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"Future Compass", a Tool That Allows Us to See the Right Horizon—Integration of Topic Modeling and Multiple-Factor Analysis

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Abstract: Coastal social–ecological systems (SES), particularly in large bays, are critical for fisheries, transportation, and disaster prevention in island and coastal countries. To achieve the sustainability of such bays, public involvement is recently considered inevitable for planning and management, but the increasing complexity of variables and future visions to be considered is one difficulty when trying to include many stakeholders and public opinions. To address this challenge, a free-associative description questionnaire survey was used in this study to extract holistic coastal residents' future visions for Tokyo Bay, including both positive and negative outcomes. By integrating biterm topic modeling (BTM) and multiple-factor analysis (MFA), this study succeeded to aggregate and visualize the various future visions of Tokyo Bay with enhanced comprehensibility. As one outcome, the linkages and differences between the major topics in the positive and negative future visions were visualized as vectors in a correlation circle. Also, the study found that these two kinds of future vectors are not always polar opposites, but, rather, some of them are interlinked, pointing in the same direction. This highlights the importance of measuring the balance between two kinds of future vectors in consensus-building in order to search for the optimal future direction. Finally, the study discusses the potential of this method as a "Future Compass", for implementing future-oriented consensus-building toward the sustainability of SES.

Keywords: consensus-building; future vision; natural language processing (NLP); biterm topic model (BTM); multiple-factor analysis (MFA); Tokyo Bay

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1. Introduction

Bays are crucial for island and coastal nations, serving as vital components of their fisheries, maritime transportation, and disaster-mitigation systems; and their ecosystem services, including their historical and cultural significance, are increasingly valued [1]. In Japan, variously sized bays contribute significantly to the development of ports and local communities. For example, Tokyo Bay, Ise Bay, and Osaka Bay, each of which has three major metropolitan areas in Japan at the back of the bay, have played an important role in regional and national development.

Such bay areas and their adjacent coastal regions comprise a multifaceted social–ecological system (SES) that involves a diverse set of stakeholders (individuals, groups, or organizations that are (or will be) affected, involved, or interested (positively or negatively) by planning, development, and management [2]) and an ecosystem that is the foundation of natural resources (including water, fishery resources, and landscapes) [3]. The SES in the bay plays a vital role in supporting human activities in the surrounding hinterland. However, it is also vulnerable to negative impacts resulting from human activities, as evident from instances of overfishing and contamination of water bodies due to domestic wastewater discharge [4].

There is a long history of struggle involved in balancing and harmonizing utilization and conservation in the context of natural resource management and landscape planning, and, when it comes to aquatic environments, ICZM (integrated coastal zone management) [5,6] and MSP (marine spatial planning) [2] have been developed as approaches to achieve integrated and sustainable management of marine spaces, balancing social, economic, and environmental considerations for the benefit of present and future generations. MSP focuses on the marine environment and is, typically, used to manage activities such as shipping, fishing, and offshore energy development, while ICZM focuses on the coastal zone and is, typically, used to manage activities such as tourism, recreation, and coastal development. When considering management plans for large bays, both perspectives are needed. There are various good practices for each approach but one common key for success is stakeholder engagement [7]. When considering ICZM and MSP for a big bay with a vast urban hinterland, specific stakeholders in the bay and their coastal zones include not only fishers, harbor authorities, local municipalities, and governmental organizations but also local residents in the hinterland of the area. Basically, as the scale of the SES expands, the proportion of space that is the domain of a particular stakeholder group narrows while the proportion of public space increases, and the number and variety of local residents who would ideally be involved become much greater. In such cases, ensuring that the needs and desires of the community are reflected in the plan, while properly identifying and considering issues and concerns, becomes challenging. Therefore, it is important to pursue public involvement consisting of the cooperation, participation, and behavioral changes, especially of local residents [8].

To date, several methodologies have been developed and practiced for public involvement (e.g., [7,9]). The prevailing understanding derived from the previous discussions on public involvement is that the "public" is not simply a blend of homogeneous stakeholder groups but, instead, a diverse and complex mix of identities and value systems which are not confined to particular interest groups [9]. Amid this complexity, it is essential to have a smooth method of decision-making with public involvement aimed at cooperative problem solving. One of these methods is widely known as "consensus-building", a conflict-resolution process mainly used to resolve complex multi-party disputes [10]. The process of "consensus-building" allows various stakeholder groups with various kinds of interests in the problem or issue to work together to develop a mutually acceptable solution. Also, more specifically focused on information sharing and agreement regarding relevant (scientific, technical, or historical) facts, "joint fact-finding" was developed as a method to subdue confusions and conflicts caused by unarranged information over stakeholders, including non-scientists. This practice aims to reach to decision-making with public involvement based on the shared scientific information which includes presuppositions, models, and, of course, the limitations of science [11].

In previous implementations of ICZM and MSP, the following scientific methods have been utilized to quantitatively assess the health and economic value of natural ecosystems: the ecosystem services (ES) valuation [12] that calculates the monetary value of ecosystems, the OHI (ocean health index) [13] which provides comprehensive and quantitative information on the benefits humans derive from the ocean and facilitates the sustainable management of ocean health, and the IMCES (integrated valuation method for coastal ecosystem services) [14,15] which aims to assess the value gained through conservation, restoration, and creation efforts in coastal environments. These studies are primarily about quantitatively assessing the scientific health status and economic value of natural ecosystems to make sense of and support paying for their conservation efforts. However, cultural ES, which was defined as the non-material benefits people obtain from ecosystems [16], for example, had been criticized for its limited evaluation within the ES monetary valuation framework, such as the one with WTP (willingness to pay), because of its intangible, (inter-) subjective, and incommensurable characteristics generated by the complex interrelation between people and nature [17–19]. Also, previous studies on public perceptions have utilized Likert-type questionnaires in an attempt for quantification. Although these questionnaires are easily quantifiable, they are often limited to capture the variety of the personal value individuals assign to the environment based on their experiences and memories since the range of questions is always limited by the experience, assumptions, and awareness of researchers [20]. In addition, from the perspective of public involvement in the management and planning of bays and coastal zones, the following challenges to its effective implementation exist. First, as the number and diversity of stakeholders increase, achieving consensus in a bottom–up manner becomes more difficult and costly [21]. Second, sustainability requires a decision-making support system that not only considers current opinions and benefits but also future visions [22]. Third, in the case of complex social–ecological systems (SES), a linear approach toward a specific goal or future vision may not adequately address uncertainty [23].

Overall, addressing these challenges is crucial to promoting effective public involvement and ensuring sustainable management of bay and coastal zones. Therefore, this study takes Tokyo Bay as an example of a bay where a public and complex social–ecological system has been formed, and conducts the following, corresponding to the challenges mentioned above: (1) collecting various future visions held by residents in the surrounding coastal area in a free descriptive manner, (2) analyzing these future visions quantitatively to visualize and understand the major factors while examining their differences and linkages, and (3) presenting the various goals, future visions, and necessary directions to achieve them. Then, the results of the study will be used to discuss the feasibility of "consensus-building on future vision", which can contribute to adaptive and flexible strategy formulation for the sustainability of SES. To accomplish the aforementioned goals, this research integrates topic-modeling technology, a quantitative method used to analyze natural language as a reflection of human consciousness, and multi-factor analysis, which enables the comparison and evaluation of the relationships between extracted topics through visualization. This methodological integration represents an academic advancement as it addresses the importance of scientific communication by minimizing the subjective influence of the analyst and enhancing the comprehensibility of the findings for non-specialist readers [24] by using a data-driven approach to interpret people's attitudes expressed through natural language. The utilization of bottom–up public opinion collection, quantitative analysis, and information visualization methods, as demonstrated in this study, can potentially aid in public involvement and consensus-building towards resolving issues confronting coastal social–ecological systems (SES), including environmental improvement projects in areas of coastal population concentration. Such approaches hold the potential to be effective not just in Japan but also in other regions globally, including developing countries.

2. Materials and Methods

2.1. Study Target

To fulfill the purpose of this study, Tokyo Bay (Figure 1), which has played an important role for the three surrounding prefectures (Tokyo, Chiba, and Kanagawa) since the political base moved to Tokyo in 1603 when the Edo Shogunate began, is taken as the target for a case study. Tokyo Bay is a closed water area with an unparalleled concentration of population and anthropogenic load, with approximately 30 million people, who account for 24% of Japan's entire population (around 126 million people), living within its watershed area [25]. Through its history with the rapid development of the bay area since the modern era, the number and diversity of the metropolitan area's residents has been increasing, and its natural resources have been forced to undergo dramatic changes. While it is important to incorporate residents' opinions and the engagement of residents in the complex and ever-changing SES, the diversity and complexity of the SES also render it costly to build consensus.

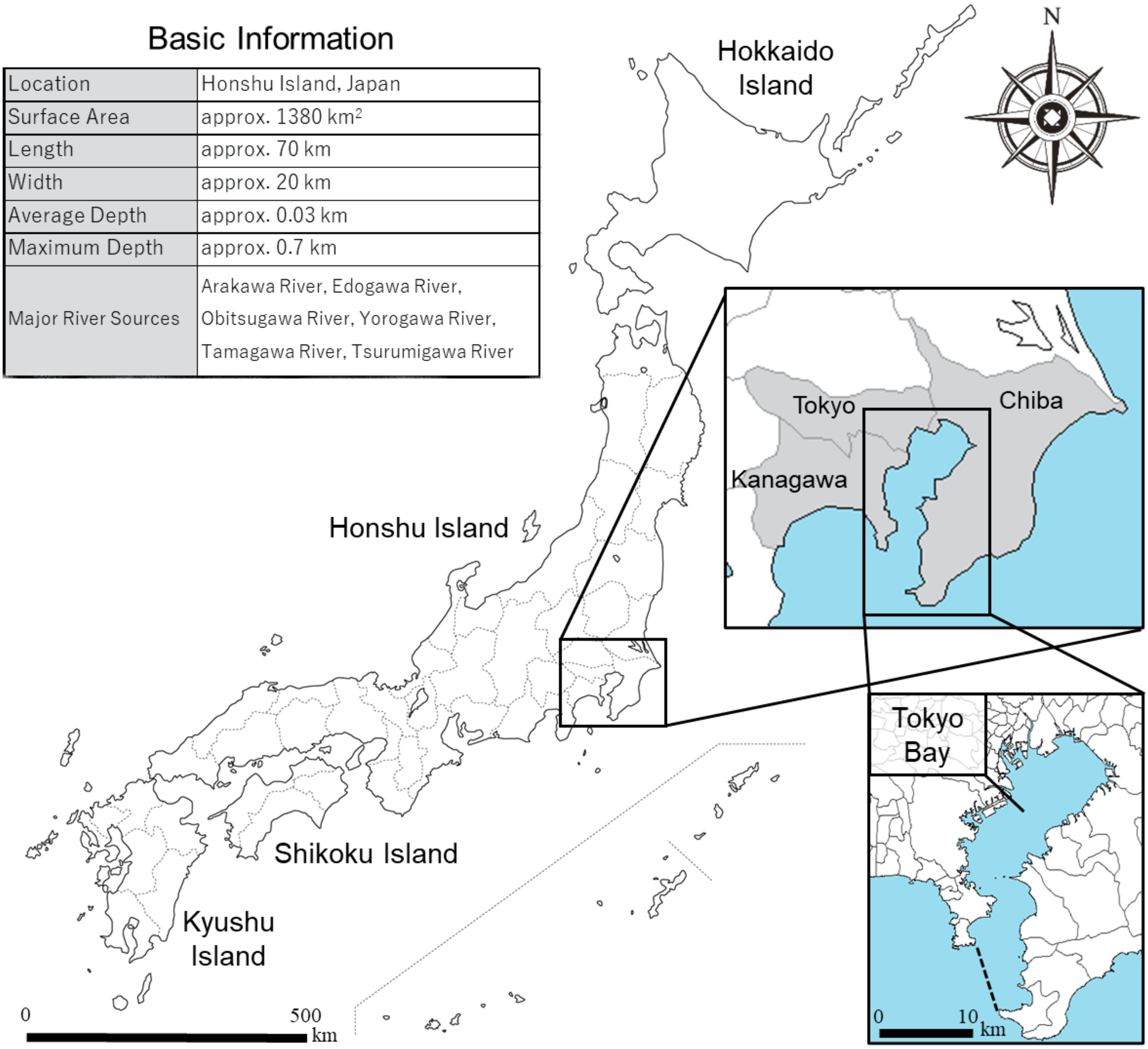


Figure 1. Map of Japan, the Location and General Information of Tokyo Bay. Source: https://www.ktr.mlit.go.jp/chiiki/chiiki00000083.html, accessed on 1 April 2023.

Tokyo Bay's natural environment was once characterized by a continuous coastal ecosystem that included large tidal flat areas, back marshes, and shallow coastal waters, which sustained many fish and coastal species, particularly bivalves and fish that migrate between fresh and salt waters [26] (Figure 2a,b). The bay also served as significant fishing grounds and a recreational area for coastal residents before the country's industrialization in the late 19th century [27] (Figure 2c). However, the rapid industrialization led to changes in the bay's environment and land-use, including many reclamation projects to accommodate industrial manufacturing and infrastructure for city functions. As a result, the bay lost 95% of its tidal flats areas, causing many native species to lose their habitats and foreign species to invade the bay [28]. Additionally, many recreational and cultural amenities, such as recreational clamming and festivals, have been lost as many of the reclaimed areas became industrial facilities (Figure 2d), restricting public entry [27].

(**a**) (**b**)

(**c**) (**d**)

Figure 2. Pictures of Tokyo Bay (photographed by the authors): (**a**) view of Tokyo Bay from Chiba side toward Kanagawa's industrial area; (**b**) many marine species can be found (picture taken at Urayasu, Chiba); (**c**) there are many spots to enjoy recreational fishing; and (**d**) empirical study site trying to revive interrupted seaweed cultivation on artificial seashores in Ota-ku, Tokyo.

The comprehensive history of Tokyo Bay teaches us about the vulnerability of the bay and coastal SES to human activities and the importance of carefully planning development and interference. In recent years, there has been a growing understanding of the closed nature of the bay and its vulnerability to water pollution and eutrophication, and there has been much discussion about bay restoration and sustainability (e.g., [26,29]). One major historical step was the establishment of the Tokyo Bay Restoration Promotion Council in response to the third decision of the Urban Restoration Project "Restoration of the Sea" in 2001, in which relevant ministries, agencies, and local governments collaborated to establish the "Action Plan for the Restoration of Tokyo Bay (Phase I)" to promote comprehensive measures to restore the water environment in Tokyo Bay. In 2013, the council assessed the status of previous efforts and formulated a new 10-year "Action Plan for Tokyo Bay Restoration (Phase II)" based on the analysis and evaluation. The ultimate goal of the new plan is to restore the health of Tokyo Bay and ensure its sustainable use for future generations, and it aims to achieve integrated ocean governance by promoting multi-stakeholder participation, building consensus, and implementing a number of partnership projects between the government and private sectors [30]. Due to the significant influence of the daily lives of residents living in Tokyo Bay's urban hinterland, the current policy proposal involves educational activities and events aimed at involving the residents in accelerating the restoration efforts [30].

2.2. Data Acquisition

The data presented in this paper were collected through a web-based survey conducted from 11–14 July 2017, through MyVoice, Inc., a research firm located in Tokyo, Japan. The survey participants were selected from residents in Tokyo, Kanagawa, and Chiba prefectures surrounding Tokyo Bay, aged 20 to 69. 1034 respondents were selected using a stratified sampling method based on actual population proportions and the number of valid responses without any blanks left in their answers was 980. Due to the Personal Information Protection Law enacted in 2005, it has become difficult to use a list of residents for random sampling throughout Japan [31], while the use of Internet-mediated survey methods has become increasingly popular due to the high Internet usage rate and the growth of PC and smartphone penetration [32]. According to Wright (2005) [33], Internet-based surveys are more cost-effective and suitable for studies requiring large amounts of data from a wide range of locations. For these reasons, we decided that it was appropriate to use an Internet-based questionnaire survey for this study. According to the Statistical Handbook of Japan 2018 [34], the Internet usage rate at the end of 2016 was over 90% for those in their 20s to 50s and over 70% for those in their 60s, while the rate was less than 60% for those aged 70 and above. Therefore, survey participants aged 70 and older were excluded from the study, as they were not considered representative of the entire population aged 70 and older.

A total of four questions, divided into two sections, were used in this study (Table 1). The first section contains questions related to the demographic information of the survey participants, gender and age, with the purpose of checking for extreme bias in the responses when narrowed down to valid responses. In the second section, referring to Suga and Oi (1995) [20] and Sugino et al. (2017) [35], which are previous studies on residents' consciousness and attitudes toward the natural environment, we employed a free-association survey method (a method in which respondents are presented with certain stimulus word(s) and asked to freely describe what they associate with the words) and asked them to describe what they "desired" and "undesired" regarding the future of Tokyo Bay; hereinafter, PFV (positive future vision) and NFV (negative future vision), respectively. In most surveys of residents' attitudes, the researcher formulates questions in line with the problem set and asks for responses in the form of a choice or a rating scale [36]. However, it has been pointed out that this type of survey method can be prone to the researcher's attitudes and ideas being incorporated into the question wording and choices, limiting respondents' attitudes and choices [37]. The reason why we adopted this method is because the free-association survey method allows respondents to respond without being restricted by the researcher's prior knowledge, preconceptions, or assumptions on the issues [24], and is particularly suitable for questions that require a survey with fewer restrictions on the range of responses, such as how to use and enjoy the benefits of a highly diverse natural environment [38]. The questionnaire was pretested in advance to check and correct for any misunderstanding of the explanatory or instructional text.

Table 1. General Framework of Questions and Section Details in the Survey.

Major Sections	No. of Questions	Details
Demographic Information Part	2	(1) Gender (2) Age
Free Association Survey Part	2	(Instruction Text) What do you associate with the following questions? Please be as specific as possible and write down as many associations as you can think of, whether they are individual words, groups of words, or sentences. (1) "What you would like Tokyo Bay to be like in the future, or with what you would like to see happen?" (PFV: positive future vision) (2) "What you would NOT like Tokyo Bay to be like in the future, or with what you would NOT like to see happen?" (NFV: negative future vision)

2.3. Data Analysis

In this study, the content of the PFV and NFV obtained by the free-association description method was transformed into a form that could be treated as a quantitative analysis. Then, the biterm-topic-model (hereinafter BTM) method [39,40] was conducted to extract topics for each PFV and NFV. The reason why we applied BTM rather than other topic-modeling methods such as LDA (latent Dirichlet allocation) [41–43] is because it can guarantee the better quality of topics compared to other methods, even when dealing with short documents (single units of text data), such as individual responses in this study. Also, BTM allows topic estimation to calculate topic scores (degree of applicability of documents to topics) on each response. The topic score calculation was followed by a multiple-factor analysis (hereinafter MFA) [44] to understand the relevance between topics (including synergistic effects due to similarity and repulsive effects due to differences) and to see the relative strength and directionality of each vision topic. This series of steps enables highly precise topic extraction while maintaining objectivity when dealing with a large number of free descriptions that are segregated into two or more groups. It also facilitates content analysis by utilizing the variations and connections among topics and groups.

The following are the major steps taken in this study: (1) pre-analysis distribution check and data cleaning, (2) preparation of annotation data and biterm list creation, (3) biterm topic models (BTMs) creation, and (4) multiple-factorial analysis (MFA) on topics. All data processing and analysis in this study was performed using R Statistical Software (v4.1.2; R Core Team [45]). The principal packages used were: "tidyverse" (Wickham et al. [46]) for data handling and cleaning, "udpipe" (Wijffels [47]) for preparation of annotation data, "BTM" (Wijffels [48]) for BTM creation, and "FactoMineR" (Le et al. [49]) for MFA. See Supplemental Materials for the details of code and data used in this study.

2.3.1. Pre-Analysis Distribution Check and Data Cleaning

Prior to preparing the BTM, we checked whether the distribution of valid responses for the demographic variables (age and gender) significantly deviated from that set at the time of the survey. After a careful examination of the text data obtained, obvious typographical errors and omissions were corrected, and synonyms that only differ in notion were unified and standardized. Responses that were difficult for the researcher to determine were left in their original forms. The survey was conducted in Japanese, and responses were obtained in the same language. To facilitate annotation followed by quantitative analysis, the original text was translated into English first, reviewed by native speakers, and used as data for subsequent analysis.

2.3.2. Preparation of Annotation Data and Biterm List Creation

Figure 3 depicts the following two sections which explain the process of BTM, including preparation phase. To obtain the data required for the BTM, we conducted morphological analysis and annotation [47] with POS (part of speech) information on the text data and created a corpus (database) for all terms included in the obtained text data. Since a single response may contain multiple topics in the obtained free-associative descriptions, a list of biterms (pairs of two words that co-occur in documents) within a three-word distance (the minimum unit to describe co-occurrence relationships between words) was created. After that, we produced a matrix linking the included terms and biterm information for all response data, which was used as data for the BTM creation. In this study, we placed our focus on nouns, adjectives, and verbs, which are considered content words in the field of linguistics [50].

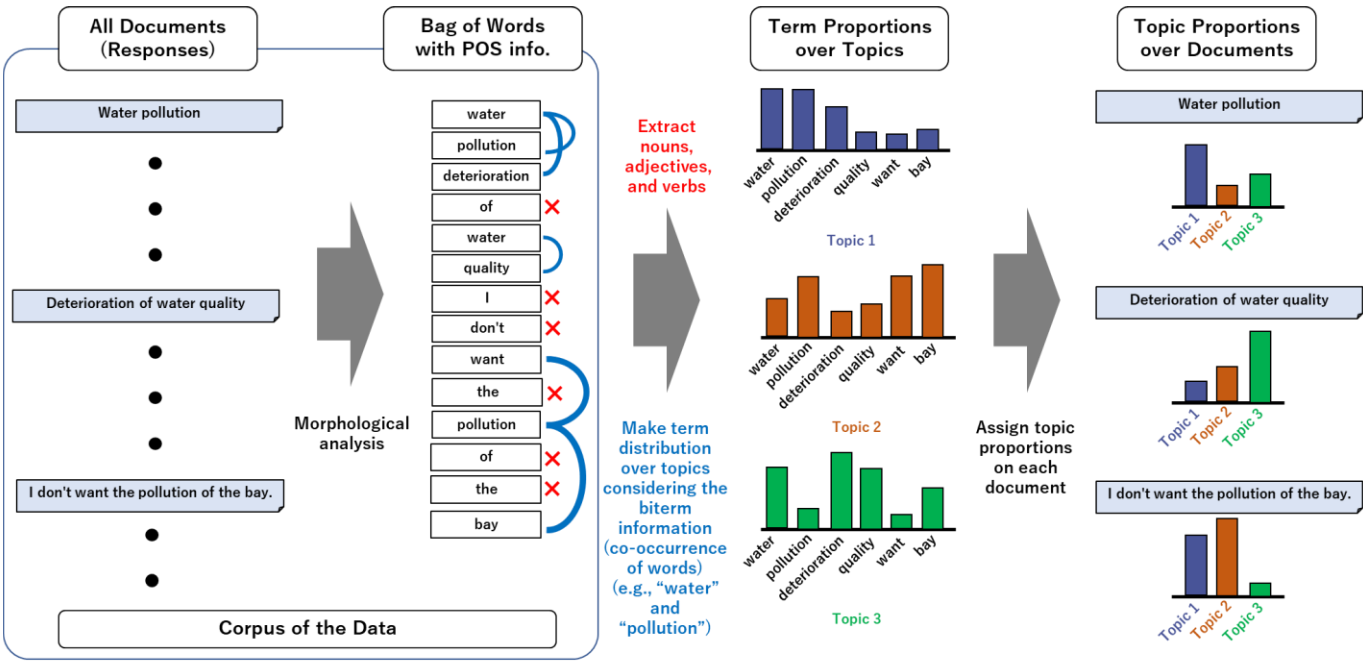


Figure 3. General Process of BTM from Preparation to Assignment of Topic Proportion.

2.3.3. Biterm Topic Models (BTMs) Creation

BTM is an unsupervised machine-learning algorithm that can learn topics from unlabeled documents automatically, but, on the other hand, the researcher must examine the number of topics for which the submitted results are sufficiently interpretable. For LDA, "perplexity" and "coherence" are commonly used as metrics for evaluating the number of topics [51], and automatic evaluation techniques have been developed (e.g., [52,53]). However, "perplexity" is not available for BTM. Therefore, in this study, the number of topics for the BTM was selected using two metrics: log likelihood, representing the prediction accuracy of the model, and coherence score, calculated by UMass [52,54,55], representing the quality of extracted topics. Firstly, the maximum number of topics was set to 10 for both the negative and positive categories. Secondly, the log likelihood and coherence score were calculated for the number of topics between 1 and 10, and the average of 10 sets was used to determine the range of topics to be considered. The final number of topics was chosen by manually inspecting the topic details. Finally, BTMs were created for both the negative and positive future vision, and the topic labels were determined by considering the term with the highest probability of being represented in each topic. The topic structure was visualized in a topic map that included word co-occurrence relationship information. Consecutively, the topic scores, which estimate the degree to which a given document is associated with each topic, were calculated and used as input data for multiple-factor analysis.

2.3.4. Multiple-Factor Analysis (MFA) on Topics

We conducted a multiple-factor analysis by combining all NFV and PFV topic scores for each response into a matrix. To ensure the appropriateness of the results as a method of providing information that contributes to consensus-building, the results were expressed in the form of vectors in a correlation circle on a two-dimensional plane, with an emphasis on interpretability. The directionality and angles of the topic vectors were used to represent similarities and differences between the topics. On the other hand, the length of the vectors indicated the relative intensity of traction that drove the variance of the data in the vector direction on the two-dimensional plane. Therefore, by focusing on the length of the vectors, we can see how dominant they are in the total information of the original data.

3. Results

3.1. Pre-Analysis Distribution Check and Data Cleaning

The distribution of the two demographic variables (age and gender) for the number of valid responses in each prefecture is summarized in Table 2 and Figure 4. Of the 929 valid responses, there were slightly more females, and the median age was in line with the Japanese population of 46 years. Although the slightly higher number of women in the age range in Kanagawa Prefecture and the slightly lower number of men in their 30s in Tokyo do not exactly match the demographics of the three prefectures, we determined that there was no significant bias observed. Therefore, we decided to include these valid responses in the subsequent analysis.

Table 2. Composition of Valid Responses in Each Gender and Prefecture Categories.

Gender	Overall (N = 929)	Kanagawa (N = 313)	Tokyo (N = 310)	Chiba (N = 306)
Male	449 (48%)	152 (49%)	149 (48%)	148 (48%)
Female	480 (52%)	161 (51%)	161 (52%)	158 (52%)

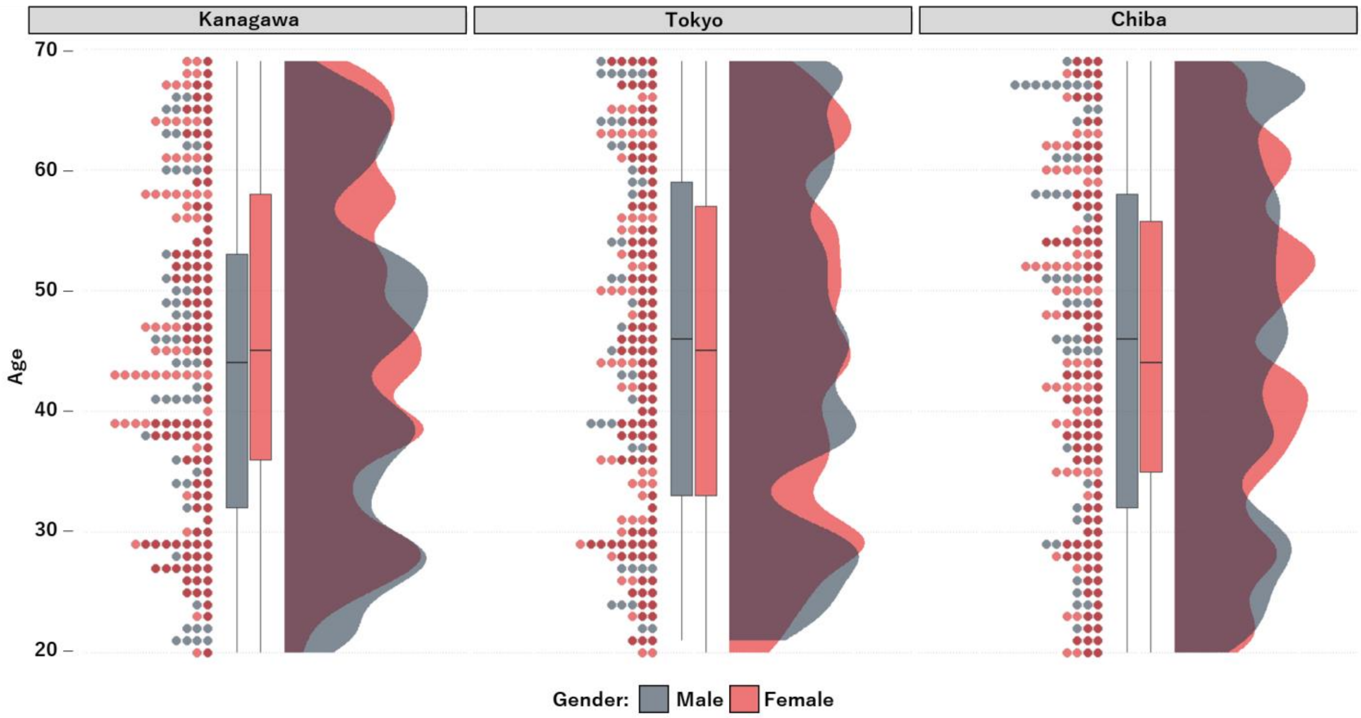
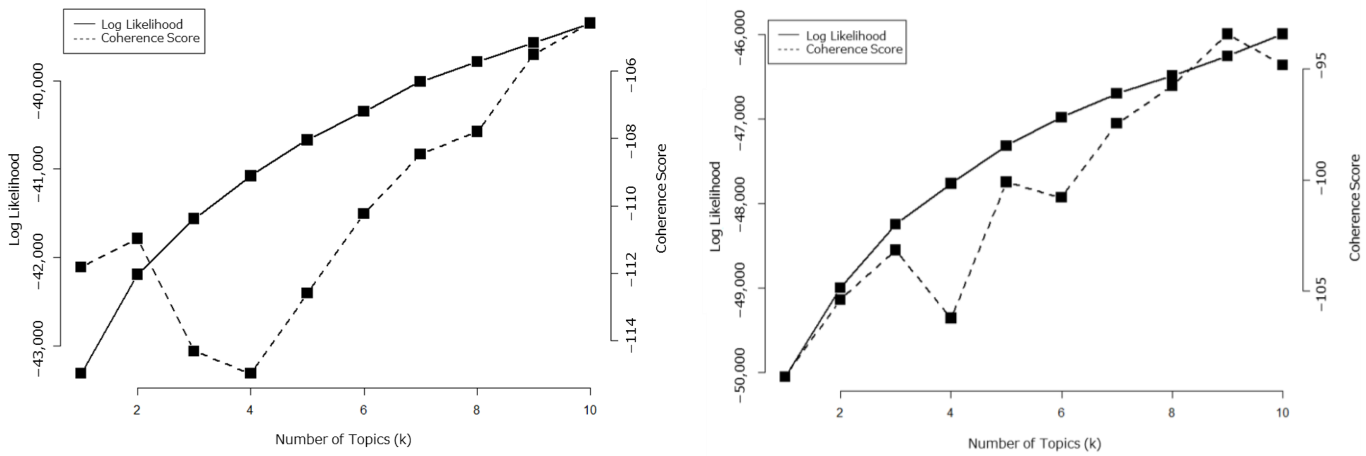


Figure 4. Histogram, Boxplot, and Density Distribution of Valid Responses in Each Gender and Prefecture Categories.

3.2. Extracting Topics of Future Visions by Biterm Topic Models (BTMs)

3.2.1. Number of Topics Determined

After conducting morphological analysis and annotation, a total of 4022 biterms were generated for NFV, while 4655 biterms were generated for PFV. This substantial volume of data is deemed sufficient to proceed with further modeling. Figure 5 shows the average of each index of BTM created by varying the number of topics extracted based on the biterm list from 1 to 10. The higher the log likelihood, the better the extracted topics are suited to explain the overall information, indicating that the largest possible number of topics is desirable in this data set. The coherence score is recommended for the number of topics where it displays a low value, and the lowest value is 4, and the slope of increase elevates when the number of topics reaches nine or more. Consequently, the topic details were examined in the range of four to eight topics for both future visions. Finally, judging from the topic interpretability, eight and six were determined to be the appropriate number of topics for the NFV and PFV, respectively.



(**a**) (**b**)

Figure 5. Log Likelihood and Coherence Score for the Model in the Range of 1 to 10 Topics: (**a**) Negative Future Vision; and (**b**) Positive Future Vision.

3.2.2. Word Probabilities and Topic Maps for Two Future Visions

The probability of each word being included for every extracted topic was calculated, and the top 10 terms displaying high probability for each topic, along with their respective probabilities, are presented in Figure 6. We determined the topic labels by considering the term with the highest probability of being expressed in each topic. Additionally, we visualized and summarized the structure of the topics in topic maps (Figures 7 and 8), which include information on word co-occurrence relationships within each topic.

For the NFV, eight topics were extracted as shown in Figures 6 and 7: (1) Uninhabitable Environment for Fish, (2) Human Pressure on the Ecosystem, (3) Water Pollution and Environmental Destruction, (4) Human-caused Accidents and Disasters, (5) Return to the Dirty Sea with Sludge, (6) Water Quality Deterioration with Red/Blue Tide, (7) Natural Disaster such as Earthquake and Tsunami, and (8) Increase and Invasion of Alien Species (in the following part, abbreviations from N1 to N8 are used). N1 reflects the voices about uninhabitable environment for fish (e.g., "*I don't want the water quality to be so bad that fish can't live in it.*"). It focuses on the marine environment and expresses concern about its degradation and unsuitability for marine life, including not only "fish" but also other "shellfish" and "creatures". N2 encompasses the human pressures on the ecosystem, mainly related to "garbage", "wastewater", and "reclamation". N3, as suggested by its name, pertains to water pollution and degradation of water quality. N4 is concerned with the characteristics of Tokyo Bay, a key marine transportation area, and the negative environmental impact of "vessel" "accidents", as indicated by the word "oil". N5 expresses a desire not to repeat Tokyo Bay's history of pollution, using the words "dirty" and "sludge" in conjunction with the words "want" and "become". N6 is about "red" and "blue" "tides"; the former refers to a phenomenon wherein phytoplankton experience abnormal growth due to nitrogen and phosphorus from wastewater, turning the seawater red. The latter refers to a phenomenon that occurs when plankton blooms decay and their carcasses sink to the seafloor, decompose, and generate anoxic water mass containing much hydrogen sulfide, which eventually rises to the sea surface due to strong winds such as typhoons, resulting in a blue sea appearance. Both can lead to oxygen depletion leading to fish mortality and landscape deterioration. N7 expresses concerns about the occurrence of earthquakes and tsunamis. N8 refers to the impact of invasive alien species on the ecosystem, which have become a growing issue in recent years.

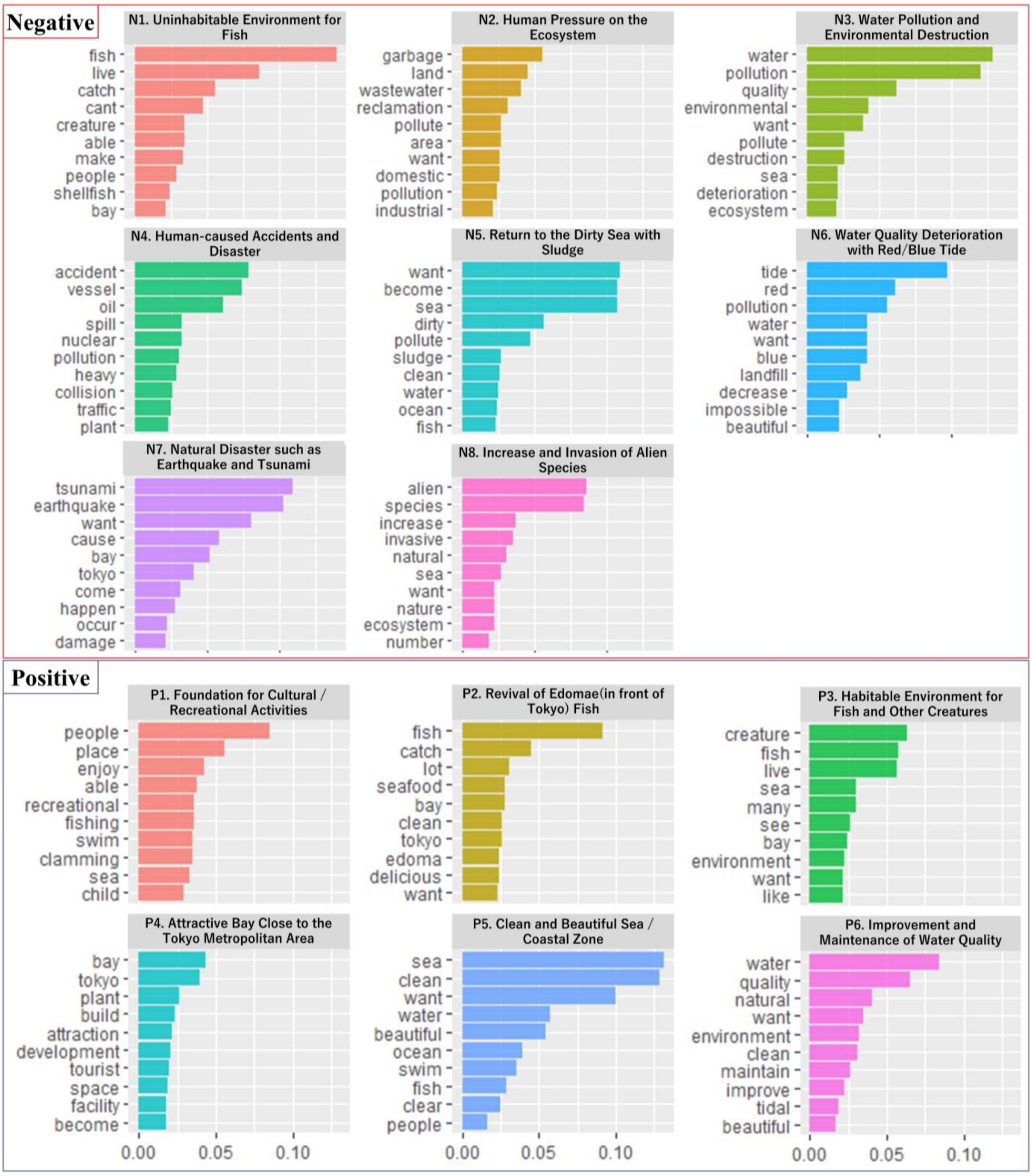


Figure 6. Top 10 Words with High Probability for Each Topic (Upper = Negative Future Vision; and Lower = Positive Future Vision).

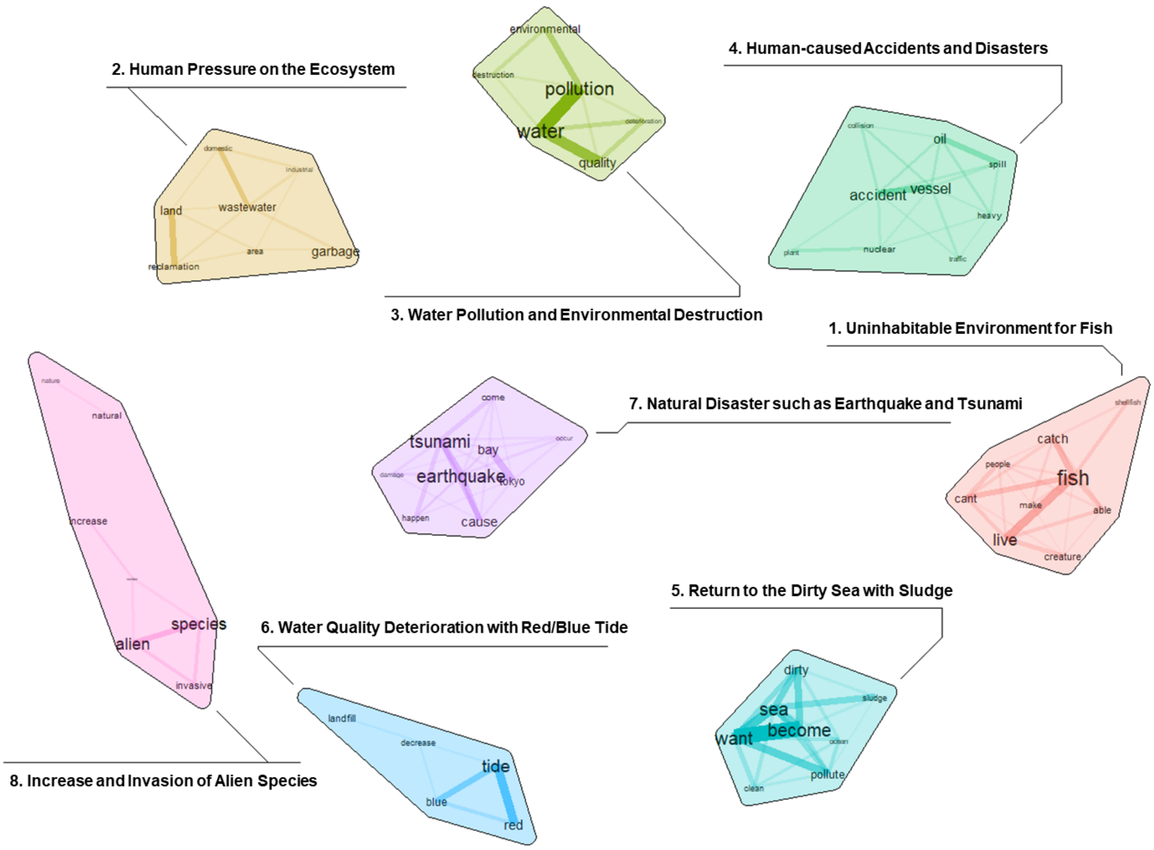


Figure 7. Topic Map of Negative Future Vision with Eight Topics and Composing Significant Words.

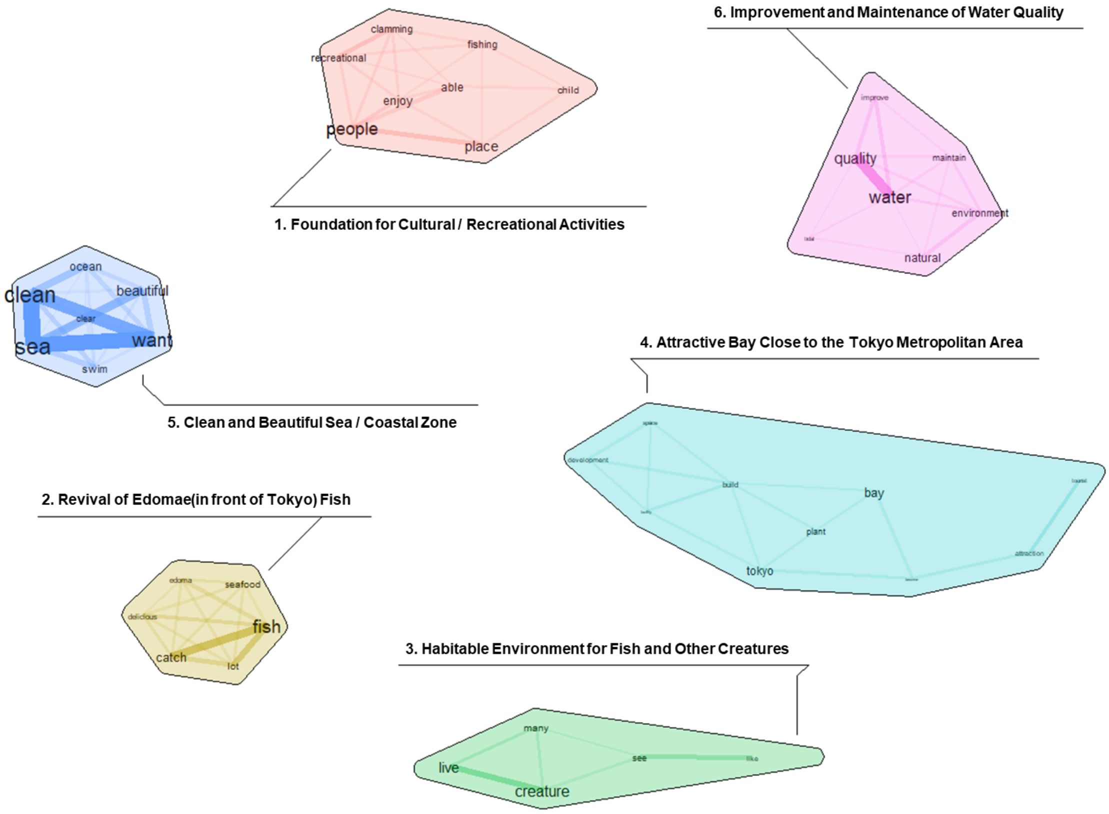


Figure 8. Topic Map of Positive Future Vision with Six Topics and Associated Significant Words.

For the PFV, six topics were identified as shown in Figures 6 and 8: (1) Foundation for Cultural/Recreational Activities, (2) Revival of Edomae (in front of Tokyo) Fish, (3) Habitable Environment for Fish and other Creatures, (4) Attractive Bay Close to the Tokyo Metropolitan Area, (5) Clean and Beautiful Sea/Coastal Zone, and (6) Improvement and Maintenance of Water Quality (in the following part, abbreviations from P1 to P6 are used). P1 pertains to the social and cultural significance of "recreational", "clamming", and "fishing" activities. P2 comprises words such as "fish" and "catch" stemmed with the word "edomae" (in front of Tokyo), reflecting the desire and demand for the revival of the once-thriving fishing industry. P3 is the counterpart of N1 and pertains to maintaining and improving the habitat for "fish" and other "creatures". P4 is concerned with the "facility", "tourist", and "attraction" of Tokyo Bay and their "development", representing one aspect of the expected functions of the bay, which exists on the side of a metropolitan area. P5 expresses a desire for a "sea" with adjectives such as "clear", "clean", and "beautiful", while P6 is focused on improving water quality to achieve this goal.

3.2.3. "Future Compass" Provided by Multiple-Factor Analysis

Figure 9 presents one of the outcomes obtained from the MFA, which is based on the topic scores assigned after estimating the above topics for each response. The figure displays the traction strength and correlation of the topics, represented by vector length and angle, respectively, within the correlation circle on the two dimensions where the variance information of the original data is maximized. The two dimensions shown in the figure accounted for a total variance information of 17.9%, indicating the diversity of topics present in the responses.

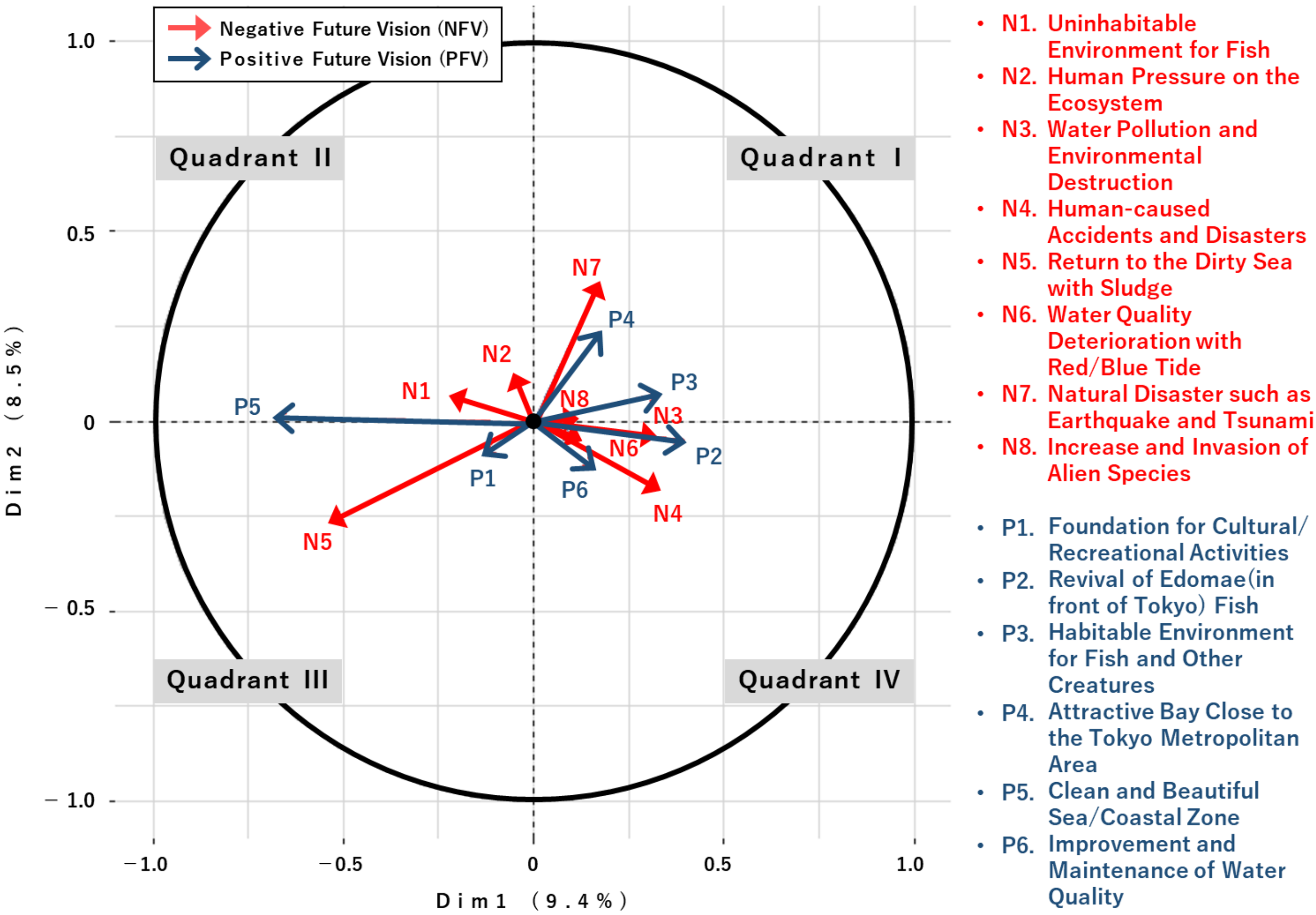


Figure 9. Vectorized Topics of Negative and Positive Future Visions in a Correlation Circle.

In the first quadrant of Figure 9, N7 displayed a high level of concern about earthquakes and tsunamis, and the original text data called for countermeasures to deal with these issues. The Great East Japan Earthquake in 2011 can be considered as a contributing factor to this situation. On the other hand, P4 in the same quadrant highlights the need for functions for bays near highly populated cities. In Japan, where earthquakes are a frequent occurrence, the coastal areas that drive attraction, development, and prosperity also face the constant risk of damage from earthquakes. This quadrant illustrates the delicate balance between value and risk that exists in densely populated regions, reflecting the reality of the situation in Japan. The direction indicated by the second quadrant, which includes N1 and N2, was expressed in the concern and fear of destroying the habitat of marine life represented by fish due to pollution from domestic wastewater and excessive landfill. P5, located at the boundary between the second and third quadrants, extends significantly in the direction between N1 and N5, suggesting that many survey collaborators mentioned topics belonging to this direction. In the case of N5, the vector of P1 indicated the same direction, demonstrating that not only commercial fisheries but also recreational activities such as clamming, which promote familiarity with the bay, were remembered especially by comparatively older respondents as one of the cultural values associated with these activities that have been lost through the history of pollution. For this very reason, sludge and pollution is seen as a detrimental influence on these activities, both presently and in the future. Furthermore, the fourth quadrant encompasses N4, N6, and P6, indicating the impact of widespread information dissemination, including through media reports, to residents about oil spills resulting from ship accidents and red/blue tides. Given Japan's heavy dependence on marine products and maritime transportation, it is understandable that concerns about vessel accidents and environmental issues extend to a wide range of individuals. This includes not only those directly involved in fishery production or the maritime industry but also residents in the coastal areas of the bay. It is noteworthy that the vectors of P2, P3, and N3 all extend in the direction of the horizontal axis on the borderline of the first and forth quadrants. This group of vectors was mainly defined by a topic that expressed a desire to avoid repeating Tokyo Bay's history of pollution and a wish to revive the Edo fishing industry that was lost due to the pollution.

4. Discussion

In this study, we developed a visualization method that provides an overview of the various future visions that residents have of Tokyo Bay and its coastal areas, and we examined the relationships and differences between these visions. To gather data, we conducted a two-directional survey to extract free-associative descriptions of the negative and positive future visions (NFVs and PFVs). The NFVs comprised concerns regarding recent environmental problems, such as water-quality deterioration and invasive alien species, as well as Japan's general anxieties, including earthquakes and tsunamis, and an understanding of the need to avoid repeating past pollution history. On the other hand, the PFVs encompassed topics such as water-quality improvement, socio-cultural elements, including the Edomae fish, recreational fishing, and clamming in tidal flats. Furthermore, the results of a multiple-factor analysis indicated connections between the NFVs and PFVs, considering that the revival of the Edomae fishing industry and recreational clamming is deeply connected, for better or worse, to the history of pollution in Tokyo Bay. Finally, we observed the coexistence of both value and risks for a bay situated in an urban area with a high population concentration.

The visualization result in Figure 9 is named "Future Compass" and that can be applied in the field of consensus-building. This visualization method aggregates the freely written future visions of different individuals into a group of vectors arranged in a correlation circle, which offers a distinct advantage: efficient selection of the direction to achieve the first step towards the future through detecting and dealing with obstacles for appropriate navigation. Decision science has extensively explored the topic of rational decision-making in consensus-building, with studies focusing on maximum expected utility [56] and the efficiency of consensus plans (e.g., [57]). Additionally, researchers such as Saaty and Ozdemir (2003) [58], who employed the analytic hierarchy process (AHP), and Hamada et al. (2018) [59], who used Bayesian network analysis, have highlighted the importance of negative factors in efficient choices for decision-making and consensus-building. It has been demonstrated that in a step-by-step decision-making or consensus-building process, negative factors are used to narrow down the options in the initial stage, and then positive factors are considered within the narrowed options to make decisions. This suggests that the "Future Compass" could be utilized to determine the first step in consensus-building, such as avoiding the direction of the NFV and then choosing the direction of the PFV. In this way of usage, "Future Compass" can contribute toward quick and efficient decision-making. However, there is also a concern that NFVs can be an avoidance goal [60], which is a type of motivation where individuals focus on preventing negative outcomes and minimizing risks, prioritizing avoidance of failure, criticism, or punishment rather than pursuing positive rewards or achievements [61]. While this is an important function, it can cause inconvenience and problems if such motivation becomes overly dominant. NFVs revealed in this study may also lead to a loss of motivation to take action to improve the environment. Our analysis of the "Future Compass" revealed that the positive and negative topics were sometimes aligned in the same direction, indicating a linkage between them. In order to avoid the NFVs becoming excessive braking, it would be important to make the NFVs play a role as counter-motivation to realize the PFVs. Hence, it may be possible to develop strategic approaches to foster motivation for achieving the PFVs by using the NFVs as a springboard.

In the specific case of the "Future Compass" for Tokyo Bay presented in this study, it was presented that N1 "Uninhabitable Environment for Fish" and N2 "Human Pressure on the Ecosystem" in the second quadrant are not desirable directions to be taken as a whole, and that P5 "Clean and Beautiful Sea/Coastal Zone", which correlates with them, is a future that should be pursued. On the other hand, P2 and P3 are drawn as the opposite direction of P5, even if they are the same in terms of PFV. For both P5 and P2, the same word "clean" has high probability to occur, but they have different associations and directions; "clean sea as human utility" and "clean sea as ideal ecosystem for marine life". It is very interesting to see how they seem to be incompatible in the consciousness of the residents. Also, the cultural and historical background of Tokyo Bay is evident in the "Future Compass" as P1 has the same direction as N5 which has a strong traction in the third quadrant showing the history of pollution in it. However, reviving and preserving places where social and cultural activities can take place, including tidal flats, may conflict with N7 "Natural Disaster such as Earthquake and Tsunami" and P4 "Attractive Bay Close to the Tokyo Metropolitan Area", which are located at opposite positions on the first quadrant in the correlation circle. Thus, techniques and mechanisms need to be devised to resolve conflicts between these goals. It should not simply a matter of picking one single direction based on the volume of opinions, but, rather, it should be an attempt to induce the stakeholders to consider the allocation of efforts, the possibility of a third direction, new technologies to resolve conflicts, while looking at both future visions and their directions on the discussion table. By acknowledging and discussing the contrasting perspectives, stakeholders can approach the future with a balanced outlook, fostering a sense of conviction and consensus among them regarding these matters. One of the benefits of incorporating the "Future Compass" is that it can visualize such future visions in advance and be used as a navigation tool to consider countermeasures in matters that require complex agreements. These results are also meaningful in that they are quantitatively visualized as a collection of individual ideas. That is because quantitative visualization eliminates arbitrariness on the part of the government or analyst and ensures that individual opinions are equally reflected in the results. Such bottom–up approach, in which residents themselves set goals as their own, could be utilized to motivate them to engage in future activities and policy proposals from the citizen side. The future visions presented in this study align with the action plan for the restoration of Tokyo Bay. In the plan, each sub-goal has its own evaluation index and has been individually aimed to be achieved, but this study reveals that residents recognize the link between the goals (future visions), which can serve as leverage to adopt a structural approach towards achieving some of these goals. Additionally, in the past, the achievement of goals has been evaluated based on how close one is to the desired future. On the other hand, the results of negative future vision suggest the possibility to consider an indicator that gauges whether one is moving away from an undesired future. Moreover, it is important to note that the "Future Compass" for Tokyo Bay created in this study represents only the opinions of residents, not all stakeholders. Nevertheless, the methodology presented in this study allows for the addition of necessary future vision data from other stakeholders to the model, and for differences in the "Future Compass" among stakeholders to be identified and addressed.

The "Future Compass" is based on a topic modeling technique that effectively reduces dimensionality and extracts major trends in texts written in natural language, extending beyond research to practical visualization for consensus-building through multiple-factor analysis. We believe its application holds significance in soliciting citizen input for policy-making and utilizing sociological data for building environmental scenarios. Moreover, as our thoughts and interactions primarily occur in natural language, the "Future Compass" demonstrates broader potential for identifying key trends in natural language data. Its application is not limited to questionnaire responses, as demonstrated in this study, but can also be applied to analyze past records, such as policy and planning documents. Considering that these records represent the past from a present perspective, reflecting on the orientation of the compass needle during that time may be one of the guiding principles for envisioning the future from the present.

Our study has several limitations that need to be addressed. Firstly, we used cross-sectional data from a single point in time through a questionnaire survey, which limits our ability to examine changes over time. To address this, future research should use a dynamic investigation to explore how changes in the environment and individual opinion/behavior interact and impact the entire SES. Secondly, due to the online nature of the survey, we were unable to include residents aged 70 years and above, who have witnessed significant changes in the coastal environment of Tokyo Bay throughout their lifetimes. These residents may have formed different attitudes from those expressed in our survey, making it essential to incorporate their opinions and attitudes into further public involvement efforts. To achieve this, future studies could utilize alternative methods such as interviews or listening methods to explore their visions for the future. Incorporating these perspectives could provide valuable insights into how we can better manage the environmental changes in Tokyo Bay.

The literature contains many academic papers discussing the complexity of natural ecosystems and their contribution to people (e.g., [17,62–64]). In this study, we demonstrate that the history of human society is reflected in perceptions of the natural environment of Tokyo Bay and the transactional relationship between human beings and the environment [65]. This relationship is expressed both in the cognition on the human side and in the physical traces [66] on the environmental side. If both of these can provide important information for consensus-building and policy-making to determine future directions, then the traditional boundaries between academic disciplines should be broken down with the same goal in mind. In addition, text-mining techniques and natural language processing methods are constantly advancing, and the analysis of complex attitudes and thoughts of stakeholders is expected to advance beyond the methods used in this study. Integrating these technologies into consensus-building coupled with EBPM (evidence-based policy-making) is a challenge that is difficult to be met by a single discipline, such as engineering or social/political science. Research that integrates methods from multiple disciplines, including this study, can be used to develop a more explorable and explainable approach to evidence-based policy-making (E3PM). We hope that further research inspired by this paper will advance the practice of future-oriented consensus-building involving diverse stakeholders, including residents.

5. Conclusions

In this study, we investigated both positive and negative future visions of Tokyo Bay and its coastal areas held by the residents living in the three prefectures surrounding Tokyo Bay. The findings suggest that these two visions are not always polar opposites, but rather they are interlinked to shape people's perceptions of the future. The future visions do not only emphasize the improvement of natural environmental factors in Tokyo Bay, but also consider how to realize the wise use of these resources. This overarching summary of both future visions serve as a future-oriented requirement for maintaining a healthy and sustainable relationship between people and the natural environment. The "Future Compass" method developed in this study, which aggregates various future visions from free-association descriptions, has achieved a certain level of success in visualizing these visions and put them on the discussion table for future-oriented consensus-building in an era of high uncertainty.

In today's age of diversity and uncertainty, it is increasingly recognized that the future is not a linear progression from the present, but, rather, a multi-trajectory pathway, and any path chosen will have a mixture of advantages and disadvantages. Therefore, in consensus-building and policy-making, there is a need to move away from an approach where there is one absolute good direction and plans are constructed to achieve it, and, instead, shift to a strategic approach that acknowledges the existence of various directions with mixed merits and demerits. In this context, the "Future Compass" can serve as a decision-support tool to determine the initial step to move forward, given the infinite number of possible solutions and outcomes. If the "Future Compass", which can be shared with everyone, can provide information on the directions "to go", "to abort", and even "to be cautious" at a given point in time, it could be used to guide the creation of a sufficient strategy for the future. Furthermore, we hope the information provided by the "Future Compass", such as selected/unselected directions and trajectories of thoughts, is archived as a social function, and become a legacy contributing to decision-making and consensus-building for future generations.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151310175/s1, CSV File S1: data4fc_sugino_etal.csv; R File: script4fc_sugino_etal.R.

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Data Availability Statement: The data presented in this study and R code for analysis used in this study are available in Supplementary Materials.

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