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Perceptions of practitioners on the importance and achievement of research and social implementation activities on marine and freshwater carbon

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Research and social implementation related to carbon in marine and freshwater ecosystems are increasingly gaining emphasis in the global quest to achieve carbon neutrality. It is important not only to advance academic research, but also to solve practical problems for improved understanding, maintenance, and dissemination of information on carbon in marine or freshwater areas. In this study, we conducted a questionnaire survey of participants in activities related to carbon in marine or freshwater areas in Japan to clarify which issues were considered important and their understanding of the degree to which activities related to carbon in marine or freshwater areas had been achieved. Based on the responses to all questions, 77.9% of respondents, on average, among the practitioners in marine areas recognized the importance of the program strongly, while 46.5% recognized that the degree of achievement was insufficient. This tendency was more pronounced for carbon in freshwater than in marine areas(72.2% and 48.6%, respectively). The results, grouped by respondent attributes, revealed that the perception of importance and level of achievement varied depending on the organization of the activity, age, and years of knowledge of carbon in marine and/or freshwater areas. Practitioners with greater experience and those working on specific implementations perceived implementation-related aspects as more important and less accomplished than academic ones. This study provides valuable insights into the research aspects of carbon in marine and/or freshwater areas to achieve carbon neutrality.

KEYWORDS

blue carbon, climate change mitigation, carbon neutrality, social implementation of research results, attitude survey

1 Introduction

The achievement of carbon neutrality, which is the balance between carbon emissions and carbon absorption from the atmosphere, is a global issue. The carbon neutrality goal and the path to carbon neutrality have been analyzed by previous research in various fields (Wu et al., 2022). Technologies reducing emissions and promoting capture from the atmosphere are important to this goal (Wang et al., 2021). The potential for various ecosystems to absorb and store atmospheric carbon dioxide has also been calculated. For instance, approximately 55% of the carbon on Earth is absorbed by marine organisms, which is currently referred to as the blue carbon (BC) concept (Nellemann et al., 2009). Specifically, shallow coastal sea areas with vegetation, such as seagrass meadows, have a high affinity for storing carbon in sediment, and therefore play an important role in reducing atmospheric $CO_{2,}$ a greenhouse gas (Watanabe and Kuwae, 2015).

The ecosystem conditions that can enhance or disrupt carbon capture and storage remain of topical interest for BC (Lavery et al., 2013). Seagrass meadow and kelp are considered dominant carbon dioxide sinks for BC. Empirical evidence proved that sequestration rates were highly variable for BC capture in seagrass systems (Lavery et al., 2013; Nakayama et al., 2020). The target areas of BC research have mainly focused on marine and coastal ecosystems, with less attention paid to inland waters where dense submerged aquatic vegetation exists. However, Lin et al. (2022) revealed that ecosystems, such as phytoplankton in a subtropical mountainous shallow lake, capture and accumulate carbon through photosynthesis even though terrestrial carbon is supplemented through inflows and autochthonous carbon is produced (Lin et al., 2021). Freshwater areas (5.0 million km^2) are larger than coastal areas (1.8 million km^2) and are expected to have greater potential for carbon sequestration (Downing et al., 2006; Verpoorter et al., 2014).

Studies of BC have included enhanced clarification of ocean currents, nutrient dynamics in the ocean, carbon dynamics in relation to carbon fluxes between the atmosphere and seawater, ocean water temperature changes, climate change projections, freshwater inflow from rivers, and ocean acidification. These are factors that can positi or negatively influence BC and were analyzed considering land use in coastal areas, for example, oyster cultivation (Nakayama et al., 2022). Undoubtedly, one of the most significant factors was the high biodiversity in coastal regions owing to the mixing of fresh and oceanic waters. Another factor was that hydraulic retention (residence time) was longer in coastal regions than in other areas because of the closed nature of these regions (Cotovicz et al., 2015; Kubo et al., 2017; Nakayama et al., 2020; Nakayama et al., 2022). Freshwater is also more enclosed than estuaries and lagoons. Similar to BC, in inland waters, submerged aquatic vegetation may significantly reduce carbon dioxide across the entire lake. However, few ongoing studies have investigated carbon dioxide sequestration in freshwater areas in terms of freshwater carbon.

Color-based descriptions are used to describe the nature and distribution of carbon (Zinke, 2020). The term BC was defined by Nellemann et al. (2009). Although the term freshwater BC was used in Lovelock and Duarte (2019), the definition differs from the term used in this study because it was related to the marine tidal system. Nahlik and Fennessy (2016) used the term teal carbon to describe carbon stored in inland freshwater wetlands. The concept of carbon in freshwater areas has not been clearly defined in existing studies. In Japan, the term BC is currently used by the government and private sector implementations to refer to freshwater carbon, which is not strictly identical to the original definition of BC, and there is no academic evidence to support this. Thus, considering the aim of this study, for clarification, the terms marine carbon and freshwater carbon are used hereafter.

Marine carbon has also been investigated from an economic perspective (Bertram et al., 2021). Offset credits, which are well established in forests and agroecosystems as an incentive for climate change mitigation, are also recognized for marine carbon (Kelleway et al., 2017; Sapkota and White, 2020). In some countries, marine carbon is included as a numerical target for greenhouse gas emission reduction (Crooks et al., 2018; Kelleway et al., 2017). In addition, marine carbon ecosystems are increasingly being restored and protected because of their potential to mitigate climate change and other benefits, such as coastal protection and fishery enhancement (Mcleod et al., 2011; Macreadie et al., 2019). However, although freshwater carbon may have significant potential for carbon dioxide sequestration, offset credit has yet to be established for it.

In conjunction with international efforts, the importance of marine and freshwater carbon has been recognized in Japan, and efforts are being made toward its social implementation, such as carbon credit (Kuwae et al., 2022a). The government is working on the dissemination of information and the promotion of policies in marine and freshwater carbon, and many institutions are working on environmental education in the region. For example, the Japan Blue Economy Association was established in 2020 for various organizations and practitioners related to marine and freshwater carbon to collaborate, conduct research, and develop practical methods to conserve and restore coastal areas (https://www.blueeconomy.jp/en/). Therefore, substantial research has been conducted, and the implementation of research findings has progressed.

To promote the understanding, maintenance, and dissemination of information on marine and freshwater carbon, it is important not only to advance academic research, but also to solve practical problems. For example, the restoration of marine carbon ecosystems is a major concern (Wiley et al., 2016). Additionally, it is necessary to solve the problem of waste in water bodies, which is a barrier to restoration and protection. The amount of discarded waste

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and its flow from rivers to the sea and other freshwater areas requires investigation, as removal of such waste is critical. Furthermore, in freshwater areas, the issue of alien species should be addressed for proper restoration and protection. In addition, public education is essential to promote the understanding, maintenance, and promotion (Barracosa et al., 2019).

All research is crucial for improving basic knowledge of marine and/or freshwater carbon; however, responding to society's expectations to promote marine and/or freshwater carbon expansion as an urgent issue is also important. Therefore, it is necessary to determine the issues that are considered important by those involved in practical work and the promotion of marine and/or freshwater carbon. Moreover, it is necessary to determine the research topics that should be studied by examining whether the research addresses concerns that are considered important in practice and promotion. In this regard, studies have been conducted to investigate people's perceptions to determine the importance of various implementation and research issues. Dutta et al. (2011) used a questionnaire to understand stakeholders' views on the likely impacts of various levels of coastal inundation on crucial issues. Marine ecosystem services, including marine carbon, have also been investigated in a variety of target sites (Quevedo et al., 2021a; Quevedo et al., 2021b; Afonso et al., 2022).

This study aims to clarify which issues are considered important by those who participate in activities related to carbon in marine or freshwater areas in Japan, whether on the job or not, and how they understand the degree to which they these goals have been achieved based on a questionnaire survey. Consequently, the issues that are important in promoting marine and/or freshwater carbon awareness, but are currently not sufficiently addressed, are clarified. This also clarifies the shortcomings of current academic research. In addition, this study aimed to understand the differences between freshwater and marine carbon. Since freshwater carbon is relatively unexplored in comparison to marine carbon, it is important to identify the measures necessary for its promotion. This study addresses the achievement of carbon neutrality from the perspective of marine and freshwater carbon.

2 Project approach and methods

In July 2022, an anonymous survey was conducted. The questionnaire was distributed *via* e-mail to an unspecified number of practitioners and citizens involved in activities related to marine and/or freshwater carbon in Japan. Responses were accepted on a website created by a web form service or in hard copy (see Supplementary materials for details). The questions were divided into three main categories: questions about the respondents' socio-demographic attributes, respondents' perceived level of progress on marine- and/or freshwater-carbon-related initiatives, and respondents' perceived level of importance and achievement of marine- and/or freshwater-carbon-related topics.

First, respondents were asked questions related to themselves, which included the attributes of their organization, their age, and the number of years they had known about marine and/or freshwater carbon (Table 1). The organizations were classified as universities and research institutes, ministries and government organizations, prefectural and other local government offices, commercial enterprises, NPO/NGO/student/citizen groups, etc., and others. Age was classified as 25 years or younger, 25 to 75 years in 10-year increments, and 75 years or older. Participants classified their years of marine and/or freshwater carbon knowledge as: unknown, less than one year, one to three years, or more than three years.

Next, questions on perceptions on the progress of efforts related to marine and/or freshwater carbon and the importance and achievement of the elements were asked for marine and freshwater areas, respectively. Marine- and freshwater-carbon-related questions were asked only if the participants had prior awareness of either, respectively. Regarding perceptions of the progress of efforts related to marine and/or freshwater carbon, respondents were asked whether they felt that efforts in "understanding the roles and effects of marine and/or freshwater carbon ", "maintenance of the marine and/or freshwater carbon ecosystem", and "dissemination and promotion of marine and/or freshwater carbon ", were progressing, on a five-point scale where 1 is "not progressing

TABLE 1 Classification of respondent attributes in the questionnaire.

Individual/Organizational Attributes	Age	Number of years of marine and/or freshwater carbon awareness
➢ Universities and research institutes	➢ < 25	➢ unknown
➢ Ministries and government organizations	➢ 25 to 34	➢ < 1
➢ Prefectural offices	➢ 35 to 44	➢ 1 to 3
➢ Local government offices	➢ 45 to 54	➢ > 3
➢ Commercial enterprises	➢ 55 to 64	
➢ NPO/NGO/student/citizen groups, etc.	➢ 65 to 74	
➢ Others	➢ > 75	

at all" and 5 is "progressing well". The statistical significance of the differences in means between respondent attributes for these questions was confirmed with a two-sample t-test.

Regarding the perceptions of the importance and achievement of elements, several elements related to the understanding, maintenance, dissemination of information, and promotion of marine and/or freshwater carbon were listed, from both research and implementation perspectives. These questions were also asked on a 5-point scale, excluding those who answered "I don't know". Specific ocean-related elements included the following (Table 2): clarification of ocean/freshwater currents, clarification of nutrient dynamics, clarification of carbon dynamics in relation to carbon fluxes between the atmosphere and sea surface, clarification of water temperature changes in the ocean, climate change projection, clarification and prediction of freshwater inflow from rivers, clarification and prediction of ocean acidification, regeneration of marine and/or freshwater carbon ecosystem, clarification of the amount of garbage dumped and the inflow of garbage from rivers, garbage removal, and education on marine and/or freshwater carbon. Regarding freshwater areas, the question of "extermination of alien species" was added, and "clarification and prediction of ocean acidification" was excluded (Table 3). This was based on the issue of alien species feeding on algae and aquatic organisms, which are the main elements of freshwater carbon ecosystems.

Based on the answers obtained, each element was classified as follows (pertaining to the degree of importance and degree of achievement): high importance and high degree of achievement, important but not achieved, and low importance. Furthermore, by using each group categorized by participant attributes, and responses to their recognition of the progress of marine and/or freshwater carbon efforts, relative comparisons of their responses could be made, according to the characteristics of participants. Through these analyses, the differences in recognition by respondent groups were clarified, as well as the requisite efforts related to research on marine and/or freshwater carbon and implementation of the research results.

3 Results

3.1 Survey implementation

Ninety-four (92 online and 2 hardcopy) valid responses to the questionnaire were received, excluding the five participants who either answered that they were not aware of both marine and freshwater carbon or did not agree to the use of their answers for this study. Figure 1 shows respondents' attributes, age, and years of involvement. Owing to the small number of respondents for some attributes, multiple sections were combined to facilitate statistical analysis. Specifically, the organization classifications became broader and were redivided into five groups: universities and research institutes, ministries and government organizations, prefectural offices, local government offices, and others. Regarding age, one group was defined as those aged 55 and over.

3.2 Marine carbon

Using a 5-point rating scale, the results for the progress of initiatives related to understanding the roles and effects of marine carbon, maintaining ecosystems, and dissemination

TABLE 2 The average and variance of the answers to the eleven questions regarding marine carbon.

		Degree of importance		Degree of achievement	
		mean	variance	mean	variance
A	Clarification of ocean currents	4.11	0.81	2.73	0.84
B	Clarification of nutrient dynamics	4.16	0.81	2.73	0.89
C	Clarification of carbon dynamics in relation to carbon fluxes between the atmosphere and sea water	4.30	0.82	2.70	0.90
D	Clarification and prediction of water temperature changes in the ocean	4.31	0.74	2.78	0.98
E	Climate change projection	4.43	0.78	2.86	0.98
F	Clarification and prediction of freshwater inflow from rivers	3.86	0.93	2.92	1.02
G	Clarification and prediction of ocean acidification	4.01	0.88	2.55	0.93
H	Regeneration of marine carbon ecosystem	4.54	0.72	2.25	0.93
I	Clarification of the amount of marine debris dumped and the inflow of garbage from rivers	3.85	1.04	2.52	1.09
J	Marine debris removal	4.14	1.02	2.32	0.96
K	Education on marine carbon	4.22	0.88	1.95	1.03

TABLE 3 The average value and variance of the answers to the ten questions regarding freshwater carbon.

		Degree of importance		Degree of achievement	
		mean	variance	mean	variance
A	Clarification of freshwater currents	4.11	0.81	2.80	1.00
B	Clarification of nutrient dynamics	4.05	0.86	2.88	0.97
C	Clarification of carbon dynamics in relation to carbon fluxes between the atmosphere and water surface	4.10	0.85	2.67	0.96
D	Clarification and prediction of water temperature changes in freshwater area	3.95	0.88	2.89	0.93
E	Climate change projection	4.17	0.88	2.57	1.03
F	Eradication of alien species	4.21	0.80	2.34	0.83
G	Regeneration of freshwater carbon ecosystem	4.14	0.83	2.19	0.88
H	Clarification of the amount of garbage dumped and the inflow of garbage from rivers	3.72	1.07	2.44	0.97
I	Garbage removal	4.05	1.00	2.32	0.94
J	Education on freshwater carbon	4.10	0.88	1.91	1.10

and promotion were averaged at 2.50, 2.51, and 2.36, respectively. Many answered that efforts had not progressed to all of the questions.

Subsequently, the answers were grouped by organization, age, and number of years they had known about marine carbon (Figure 2). The group that was aware of marine carbon for longer gave higher ratings (2.81) than others for questions regarding the roles and effects of marine carbon, indicating that they consider efforts to be progressing. Regarding the question about the maintenance of the marine carbon ecosystem, the answers from the group that was 25 years old or younger (3.06) or whose organization was a university (2.83) were more positive than those from others. Responses to the dissemination and promotion questions were lower, regardless of age or organization. However, these differences were not statistically significant, as the overall trend was the same, even when the respondent groups were divided.

Subsequently, the average value and variance of the answers to the 11 questions regarding the degree of importance and achievement were calculated for all respondents (excluding those

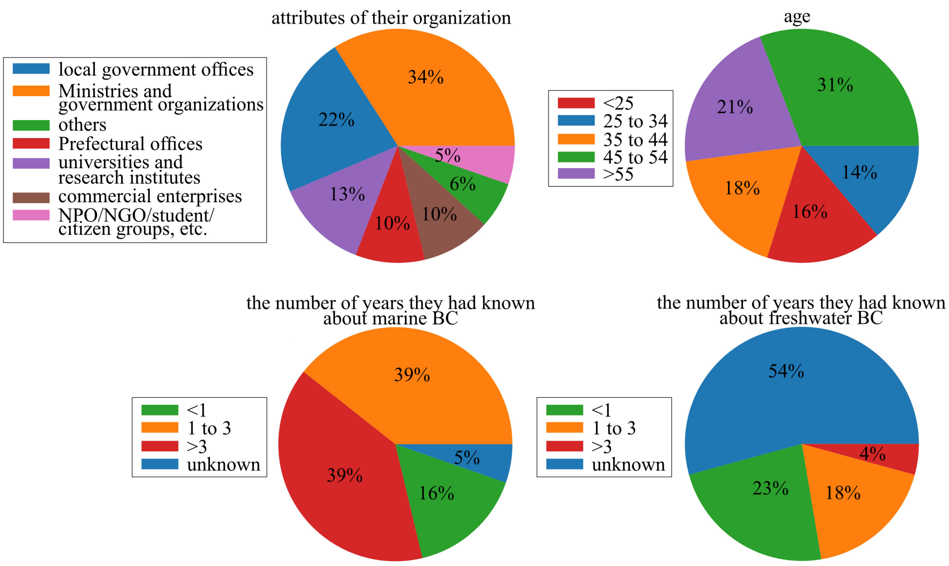

FIGURE 1
Respondent attributes in the results.

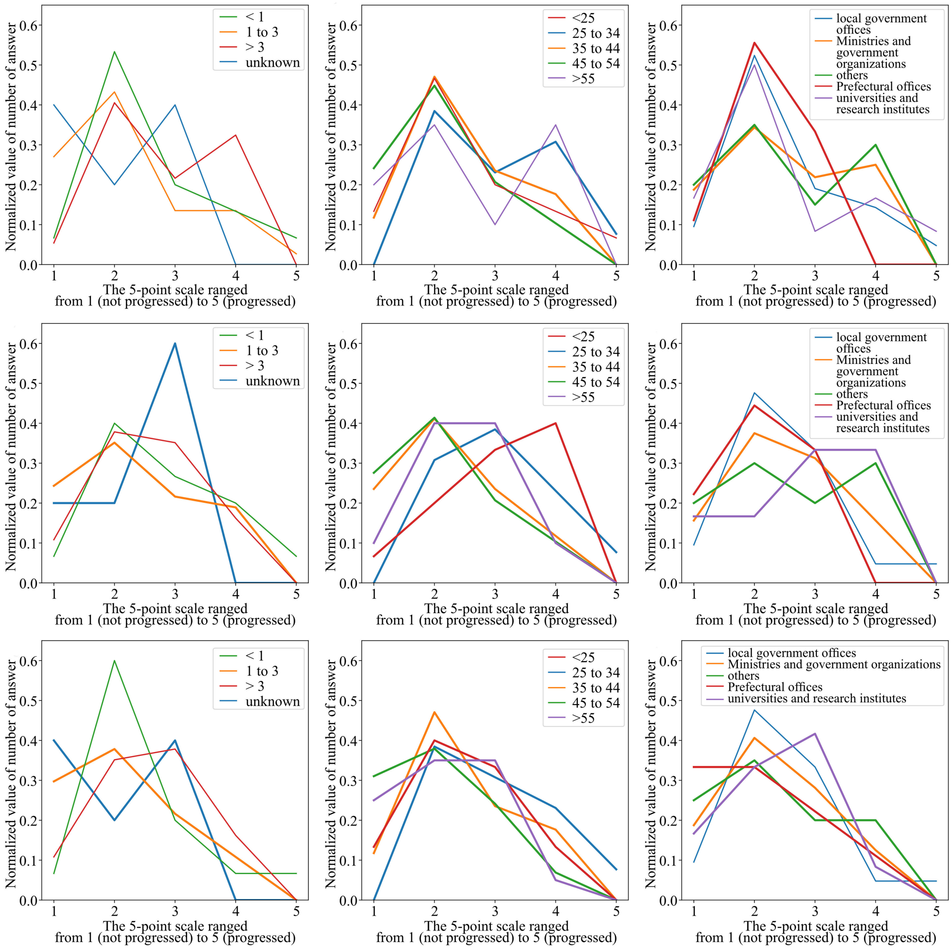

FIGURE 2
Results on the progress of marine carbon-related efforts grouped by attributes. For each of the three questions (each row), the results are shown for each of the three respondent attributes (each column). The questions are "understanding the roles and effects of marine carbon" (left column), "maintenance of the marine carbon ecosystem"(center column), and "dissemination and promotion of marine carbon"(right column). The respondent attributes are "the number of they had known about marine carbon" (top row), "age" (center row), and "organization" (bottom row).

who answered that they did not know) (Table 2). The percentage of respondents who rated the importance as 4 or 5 was 77.9% on average for all questions, while the percentage of respondents who rated achievement as 1 or 2 was 46.5%.

Furthermore, the distributions of the combinations of degrees of importance and achievement for each question were calculated (Figure 3). While the average score for the degree of importance exceeded 3 for all questions, that for the degree of achievement was below 3. These results indicated that the question on restoring the marine carbon ecosystem had the highest average degree of importance (4.54), the second lowest degree of achievement (2.25), and strong recognition that the degree of achievement had not progressed despite its importance. The results showed that the degree of achievement of aspects directly related to activities, such as marine debris removal (2.32) and marine carbon ecosystem restoration (2.25), was low compared to academic content, such as nutrient dynamics (2.73) and carbon dynamics (2.70). The analysis results of the combination of the degrees of importance and achievement showed that the recognition of the degree of importance of the carbon flux (between the atmosphere and sea surface) was divided between 3 and 5. However, the other answers had a unimodal distribution centered on the mode; therefore, the tendency of the answer results to be divided into two groups could not be confirmed.

The answers regarding education displayed the lowest degree of achievement (1.95). The answers indicated that the respondents who thought education was important also thought that the degree of achievement was low. Conversely, the results

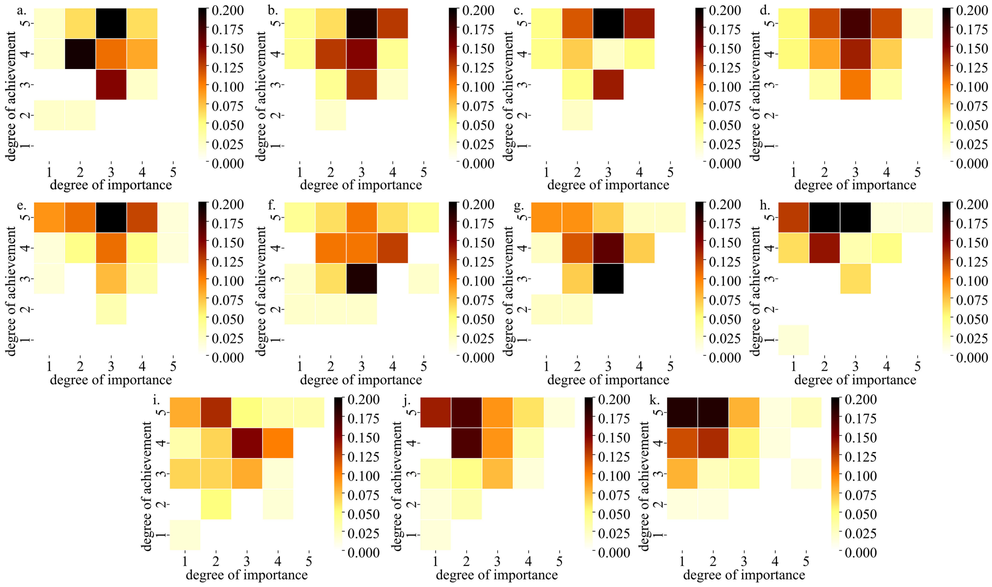

FIGURE 3
Distributions of the combinations of degrees of importance and achievement for each question (**A–K**, corresponding to Table 2) regarding marine carbon.

showed that the second least degree of importance was for freshwater inflow from rivers (3.86), and the degree of achievement was the highest (2.92), but still less than 3.

In terms of academic issues, trends differed between wide-area phenomena (climate change and water temperature) and local phenomena (flow, nutrient dynamics, and carbon dynamics). Freshwater inflow and ocean acidification had a lower percentage of low responses than the others, with 3 being the most frequent response (18.7% and 20.9%, respectively). However, the results for water temperature change and climate change showed a combination of high importance and medium degree of achievement. The most frequent values for the degree of importance and achievement were 3 and 5 (27.7% and 17.2%, respectively).

3.3 Freshwater carbon

Figure 4 shows the attributes of the participants who answered that they knew about freshwater carbon. Compared to marine carbon, many local government officials and others (in terms of organizations) responded; however, the percentage of ministry and government officials with the largest number of answers decreased considerably. No significant changes were observed in any age group. Regarding the number of years of knowledge of freshwater carbon, many answers were "less than one year." This was vastly different from marine carbon, where 78% of the respondents had known about it for more than one year.

The responses on the progress of initiatives related to understanding the roles and effects of freshwater carbon, maintaining freshwater carbon ecosystems, and dissemination and promotion averaged 2.11, 2.18, and 2.09, respectively. Additionally, the answer to many questions was that efforts had not progressed beyond marine carbon. The response results were then checked by organization, generation, and number of years they had known about freshwater carbon (Figure 5). The results showed that the understanding of roles and effects was high among universities and research institutes (2.87). Additionally, regarding administration, there were higher responses among ministries and government officials (2.60) compared to local governments (1.84) and prefectures (1.67). Similarly, many young respondents answered that efforts were progressing (3.00). Conversely, the age groups of 35-45 and 45-55, which are considered to be central groups for rating efforts, gave low ratings (1.86 and 1.68, respectively). Regarding the maintenance of freshwater carbon ecosystems, the same tendency had been observed in efforts to understand their roles and effects. As for dissemination and promotion, similar to the responses regarding administration, those from local governments and prefectures were particularly low (average 1.85 and 1.90, respectively), while ministry and government responses were slightly higher (average 2.40). Regarding dissemination and promotion, the number of answers with

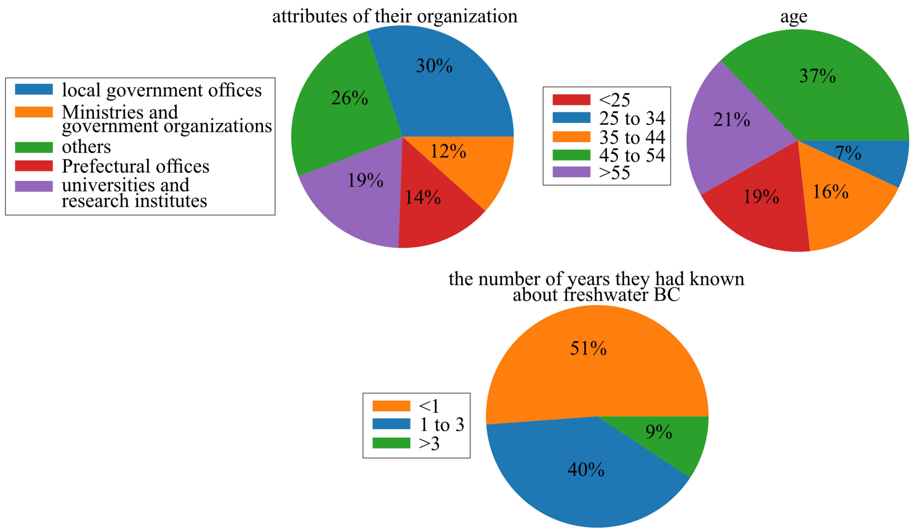

FIGURE 4
Respondent attributes in the results regarding freshwater carbon.

low values tended to decrease as the years of freshwater carbon awareness increased.

Next, responses to the 10 questions about the degree of importance and achievement were examined in the same way as for marine carbon (Table 3; Figure 6). Resembling the marine carbon results, the average degree of importance responses exceeded 3 for all questions, while the average degree of achievement was less than 3. The percentage of respondents who rated the importance as 4 or 5 was 72.2% on average for all questions, while the percentage of respondents who rated achievement as 1 or 2 was 48.6%.

The highest average degree of importance was for invasive alien species control (4.21) (which was asked only for freshwater bodies). Their degree of achievement was the fourth lowest (2.34). Clarification of water temperature change had the highest average degree of achievement (2.89), and its importance was second lowest (3.95). Results with a large variance in degree of importance were related to garbage waste (1.07 and 1.00), which differed by region. Eradication of alien species and restoration of the freshwater carbon ecosystem had the smallest variance in terms of degree of achievement (0.83 and 0.88, respectively), and these average values were also low, which indicated that although the respondents commonly recognized this as an issue, it had not been achieved.

From the distribution of the responses, the degree of importance of nutrient dynamics, carbon flux, and garbage removal were medium (3) or high (5). There were no clear layers of distinction in terms of degree of achievement. Additionally, there were only a few responses with greater values for the degree of achievement than for the degree of importance. Regarding the combination of answers for the degrees of importance and achievement, there were three general responses. The four elements of freshwater currents, nutrient dynamics, carbon flux, and climate change showed a high degree of importance (4.11, 4.05, 4.10 and 4.17, respectively) and a medium degree of achievement (2.80, 2.88, 2.67 and 2.57, respectively). For the elements of eradication of alien species, regeneration of freshwater carbon ecosystem, garbage removal, and education: a high degree of importance (4.21, 4.14, 4.05 and 4.10, respectively) but a low degree of achievement (2.34, 2.19, 2.32 and 1.91, respectively). Lastly, the two elements of water temperature changes, and the amount of garbage dumped and inflow of garbage from rivers, showed a comparatively low degree of importance (3.95 and 3.72, respectively). The tendency shown in the results for marine carbon, in which academic elements were accomplished to a greater extent and practical items to a lesser extent, was more clearly demonstrated in the results for freshwater carbon.

3.4 Relative analysis of perceived importance and achievement by respondent attributes

Finally, a relative comparison was made of the responses of each respondent group according to their attributes (Figures 1, 4) regarding the degree of importance and achievement (Figure 7). From the analysis results differences in what was considered important and how much was perceived to be achieved clearly depended on the attributes of the respondents.

Regarding the difference in recognition by affiliation, respondents belonging to the local government tended to

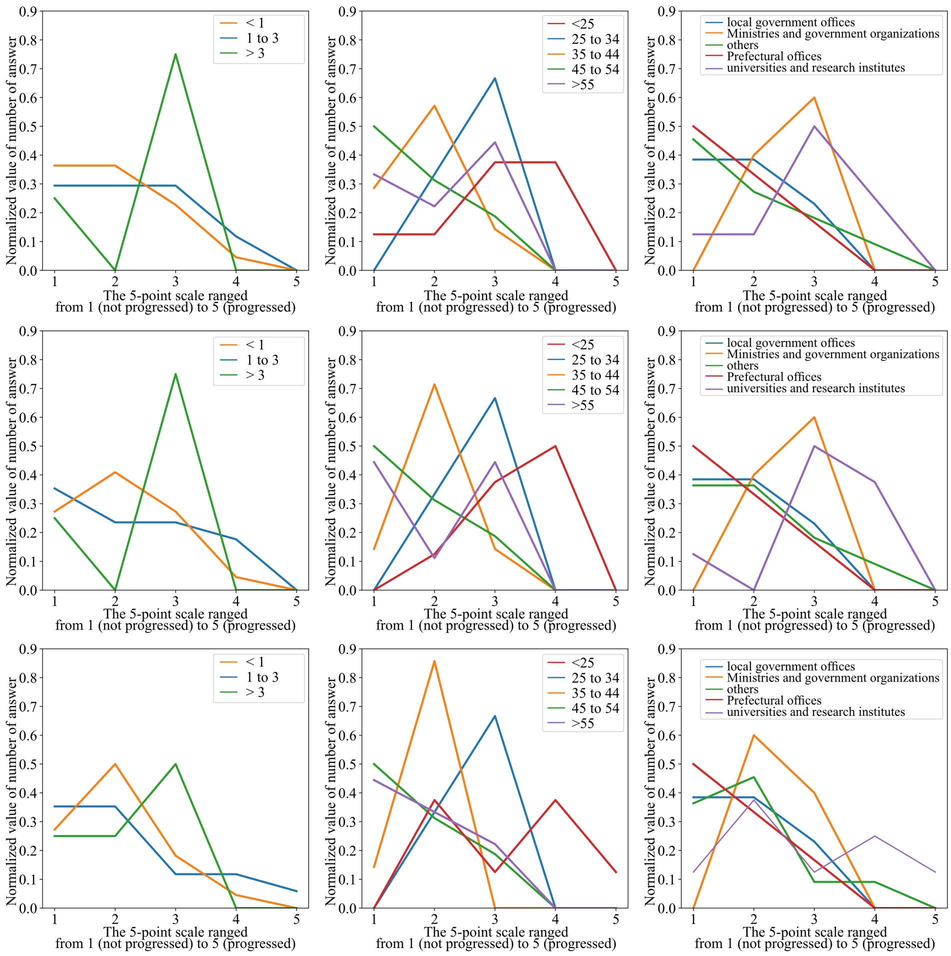

FIGURE 5
Results on the progress of freshwater carbon-related efforts grouped by attributes. As in Figure 2, the results of the three questions are summarized for each of the three attributes. The questions are "understanding the roles and effects of freshwater carbon" (left column), "maintenance of the freshwater carbon ecosystem"(center column), and "dissemination and promotion of freshwater carbon"(right column). The respondent attributes are "the number of they had known about freshwater carbon" (top row), "age" (center row), and "organization" (bottom row).

perceive the degree of importance as low across all questions, whereas those belonging to the ministry and government tended to recognize it as high. Respondents belonging to prefectures tended to recognize the degree of importance of marine carbon as high, whereas they recognized the degree of achievement related to fields such as education and waste removal as lower than others. Additionally, universities and research institutes recognized the degree of achievement of academic content, such as the clarification of nutrient dynamics. The importance of freshwater carbon has also been recognized by this group as high.

As for the difference in recognition by age, younger people rated the degree of achievement higher than average, whereas those between 45 and 55 years had the highest recognition of the degree of importance and the lowest evaluation of the degree of achievement. However, recognition of the degree of importance was low among those aged between 25 and 35 years, as well as among those aged over 55 years. Additionally, the recognition of the degree of importance related to freshwater carbon was higher than average for participants between 35 and 45, except for the amount of waste dumped and the clarification/prediction of the actual state of waste inflow from rivers.

Regarding the difference in recognition by the number of years of marine and/or freshwater carbon knowledge, where the number of years was long (>3), implementation-related issues (e.g., regeneration of marine and/or freshwater carbon ecosystem, amount of garbage dumped and the inflow of garbage from rivers, and garbage removal) had a low degree of

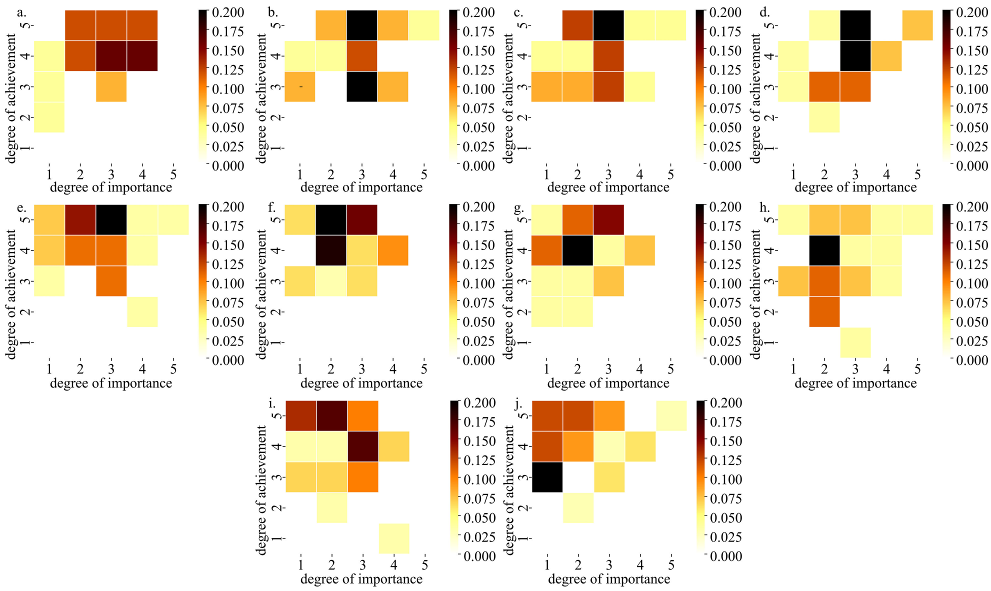

FIGURE 6
Distributions of the combinations of degrees of importance and achievement for each question (**A**–**J**, corresponding to Table 3) regarding freshwater carbon.

achievement, whereas academic issues (such as ocean or freshwater currents, nutrient dynamics, carbon dynamics, and water temperature changes) had a high degree of achievement. However, the degree of importance was generally slightly lower when the number of years of marine and/or freshwater carbon awareness was high.

4 Discussion and conclusion

In this study, to clarify the research and practical issues that need to be addressed for the information distribution and promotion of marine and/or freshwater carbon, a survey was conducted to clarify what practitioners and citizens that participate in activities related to marine and/or freshwater carbon recognize as challenges and to what extent they have been achieved.

The results indicated that the importance of marine and freshwater carbon is highly recognized, although the achievement of marine and freshwater carbon is inadequate. For marine carbon, Nellemann et al. (2009) and many other studies have revealed its importance. While studies on freshwater carbon are still limited, results indicating its potential have been revealed in recent years. For example, Lin et al. (2021); Lin et al. (2022) showed that pCO_2 partial pressure can be lower than that of the atmosphere throughout the year in freshwater lakes above mesotrophic levels, indicating the feasibility of freshwater carbon through the planting of water plants. Additionally, Gu et al. (2020) revealed the high possibility of carbon capture and storage by Phragmites australis (common reed) in a St. Lawrence Estuary Marsh. Since Phragmites australis is a cosmopolitan species growing in inland waters, there could be a high potential to enhance freshwater carbon sequestration. The accumulation of these studies has contributed to enhance awareness of the importance of this issue.

The pattern of responses to questions regarding the importance and achievement of elements considered relevant to the understanding, maintenance, and dissemination of information and promotion of marine and freshwater carbon showed a trend toward higher achievement related to understanding marine and freshwater carbon ecosystems and the surrounding environment, and lower achievement in other elements. This was especially true in freshwater areas. This suggests that research issues related to implementation have not been adequately addressed compared to physics- and chemistry-related research issues. Specifically, there is a need to accumulate research results to promote its implementation in freshwater areas. Implementation contributes to achieving carbon neutrality because it is essential to increase carbon credit certifications. Regeneration of marine and freshwater carbon ecosystems is a direct effort to increase carbon credit certification. Education is also important for gaining public

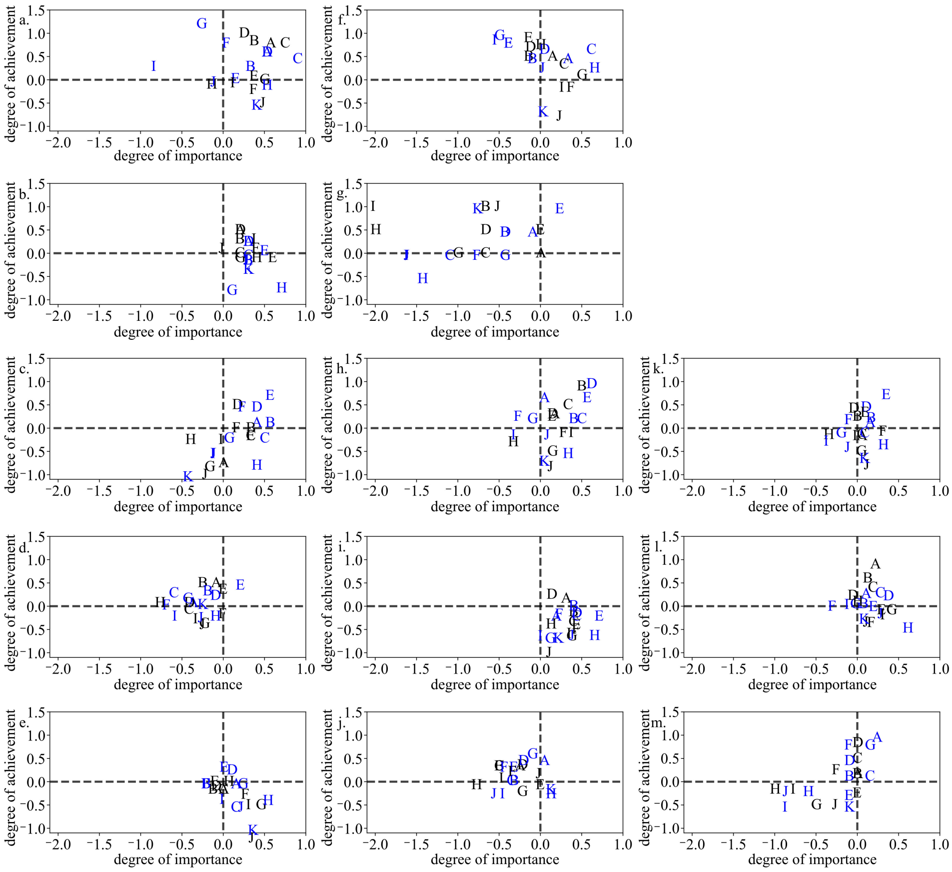

FIGURE 7
Relative comparisons of importance and achievement perceived by the respondent. The alphabets plotted in each figure are the relative importance and achievement, which is the difference of mean between each attribute and all, for the 10 questions (**A** through **I**, questions common to Tables 2, 3). Comparisons performed for each of the organizations (left column), ages (center column), and the number of years are presented (light column). Organizations are university and research institutes **(A)**, ministries and government offices **(B)**, prefectures **(C)**, local governments **(D)**, others **(E)**. Ages are less than 25 **(F)**, 25 to 34 **(G)**, 35 to 44 **(H)**, 45 to 54 **(I)**, and more than 55(j). The number of years are less than 1 **(K)**, 1 to 3 **(L)**, and more than 3(m).

support for marine and freshwater carbon implementation. Issues related to implementation vary widely among regions, and this can be a hindrance to increasing achievement. Kuwae et al. 2022b reviewed three marine carbon implementation projects in Japan. The accumulation and sharing of case studies are important to resolve this issue.

The results of the classification of respondents by attributes showed that the organization in which the activity was conducted, the respondent's age, and the number of years of knowledge of marine and/or freshwater carbon tended to make a difference in the perception of importance and achievement. This result is consistent with the analysis in Dutta et al. (2013). The organizations that carried out activities related to marine and/or freshwater carbon had many responses pertaining to actual sites. Respondents from these organizations recognized less progress in terms of dissemination and promotion of information than those in ministries and governments. Additionally, the low degree of importance of academic consideration in the results signifies that practitioners may not sufficiently recognize their importance. It is essential to understand the perceptions of each respondent group to resolve this difference. Progress in mutual understanding can lead to the identification of new research topics and the implementation of measures by the ministry and government, which in turn is expected to further promote mutual understanding, thereby generating positive feedback.

Kim et al. (2022) evaluated the economic value of marine carbon determined by the general public and showed that marine carbon restoration is socially profitable. Previous studies have conducted economic analyses of carbon in forested and marine areas. Commercially viable and scientifically robust analyses of marine carbon initiatives have also been conducted (Vanderklift et al., 2019). The difference between the two may be that these economic values have not yet been evaluated for freshwater areas. Economic analysis needs to be conducted in the same manner as in the ocean. The difference between freshwater and marine areas can be attributed to the difference in progress regarding the evaluation of economic value. The same economic analysis needs to be conducted in freshwater areas as in marine areas.

When considering this survey, it must be noted that those who responded to the survey were more concerned about marine and/or freshwater carbon than the general public. Based on the results of the grouped respondents, there is a possibility that the general public, who were not the target of the questionnaire, had low awareness of the importance of marine and/or freshwater carbon. The key to the promotion of marine and/or freshwater carbon is to get these groups to recognize its importance. Most of the general public and government agencies know about biodiversity and waste issues, even if they do not know about marine and/or freshwater carbon. It is expected that association with familiar issues can increase awareness of them. In addition, the linkage with the perspective of disaster prevention, which is a globally important issue in climate adaptation, is also important. Ecosystem protection also contributes to reducing disaster risks.

The survey results revealed the perceived importance and achievement of the issues by practitioners and citizens participating in activities related to marine and freshwater carbon. The perceptions varied depending on the attributes of the respondents. Further analysis of these differences in perceptions could provide valuable insights into research and implementation efforts to achieve marine and freshwater carbon implementation. Advancing mutual understanding between researchers and practitioners through analysis as in this study is necessary for ensuring marine and freshwater carbon implementation.

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.

Ethics statement

The studies involving human participants were reviewed and approved by Kobe university. The patients/participants provided their written informed consent to participate in this study.

Author contributions

SW, SY and KN contributed to the conceptualization and design of the basic framework of the survey. SW and YM contributed to the data analysis and visualization of survey results. All authors contributed to the writing of the manuscript and approved the submitted version.

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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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.1036248/full#supplementary-material

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