Marine Policy 33 (2009) 466–471

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Public acceptance of the oceanic carbon sequestration

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ARTICLE INFO

Article history:
Received 5 September 2008
Received in revised form
12 October 2008
Accepted 12 October 2008

Keywords:
Ocean CO_2 storage
Public acceptance
Questionnaire survey
Covariance structure analysis
Risk communication

ABSTRACT

CO_2 ocean sequestration may be an effective option for mitigating global warming. There are risks associated with this process, particularly the local impact on deep-sea environments. Public acceptance is required for the implementation of this technology, even though the impacts have been proven to be trivial. In this study, a questionnaire survey was conducted to find the correlation between public acceptance of CO_2 sequestration and influential factors by covariance structure analysis. In addition, risk communication via the Internet was carried out. These analyses revealed that careful investigation of the target oceanic site and field experiments are important in gaining public acceptance of CO_2 sequestration.

1. Introduction

The use of fossil fuels must be decreased in order to stabilise the atmospheric CO_2 concentration at 550 ppm or less at the end of this century. Maintaining a balance between the economy and the environment requires that a shift from such fuels to cleaner energies like renewable energy sources should be gradual. Like CO_2 geological storage (CGS), CO_2 ocean storage (COS) is also regarded as a bridge technology to the future emission-free world by sequestering CO_2 from the atmosphere into the ocean.

CO_2 released to the atmosphere is absorbed by the ocean surface and it takes thousands of years for CO_2 concentration to reach an equilibrium between the atmosphere and the ocean due to the slow dispersion of CO_2 across the thermocline in the ocean. Atmospheric CO_2 concentration is expected to peak around the year 2100 (e.g. [1,2]) and global warming caused by this peak may have negative effects for society including increased incidence of natural hazards (e.g. [3]). COS may reduce the height of this peak, although it will not change the equilibrium concentration in the ocean–atmosphere system after thousands of years. COS can be viewed as a technology that artificially accelerates the natural vertical dispersion process.

Whilst COS has benefits in the mitigation of global warming, it has local environmental impacts in the vicinity of the CO_2-injection points in the deep ocean, such as acute mortalities of deep-sea biota (e.g. [4–6]). All ecosystems, including those in the ocean, have uncertainty regarding matters such as the number of species, their behaviour, and food chain, which scientists do not and will not be able to understand completely. If technological development in the ocean is only permitted when the environmental impacts are completely understood, the balance between environment, economy, and security against natural hazards may collapse, disadvantaging society: the risks that may result because the technology has not been implemented may outweigh the localised impacts. In such a case, the adaptive management approach (e.g. [7–9]) is effective. This approach was proposed to make technical developments compatible with their environment through the adaptive execution of policies based on the assumption that the ecosystem concerned is uncertain. Therefore, it consists of the cycle of execution, monitoring, disclosure, communication, and decision-making.

When the biological impacts of COS are not completely understood, the approval of society becomes important for the implementation and spread of this technology. The adoption of adaptive management is key in obtaining public acceptance of COS, and this approach makes information disclosure on technological development and field observations to the public necessary. Risk communication, which is a dialogue between execution body and stakeholders, is also necessary.

In this study, the same questionnaire survey on the acceptance of COS was conducted twice, before and after information disclosure, and the change in acceptance and the correlation of each factor in the questionnaire to each other and acceptance were examined. Risk communication was trialled through a

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doi:10.1016/j.marpol.2008.10.004

website. On this website, virtual COS experiments were conducted and the way people perceive this technology was analysed through the arguments written on the bulletin board system (BBS).

Such studies may provide us with a grasp of the issues that will arise in the practical phase beforehand in the research and development (R&D) phase. This is effective because the issues of most concern can be known in advance and thus it becomes possible to invest research funds efficiently in the R&D phase. Therefore, evaluating public acceptance and understanding people's awareness of the issues in the R&D phase are important in enabling the spread of this technology in the future.

2. Questionnaire survey concerning public acceptance of COS

2.1. Outline of questionnaire

There has been no adaptive management in the R&D or practical phases of COS and few studies specializing in quantitative or statistical analysis of its public acceptance. Studies focusing on the public acceptance of CGS were conducted by Tokushige et al. [10,11]. They found that its public acceptance was affected by both benefit and risk perceptions.

According to Slovic [12], when ordinary people think of risk, they do not depend on scientific analysis but on their own experience or sense of value. This is also true for benefit perception. COS is not well-known amongst the general public and people cannot recall their experiences or imagine even ambiguous images about it. The first step in obtaining society's understanding is the disclosure of information. For this purpose, it is necessary to investigate what people already know and what kind of information they want to have about COS.

In the questionnaire survey, several factors that may influence public acceptance of COS were analysed, as described in Section 2.2. To examine the effect of information disclosure, the survey was conducted twice by the same question paper, before and after provision of information on COS. The participants were 178 students of undergraduate and postgraduate courses of four Japanese universities: Nagasaki, Tokai, Kyoto, and Tokyo. The collection ratio of the question paper was almost 100% because the questionnaires were completed in lecture time. Only students pursuing science course were targeted in this study due to time and budget restrictions, and it is noted that the participants were not ordinary civilians because of their age composition and positions in society. On the other hand, they may be more likely to be aware of the issues surrounding greenhouse warming and be able to grasp the scientific concepts behind COS.

2.2. Factors in the questionnaire

Answers were requested in the seven-point standard of the semantic differential method to 29 questions shown in Table 1. The questions were formulated based on latent factors that are thought to influence public acceptance of COS. These factors were benefit perception, risk perception, environmental ethics, and faith in an execution body, following the suggestion of Tokushige et al. [11]. Public acceptance is a factor that indicates how people receive COS, and the benefit and risk perceptions refer to how people perceive benefits and risks of the COS, respectively. Environmental ethics and faith in the execution body are factors that indicate how people attach importance to these issues. We applied a covariance structure analysis (e.g. [13]) and quantitatively evaluated the contribution of the four factors to public acceptance and the confirmatory causal relations amongst the factors.

Table 1
Contents of questionnaire.

Factors	Specifications	Question items
Benefit perception		Social benefit
		Individual benefit
		Benefit for future generations
		Contribution to society
		Individual necessity
Risk perception		Safety
		Seriousness of results
		Observability of risks
		Scientific knowledge of risks
		Familiarity of risks
		Impacts on marine environment
		Impacts on marine organisms
Environmental ethics	Global warming	Positiveness of prevention
		Adaptivity to natural providence
		Credit of civilisation
	Marine environment	Propriety of man's admittance
		Adaptivity to natural providence
		Control of nature
	The nature	Environment or economy?
		As natural
		Right of nature
Faith in execution body		Faith in organisation
		Information disclosure
		Ability of organisation
Public acceptance		Individual acceptance
		Acceptance depending on site
		Public acceptance
		Acceptance of future generations
		Propriety of promotion

Table 2
Contents of information disclosure.

Subjects	Items
Global warming	Causes of global warming
	Carbon cycle
	Mechanism of global warming
	Prediction of global warming
	Impacts of global warming
	Measures against global warming
CO_2 ocean sequestration (COS)	Concept of COS
	Outline of COS technology
	Benefits of COS
	Risks of COS
	State-of-art of COS technology
	Future development of COS technology
	Research organisation for COS project

2.3. Disclosure of COS information

Following Tokushige et al. [11], general information about global warming and COS was offered between the two surveys. The items of information offered are shown in Table 2. The information sheet comprised 16 slides, in which many figures and graphs were used.

2.4. Results and discussion

2.4.1. Change in factor scores by disclosure

The factor scores of benefit perception, risk perception, and public acceptance of COS were obtained using the results of the two questionnaire surveys. The scores were polarised depending on whether the participants thought benefit or risk was important; hence the participants were classified into two groups, namely those whose factor score of the benefit perception was larger than that of the risk perception (Classification 1) and the opposite (Classification 2). The ratios of the participants categorised in Classifications 1–2 were 49.3% before and 56.1% after information disclosure. The changes in factor scores of public acceptance, benefit perception, and risk perception before and after information disclosure are shown in Fig. 1.

The participants in Classification 1 responded positively for public acceptance and benefit perceptions and negatively in risk perception both before and after the disclosure, and it was vice versa for the participants in Classification 2.

Information disclosure was effective in improving public acceptance of COS as well as the benefit and risk perceptions for both groups. For Classification 1, risk perception rose after disclosure although by less than that of benefit perception. This may be because the participants understood vague risks more clearly after disclosure. The same trends were also recognised for Classification 2, i.e. the score of the benefit perception increased more than that of the risk perception. The increased score for public acceptance for Classification 2 was smaller than that for Classification 1. This may imply that factors not changed by the disclosure, such as ethics and morals, influence the participants in Classification 2.

2.4.2. Factors that influence public acceptance

According to Tokushige et al. [11], there are other factors besides the risk and benefit perceptions and hence two more factors were added namely environmental ethics and faith in a COS execution body. This time the causalities of the four latent factors to the public acceptance of COS were evaluated using the results of the second questionnaire. The result of the analysis is shown in Fig. 2, where correlations with coefficients of determination (R^2) of 0.84 or more were drawn. The numbers in Fig. 2 indicate path coefficients, which are the standardised regression coefficients indicating magnitudes of causality, and a negative value means a negative influence, not the change of path direction.

Fig. 2 shows that benefit perception and the faith in the execution body have positive influence on the public acceptance of COS and that risk perception and environmental ethics had negative influences on public acceptance. The benefit perception had a higher coefficient than the faith in the execution body, and the path coefficient of the ethics was larger than that of the risk perception. A person with strong environmental ethics was likely to perceive the benefits of COS as low and the risk as high, and a person whose faith in the execution body was strong tended to consider the benefits of COS as important.

Fig. 3 shows the path coefficient from each latent factor to each observed variable (question item). There are strong causal relations between the benefit perception and the items: "contribution to society", "social benefits", and "benefits to future generations". For the factor faith in the execution body the path

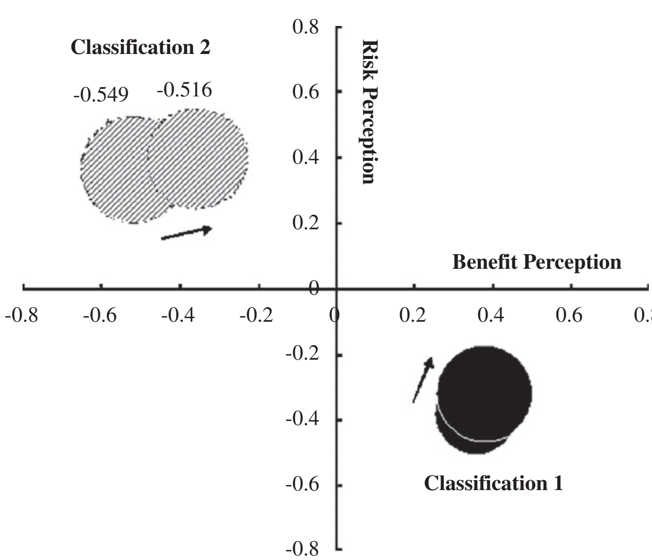

Fig. 1. Changes in public acceptance, benefit, and risk perceptions in factor scores from a questionnaire survey before and after information disclosure for participants in Classifications 1 and 2. In the figure, the size of a circle shows the factor score of public acceptance and a hatched circle indicates that the score is negative. The arrows show the changes between scores before and after information disclosure.

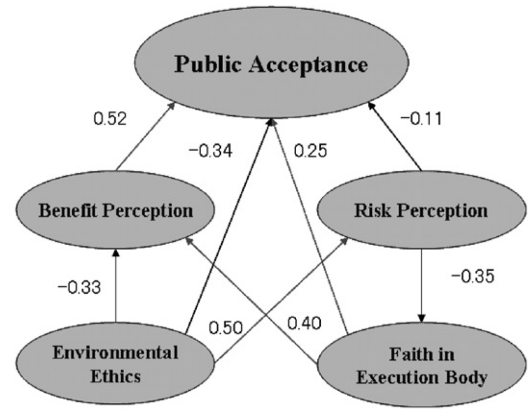

Fig. 2. Correlation of four factors to public acceptance of COS analysed by covariance structure analysis found in the second questionnaire survey.

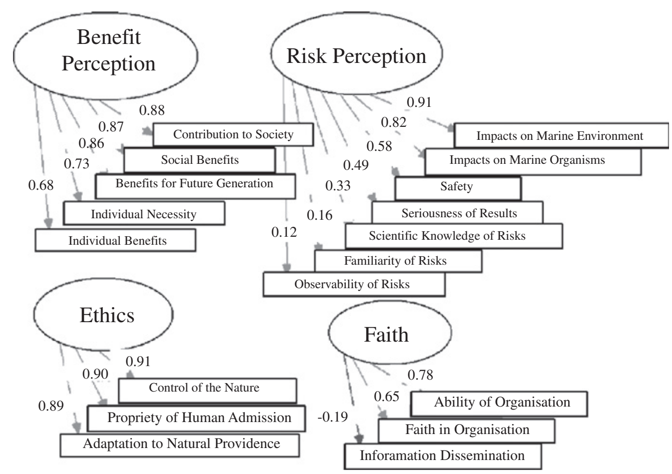

Fig. 3. Pass coefficients from four factors influencing public acceptance of COS to question items in the questionnaire survey.

coefficient of "limited information disclosure" is negative. The direct question corresponding to this item was "Do you think that the organization that executes the COS discloses information fully including negative aspects?" Therefore, the body responsible for the execution of COS should not control the disclosure of information, or else it may lose the faith of society. It may also be inferred that some people give up receiving correct information from the beginning.

The main concerns for risk perception were the impacts on marine environment and marine organisms. This implies that in order to decrease risk perception, it is important to invest R&D fund in research to clarify these impacts rather than "safety" and "observability of risks". Environmental ethics had the most negative influence on public acceptance, which implies that public acceptance may decrease if COS is perceived as unnatural. As was mentioned in Section 1, COS is an acceleration of the natural carbon cycle in the ocean, and it is important to promote this concept to the public. The above examples show that there is a possibility to improve public acceptance of COS by directly allotting R&D, and publicity and education to the items with large path coefficients for the factors that have strong influence on public acceptance.

3. Trial of risk communication by website

3.1. Outline of risk communication

Since field experiments in the ocean are very expensive, we opened a website where a virtual field experiment was conducted using numerical models for ocean currents and biological impact. The website was composed of explanations of the COS concept and its state-of-art technologies, the virtual experiment, and a BBS for discussion in order to extract people's opinions about COS. The top page of the site offered "news" (notice of updated information) and the site map. The participants could go to the explanation pages from here. The participants first read about general issues concerning COS, then were informed of the results of the ongoing virtual experiment from time to time, and then moved to the BBS page.

The virtual experiment page explains the initial concentration of injected CO_2 and the biological impact calculated by the mortality model of Sato [14] and Sato et al. [15]. The initial concentration was diffused by the turbulent eddy diffusivity resulting from the calculation of Sato et al. [16] until it reaches the tentatively proposed predicted no-effect concentration, pCO_2, of 500 ppm. Mortality was calculated using the decreased concentration, not the initial value. One example of the time variations of pCO_2 is shown in Fig. 4.

The website was opened to the participants for 20 days from 5 January, 2006. The participants who had registered on the mailing list when they participated in the questionnaire survey were notified of changes in CO_2 concentration in the virtual experiment via electronic mail. Some of them visited the site and participated in discussions on the BBS page. The total number of arguments on the BBS during the 20-day experiment was about 200.

We also analysed the transition of arguments in the BBS by changing the initial CO_2 concentration at the request of the participants, who could also ask to stop the experiment. When the initial concentration was changed, the mortality of marine organisms resulting from the model calculation was shown to the participants. Eventually, the participants always required the increase in the initial concentration. Changes in the initial CO_2 concentration and the resultant mortality of organisms are shown in Fig. 5.

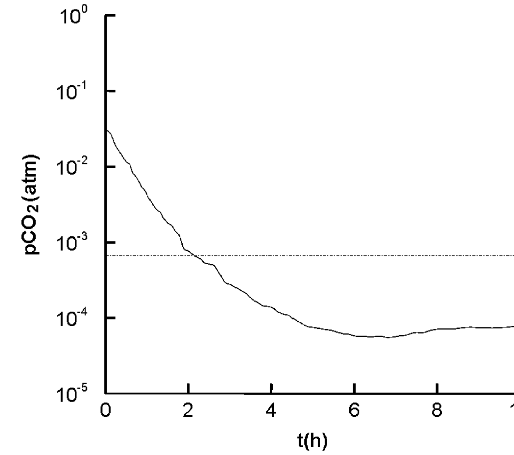

Fig. 4. Time variation of calculated pCO_2 additional to the background value.

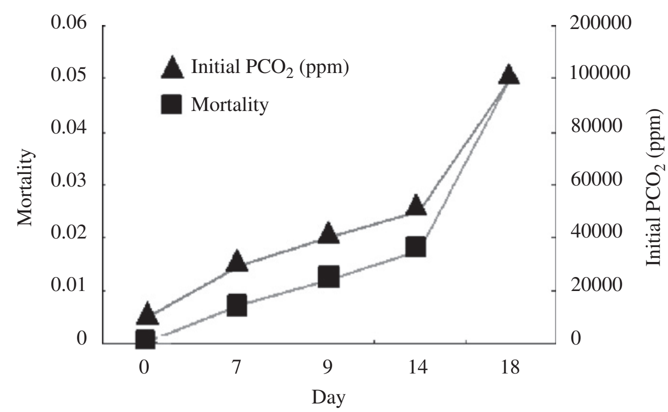

Fig. 5. Changes in initial CO_2 concentration and mortality of marine organisms in the virtual COS experiment.

3.2. Analysis method

All the arguments from the BBS were collected and formed into a tree structure. The arguments were then analysed using a method of logic analysis. Table 3 shows the definitions used to categorize each argument, following Horita [17] and Horita and Kanno [18], who also suggested the following axioms for the logic analysis of arguments:

$$pp \equiv sp \equiv p, \tag{1}$$

$$ps \equiv ss \equiv cc \equiv cd \equiv dc \equiv dd \equiv s, \tag{2}$$

$$pc \equiv cp \equiv sc \equiv cs \equiv dp \equiv ds \equiv c, \tag{3}$$

$$pd \equiv sd \equiv d, \tag{4}$$

$$op \equiv os \equiv oc \equiv od \equiv oo \equiv o. \tag{5}$$

By repeatedly applying these axioms, each argument derived from another argument can be expressed as one of the five patterns: a concerned argument can be grounded on immediate relation to the child argument in the tree structure and the correlations are categorized as p, s, c, d, or o. Then, an argument chain of arbitrary length from any descendant argument can be analysed and the relation between them reduced to one of the five patterns. For instance, for an argument A_1 derived from an argument A_0 with the chain shown by the left-hand side of Eq. (6),

Table 3
Definitions for categories for each argument by Horita and Kanno [18].

Categories	Symbols	Equations	Meaning
Proof	*p*	*ApB*	Argument B is inevitably the truth by Argument A
Support	*s*	*AsB*	Argument B is possibly the truth by Argument A
Challenge	*c*	*AcB*	Argument B is possibly the false by Argument A
Disprove	*d*	*AdB*	Argument B is inevitably the false by Argument A
Others	*o*	*AoB*	Argument B does not have logical result by Argument A

their relation becomes *s*, as shown on the right-hand side of Eq. (6)

$$A_1 ccccssccA_0 = A_1 sA_0. \quad (6)$$

Horita [17] and Horita and Kanno [18] also proposed the following two parameters to evaluate the relative importance of arguments, the positive ground ratio (*PGR*) and the attention ratio (*AR*):

$$PGR_A = \frac{i_p(A) + i_s(A)}{i_p(A) + i_s(A) + i_c(A) + i_d(A)}, \quad (7)$$

$$AR_A = \frac{\sum_{j \in \{p,s,c,d,o\}} i_j(A) + 1}{\sum_{a \in \Omega} \sum_{j \in \{p,s,c,d,o\}} i_j(a)}, \quad (8)$$

where *i* indicates the number of arguments and Ω is a set of an argument *A* and its object argument of comparison, *a*. *PGR* is the ratio of the number of arguments categorised in *p* and *s* to that of all the arguments derived from *A*, and shows how other arguments can ground *A* affirmatively. When the arguments derived from *A* are all affirmative to *A*, the *PGR* takes its maximum value of 1 and becomes 0 if they are all rebuttal or counter-evidential (categorised in *d* to *A*). *AR* is the ratio of the number of arguments derived from *A* to that of all the object arguments of comparison for *A*, and takes the range (0, 1). If *AR* of an argument *A* is low, its *PGR* can easily be fluctuated by the entry of every new argument because the number of arguments that ground *A* is small.

3.3. Results and discussion

3.3.1. Main structures of arguments

In this study, all arguments started from the subject argument “approval or disapproval of COS”, and it was possible to understand the logical and semantic correlation of each argument to the subject, and the extent to which the argument was grounded by others.

The two main structures with large *AR* in this study are shown in Fig. 6, where the *PGR* of each argument is also given. Fig. 6(a) shows that the argument “concern about ecological impact” diverged into two arguments, “conduct field experiment carefully” and “impacts are inevitable”, the former of which has larger *PGR*, and the two never converged. There was also an argument from an ethical point of view: “may we sacrifice the organisms for our sake?” These arguments show the necessity of promoting the fact that COS technology enhances rather than depresses natural processes. It is thought that this is important to increase public acceptance of COS.

Fig. 6(b) shows that the argument “COS is acceptable in the sites where biomass is small” diverged into two arguments: “there may be precious species” and “we can expect the recovery of the ecosystem”, and finally converged into “careful investigation of ecosystems at the site”. There were also a number of arguments on the amount of biomass in the target sea site raised from the argument “raise CO_2 concentration in the (virtual) experiment and see what will happen”. This implied that the participants were interested in the selection of the site. Investigating the biomass of candidate sites accurately and selecting a target site where the impact on the ecosystem is as small as possible (i.e. smaller biomass) may lead to an increase in the public acceptance of COS.

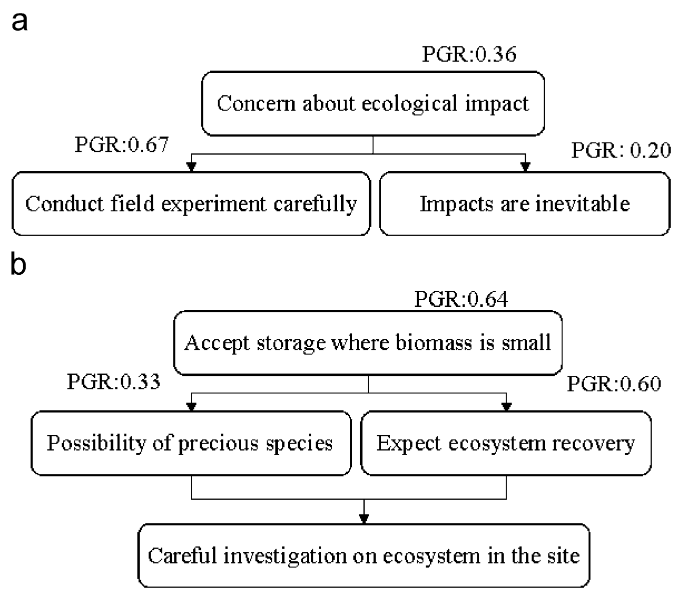

Fig. 6. Two main argument-structures with high *AR* on the BBS for the risk communication website for COS.

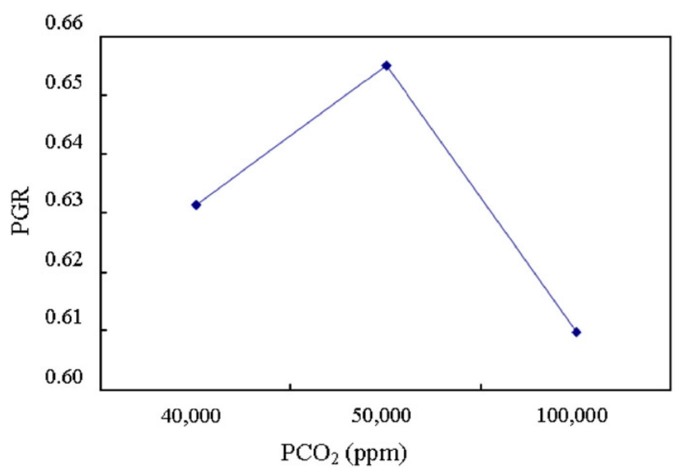

Fig. 7. Transition in *PGR* for COS found by increasing initial CO_2 concentration in the virtual COS experiment.

3.3.2. Transition of arguments

Next, the transitions in the argument trends when CO_2 concentration was increased were analysed. Fig. 7 shows the transition of the *PGR* for the subject “approval or disapproval of COS” after 17 January. The *PGR* was highest for the initial concentration of 50,000 ppm. This may be because there was an argument “organisms’ mortality rate is less than expected” and many participants supported this. The *PGR* decreased when the concentration was set at 100,000 ppm.

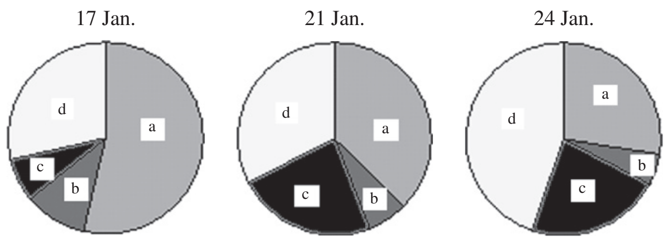

Fig. 8. Transition of *AR* distribution for the arguments on the BBS found by increasing initial CO_2 concentration in the virtual COS experiment. (a) "concern about ecological impact"; (b) "(virtual) experiment should not be stopped"; (c) "raise CO_2 concentration in the (virtual) experiment and see what will happen"; and (d) "others".

Fig. 8 shows the transition in *AR* of the three main arguments: "concern about ecological impact", "(virtual) experiment should not be stopped", and "raise CO_2 concentration in the (virtual) experiment and see what will happen". It is clearly observed that, at the beginning, the ecological impact was chiefly discussed and then the main topic shifted gradually to the argument "raise CO_2 concentration in the (virtual) experiment and see what will happen", which is the concern about the initial CO_2 concentration in the virtual experiment.

From the result of the questionnaire, it is suggested that there certainly are people who do not accept or negatively accept COS because they take ethics or risks seriously. As shown by "a" on 24 January in Fig. 8, the arguments concerning ecological impacts repeated throughout this experiment. However, the shift in the argument topics implies that elucidating the response of marine organisms by conducting field experiments may result in an increase in public acceptance of COS.

4. Conclusions

Questionnaire surveys and a trial of risk communication via the Internet were conducted in order to understand what people think about COS and what may be effective in increasing its public acceptance. The results of the covariance structure analysis to the questionnaire show that information disclosure about COS leads to higher public acceptance and that benefit perception and faith in execution body are the factors that positively influence public acceptance of COS. On the other hand, risk perception and environmental ethics negatively influence public acceptance of COS. Therefore, public acceptance of COS may be raised by researching the safety of marine organisms and convincing the public that COS is not against the law of nature as it accelerates natural vertical diffusion in the ocean.

The logic analysis of the arguments written on the BBS on the website suggested that in order to increase public acceptance, it is necessary to conduct field investigations and experiments to better understand the ecosystems and the impact of injected CO_2 on them at the candidate sea sites. Also, all known information obtained by such investigations should be disclosed.

Acknowledgements

This study was sponsored financially by the Research Institute of Innovative Technology for the Earth (RITE). We are grateful to Drs. K. Akimoto and K. Tokushige of RITE for their kind advice about the questionnaire survey, Drs. S. Murai and M. Magi of RITE for providing figures used on the website, Profs. A. Ishimatsu of Nagasaki University, Y. Shirayama of Kyoto University, K. Nakata of Tokai University, S. Someya of the University of Tokyo and Dr. R. Yatsu of the ME for conducting the questionnaire survey in their lecture time, and Dr. Y. Maruyama of the AIST and Prof. M. Horita of the University of Tokyo for their advice on risk communication. We also wish to express our gratitude to the students who participated in the questionnaire and the risk communication.

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