reflect some progress made on the issues raised by Lucieer et al. (2018); we have seen the development of several recent software packages that target specific applications, which are simultaneously open source and well-documented. These include, for example, *themachinethatgoesping*

Python package for processing single and multibeam water column data (https://github.com/themachinethatgoesping); the Matlab toolboxes *CoFFee* (https://github.com/alexschimel/CoFFee) and *Iskaffe* (https://github.com/alexschimel/Iskaffe), for multibeam data reading/manipulation and backscatter quality control; and the R package *bulkshift* (Misiuk et al., 2020) for relative backscatter mosaic calibration and harmonization (https://github.com/benjaminmisiuk/bulkshift). Each of these targeted software solutions is limited in scope, yet survey results here and from Lucieer et al. (2018) indicate that perhaps a range of tailored open-source backscatter tools is desirable to users in order to address specific data processing challenges.

In terms of the users' ability to use processing methods to discriminate between different seafloor substrates and habitats at specific spatial resolutions, which was highlighted in the 2014 survey (Lucieer et al., 2015; 2018) and the reason behind the VARIMONIT survey (Montereale-Gavazzi and Roche, 2020), our results show that it remains a topic of particular interest, as there were enough questions to make a theme regrouping them (Theme 8.2, Table 1). However, this theme did not rank very high (6 out of 10), although it was the highest among the "Applications and end uses" sub-themes. We also note that this issue of discrimination now extends beyond seafloor substrates and habitats, with users having a renewed interest in discriminating what is within the water column through backscatter data. For example, the question "What type of information can we get from multispectral water column backscatter data, and for which existing and new applications can it be used?" ranked 34th.

4.4.2 What has not changed

On the other hand, our results suggest that as a whole, and while important progress was made, perhaps not much has changed when it comes to expectations, concerns, and priorities. Our results suggest that many of the user expectations from 2014 (Lucieer et al., 2015; 2018) and 2020 (Montereale-Gavazzi and Roche, 2020) still exist, and in particular those of calibration for optimizing backscatter data use and standardization of procedures and workflows. Progress has been made on the calibration front (*e.g.*, Eleftherakis et al., 2018; Weber et al., 2018; Roche et al., 2018; Fezzani et al., 2021, development of ISO standard ISO/CD TS 13604), but studies remain scarce and too few to facilitate the development of broadly implementable procedures. Also, manufacturers of acoustic systems must be willing to collaborate with scientists and other users to facilitate absolute calibration. In the meantime, relative calibration is increasingly done using reference areas (*e.g.*, Roche et al., 2018) and post-processing workflows such as bulk shift harmonizations (*e.g.*, Misiuk et al., 2020; 2021). However, our results strongly suggest that these efforts are not enough and that our community should focus on resolving issues associated with calibration so that procedures can be defined and implemented broadly. Questions related to calibration are considered critical by the community, with many of the questions ranking highest in priority. In fact, some of the highest priority questions were not assigned to the calibration theme but are directly related to calibration concepts. For example, the question, "How can we move towards absolute calibration of different systems (from different manufacturers, with different engineering designs) to allow interregional comparisons?" was included in the "Technologies" theme. Similarly, the question, "How can we create an e-catalog or atlas of reference backscatter signatures for different habitats and sediments that includes only calibrated backscatter with associated bathymetry derived morphological maps, backscatter mosaics, angular responses, and visual and physical ground-truthing samples?" was assigned to the theme "Post-processing, quality control, data handling, and curation." This classification is due to the significant impact that calibration and calibrated data have on other stages of the backscatter data life cycle. The importance of calibration was also already identified by users of backscatter in 2014 (Lucieer et al., 2015; Lucieer et al., 2018), and our results indicating the persistence of this theme show that perhaps not much has changed in this regard. As suggested by Lucieer et al. (2018), it may be because accuracy requirements are not well understood, leading to a lack of quality metrics for backscatter data. In addition, calibration involves increased planning and informed decision-making prior to acquiring data, and also costs more financially and in terms of efforts (Rice et al., 2015), potentially hindering developments in calibration protocols that would benefit applications requiring monitoring and eventually improve the cost-benefit ratio of backscatter datasets.

Finally, standardization, which relates to some extent to the stability and accuracy of backscatter data products, remains of actuality. Nine of the provided questions explicitly stated standards or standardization, and they all ranked in the top 40, including four in the top 10. Like for calibration, standardization affects the entire data life cycle and would facilitate monitoring applications and comparisons among systems, among other things. Unlike for bathymetry, standards related to acoustic backscatter measurements have yet to be established (Trzcinska et al., 2021), despite a number of best practices and guidelines documents having been prepared by various organizations, such as the BSWG (Lurton and Lamarche, 2015), the German Federal Maritime and Hydrographic Agency (BSH, 2016), and Australia's Marine Biodiversity Hub (Przeslawski and Foster, 2020). The International Hydrographic Organization has recently shown interest in looking into standards for multibeam backscatter data to complement their standards for bathymetric data, but such standards will need to be strongly supported by scientific evidence provided by the research community. Similarly, ISO standard ISO/CD TS 13604 is under development and addressing in-the-field calibration with techniques within reach of most backscatter users. Standardization can be applied at different stages of the data life cycle, and this is reflected in the priority questions received. For example, the question "How accurately can multibeam sonar backscatter (both single frequency and multispectral) data predict seafloor sediment properties–and can we standardize a classification approach for all data sets?", which ranked 39th, addresses classification accuracy, while the question "What metadata standards and data archive infrastructure are required for backscatter data to achieve FAIR (findable, accessible, interoperable and re-useable) principles?", which ranked 30th, addresses metadata standards. We note that in some cases, standards have been proposed but need wider adoption. This is the case for metadata standards for backscatter data, which have been proposed in Lurton and Lamarche (2015), Lamarche and Lurton (2018b), and refined by Schimel et al. (2018), but are yet to be widely documented in a standardized way. Lucieer et al. (2018) argued that one of the main impediments to standardization in backscatter data use relates to the diversity of background disciplines, expertise, and experience within the user community. We argue that perhaps the issue is even broader and related to the lack of formal training in (geographical) data sciences, for which best practices such as metadata recording are central.

4.5 How research on acoustic backscatter can help address applied research challenges

Many priority questions are fundamental and theoretical in nature, yet solving them will have direct implications for applied research. It is likely that repeating this effort in 10 years from now will show a different portrait where theoretical and practical questions have been answered and standards have been established, opening the way for more applied research questions to become priorities and be answered.

One of the more applied priority questions that was submitted to this effort is "What can backscatter data contribute towards achieving the United Nations Decade of Ocean Science and Development targets?". Natural resource management associated with and in support of the United Nations Sustainable Development Goal 14 "Life below water" is critically dependent on accurate inventories and baselines–often taking place in dynamic and vulnerable marine ecosystems where anthropogenic change is already well established. Acoustic backscatter gives us a powerful language and interrogative framework within which to ask these applied questions. By refining our understanding of these relationships in a reproducible manner, we can increase the predictive capacity of our distributional models, better manage our fisheries and priority habitats in our respective territorial waters and on the high seas. We can find the acceptable limits of the available technology, beyond which we may experience diminishing returns. In many instances, the acceptable resolution of the tool depends largely on the question to which it has been applied–and in many cases it is possible to study contemporary environmental issues using legacy technologies.

As a research community, it is important to engage with end users and to provide education on the subtleties and challenges of working with backscatter data. At best, failure to do so may result in over-confidence in the results provided by backscatter tools. At worst, inappropriate use of these tools may compromise the efficacy of area-based management and conservation. Similarly, it is critical to avoid mistaking technological novelty for enhanced understanding of process and function in natural systems. There is much value in developing relationships between the technologists and the scientists to develop creative solutions to outstanding challenges related to the use of acoustic mapping technologies. There is much work to do, which will require enhanced collaboration in a truly multidisciplinary setting.

5 Conclusion

Prioritizing scientific inquiry is essential for synergistic benefits and accelerating the pace of scientific discovery (Hoegl et al., 2004; Dey et al., 2020). By providing a roadmap to guide acoustic backscatter research both within and beyond the BSWG, this prioritization exercise will unify teams and resources, fostering advancements in the field through a community of practice approach. We acknowledge that the questions listed in this effort reflect what the contributors provided, and may therefore be biased in terms of geography, expertise, access to resources, and knowledge. For example, there were very few questions about metadata standards, which may reflect a lack of awareness about the importance of metadata.

The 2014 survey by Lucieer et al. (2015, 2018) identified an expectation from users of backscatter data that these datasets will become even more useful given standardized processing procedures and an ability to address common constraints in data handling such as calibration. Our results showed that unfortunately, calibration and standardization remain priorities that are not widely addressed by our community; our results revealed a growing gap in the community for hydroacoustic acquisition and data processing skills, *i.e.*, those that require a comprehensive understanding of the physics behind acoustic backscatter, which are required to switch the lead back from the user community to the source - the data acquisition and processing methods.

In conclusion, our prioritization effort showed that we need to solve issues from multiple fronts and perspectives. We hope that all within our community can find in our prioritization exercise specific orientations for their upcoming work, as we believe that the collective effort presented here will ensure that research is strategically directed, facilitating collaboration, innovation, and the efficient use of resources to address the most critical questions in acoustic backscatter research.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

VL: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing. BM: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing. FB: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. PB: Data curation, Formal Analysis, Investigation, Methodology, Validation, Writing–original draft, Writing–review and editing. GM-G: Conceptualization, Data curation, Formal Analysis, Methodology, Writing–original draft, Writing–review and editing. VLL: Data curation, Formal Analysis, Methodology, Writing–original draft, Writing–review and editing. CM: Data curation, Formal Analysis, Methodology, Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. We acknowledge the contribution of the University of Florida that granted access to the Qualtrics™ platform to VL. VL's participation to the 2022 BSWG workshop for the validation of the themes was made possible by contributions from the *Département des sciences humaines et sociales* and the *Décanat de la recherche et de la création* of the *Université du Québec à Chicoutimi*. Article publishing charges are paid for through a Discovery Development Grant (DDG-2024-00018) from the Natural Sciences and Engineering Research Council of Canada awarded to VL, and by the Décanat de la recherche et de la création of the Université du Québec à Chicoutimi. FB's contributions were carried out with the support of the Marine Institute (Grant-Aid Agreement No. CS/21/010) and funded under the Marine Research Programme by the Irish Government.

Acknowledgments

We wish to thank all who contributed questions to this effort, without whom this project would not have been possible, in particular: Pavanee Annasawmy (Université de Bretagne-Occidentale, UMR LEMAR), Alex Bastos (Universidade Federal do Espírito Santo), Jonathan Beaudoin (HydroOctave Consulting Inc.), Valérie Bellec (Geological Survey of Norway), Jennifer Brizzolara (U.S. Army Corps of Engineers, Mobile District, Joint Airborne Lidar Bathymetry Technical Center of Expertise), Craig J. Brown (Department of Oceanography, Dalhousie University), Shyam Chand (Geological Survey of Norway), Mark Coughlan (School of Earth Sciences, University College Dublin), Samuel Deleu (Flemish Hydrography, Agency for Maritime and Coastal Services), Markus Diesing (Geological Survey of Norway), Margaret F.J. Dolan (Geological Survey of Norway), Tracy Dornan (British Antarctic Survey), Agata Feldens (Subsea Europe Services GmbH), Peter Feldens (Leibniz Institute for Baltic Sea Research Warnemünde), Paul G. Fernandes (Heriot-Watt University), Maximo Florin (Regional Center of Water Research, Universidad de Castilla-La Mancha), Iason Zois Gazis (DSM Group, GEOMAR Helmholtz Centre for Ocean Research Kiel), the IFREMER French Oceanographic Fleet, Alexander R. Ilich (University of South Florida College of Marine Science), Tim Le Bas (National Oceanography Centre, United Kingdom), I. D. Lichtman (National Oceanography Centre), Tor Inge Birkenes Lønmo (Kongsberg Discovery), Duncan Mallace (XOCEAN), Giuseppe Masetti (Danish Geodata Agency), Amelia McReynolds (University of Vermont), Pedro Menandro (Universidade Federal do Espírito Santo), Sebastiaan Mestdagh (TU Delft), Garrett A. Mitchell (Fugro), Neil C. Mitchell (University of Manchester), Irène Mopin (ENSTA Bretagne), Iain Parnum (Curtin University), Peter Porskamp (Dalhousie University), Katleen Robert (Fisheries and Marine Institute of Memorial University), Marc Roche (FPS Economy - Continental Shelf Service), Alexandre C. G. Schimel (Geological Survey of Norway), Val Schmidt (Center for Coastal and Ocean Mapping, University of New Hampshire), Stephen M. Simmons (Energy and Environment Institute, University of Hull), Craig Smeaton (University of St. Andrews), Terje Thorsnes (Geological Survey of Norway), Karolina Trzcinska (University of Gdansk), S. Harper Umfress (NOAA Office of Coast Survey), Christopher A. Unsworth (Bangor University), Thomas Vandorpe (Flanders Marine Institute (VLIZ)), Vera Van Lancker (Royal Belgian Institute of Natural Sciences), Francisco de Melo Viríssimo (Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science), Benjamin J. Williamson (University of the Highlands and Islands), and the other contributors who either wished to remain anonymous or from whom we could not get an authorization to be listed. We also extend our thanks to the many respondents who took the time to answer our survey. This work would not have been possible without these contributions, and we thank you all.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsen.2024.1484283/full#supplementary-material

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