Study of the Contribution of Sustainability Indicators to the Development of Sustainable Coastal Zones - A Systems Approach

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ABSTRACT

Sustainability indicators are an important management tool used to realize and sustain the desired state of coastal zones. They simplify, quantify, analyze, and communicate the complexity of coastal zones. However, because of such simplification, indicator selection needs to consider two primary issues, namely, the causal relationships between indicators and other components of the coastal zones as a complex social-ecological system, and the contribution of the selected indicators to management goals (e.g., sustainable coastal zones). Since the root cause of these issues is the "systemness" of coastal zones, which is difficult to capture with indicators, this study applied Causal Loop Diagrams (CLD) as a type of systems approach as a solution; As a case study, the sustainability indicators set in the action plan for Omura Bay, Western Japan, were translated into a CLD. The plan was aimed at realizing and sustaining "Satoumi," a Japanese concept of desirable socio-ecological production landscapes. This study showed that the CLD 1) helped indicator selection by assessing current indicators and identifying those missing with regards to their contributions to Satoumi, and 2) identified research priorities to verify hypothetical relationships that lack hard data.

KEYWORDS

Causal Loop Diagrams; Systems approach; Sustainability indicators; Social-ecological Systems; Integrated Coastal Zone Management; Hypothetical Relationships; Hard data; Omura Bay; Satoumi

1. INTRODUCTION

Coastal zones are Social-Ecological Systems (SESs) where humans are a part of nature (Berkes & Folke, 1998). SESs including coastal zones are complex due to the dynamic interactions and feedback between components, processes, and systems that make up these SESs (Costanza & Ruth, 1998; Limburg et al., 2002). They can also be considered as complex adaptive systems that exhibit nonlinear feedbacks, strategic interactions, individual and spatial heterogeneity, and varying time scales (Atkins et al., 2011; Levin et al., 2013). Therefore, understanding and assessing this complexity is imperative to successful coastal zone management.

Since coastal zones include the sea and the surrounding land areas, the management of these zones require covering both areas in an integrated system to capture their dynamic interactions. Integrated Coastal Zone Management (ICZM) has been adopted as an effective measure to manage coastal zones sustainably (Pickaver, Gilbert & Breton, 2004; Maccarrone et al., 2014; Karnauskaitė et al., 2018).

To aid SES management including ICZM, there has been a growing literature in ecosystem services and sustainability science. However, their practical impacts on the ICZM are limited (Abson et al., 2017; Saarikoski et al., 2017). As a result, mainstreaming, or linking science to policy, requires immediate attention (Cowling et al., 2008; Olander & Maltby, 2014; Luederitz et al., 2017; Potschin-Young et al., 2017).This study aims at bridging the gap between science and policy by focusing on the current ICZM practices rather than designing a desirable ICZM from the beginning. The policy arena in which ICZM is designed and implemented is contextually objective and to contribute to the policy, studies should be relevant to the current context.

Among various approaches to ICZM, this study focuses on indicators because they have been recognized to be one of the primary inputs to ICZM and are in increasing demand (Maccarrone et al., 2014). Indicators can simplify, quantify, analyze and communicate complex SESs (Singh et al., 2012). In addition, they also help in assessing the progress of management programs (Karnauskaitė et al., 2018) by providing a simple interface to integrate the complex SESs into a set of comparable quantities (Singh et al., 2012). This is an indispensable source of information as it provides an analysis of the overall performance of various departments (e.g., fishery department, environmental conservation department, etc.), which typically conduct management programs independently.

While such a simplification is inevitable for managing complex SESs, there are at least two primary challenges indicators face, that sustainability indicators should reflect the causal relationships of SESs (Perdicoúlis & Glasson, 2011; Maccarrone et al., 2014; Costanza et al., 2016) and that they should have their intended impact with regards to sustainability, which might not always occur (Singh et al., 2012; Maccarrone et al., 2014; Costanza et al., 2016). Due to simplification of the complex interface, the relationship between indicators and the nature of their impact in SESs is often neglected, and the contribution of indicators to the system objectives (i.e., sustainability) is overlooked. Since in reality, the indicators form causal relationships in SESs, (e.g. an improvement of one indicator (e.g., fish catch) could result in the deterioration of another (e.g., marine ecosystems)), trade-offs and synergies between indicators should be considered. These relationships are not necessarily direct but may include some components of SESs. Therefore, SES indicator selection demands a careful investigation of their causal relationships. Similarly, since sustainability activities often involve various entities (e.g. multiple departments at the municipality) acting independently (Singh et al., 2012), supervising all activities aimed at improving the indicators is a challenge. For example, each department in charge of some of the indicators could try to optimize locally without realizing its impact on the whole, which does not necessarily lead to optimization at a system level (Stroh, 2015). Therefore, assuming that individual actions will naturally lead to system-level sustainability is even dangerous (Anderies et al., 2013).

The “systemness” (Lendaris, 1986) of SESs is the root cause of these challenges. A system is “more than the sum of its parts” (Meadows, 2008); a change in one component of a system could influence the entire system, including its own component, via feedback process. Also, a system is organized to achieve some objectives (e.g., the sustainability of the system) (Meadows, 2008). Assuming the systemness as the key to successful indicators, this study hypothesizes that a systems approach improves sustainability indicators. In other words, using a systems approach, we can improve indicator selections in spite of the two challenges involved. The purpose of this study is to describe and assess existing sustainable indicators in order to improve their performance regarding sustainability developments by using a systems approach in the form of Causal Loop Diagrams (CLD). Omura Bay, an enclosed sea located in Western Japan with an action plan for ICZM is chosen as a case study. There have been various attempts at using a systems approach for indicator selection. For example, the PSR (pressure–state–response) framework and the DPSIR (Drivers-Pressures-State Change-Impact-Response) framework have been developed as a system-based approach (Atkins et al., 2011). However, they do not reflect the systemness well as we discuss later (Perdicoúlis & Glasson, 2011).

The rest of the paper is organized as follows. In Section 2, the basics and advantages of CLD, the primary method applied in this study, are explained after a short description of the case study. Section 3 demonstrates and discusses a CLD for Omura Bay. In Section 4, the conclusions of the study are summarized. Finally, Section 5 gives an overview of the scope of future research related to this study.

2. MATERIALS & METHODS

This section first describes a site in which CLD was applied to indicators as a case study. Then, it explains the basics and discusses the advantages of CLD.

2.1. Case Study: Omura Bay

Omura Bay is an enclosed coastal sea located in Nagasaki Prefecture, Western Japan (Figure 1). The sea covers an area of 320 km^2 and is approximately 14.8 m deep with a coastline of length 360 km (Ocean Policy Research Institute & Nagasaki Prefecture, 2011). Because there are few shallow bottoms, nutrients from the land areas directly sink to the deep bottoms (Ocean Policy Research Institute & Nagasaki Prefecture, 2011).

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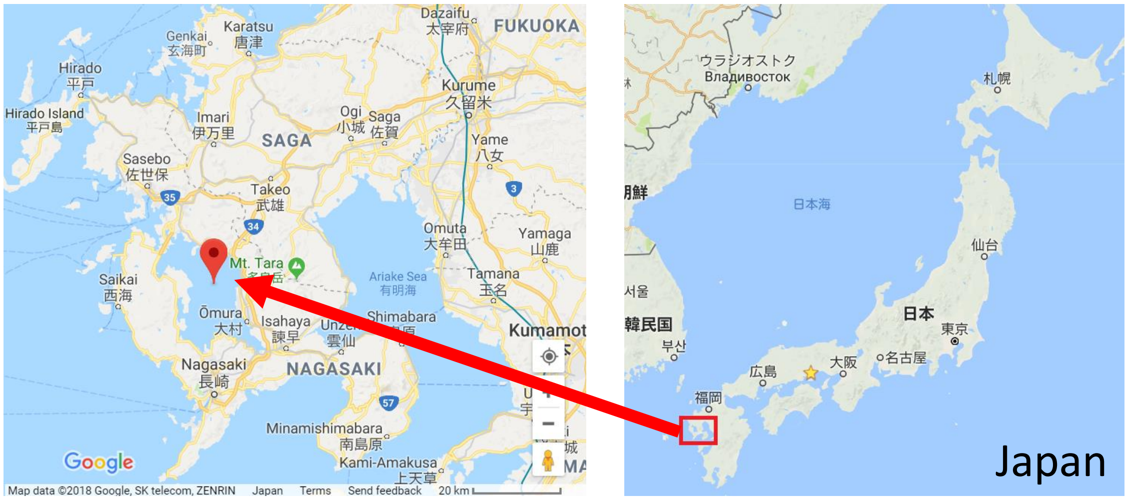

Figure 1. Location of the site selected for the case study - Omura Bay

About 280,000 people live along the coast, accounting for 20 % of the total population of Nagasaki Prefecture (Nagasaki Prefecture, 2014). The bay is not accessible to the residents for recreational purposes like swimming, owing to its depth at most points. It is an ecologically important site, as it contains several endangered species, including finless porpoises (*Neophocaena phocaenoides*) and Horseshoe crabs (*Tachypleus tridentatus*) (Nagasaki Prefecture, 2017). Additionally, the bay is important for the fishery industry, since several species of fish are found here (including squillas (*Oratosquilla oratoria*), sea cucumbers (*Holothuroidea*), and turban shells (*Turbo sazae*) (Omura City, 2016)) and it also acts as a fish nursery both inside and outside the bay (Nagasaki Prefecture, 2014). However, it has faced several challenges including a decline in fish catch, the deterioration of sea bottoms reportedly due to eutrophication, red tide, and dysoxic water mass (Nagasaki Prefecture, 2014).

In response to the deterioration of the bay, Nagasaki Prefecture has implemented action plans for conserving and revitalizing Omura Bay since 2003 (Phase 1). The current plan is the third phase adopted in 2014 (Nagasaki Prefecture, 2014). The plan was formulated by a panel of experts from private sectors, fishery, Non-Profit Organizations (NPOs) and universities. Its objective is to realize Satoumi, a Japanese concept describing a desired state of socio-ecological production landscape (Duraiappah et al., 2012; Gu & Subramanian, 2014), in which high productivity and rich biodiversity is maintained through human intervention (Yanagi, 2012). The action plan adopted an image (Figure 2), called the "sea of treasure", provided by the Japanese Ministry of the Environment as the desired state where economic activities thrive and people recreate and communicate (Nagasaki Prefecture, 2014).

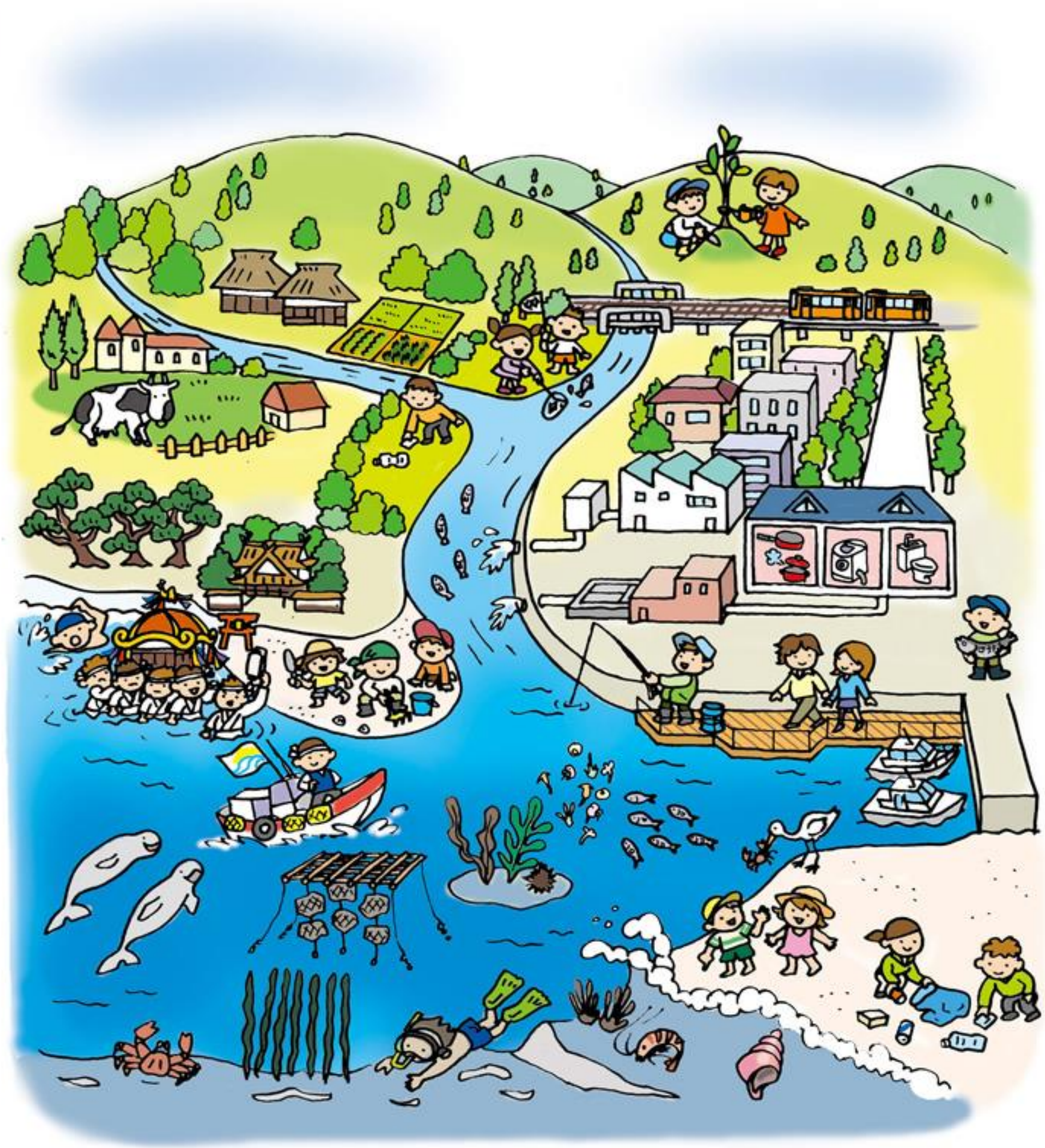

Figure 2. An image depicting Satoumi. [Adopted from the Japanese Ministry of the Environment]

To realize and sustain the desired state, the plan stipulates four major items followed by ten intermediate and seventeen minor items as shown in Table 1. To operationalize the plan, it sets indicators corresponding to each minor item, that is, there are seventeen indicators. Each of these indicators were assigned to a relevant department at Nagasaki Prefecture, where each department is in charge of achieving the target level of its assigned indicator and is expected to work with relevant stakeholders such as municipalities and NPOs.

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151 Table 1. Phase 3 Action Plan: Organization of Measures

Major Item	Intermediate Item	Minor Item	Indicator
Creating unified Satoumi from mountain to sea	Curbing inflow of domestic wastewater	Approaches for promoting wastewater treatment	Population penetration rate of Omura Watershed basin contamination treatment
		Approaches for advanced sewage treatment	Formulation of a comprehensive sewerage improvement plan by basin area
		Regulation of wastewater from factories, workplaces, etc.	Standard wastewater conformity rate for the Omura Bay basin
	Curbing inflow loads from surface sources	Promotion of environment conservation-type agriculture	Land area for addressing organic/special cultivation
		Ongoing demonstration of the public functions of forestry	Maintained forestry area
		Promotion of resource recycling and livestock farming practices	Number of cases of administrative guidance in the Omura Bay basin area based on the livestock waste management law
	Measures to prevent oxygen deficient water, deterioration of bottom sediment, etc.	Measures to prevent oxygen deficient water, deterioration of bottom sediment, etc.	Research into practical applications of aeration technologies to ameliorate poor water oxygenation
Creating Satoumi through conservation of biodiversity	Ecosystem surveys	Implementation of monitoring surveys of living organisms	Number of surveys of wild animals and plants implemented by experts
	Protection of rare fauna and flora, etc.	Protection of rare fauna and flora, etc.	Designation of preservation areas for rare animal and plant species
	Maintenance of habitats for living organisms	Creation of shallow bottom	Creation of shallow bottom using recycled sand and other materials
		Improvement of environments where living organisms can thrive	Number of sites with active work for conservation of flora and fauna (conservation of biodiversity) (cumulative)

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Creating a thriving Satoumi	Promotion of the fishing industry	Maintenance and recovery of marine resources by resource management and seedling release	Sea surface fishery output
		Creation of fishing grounds for maintenance and recovery of marine resources	Number of environmental conservation activities
	Expansion ‘Omura Bay’ brand product consumption	Expansion of ‘Omura Bay’ brand product consumption	Number of times "food business meetings" are held
Creating Satoumi through all of our joint efforts	Environmental considerations	Approaches for building a low-carbon, recycling-oriented society	Number of Nagasaki Environment Prefectural Congress Conferences held
		Promotion of environmental education	Number of times environmental advisers are dispatched
	Approach for regional collaboration	Approach for regional collaboration through the Omura Bay Environmental Network	Number of activities presentation meetings, etc., held

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2.2 Causal Loop Diagrams

Causal Loop Diagrams (CLD), drawn from a systems approach (Bastianoni et al., 2018), was adopted to describe and assess the indicators set in Phase 3 of the Action Plan. A systems approach is effective particularly when a target is complex, and its complexity is attributed to systemness (Lendaris, 1986), that is, the feedback structure of elements, processes, and sub-systems in the system (Sterman, 2000). Because it is a holistic approach, it helps to avoid neglecting important components and optimize the selection of details to draw a complete picture of the reality (Bastianoni et al., 2018).

2.2.1 Basics of CLD

Causal Loop Diagrams (CLD) draw a system's feedback structure using elements of the system and arrows connecting them. The direction of the arrow indicates the cause and effect relationship. "+" indicates cause and effect change in the same direction. "−" indicates cause and effect change in the opposite direction. Figure 3 illustrates an example of a CLD of population dynamics in which it is observed that an increase in population increases birth but results in a decrease in death. When cause and effect relationships are closed, it constitutes a feedback structure. For example, an increase in population will increase birth, which in turn increases population. When feedback reinforces the elements of the system, it is called a reinforcing or positive feedback loop (depicted by R with a circular arrow), while when feedback has a reducing effect on the elements is called a balancing or negative feedback loop (depicted by a B with a circular arrow). A system, in general, comprises combinations of reinforcing and balancing feedback loops.

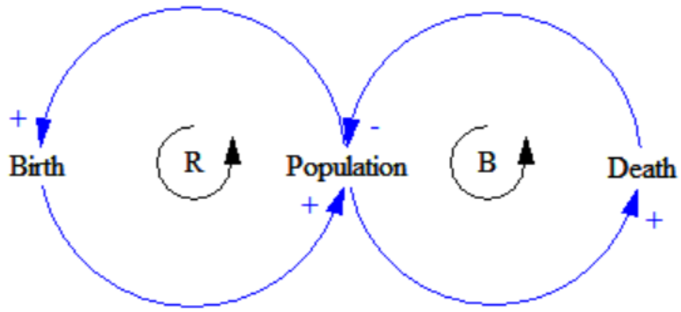

Figure 3. A CLD of population dynamics.

Studies have been conducted using CLD for coastal zone management. For example, Tan et al. (2018) adopted a CLD to select the driving-force, state, and response indicator set for an ICZM at Kaohsiung, a city port in Taiwan. They conducted the Delphi method by involving stakeholders to develop the CLD and select indicators (Tan et al., 2018). They further developed a system dynamics-based decision support system for Kaohsiung. Similarly, Lopes and Videira (2017) developed CLD with their stakeholders for a natural park in Portugal, using participatory systems mapping, and proposed a set of indicators (Lopes & Videira, 2017). However, most studies develop CLD to capture what stakeholders wish or demand, rather than describing current ICZM practices (or supply side).

2.2.2 Strengths of CLD

There are two primary strengths regarding the use of CLD for sustainability indicators. First, CLD can describe interactions between indicators along with their relationships with other components of the SESs. Second, it can also describe how each indicator contributes to system objectives (e.g., sustainability). With these descriptions, we can assess the

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appropriateness of the current indicators and identify missing indicators concerning their contributions to the system objectives.

In addition to these two primary strengths, CLD have two further benefits. Since they encourage the use of soft data (e.g., narratives, news articles, etc.) (Sterman, 2000), we can incorporate “hypothetical” relationships, in the sense that their relationships are not verified with hard data (i.e., numerical data which enable to build mathematical formulae to explain the relationships), allowing us to identify data and research topics we should priotize. In addition, because of the complexity of SESs, it may be impossible to obtain a complete set of mathematical formulae which explains the relationships between elements and the corresponding hard data (Akmalah & Grigg, 2011), so that we often rely on some soft data, rather than waiting for the availability of numerical data or ignoring it. Another advantage of CLD is that while they are a qualitative description of a system, they can be a base for system dynamics, that is, a quantitative description of a system (Sterman, 2000). Tan et al. (2018) developed a system dynamics model based on the CLD. However, given the dynamic complexity of SESs, making indicators dynamic is critical (Karnauskaitė et al., 2018).

2.2.3 Procedure of drawing a CLD

A CLD was drawn to reflect the aim of the action plan and its implementation, as designed by Nagasaki Prefecture for the conservation and revitalization the Omura Bay (Nagasaki Prefecture, 2014), as accurately as possible.

To verify the CLD drawn based on the action plan, several interviews with government officials at Nagasaki Prefecture were conducted in August 2018. The purpose of the interviews was not to enrich the CLD by reflecting their opinions but to confirm if the CLD reflects what the action plan states. With the results from these interviews, amendments to the CLD were implemented to reflect the action plan more accurately.

3. RESULTS & DISCUSSION

Figure 4 shows the CLD developed based on the action plan. It describes how the sustainability indicators relate to each other in the SES of Omura Bay and their contributions to the management goals (i.e., Satoumi, the desired state set in the action plan).

3.1 Assessing the current indicators and identifying the missing indicators

The CLD helped assess indicators and identify missing indicators according to the management goals. It showed that the current indicators require further improvement to attain the specified standards of the action plan. First, the plan was particularly focused on water quality with eight out of seventeen indicators targeted at its improvement. Although this is critical for a water body in general, better water quality cannot be measured by a single entity (for example, Chemical Oxygen Demand (COD) is not the sole means to enrich the sea) In addition, better water quality is not necessarily a good thing for a rich ecosystem. For example, the relationship between the transparency of water and fish catch is nonlinear, as completely clean (or transparent) water could have negative impacts on fish population because of the shortage of nutrients (Yanagi, 2017). Second, although the management goals stipulated that the plan encourage various economic activities, the CLD shows that indicators were targeted solely at fishery (“I12 Sea surface fishery output” and “Consumption of products made in Omura Bay”) during the implementation. Therefore, other indicators which encourage a variety of economic activities should be considered. Third, in consistency with the management goals, the CLD shows that the plan could contribute to enhancing biodiversity by “I8 Number of surveys of wild animals and plants implemented by experts”, “I9 Designation of preservation areas for rare animals and plant species”, “I10 Creation of shallow bottom using recycled sand and other materials”, and “I11 Number of sites with

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active work for conservation of flora and fauna (conservation of biodiversity) (cumulative)" [Figure 4]. Fourth, "I15 Number of Nagasaki Environment Prefectural Congress Conferences held" and "I16 Number of times environmental advisors were dispatched" is considered to contribute to "Recognition as shared property" [Figure 4] but it is not clear how the recognition contributes to the management goals. Lastly, there was no indicator explicitly mentioned, which improved Omura Bay as a place where people recreate and communicate, although the recognition of the region as shared property could be pertinent to this goal by spreading awareness. Without a specific indicator, there is no obligation or incentive to make an effort. Another interesting observation was that, in an interview for verifying the CLD, one interviewee asserted "I10 Creation of shallow bottom using recycled sand and other materials" [Figure 4] promoted the recreation and communication among the residents, rather than improving water quality.

Nagasaki Prefecture developed a shallow bottom and beach by depositing large quantities of sand, made of finely crushed glass, in Omura Bay. The original aim was to improve water quality by creating an environment suitable for Japanese littlenecks (*Ruditapes philippinarum*) which feed on Phytoplankton. However, because sand crystals are made of colorful recycled and finely crushed glass, it adds to the scenic beauty of the place, making it a popular tourist destination (The Yomiuri Shimbun, 2018). This relationship was not included in the CLD as it was not a part of the original action plan and was an unexpected benefit of the ICZM (The Yomiuri Shimbun, 2018).

3.2 Hypothetical relationships and research priorities

The causal relationships in Figure 4 are mostly hypothetical as hard data were not available for verification. For example, it should be reasonable to assume that "I2 Formulation of a comprehensive sewerage improvement plan by basin area" contributes to "influx of living drainage" and thus, "water quality" [Figure 4], but the mathematical form of these relationships is not known. Another example of a hypothetical relationship, which is also the key relationship to the ICZM, is the balance described with reinforcing loop ("Promotion of self-recovery") and balancing loop ("Trade-off") in the CLD. The dynamic state of the "Marine ecosystem" depends on the relative strength of these feedbacks (for e.g., if the balancing loop dominates (i.e., overfishing), the "Marine ecosystem" deteriorates) [Figure 4]. Therefore, it is important to gather more information about the causal relationship regarding the reinforcing and balancing loops.

While the CLD help identify research priorities, it is also important to know that it may be unrealistic to expect the availability of hard data, usually in the form of observations, within a reasonable time period. The complex nature of SESs (Costanza et al., 1993; Limburg et al., 2002) makes it critical to keep adopting hypothetical relationships based on soft data and updating the CLD as new information becomes available. The ICZM and indicator selection should therefore be adaptive (Folke et al., 2002).

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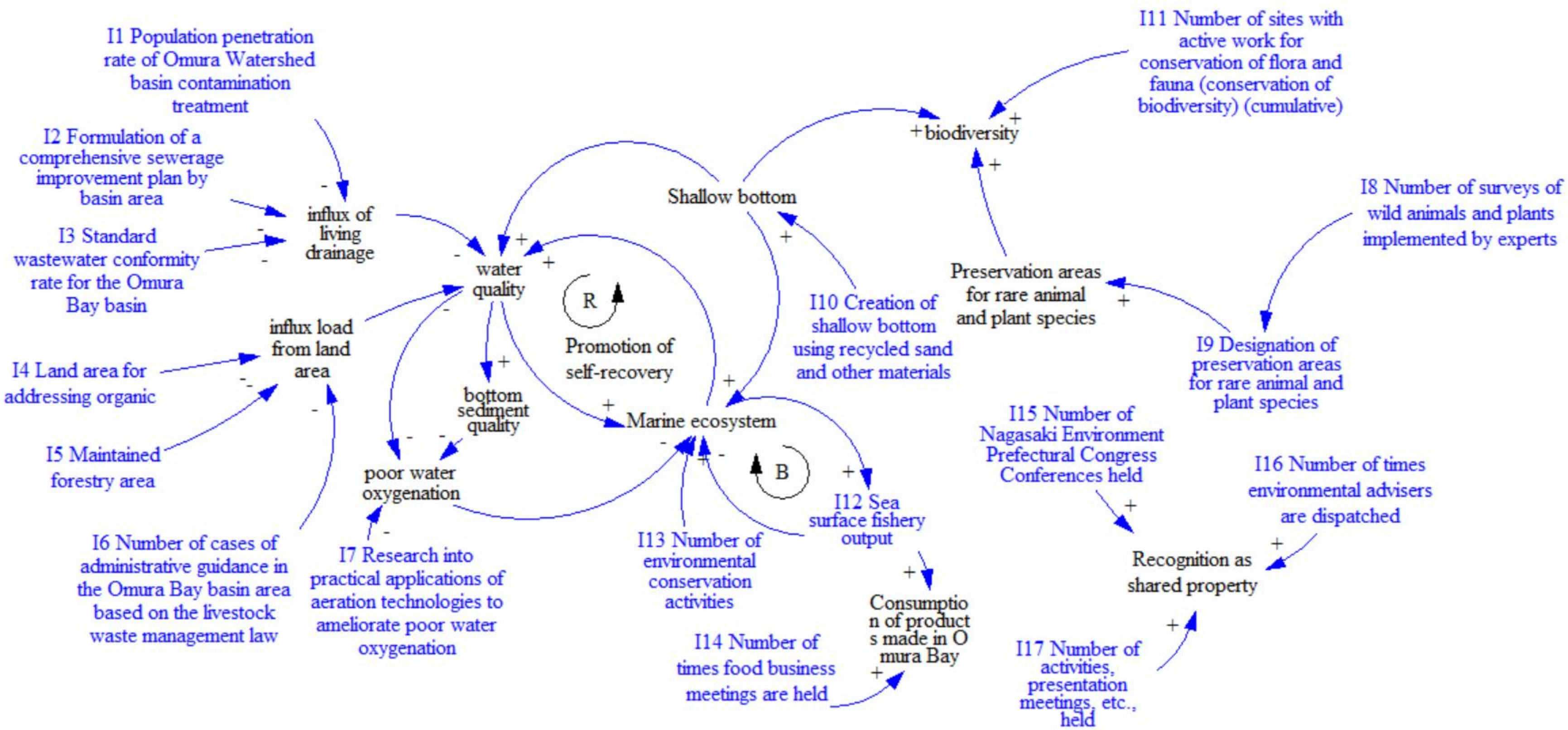

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276 Figure 4. A CLD developed based on the action plan. Variables from I1 to I17 were adopted from Phase 3 Action Plan (Table 1).

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4. CONCLUSIONS

Sustainability indicators have previously been used as a promising tool for ICZM (Maccarrone et al., 2014). However, the systemness of coastal zones raises two challenges regarding the selection of sustainability indicators; the reflection of causal relationships between indicators and other critical components of coastal zones, and the contribution of sustainability indicators to sustainability. This study proposed the use of Causal Loop Diagrams (CLD) to deal with these challenges.

Using Omura Bay, an enclosed sea in Western Japan, as a case study, our study translated the indicators set in the action plan into a CLD to describe and assess these indicators with regards to their contribution to the system objective, i.e., Satoumi. The CLD described interactions between indicators along with their relationships with other components of SES of Omura Bay. It also elucidated how each indicator contributes to the realization and sustainability of Satoumi. The CLD shows that indicators put particular emphasis on water quality improvement and fishery, which, although important, are not sufficient to realize and sustain Satoumi. Indicators for other economic activities and the promotion of recreation and communication are lacking, while those regarding the recognition of the sea as a shared property do not indicate any clear contribution to Satoumi. In addition to assessing the indicators, the CLD helped identify research priorities because it includes hypothetical relationships among indicators and other components of Omura Bay. Important hypothetical relationships such as the reinforcing and balancing feedback loops in Figure 4 require hard data for verification. It helps policy makers and scientists invest their limited resources in topics with priority. However, at the same time, availability of hard data within a reasonable time frame is impractical because of the complexity of SESs (Limburg et al., 2002). Therefore, adaptive management in which ICZM adjusts to new scientific information is recommended.

5. SCOPE OF FUTURE WORK

There are at least two future research directions to make a better contribution to ICZM. First, to better inform ICZM, it is critical to reflect the demand side of the ecosystem services, or what people desire. This study described and assessed the current ICZM practices based on the indicators set in the action plan, or supply side of ecosystem services provided by Omura Bay. Although the action plan reflects the stakeholders' opinions in its target to some degree, it does not sufficiently reflect what people desire because it included a small committee with limited stakeholders and took an overall top-down approach. Therefore, it would be insightful if another CLD is drawn from what people desire by using a participatory process (e.g., Lopes and Videira (2017)) and is compared with the supply side CLD (i.e., the CLD in this study) to improve ICZM by elucidating the difference between demand and supply side.

Second, since CLD can be a base for the system dynamics modeling, a quantitative approach (Sterman, 2000; Uehara, Nagase & Wakeland, 2015; Cordier et al., 2017; Tan et al., 2018; Uehara, Cordier & Hamaide, 2018), they can be used to quantify the relationships between indicators and other components of SESs as a representation of the system dynamics (Karnauskaitė et al., 2018).

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