Collaborative approach to assessment of social-ecological systems based on ontology engineering

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Abstract

How do we assess the social-ecological systems? There are actually various perspectives towards a social-ecological systems in a particular field among stakeholders, and therefore it is difficult to share this assessment result. The social-ecological systems (SESs) framework supports sharing the perspectives by providing the common items. However, it is necessary to share not only what to be identified as items but also how to link semantically between items in order to understand the mutual difference between perspectives explicitly. Ontology engineering, which is one of the base technologies in semantic Web technology, is a method to design some sort of guideline facilitating knowledge-sharing. It enables us to share a mutual difference between perspectives through explicating a definition of a concept.

This paper aims at proposing the collaborative approach to assessment of social-ecological systems by means of ontology engineering approach. For this purpose, we first define the concepts reflected by the items in the SESs framework and incorporate these into the ontology dealing with sustainability science (SS).

Second, we incorporate the goal items and indicator items proposed in the workshops of the Satoyama planning. As a target case we review the practice carried out in a Kizugawa city of Kyoto prefecture in Japan, which deals with the planning and management to maintain Satoyama and conserve ecosystems within the city while preserving unique history and cultures by means of the partnerships among various stakeholders. In this planning process a series of workshops were organized in which activity groups and city workers participated and discussed such essential issues as goals of the plan, principles of actions and evaluation indicators between 2012 and 2013.

Third, we assess the proposed goal items and indicator items from the aspect of the SESs by means of the constructed SS-SESs ontology. As an assessment result the semantic linkages which represent the knowledge structure of the stakeholders are shown, and it enables us to understand the differences of the perspectives between stakeholders.

Finally, we discuss how we actually use the SS-SESs ontology in the context of environmental planning and management. Concretely, we propose some ideas to implement collaboration by sharing all sorts of knowledge in different contexts.

Keywords

structural assessment, social-ecological systems, ontology engineering, indicator design, planning process

1. Introduction

How do we assess the social-ecological systems? There are actually various perspectives towards a social-ecological systems in a particular field among people, and therefore it is difficult to share this assessment result. The social-ecological systems (SESs) framework proposed by Ostrom (2007, 2009) supports sharing the perspectives by providing the common items (Figure 1, 2). The SESs framework play a role of a kind of platform to harmonize not only different theories related to the SESs (Poteete et al. (2010)) but also different case data. Therefore, the SESs framework also supports sharing the case information in the same way. As a recent activity the social-ecological meta-analysis database (SESMAD) project actually adapted this framework to the requirements of analyzing large-scale SESs, resulting in their own SES framework and database structure (Cox (2014)).

However, it is necessary to share not only what to be identified as items but also how to link semantically between items in order to understand the mutual difference between perspectives explicitly. Ontology engineering, which is one of the base technologies in semantic Web technology, is a method to design some sort of guideline facilitating knowledge-sharing. In other words, an ontology plays a role as reference of a model, an indicator system or analytical framework (Kumazawa et al. (2009)). It enables us to share a mutual difference between perspectives through explicating a definition of a concept.

When we apply the assessment approach focusing on the SESs to the social practice, the process of environmental planning and management is considered to be its first opportunity. To take the collaborative approach in this process is crucial from the aspect of securing the legitimacy, and therefore, the methodology for designing a deliberative space (Bryson et al.(1996)), a communicative planning process (Healey(1996)) and a policy making process (Innes(2003)) has been continuously discussed.

However, these planning theory approach is within procedural approach. We need the more inclusive theory and methodology incorporating the content-oriented approach into the existing theory and methodology in order to understand the mutual perspectives among varieties of communities or stakeholders in particular contexts of environment. Ontology engineering approach enables us to connect the procedural aspect and the content-oriented aspect.

Based on the needs both from the theoretical aspect of the SESs and from the planning and management aspect, this paper aims at proposing the collaborative approach to assessment of social-ecological systems by means of ontology engineering approach.

For this purpose, we first define the concepts reflected by the items in the SESs framework and incorporate these into the ontology dealing with sustainability science (SS). Second, we incorporate the goal items and indicator items proposed in the workshops of the Satoyama planning case in Kizugawa City, Kyoto Prefecture, Japan. Third, we assess these items from the aspect of the SESs by means of the constructed SS-SESs ontology. Finally, we discuss how we actually use the SS-SESs ontology in the context of environmental planning and management. Concretely, we propose some ideas to implement collaboration by sharing all sorts of knowledge in different contexts.

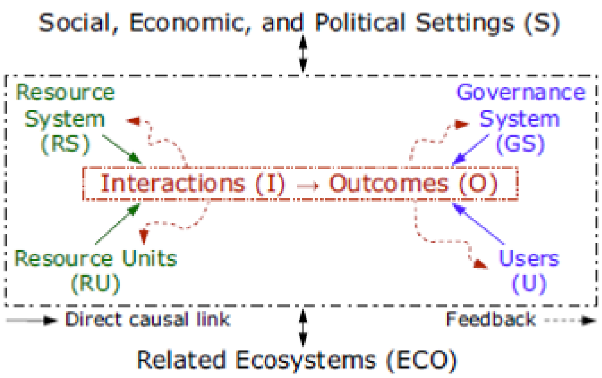


Figure 1 SESs framework (first tier)　(Ostrom(2007))

Figure 2 SESs framework (second tier)　(Ostrom(2009))

2. Identification of the Ontology engineering approach

2.1. What is ontology engineering?

In the artificial knowledge field ontology is defined as "explicit specification of conceptualization" (Gruber(1993)). Ontology engineering is the key method for information technology which people and computer both can understand. An ontology consists of concepts and relationships that are needed to describe the target world. It provides common terms, concepts, and semantics by which users can represent the contents with minimum ambiguity and interpersonal variation of expression. It is expected to contribute to the structuring of the knowledge in the target world. Construction of a well-designed ontology presents an explicit understanding of the target world. An ontology, however, is identified not by the form of the knowledge, such as description languages and representation forms, but by the contents of some described knowledge and the roles that some described knowledge plays.

Figure 3 shows the concept definition using the Hozo ontology development tool, which is based on fundamental theories of ontology engineering. In Figure 3, *is-a* relationships describes the categorization of the concepts. Meanwhile, the introduction of other relationships including *part-of* relationships (*has-part* relationships) and *attribute-of* relationships refines the definition of the concepts. In Figure 2 *site*, *input* or *output* includes concept dependent on a context, called a role. The greatest characteristic of Hozo is to be able to deal with a role concept. A role concept enables us to create a model to explicate what plays a role. For example, human, fruits or heating oil can play a role of teacher, food and fuel respectively.

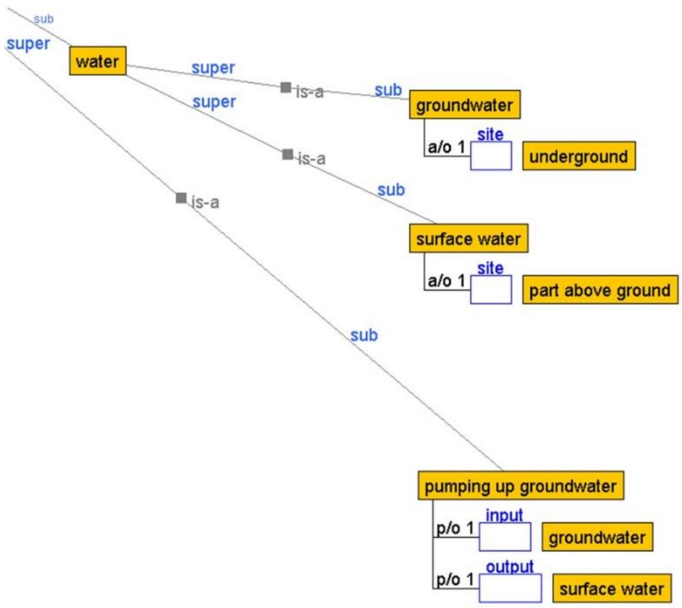


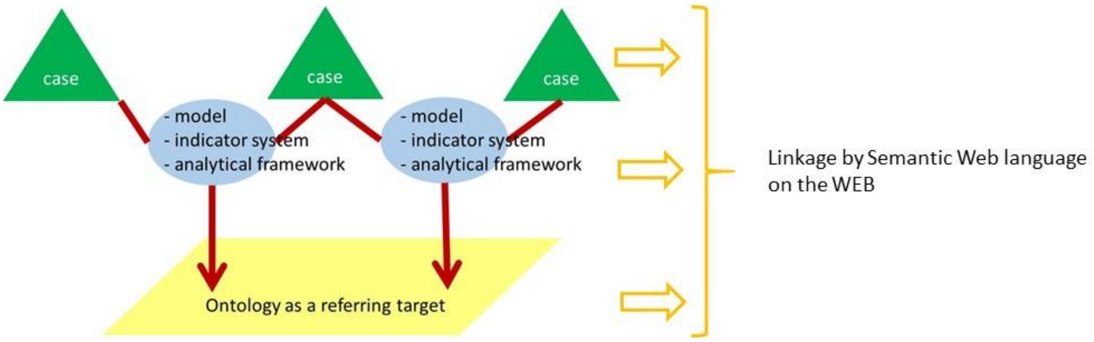
Figure 3 concept definition using ontology engineering

2.2. How do we use ontology?

The ontology can deal with a model / an indicator system / analytical framework rather than a case itself as a design or assessment target. The model here covers from the academic model to the business scheme. Therefore, the mutual relationships are structured by case, model and ontology.

As shown in Figure 4, an ontology plays a role as reference of a model, an indicator system or analytical framework. For example, ontology is utilized to refer the definition of a term used in a model, an indicator system or an analytical framework. These items can mutually connect through the concepts in an ontology. Finally, a concept in the ontology and a metadata term can be linked as is shown in the relationship ontology and RDF[v]. In addition, RDF is one of the semantic web language, and by using RDF we can connect the URL of a website to an ontology described by web ontology language.

Case ⇔ model / indicator system / analytical framework ⇔ ontology



How to use the ontology

①Sharing the definition of a term
②Sharing the relationship between items.
③Sharing the relationship between models / indicator systems / analytical frameworks
④Sharing the relationship between a defined term and a metadata item

Figure 4 Mutual relationships structured by cases, models and ontology

3. Constructing SS-SESs ontology

3.1. From SS ontology to SS-SESs ontology

We define the concepts reflected by the items in the SESs framework and incorporate these into the ontology dealing with sustainability science (SS). SS seeks to clarify the

[v] Resource Description Framework. It is a language to represent information resources on the Web.

complexities in sustainability issues and attempts to provide comprehensive approaches to solving sustainability issues (Kates et al. (2001), Kates(2011), Komiyama and Takeuchi (2006)). The main characteristics of an SS ontology can be seen in its attempt to simultaneously conceptualize two different aspects of its static domain and the dynamic process of problem solving as targets. Hence, two kinds of top-level concepts shall be set in the SS ontology (Kumazawa et al. (2014a)): one is *domain concept* as a top-level concept of the SS domain and the others are *goal*, *problem*, *countermeasure*, and *assessment* as top-level concepts of problem-solving.

The *domain concept* world is constructed by conforming with YAMATO (Mizoguchi 2010, Mizoguchi 2012), which is a top-level ontology being developed at former Mizoguchi Laboratory, Osaka University. On the other hand, *Problem* covers problems related to sustainability. *Solution*[vi] covers countermeasures implemented for problem-solving. *Assessment* covers concepts to understand present situation and state of the achievement. Goal covers concepts as controls for comparing with present states/situations.

Based on this SS ontology, we attempt to define the subconcepts of *domain concept* by conceptualizing the items proposed in the SESs framework. This updated ontology is temporarily named the SS-SES ontology (Kumazawa et al. (2014b)). As a first step for this updating, we additionally introduce/reflect the concept structure of the YAMATO in order to define the items in the SESs framework more accurately. The newly added concepts are, *semi-abstract*, *dependent entity* and *dissective*. *Semi-abstract* and *dependent entity* are the subconcepts of *domain concept*, while *dissective* is the subconcept of *concrete object* (Figure 5). After finishing this ontology construction, we add the concepts corresponding to the items in the SESs framework according to the definitions of these upper concepts.

[vi] *Countermeasure* in Kumazawa et al.(2014a) was improved to *solution* in this paper so that the problem-solving approach can be reflected correctly in the SS-SESs ontology.

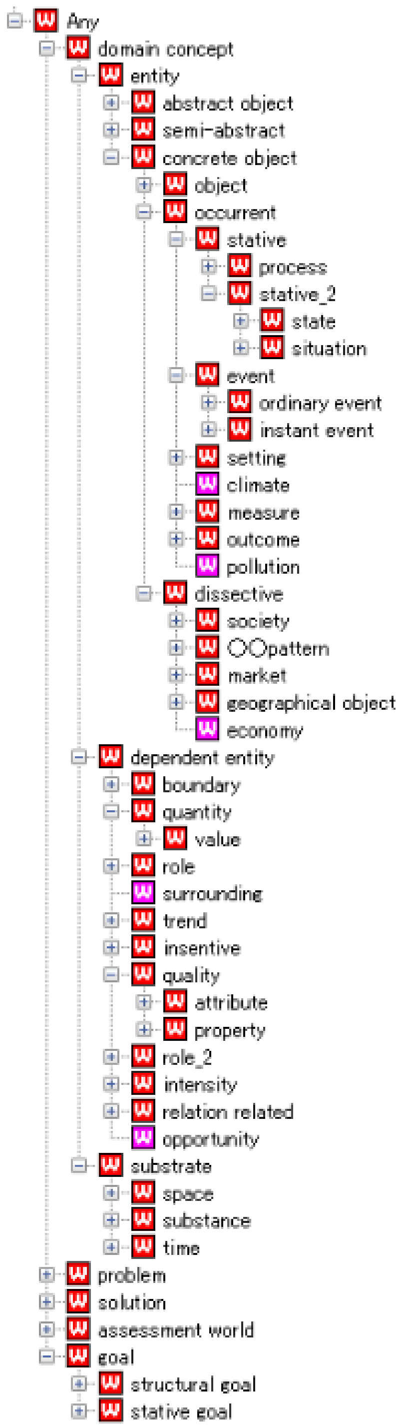


Figure 5 Tree of SS-SESs ontology

3.2. Definition of SESs

We define the SESs itself in the SS-SESs ontology. As a first step we explicate what system means. The YAMATO doesn't define *system* but many items related to system is included in the SESs framework. Therefore, we define *system* as a subconcept of *object*. The concept of system is defined by the role of *system boundary* and *surrounding*. The definition of system and its subconcepts are shown in Figure 6. In addition, *society* is the subconcept of *dissective* set at the subconcept of *concrete object* according to the YAMATO. This definition is explicating the difference between *society* and *social system*.

The figure 7 shows that SESs framework consists of the following elements: interaction process consisting of I and O, system boundary, Direct causal link, Feedback, RS, RU, GS, GU, S and ECO. RS, RU, GS and GU mean the subsystems of the first tier, while S and ECO mean the external system of the SESs. As these elements play roles of SESs, we define SESs by setting the slots of *subsystem*, *interaction process*, *external system*, *SESs boundary*, *direct causal link* and *feedback* as *part* slots as a subconcept of *system* (Figure 7). By referring to these slots we are able to trace the SESs framework.

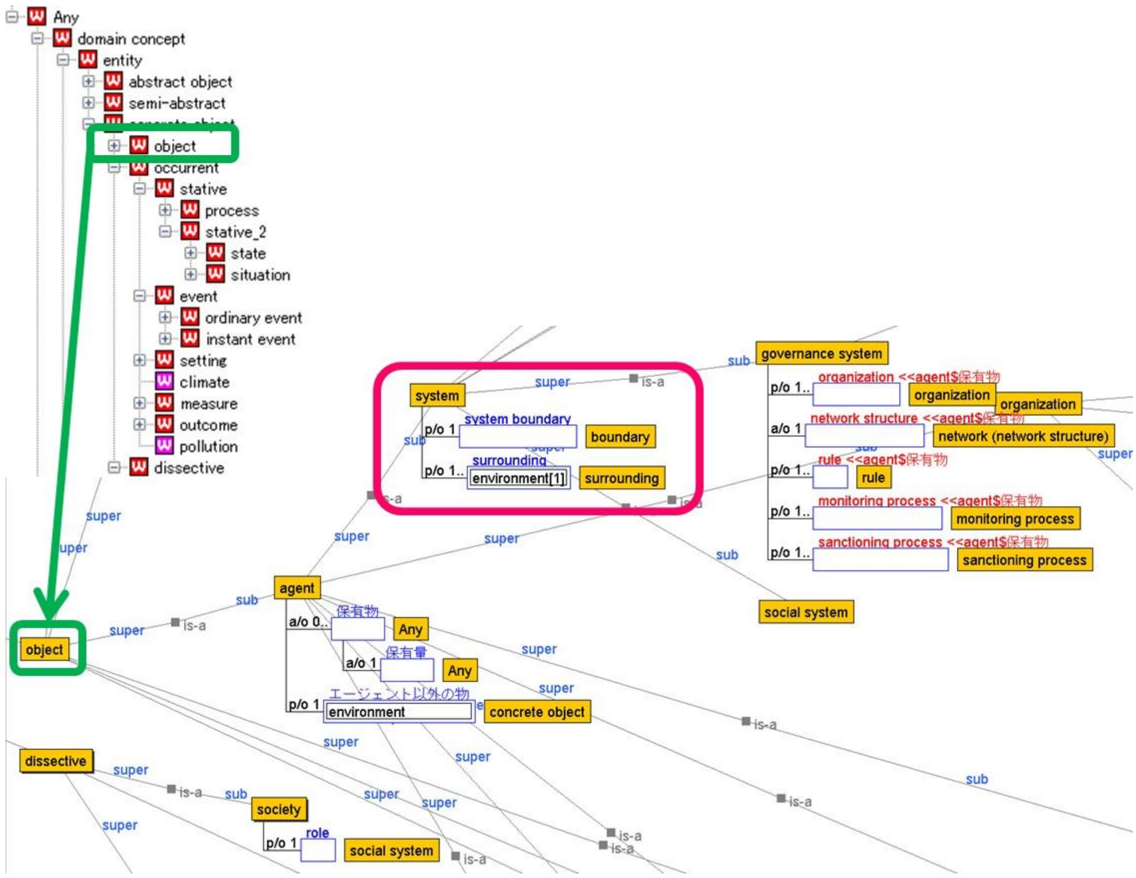


Figure 6 Definition of *system* and its subconcepts

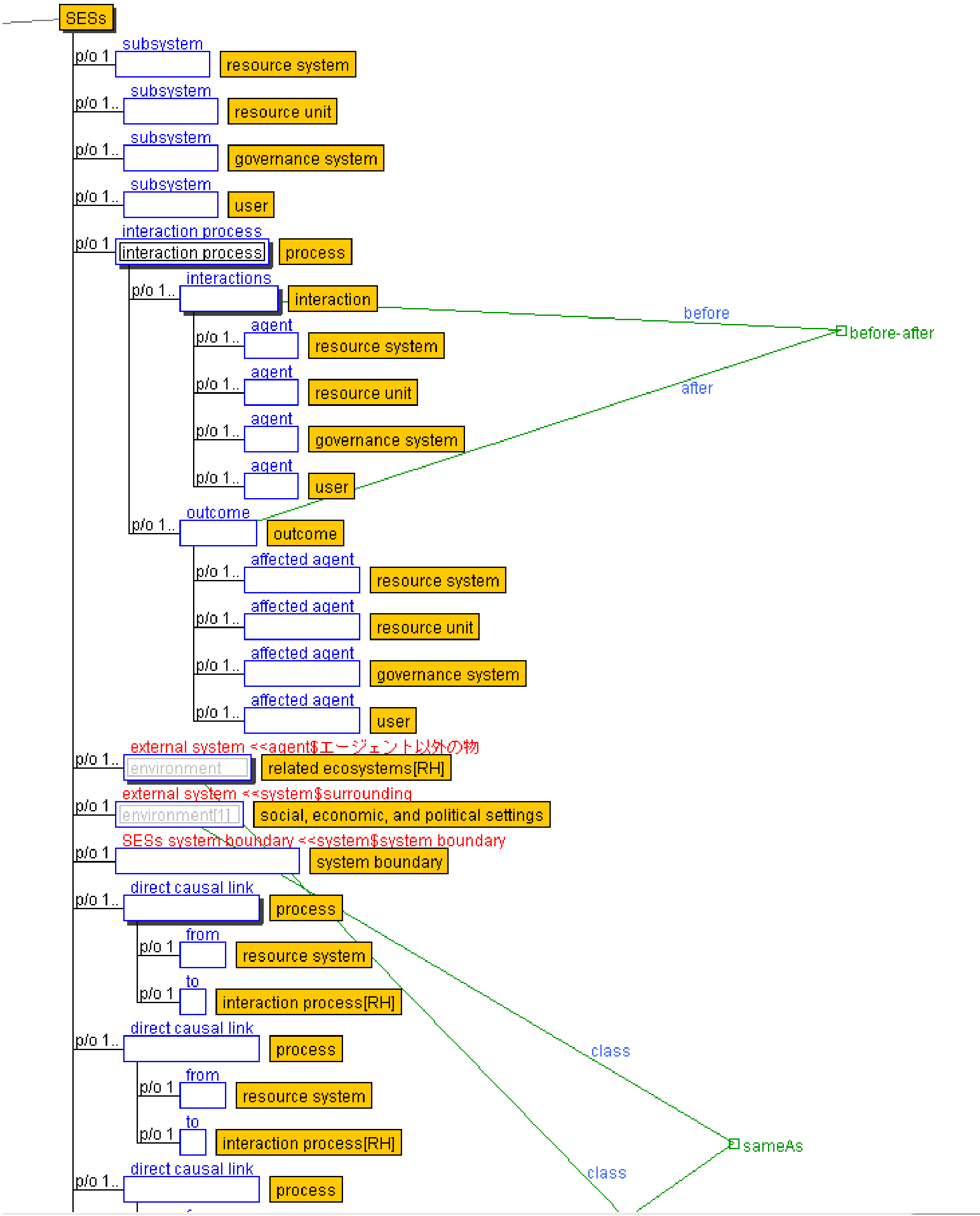


Figure 7 Definition of *SESs* (a part of the structure)

4. Incorporating the information of action planning case into the SS-SESs ontology

In this section we incorporate the goal items and indicator items proposed in the workshops of the Satoyama planning. As a target case we review the practice carried out in a Kizugawa city of Kyoto prefecture in Japan, which deals with the planning and management to maintain Satoyama and conserve ecosystems within the city while preserving unique history and cultures by means of the partnerships among various stakeholders.

4.1. Case overview

Kizugawa city is a city located in southern Kyoto Prefecture, Japan with a population over 70,000 (Figure 8). In the district called “Kaseyama” of the city, several local communities and NPOs have recently carried out activities in such fields as maintenance of bamboo trees and walkways, cultivation of mushroom, and environmental education for small children.

To pass on the natural environment of Satoyama and other areas to future generations and to promote management for sustainable use, the municipal government formulated the Kizugawa City Action Plan for Maintaining Regional Cooperation on Biodiversity in February 2014 (literally translated from Japanese) (Kizugawa city, 2014).

Figure 9 shows the planning area and its zoning. In addition, Table 2 presents the citizen groups and NPOs and their activities back in the period of planning process.

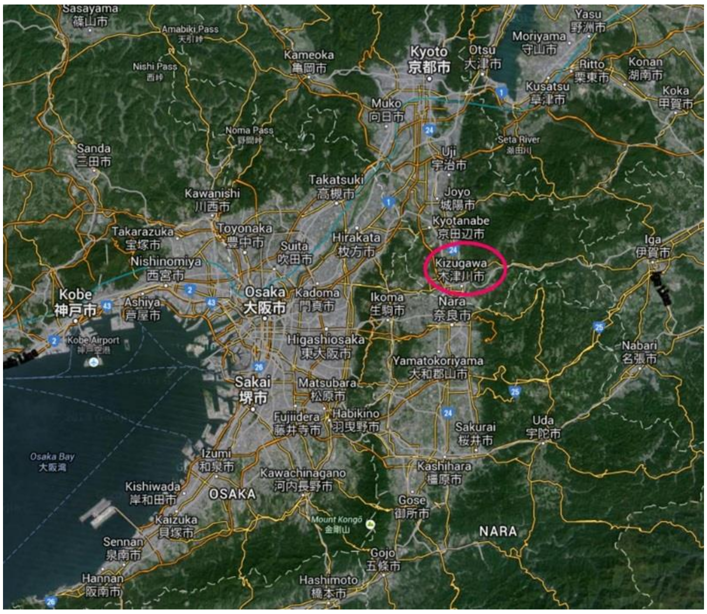


Figure 8 Location of Kizugawa City

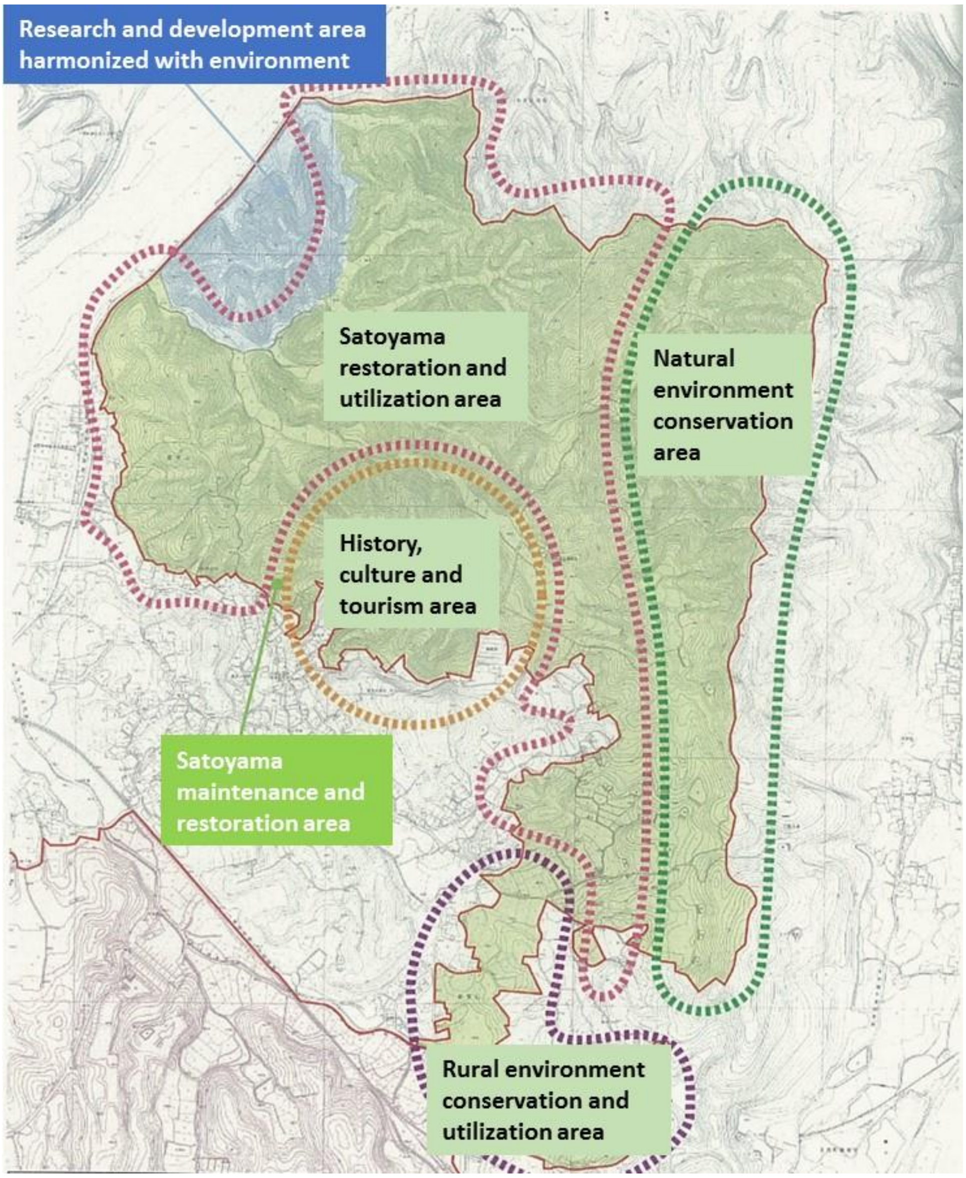


Figure 9 Zoning of the planning area

Table 2: Activities of citizen groups and NPO back in that period of planning process[vii]

ID	Group Name	Main activities
1	**Kaseyama Club**	Cultivation of ancient rice, seasonal vegetables, etc., maintenance of bamboo grove
2	**Nonprofit Organization Kyoto_Hatsu Take-Ryuuiki_Kankyou_Net**	Maintenance of bamboo grove, maintenance and management of Satoyama landscape

[vii] Currently more several groups after that planning period started the activity in Kaseyama.

3	**Kizu no Bunkazai to Midori wo Mamorukai**	Setting of route sign to Kaseyama castle, maintenance of walkways in mountainous areas
4	**Kaseyama no Kaki wo Sodateru Network**	Advertising Kaseyama persimmon, organizing tours to persimmon cultivation,
5	**Kaseyama Genki Project**	Regeneration of pine trees and persimmon and blueberry cultivation fields, organizing camping and environmental education program
6	**Kizugawa-shi Kodomo Eco Club Supporter no Kai**	Organizing nature observation meetings and eco-friendly crafts making

4.2. Series of workshops for planning design

In this planning process a series of workshops were organized in which activity groups and city workers participated and discussed such essential issues as goals of the plan, principles of actions and evaluation indicators between 2012 and 2013. In this process the main members of all the group from ID 1 to 6 participated in.

In the process of the workshop series we requested all the groups plus the municipal government itself to propose the activity goals and outcome indicators which their minds and concepts were reflected. That requirement of goal - indicator proposals was what the groups would be able to attain rather than what they took the strictly quantitative approach. As a result, the indicator items based on stative perspectives were proposed in relatively large numbers.

Photo 1 One scene of the workshop

4.3. Incorporating goal and indicator items into the SS-SESs ontology

There are two steps to incorporate the goal and indicator items into the SS-SESs ontology. First, the activity goal items and outcome indicator items proposed by each group were divided into simple keywords so that the contexts these goal items and indicator items have could not be lost as possible as we can. Second, the divided keywords were described as defined concepts or instances in the SS-SESs ontology based on the ontology engineering theory.

Figure 10 presents the part of newly incorporated concepts and instances into the SS-SESs ontology. The yellow boxes mean the (class) concepts, while the blue boxes mean instances.

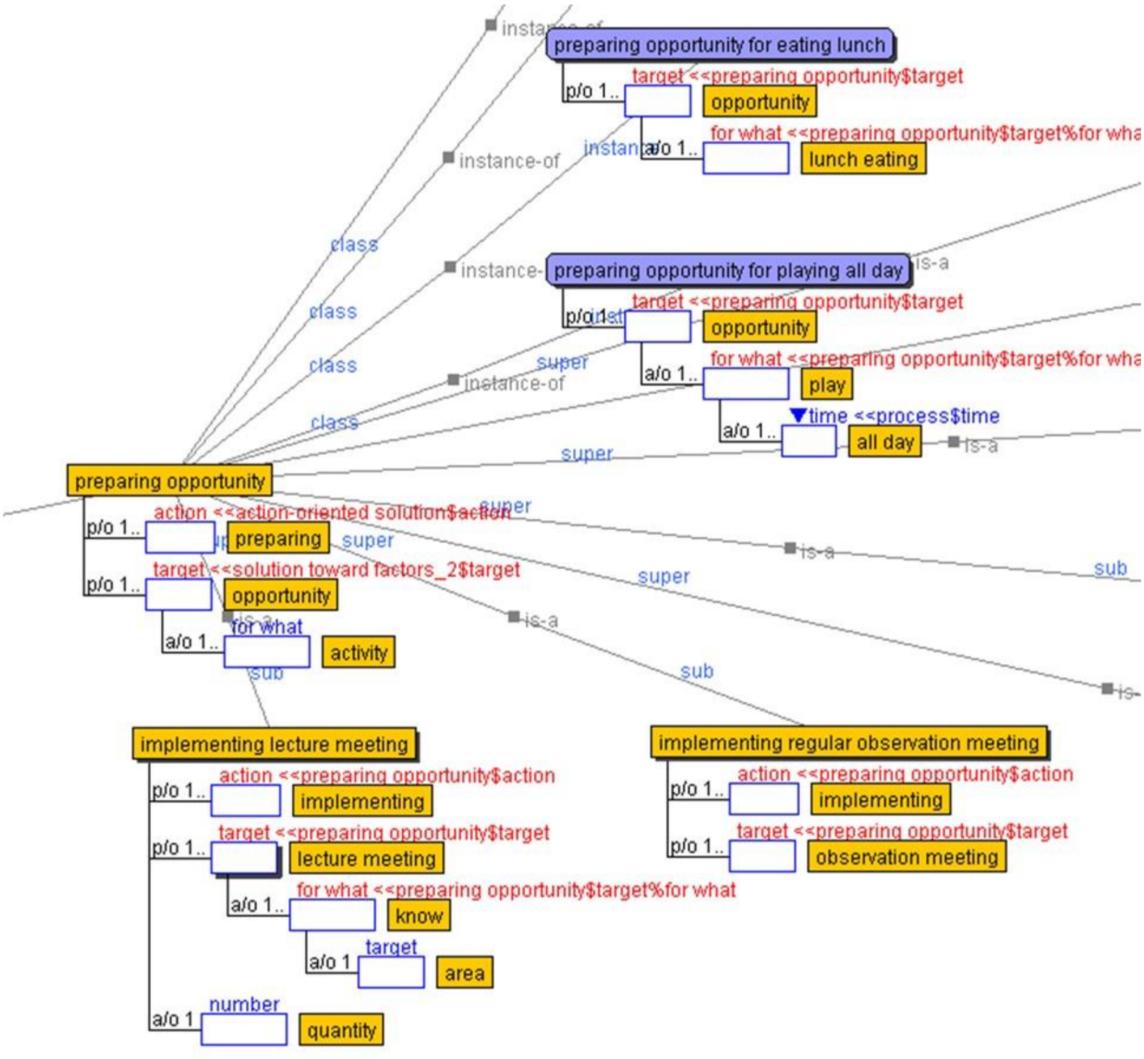


Figure 10 Part of newly incorporated concepts and instances into the SS-SESs ontology

5. Assessment of the SESs based on ontology engineering

5.1. Assessment experiment

We assess the goal items and indicator items proposed in the workshops of the Kizugawa case by means of the constructed SS-SESs ontology. The assessment, which is from the SESs perspective, is implemented through examining how the goal items or indicator items link with the concepts of SESs by each activity group. As an assessment result the semantic linkages which represent the knowledge structure of the stakeholders are shown, and it enables us to understand the differences of the perspectives between stakeholders.

The semantic linkages are shown by using the Conceptual Map Creation Tool, hereinafter referred to as the map tool as shown in Figure 11. The tool enables us to generate a conceptual map with the classes in the SS-SESs ontology. The algorithm for linkage exploration adopted by the map tool is basically the breadth first search. This is the algorithm that stops exploration for avoiding redundant exploration once the same concept is reached.

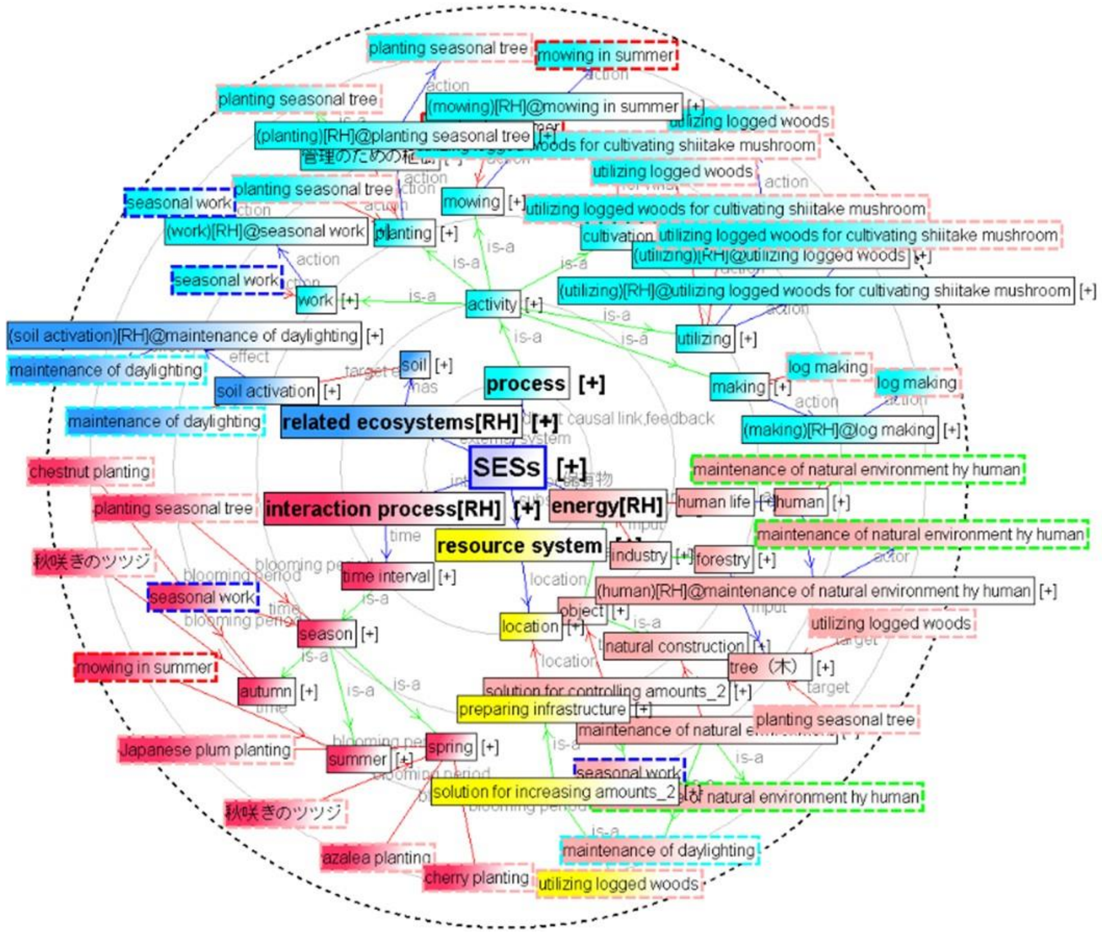


Figure 11 Example of ID4 from the SESs to the indicator items

5.2. Assessment results

The situation of the linkages between the first tier items of the SESs framework and the goal or indicator items proposed by groups is shown in Table 3. However, we found the further improvement of the SS-SESs ontology including definition of *ecosystem* was necessary in the process of the assessment. Therefore, the following results are tentative ones and will have to be updated.

First, we found the several number of linkages through RS, RU and ECO, but the variety of these linkages are small. Second, we found few linkages through U. Third, we found no linkage through GS including the municipality government. Regarding the municipality government the reason is currently considered that the terms of GS are self-evident aspects or tasks as a government, but further discussion is necessary. On the other hand, regarding the other groups, the reason is currently considered that GS is not originally the target of concern or task, or that the activity stage of all the groups is only in the initial one. In any case, the cause is still unclear, but therefore, it could be meaningful to watch why there is no linkage through GS carefully in the future process.

Focusing on the particular group or municipal government, for example, ID 4 doesn't use the Kaki which means Japanese persimmon in spite of the group focusing on Kaki. According to the follow-up interview to the members of this group, they don't find out any meaning of setting the goal on the crop yields and sales of Kaki. In addition, in ID 6 case the target of the indicator items are focused on *preparing opportunity*. On the other hand, the indicator items of ID 7 covers the large part of the first tire items in spite of the small number of indicator items. This result indicates that the municipal government has the function to complement the group activities. In addition, the experiment of the linkage between the goal items and the SESs items targeted the *stative goal*. But we found the all the linkages from SESs to *stative goal* traced through *structural goal*. This result indicates that more in-depth discussion focusing on *structural goal* is important.

However, we actually found the linkage as shown in Figure 12 as a major linkage between the SESs concept and the goal or indicator related concepts. In the SESs framework the concept of process corresponds to the direct causal link or feedback arrows. This result indicates that this kind of goal-indicator proposal opportunity places emphasis on the *process* concept. The implications are shown as below.

- Emphasizing the reflection of a sense of values.
- The way of thinking of the tentative practice without any concern for content or environment.
- Focusing on the change of time
- Ensuring the dynamic aspect of the SESs because the essential property of the process is ongoing. In other words, we can discuss the change of states based on the flow of time.

Table 3 Situation of linkages between the first tier items of SESs and the goal or indicator items

ID	Group Name	Type	I	O	RS	RU	GS	U	S	ECO
1	Kaseyama Club	goal			○					
		indicator			○	○		△		○
2	Nonprofit Organization Kyoto_Hatsu Take–	goal			○					
		indicator	○		○	○				○
3	Kizu no Bunkazai to Midori wo Mamorukai	goal								○
		indicator								○
4	Kaseyama no Kaki wo Sodateru Network	goal			○					○
		indicator	○		○					○
5	Kaseyama Genki Project	goal			○	○				○
		indicator	○		○	○				○
6	Kizugawa-shi Kodomo Eco Club Supporter no Kai	goal				○				
		indicator								
7	Kizugawa City (Municipal Government)	goal								
		indicator			○	○		○		△

I : interaction (It includes *interaction process*)
O: outcome
RS: resource system
RU: resource unit
GS: governance system
U: user
S: social economic and political settings
ECO: related ecosystems

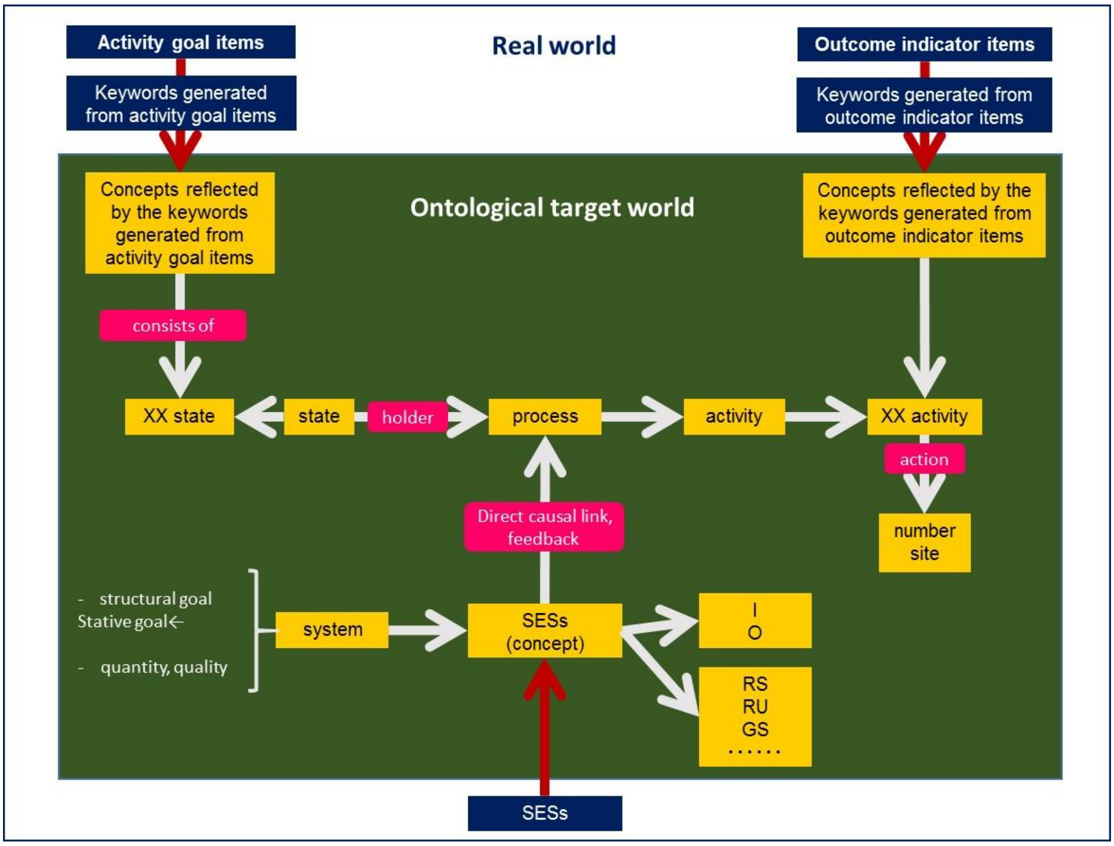


Figure 12 Relationship between the approach of goal-indicator item design and SESs

6. Discussion

We discuss how we actually use the SS-SESs ontology in the context of environmental planning and management. Basically, we can realize knowledge information management by the linkage with information inside/outside of cases or with different fields if we use the ontology. In this section we focus on the utilization in the following two kinds of spaces. One is a workshop space, the other is a web space.

6.1. Collaboration support in the workshop in the planning or management process

If we develop the supporting tools by means of the SS-SESs ontology, we consider that we can support a round-table meeting and a workshop from the following three aspects.

- Complementing and verifying the grouping implemented by means of the approach similar to the KJ method.

- Verifying and complementing the facilitation.
- Managing the information of work products written in white boards and papers by the participants

Especially focusing on the last aspect, the SS-SESs ontology can provide the common terms to link the terms from a work product with the terms from another work product. The way incorporating the terms from a work product into the SS-SESs ontology is similar to the approach taken by the goal-indicator items case in Kizugawa planning case, but more organized division method is better in terms of securing generality and reproducibility. As a concrete approach we first make the sentences which consist of subject, predicate and object like RDF triples by using these terms (Figure 13). Second, we add the classes and instances into the SS-SESs ontology by using these terms categorized into subject, predicate and object. In addition, the case study taking this approach is described in Huang et al. (2015).

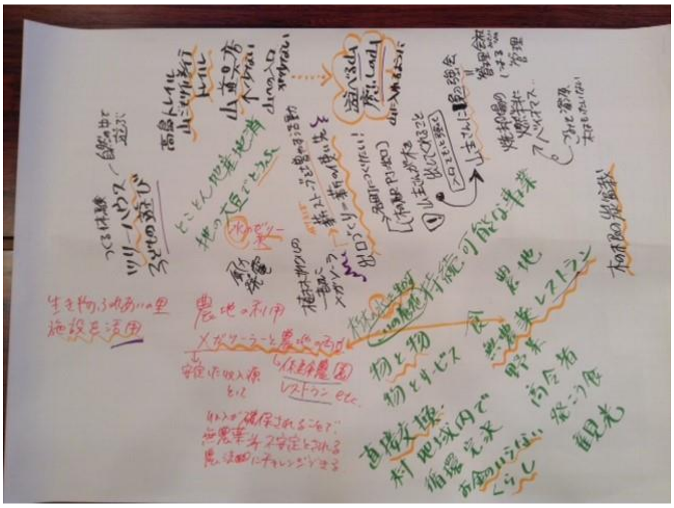


Photo 2 Example of the work products

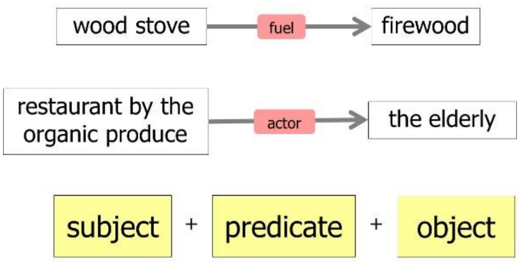
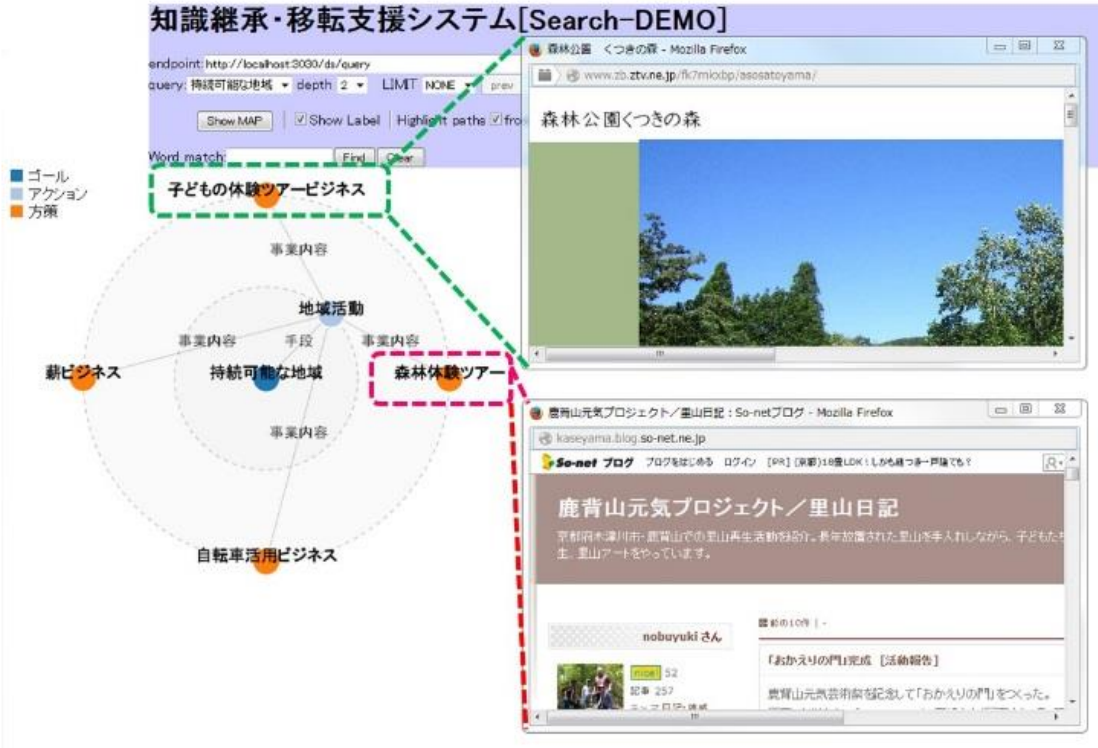


Figure 13 Sentence design by means of the terms in the work product

6.2. Collaboration support by means of Linked Data based on ontology

By incorporating the SS-SESs ontology into the Linked Data (Heath et al. (2011)), we can realize the linkage with another case information. For example, Figure 14 presents the website of the activity group in Kaseyama, Kizugawa City ("Kaseyama Genki Project") is linked with the website of the NPO in Takashima City in Shiga Prefecture, Japan, named the "Nonprofit Organization Aso Satoyama Center" through the SS-SESs ontology based web tool.

To find out and understand similar cases in other areas or in other kinds of business enables us to introduce the new idea smoothly which it is difficult to come up with only by the information existing in the inside of the area. In addition, the information from the outside of the area is expected to support discussing the newly introduced idea more concretely.



Translations into English
・"持続可能な地域"(sustainable region), "地域活動"(local activity), "森林体験ツアー"(forest tour), "子どもの体験ツアービジネス"(tour business for child's experience), "薪ビジネス"(wood business), "自転車活用ビジネス"(business utilizing bicycles)

Figure 14 Sharing the similar activity case in/of the different area through the SS-SESs ontology[viii]

[viii] This trial website was developed based on the "The Web version of the ontology exploration

7. Conclusion

This present paper focused on proposing the collaborative approach to assessment of social-ecological systems by means of ontology engineering approach. The results are as below. First, we defined the concepts reflected by the items in the SESs framework and incorporate these into the ontology dealing with SS. Second, we incorporated the goal items and indicator items proposed in the workshops of the Satoyama planning case in Kizugawa City, Kyoto Prefecture, Japan. Third, we assessed these items from the aspect of the SESs by means of the constructed SS-SESs ontology. Finally, we proposed the ways we actually use the SS-SESs ontology as a tool for linking cases by focusing on the utilization in the workshop space and the web space.

As a result of the assessment experiment by generating the linkages between the first tier items of the SESs framework and the goal or indicator items proposed by groups we found the following four points: First, we found we the several number of linkages through RS, RU and ECO, but the variety of these linkages are small. Second, we found no linkage through GS including the municipality government. The cause is not necessarily clarified, but therefore, it could be meaningful to watch why there is no linkage through GS carefully in the future process. However, we found the SS-SESs ontology needed further improvement in the process of the assessment. Therefore, the following results are tentative ones and will have to be updated. Third, we found the all the linkages from SESs to *stative goal* traced through *structural goal*. This result indicates that more in-depth discussion focusing on *structural goal* is important. Finally, we found a major linkage between the SESs concept and the goal or indicator related concepts consists of *state*, *process*, *activity*. This result indicates that this kind of goal-indicator proposal opportunity places emphasis on the *process* concept.

Based on these results, we concluded that the SESs in the planning case are dealt with emphasis on the process, and therefore the dynamic aspect of the SESs is ensured, but, on the other hand, it is a challenge to concretize the linkage with objects.

As a future task we will find the points to collaborate with each other through exploring the common points and different points between activity groups after the further improvement of the SS-SESs ontology. In addition, we will discuss what the subconcepts of *process* which each group focuses on mean for the group itself. Furthermore, it is also a future task to propose the new viewpoint by tracing the concepts related to the instances derived from another area case.

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tool" developed by Kouji Kozaki, Associate Professor, The Institute of Scientific and Industrial Research, Osaka University.

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