An Operational Sustainability Assessment Framework for a Regional Scale ICZM: Inclusive Wealth, Satoumi, and Ecosystem Services Science

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Abstract. This study proposes a novel operational sustainable assessment framework for integrated coastal zone management (ICZM) at a regional scale by applying it to Seto inland sea, Japan. Although the sustainability concept has been ubiquitous and applied over the past few decades, its operational usefulness has not been always clear. In other words, some sustainability assessments may not provide decision makers with practical information about what to do with the assessment. The framework draws upon three rather separately developed concepts: the Inclusive Wealth (IW) as a technical framework for sustainability indicators, Satoumi (Japanese traditional multifaceted concept of coastal zones) and ecosystem service science. The three concepts complement each other to corroborate the assessment framework. Although Satoumi is traditional knowledge local to Japan, we believe that its application is instructive for other areas since similar concepts can be found and utilized for their conducting sustainability assessment for ICZM.

1 Introduction

This study proposes a novel operational sustainable assessment framework for integrated coastal zone management (ICZM) at a regional scale by applying it to Seto inland sea, Japan.

ICZM or Integrated Coastal Management (ICM) has been well adopted by all over the world. It deals coastal zones and their adjacent land areas in order to manage coastal benefits effectively. The European Commission launched a new joint initiative on integrated coastal management and maritime spatial planning in 2013. In the United States, the National Coastal Zone Management Program has been adopted by 35 states, territories, and commonwealths in order to protect, restore, and responsibly develop their nation’s coastal communities and resources (http://oceanservice.noaa.gov/tools/czm/). In Japan, the Japanese government promotes ICZM in order to manage the coastal zones effectively (The Japanese Basic Act on Ocean Policy, Act No. 33 of April 27, 2007).

While its popularity, it faces a challenge, namely, ICZM needs to be more operationalized in order to be a successful management. ICZM requires interdisciplinary approaches (Reis et al., 2014) that involves scientists with various backgrounds and stakeholders working together to tackle with ill-defined problems, results in facing difficulties associated with lack of coordination among participants, uncertainty, jargon, conflicts among different disciplines and methodologies (Reis et al., 2014). Among scientific information used for ICZM, most of the existing best practices for ICZM underline the importance of indicators (Maccarrone et al., 2014). At the same time, however, the current ICZM indicators have several shortcomings. For example, Maccarrone et al. (2014) raised four principal shortcomings: they are difficult to "(a) understand fully the interaction between the coastal ecosystems and the socio-economic system, (b) translate the research outcomes into useful management information for evaluating the responses to previously adopted actions, (c) line up the indicators with the ICZM objectives, (d) more available and homogeneity of the indicators set."

In response to these shortcomings, we propose an operational framework for sustainability assessment, which particularly put emphasis on stocks (capital assets), the desirable state of coastal zones, and linkages between human well-being and ecosystems. "Operational" refers to being readily useful and effective for ICZM to attain and sustain the desirable coastal zone's state.

Our framework is based on the three distinct concepts: Inclusive Wealth (IW) (Pearson et al., 2013), Satoumi (Yanagi, 2008), and ecosystem services approach (Gómez-Baggethun et al., 2010). IW is a stock based sustainability indicator. Since what ICZM can manage or change are in general stocks (e.g., ecosystems) rather than flows benefited from them (e.g., provisioning services and cultural services), an indicator should monitor the state of stocks. In addition, stocks tell the future flows of ecosystem services. Satoumi, a Japanese traditional concept of how a coastal zone should be, may help us to establish the desirable state of the coastal zone. Ecosystem services tell us what ecosystems we need in order to enjoy certain ecosystem services.

Although our purpose of the paper is to present a general operational framework which can be tailored and adopted by other areas, we pick a case of Japan. There are two reasons for it. First, there is a paucity of Japanese cases published in journals in English (Liquete et al. (2013) for a review). Second, Japanese case provides a unique case and it could be instructive for other areas in the future. While coastal zones in Europe and United States are under pressures such as development and population growth, Japanese coastal zones face shrinking population resulted in the decline in ecosystem services after the destruction of the areas during economic growth in 1960's and 70's.

In this paper, we present indicators based on the framework but do not complete the whole process such as computation of shadow prices. It is a tall order for sure and it will be a long endeavour. Rather than waiting for its completion, we propose the conceptual framework and discuss the future directions of the research to invite other researchers.

The rest of paper is organized as follows. The second section discuss the need for an operational sustainability assessment framework for ICZM. The third section proposes the framework with the detailed discussion on the three concepts which comprise the framework. The fourth section applies the framework to Seto Inland Sea. And the last section concludes with further research topics to complete the implementation of the framework.

2 Motivations: Need for an operational sustainability assessment framework for ICZM

There are at least four attributes for an indicator to be useful for ICZM. First, an indicator should have a long-term perspective. The impact of ICZM may not take effect in short-term but rather long-term as it involves changes to ecosystems. We want to attain and sustain a desirable state of coastal zones not only for the current generation but also for generations to come. Second, an indicator needs to takes into account social and ecological systems as an integrated system (The Japanese Basic Act on Ocean Policy). ICZM deals with not only coasts but also surrounding land areas as they are highly interrelated. Third, an indicator should reflect an appropriate system boundary. Fourth, an indicator should be a readily useful input for ICZM. It should tell how ICZM should be implemented. For example, an indicator should tell the target to manage (e.g., size and type of ecosystems) and desired states to attain or sustain. Changes to ecosystems made by ICZM should result in a change toward the desirable states which increases human-welfare.

3 Proposed framework

We propose a framework which meets the four criteria by combining three concepts: IW, Satoumi, and ES approach. Our novelty is to combine the three separately developed concepts which complement each other and contribute to the production of useful information for ICZM.

3.1 Inclusive wealth: A sustainable indicator

Sustainability indicators in general meet the first two criteria: the long-term view and an integrated system approach. For example, Researchers doing Integrated Coastal Zone Management (ICZM) usually compose their indicator sets based on well-known sustainability principle, i.e., “triple bottom line approach” (environmental, economic and social aspects) (NOAA (2010); SUSTAIN (2012)). In addition, “Most of the existing best practice for ICZM underlines the importance of developing indicators and promoting their use” (Maccarrone et al., 2014).

Among various sustainability indicators, we adopt IW for its fitness into our purpose. IW is a sustainable development measure that “represents the summation of the real social values of all capital assets–human, manufactured, and natural–in a particular region“(Pearson et al., 2013). The value of IW at time t is derived by the following formula.

$$V_t = \sum_i (p_{it} \times K_{it})$$

Where K_{it} is the number of stock *i* at time *t*, and p_{it} is corresponding shadow price.

Particularly there are two strengths with IW: a stock-based measure and its direct treatment of human-welfare via shadow prices for each stock.

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First, what ICZM can directly target at is stocks (e.g., state of ecosystems) rather than their benefits (e.g., provisioning, regulating, and cultural services). While we value flows obtained from coastal areas (e.g., fish catch, carbon sequestration per year, and the number of visits to a beach per year), the past flows do not guarantee that we can enjoy the same amount of the flows. In addition, and more importantly in view of ICZM, since the future flows depend on the stocks, which are called productive base (Boyd, 2007), what ICZM can change is the stocks. ICZM, for example, may sustain or improve a state of ecosystems (i.e., stocks) in order to sustain the benefits (i.e., flows) we can enjoy from them. Flows (i.e., ecosystem services) are a social construct as we discuss in a later section.

Second, since IW employs shadow prices (or true values) of the stocks, it can evaluate ecosystems in a positive manner. We believe this is not a subtle issue. For example, in NOAA (2010) and SUSTAIN (2012), environment, economy and society should progress in harmony, especially the development of latter two should not be at the sacrifice of environment. Therefore, using indicators to monitor the degradation of environment is always emphasized in order to keep the environment unharmed. Nevertheless, the efficient marine management requires not only protecting nature but also perusing human welfare of coastal zone through exploiting biodiversity. Hence, finding the balance between conservation and utilization is of vital importance. To capture the value of ecosystem or environment, we need to value it rather than try not to degrade it. While the former includes an assessment to attain a desirable and better state, the latter seems to try to sustain the current state. However, ICZM is not only aimed at maintaining a current state. Rather, like our case in Japan, coastal zones have been degraded and what is needed to attain some desirable state. With the use of shadow prices, we can value ecosystems rather than monitor not to harm them.

However, IW is not without drawbacks which are also shared by other sustainability indicators. First, the criteria for indicator system establishment has not been well mentioned. Instead, only in certain cases the functions or meanings of specific indicators were roughly explained (Yuan et al., 2003). Second, IW does not provide a clear guidance about the system boundary. The system boundary (i.e., how large area we include for the assessment) is not a simple issue especially for a regional level sustainability assessment (Bell and Morse, 2008). A region may heavily depend on other surrounding areas. In addition social, economic, political, administrative, and ecological boundaries may not be identical. Third, it does not tell a desired state of a coastal zone. Since there are trade-offs between the use of coastal zones (e.g., fishery vs. recreational use), we need a clear guidance to decide the goal.

3.2 Satoumi

Satoumi contributes to the construction of an operational framework for sustainability assessment of coastal zones in different ways from IW and ecosystem services approaches, leading to corroborate the framework. Satoumi is a multi-faceted concept. Yanagi (2008), who originally proposed the concept, defines Satoumi as “the coastal areas where human interaction has resulted in a higher degree of productivity and biodiversity”. Broadly speaking, Satoumi can be defined as the traditional coastal zone management regimes in Japan (Duraiappah, 2012). Hence Satoumi provides us with the traditional wisdoms of how to manage the coastal zones.[1] In addition and more importantly, Satoumi tells us the state of the coastal zone which the local community desires (Berque and Matsuda, 2013). Since the states of coastal zones are not necessarily what we want to sustain, what we need is to a clear guidance for the desired state to attain. IW and ecosystem services approaches do not provide the clear guidance. Satoumi provides such “value systems” that refer to “intrapsychic constellations of norms and precepts that

[1] Although Satoumi is the Japanese concept, Henocque (2013) pointed out that is a form of adaptive co-management which is proposed by Folke et al. (2002).

guide human judgment action" (Farber et al., 2002). Although IW tells us how we have done and where we are going, it does not tell us if this is the direction we want to go. Ecosystem services approaches have not provided such knowledge (Abson et al., 2014) as well.

As it provides a desired state of coastal zones, it can help us determine what ecosystem services we want to sustain and/or increase. For example, some areas in the Seto inland sea want to sustain oyster production; others may want to promote sports fishing; or maintain the balance between the two.

In sum, IW provides a technical framework for computing sustainability using stocks and their shadow prices; Satoumi provides a desired state of coastal zones with ecosystem services of the community's interest, and management wisdoms. So what else do we need? We need science which can link Satoumi concept to IW. Satoumi is rich but is the traditional knowledge rather than scientific knowledge. Therefore, although Satoumi can tell us what ecosystem services we want to attain and/or sustain, we do not know what stocks (e.g., seagrass bed and mudflat) we need to keep and what extent (e.g., areas and qualities). The traditional knowledge is rich and some cases more precise than science but science could provide useful knowledge especially when a coastal zone has changed and the traditional knowledge cannot fully adapt to such change at a sufficient speed. The Seto inland sea faces such drastic social-ecological changes as shrinking population and degradation of ecosystems.

3.3 Ecosystem Services Science

Ecosystem services (ESs) science has been gaining larger interests both in academics and policy arenas. Abson et al. (2014) reported that the exponential growth of literature on ecosystem services. Matzdorf and Meyer (2014) evaluated the ESs based approaches taken in EU and the US and proposed an ideal ES-driven policy. Based on the ecosystem services framework proposed by the Millennium Ecosystem Assessment (Assessment, 2005), UK National Ecosystem Assessment (NEA, 2011) was conducted and it includes coastal and marine ecosystem assessment.

There are two major contributions of ESs science for our purpose: reflection of the ESs' contribution to human well-being and scientific knowledge for liking ecosystems and human well-being.

In sustainability indicators, environmental aspects are often captured as something should be kept unharmed (e.g., water quality and pollution level). So the basic epistemological standpoint is environment is something not damaged rather than something contributing to our human well-being. ESs science explicitly deals with ecosystems' contribution to human well-being. ESs can be defined as "the goods and services provided by ecosystems that generate benefits to people." (Granek et al., 2010).

More importantly, it provides and strives to provide scientific knowledge for linking ecosystems and human well-being. Among various conceptual frameworks, a cascade model demonstrates the relationship well. Mononen et al. (2015) proposed a cascade model to construct national ecosystem services indicators for Finland in Figure 1.

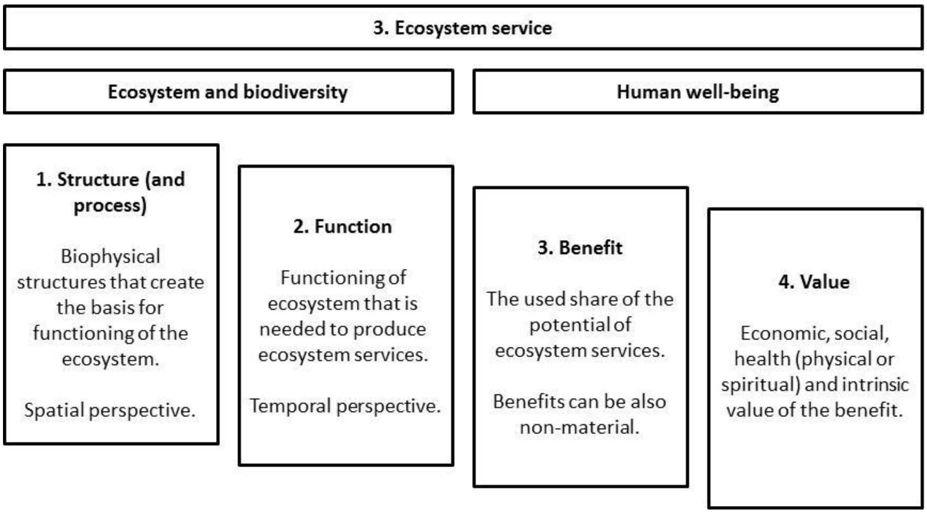

Fig. 1. Cascade model with integrated ecosystem services indicators. Adapted from Mononen et al. (2015).

Employing various disciplines, ESs science strives to provide for each process and within and across interactions. To conduct ICZM effectively, it is not enough simply to keep the structure (or stocks) of ecosystems as they are since it does not necessarily provide desired ESs at their desired amount. To understand what benefits we want is also not enough since it does not tell what structure leads to what benefits. Hence we need knowledge of the whole paths 1. Structure through 4. Value. For example UK NEA identified the structure, processes, ecosystem services and goods and benefits of coastal and marine ecosystems (Turner, 2014). Mononen et al. (2015) identified indicators for Finland.

So can ESs indicators be an alternative to sustainability indicators? Given the current study of ESs, we do not think so. First, ESs do not provide explicit criteria for the indicator selections. Mononen et al. (2015) employed expert group meetings and stakeholder consultation workshops to select indicators. However, as they admit the need for the establishment of more transparent criteria for determining important ecosystem services.

More importantly, indicators in ESs science are focused on ecosystems. Although scholars are aware of the importance of other capital assets to provide ESs (Mononen et al. (2015); Turner (2014)), it is rare that capital assets other than ecosystem structures are listed. In view of the sustainability of coastal zones which are surrounded and interrelated with social-economic systems, man-made capital and human capital are equally important. These forms of capital are non-negligible. For example, some areas in Seto-inland Sea face shrinking population. Without fishermen, we cannot enjoy fish. Fish cannot come to our table without fishermen, transportation etc. ESs are a joint production of ecosystems, man-made capital, and human capital (Costanza et al., 2014).

4 Case study—Seto Inland Sea

4.1 Study Area

Seto Inland Sea, around 20,000km2 with the length of 450 km from east to west and width of 15 to 55 km from south to north, is surrounded by the three main islands of Japan, i.e., Honshu, Shikoku and Kyushu islands. There are around 3,000 islands located in Seto Inland Sea (Figure 2).

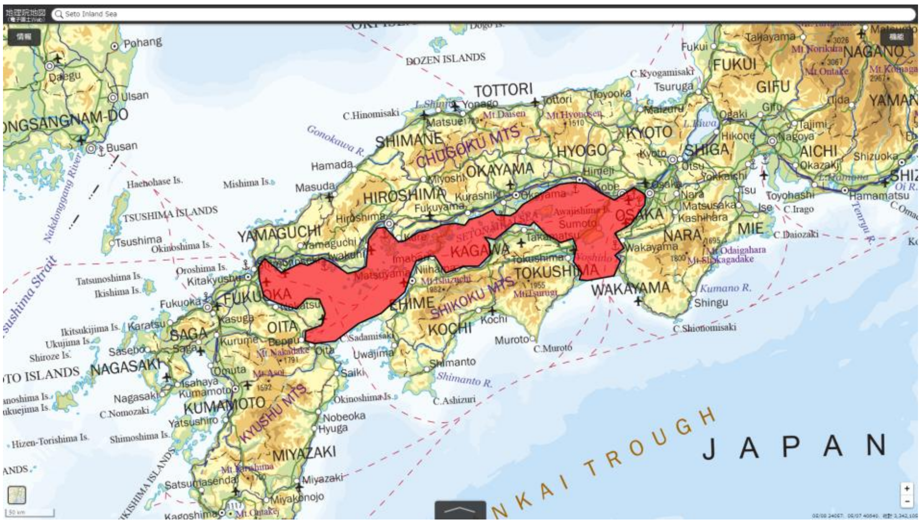

Fig. 2. Seto Inland Sea (in red).

Over centuries, it was regarded as the main transportation route between its coastal areas and foreign countries, resulting the establishment of many ports along the coastline. Since the construction of railway in 20th century, the importance of Seto Inland Sea as transportation route decreased. Even so, it still serves as line for international or domestic cargo transportation and local transportation. Several important industrial cities, e.g., Osaka, Kobe, Hiroshima, owned the coastline of Seto Inland Sea. These cities are famous for the industries of ship construction, steel production, oil refining and oil-derived production. There are about 30 million people (1/4 of Japanese population) living in the coastal area of Seto Inland Sea.

Besides, this area is considered as the production base of Japan because it is rich of fishery products (more than 500 species of fauna) and salt, especially production of oyster in Hiroshima Bay (Assessment (2010); Yanagi (2008)). The annual fish catch from the Seto Inland Sea in the early 2000's is around 500,000 tones, 10% of its national figure. It decompose the ratio of total fish to total aqua farming approximately at 2:3. (Matsuda, 2012). Compared among four other closed seas (Chesapeake Bay, North Sea, Baltic Sea, and Mediterranean Sea) based on the data of 80's and 90's, Seto Inland Sea shows much larger fish catch (wet-weight-ton/year/km2) (Matsuda, 2012). The reason for this high productivity of fishery is three fold (Uye, 2007). Topographic patterns consisted by large and small bays (called "Nada" and "Wan" in Japanese) generate tranquil environment for phytoplankton growth and upwelling circulation of water for nutrient provision. The Sea shows relatively high primary productivity of lower trophic organisms and high transfer efficiency from phytoplankton to zooplankton. Finally, the ecotone consisted of tidal flat, seaweed beds and shallow coastal sea provides diverse habitats.

With the moderate climate and beautiful scenery, it is also known as the most famous tourist site of Japan. One of the oldest national parks of Japan, Setonaikai National Park, was constructed along its coast. Besides, there are several literatures were created by using some sites in Seto Inland Sea as the source of inspiration.

After Second World War, due to the uncontrolled development of industry, this area has gone through devastating pollution and dramatic decrease of productivity and biodiversity, e.g., red tidal, diminishing of area of seaweed beds and tidal flats (Takeoka, 2002). The area of landfill in the Seto Inland Sea becomes 455 km2 since 1898, with the largest loss 225km2 between 1950-1973, though the reclamation area rapidly decreased after issuance of "Seto Inland Sea Law" in 1973 (Matsuda, 2012). The area of tidal flat in 1978 becomes half of one in 1898. The area of seaweed bed in 1971 also becomes one fourth of one in 1898 (Uye, 2007). The number of occurrences of red tides is around 100 in 2000's, though the number decreases by one third of 1970's with strict nutrient control after law issuance in 1973 (Matsuda, 2012). In addition, sand collecting mainly used for concrete construction made severe impacts such as coastline erosion, land subsidence, loss of seaweed beds, modified currents. Collected sand volume since 1968 to 1999 becomes 730 million m3 in 4 main prefectures (Matsuda, 2012). As of 2015, the collecting sea sand is prohibited. These deterioration of fish production environment, population aging, and decrease of fish consumption rate result in dramatic decrease of the number of fishermen and fishery management entities (Uye, 2007). The number of fishery management entities in 2013 (15,867) decreases by 18% of 2008 (Ministry of Agriculture Forestry and Fisheries, 2014). As people's awareness of environmental conservation is gradually evoked, the situation keeps on improving.

4.2 Criteria for indicator system establishment

Since the concept of sustainable development came out in Brundtland Report (Brundtland, 1987), new definitions have been continuously proposed, and the measurement of sustainability has been widely carried out (Liverman et al. (1988); Palmer et al. (2005); Singh et al. (2012)). Up to now, physical indicators method (Singh et al., 2012) is one of the most extensively accepted methods to evaluate the sustainability of an object or a region/area and make suitable recommendations for policy-making and development strategy (Booth et al. (2013); Hanson (2003); Henocque (2003)). However, the criteria for indicator system establishment has not been well mentioned. Instead, only in certain cases the functions or meanings of specific indicators were roughly explained (Yuan et al., 2003). As a result, the available indicator systems are not operational when they are applied to other specific context.

Researchers doing Integrated Coastal Zone Management (ICZM) usually compose their indicator sets based on well-known sustainability principle, i.e., "triple bottom line approach" (environmental, economic and social aspects) (NOAA (2010); SUSTAIN (2012)). In their opinion, environment, economy and society should progress in harmony, especially the development of latter two should not be at the sacrifice of environment. Therefore, using indicators to monitor the degradation of environment is always emphasized in order to keep the environment unharmed. Nevertheless, the efficient marine management requires not only protecting nature but also perusing human welfare of coastal zone through exploiting biodiversity. Hence, finding the balance between conservation and utilization is of vital importance. Accordingly, an innovative concept - Satoumi - was proposed by a Japanese researcher, which refers to "the coastal areas where human interaction has resulted in a higher degree of productivity and biodiversity" (Yanagi, 2008). The coastal area also features a smooth, stable and sustainable material circulation among forest, lake, river and sea. Toward the realization of Satoumi, people are able to obtain the fertile natural resources from well regulated environments. In addition, they can enjoy the cultural services of coastal zone ecosystems, e.g., sense of identity, tourism and recreation.

Apparently, the core of Satoumi is the positive link between ecosystem services of coastal zone and human well-being (Berque and Matsuda, 2013). Unfortunately, people's quest for ecosystem services has rarely been reflected in the conventional sustainability assessment for ICZM.

4.3 Indicator selection

In this study, the criteria for indicator system establishment included the components of ecosystem services, the concept of Satoumi, the indicator attribute (stock), and the characteristics of the target area (Seto Inland Sea). In terms of the selection and design of indicators, several literatures were used as important references as well (Böhnke-Henrichs et al. (2013); Hattam et al. (2015); Assessment (2010); Turner (2014)). The two-step process is illustrated in Figure 3. The first step is indicator selection. In order to give practical guidance for ICZM, stock-indicators were selected, which can be further computed through IW method to measure sustainability of a designated region. Thus, principles for indicator selection involved in IW method were applied to identify critical capital stocks, i.e., "(i) underpin the production of key goods and services (flows) in the region and (ii) are likely to change or (iii) have possible alternate states with significant different consequences for goods and services" (Pearson et al., 2013). The desired state described by Satoumi, i.e., what ecosystem services we can enjoy, was also taken into account during indicator selection. According to the opinions held by van Oudenhoven et al. (2012) and Mononen et al. (2015), the selected indicators should be able to reflect ecosystem property, function, and service. Furthermore, the indicators must be tailored to fit Seto Inland Sea specifically, by considering the fact that this target area is one of the country's most important sea food production bases and tourist sites, and the industrial sector in that region once resulted in devastating environmental pollution (Takeoka, 2002). Then in the second step, these stock-indicators were classified into human capital, manufactured capital and natural capital, for the convenience of further operation of IW method.

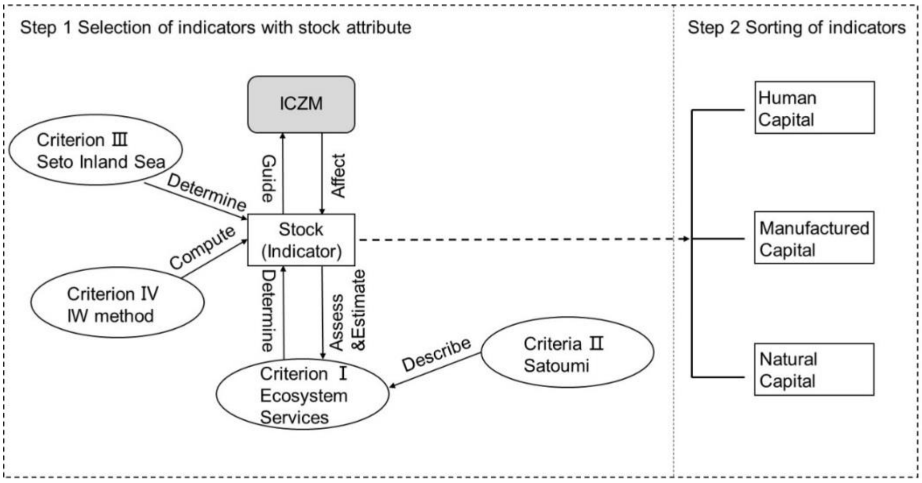

Fig. 3. Process of indicator system establishment.

The result of step 1 and step 2 are presented in Table 1 and Table 2, respectively. Regarding the selection of certain specific indicators, detailed explanations and instructions are made as follows. In terms of provisioning service, "stock of fish" was first picked up, because fishery is one of the main industries in Seto Inland Sea. In addition, indicators like "stock of fishing boat", "stock of fishing gear" and "number of fishermen" were selected, as these are indispensable elements supporting the fishery and thus the provisioning service. Besides, as the most representative sea food of Hiroshima Prefecture, oyster was selected to reflect provisioning service. In fact, "stock of oyster" also indicates the regulating service associated with environmental quality, as oysters work as filter for suspended solids originating from neighboring land (Matsuda, 2007). Apparently, an indicator can tell more than one aspect of ecosystem service. Similarly, when areas of "seaweed beds" and "tidal flats" were selected, both their regulating service as nursery for creatures (Hattam et al., 2015) and supporting service as purifier for water-borne pollutants (nitrogen, phosphorous, etc.) were taken into consideration. Regarding cultural service, it comprises both recreation function and cognition function. Therefore, "number of national parks" and "area of beach for bathing" were selected to display the level of its tourism development, and "number of people and NGOs working for Seto Inland Sea conservation" and "Stock of habitats and places for the purpose of monitoring environment and studying" were selected to reflect the local research and education level. With respect to supporting service, indicators like "number of riverway" and "area of vertical revetment" were regarded as key factors ensuring the smooth and sustainable material circulation of Satoumi (Ministry of the Environment, 2015).

Table 1. Indicators (stocks) selection based on ecosystem service described in Satoumi and characteristics of Seto Inland Sea.

Criterion I (Ecosystem services)	**Criterion Ⅱ (Concept of Satoumi)**	**Criterion Ⅲ (Characteristics of Seto Inland Sea)**	**Criterion Ⅳ (IW method) Indicators**	**Justification of indicator selection**
Provisioning services	Food (Marine fishery, Maricultures) productivity and biodiversity	Plankton	• Stock of plankton • Number of species of plankton	Plankton provides food for other fauna in water. Besides, it reflects marine environment conditions.
		Fish	• Stock of fish. E.g., ayu, amphidromous fish, finless porpoise, great white shark. • Stock of jellyfish • Stock of fishing boat • Stock of fishing gear • Number of fishmen • Number of fishmen (age<60) • Number and Area of "no fishing" zone	Fishery is the main industry in Seto Inland Sea. This place provides high amount of fish compared with other similar type of enclosed sea, e.g., Mediterranean Sea, Baltic Sea, North Sea. Jellyfish is considered as main competitor to fish for food. Fishmen are the main participants of fishery.

				Fishmen at young ages are the successors of fishery. "No fishing" zone indicates preservation of marine life and biodiversity.
		Demersal fish	• Stock of Demersal fish (clams, shrimp, crab)	It reflect food production of demersal fish.
		Oyster	• Stock of oyster	Oyster farming is very famous in Hiroshima. It can also reflect environment conditions.
		Salt	• Stock of salt	Salt is an important staple in Seto Inland Sea.
	Biotic raw materials provisioning	Living organisms in coast	• Stock of living organisms. E.g., sandeels, waterfowl.	It indicates sustainability of food chain of coastal organisms.
		Raw materials for genetic resources, medicinal resources, ornamental resources.	• Stock of genetic material from marine flora and fauna • Stock of material for medicinal benefits • Stock of material for decoration,	It reflects productivity of non-food materials for human-beings.

			fashion, handicrafts, souvenirs, etc.	
Regulating services	Air quality regulation	Air quality regulation	• Concentration of NOx, SOx	It represents air quality of the area.
	Water environment	Nutrient (N, P) removal; Water environment	• Area of seaweed beds • Area of low oxygen water and anoxic water; • Amount of sulfide	Seaweed bed and tidal flats are considered as a filter or buffer area and play an important role in purifying water quality. Decrease of these areas reflect deterioration of coastal area. Area of low oxygen water and anoxic water as well as amount of sulfide reflect adverse living environment.
	Climate control	Carbon dioxide fixation	• Area of tidal flats	
	Regulating flux of greenhouse gas	Coastal area	• Area of sediment	Sediment conducts carbon turnover.
	Water flow	Water flow	• Total Length of shoreline	It reflects impact of water flow and erosion of beach.
	Waste treatment and assimilation	Waste treatment and assimilation	• Amount of waste; • Poisonous substance (heavy	All of them reflect contamination of coast. PCB and dioxin are

			metals, dioxins, PCB); • Stock of sensitive species. • Number of industrial factory in coast	main poisonous substance.
Cultural services	Cultural heritage	Scenic area	• Number of national parks	National parks, beach for bathing, place for worship and people organizing festivals reflect the benefit for human beings.
	Sense of identity	Spiritual benefit	• Area of beach for bathing; Area of places for worship (shrines, temples) • Number of people organizing festivals	
	Recreation	Tourism	• Hotel rooms in coast	It reflects the capacity of area to accommodate tourists.
		Education (field trips, field observation and environmental education	• Number of people and NGOs working for Seto Inland Sea conservation	Environmental education leads to people's awareness and concern of nature and its conservation.
			• Stock of habitats and places for the purpose of monitoring environment and studying	
			• Number of children in coastal area	Children's activities in nature reflect interaction between human and

				nature.
			• Number of researchers doing study on coast	It reflect information for cognitive development.
			• Number of school; • Number of museum for the purpose of broadcasting nature conservation	They reflect the education degree of people in coastal area.
	Art	Traditional crafts	• Number of craftsmen	The number of people involved in the activity reflect cultural service that people can enjoy.
		Contemporary art	• Number of professionals	
Supporting services	Water circulation	Water circulation	• Number of riverway, • Number of deep channel, Number of artificial beaches • Area of vertical revetment • Area of slope revetment • Area of revetment made of stone • Area of forest • Area of paddy field • Length of pipe	These habitats support ecosystem functions and services Slope revetment and stone revetment are good for material cycle. Forest, paddy field and pipe reflect circulation of material from land to sea.
	Life cycle maintenance	Migratory and nursery	• Area of seagrass,	They reflect the

	and gene pool protection	habitat	• Area of kelp beds • Abundance of species using the area for nursery	usage of habitat for nursery and reproduction.

Table 2. Indicators sorted by capitals.

Capital	Stocks	Unit
Human capital	• Number of fishmen	person
	• Number of fishmen (age<60)	person
	• Number of people working for Seto Inland Sea conservation	person
	• Number of children in coastal area	person
	• Number of craftsmen	person
	• Number of professionals	person
	• Number of people organizing festival	person
	• Number of researchers doing studies on coast	person
Manufactured capital	• Stock of fishing boat	boat
	• Stock of fishing gear	gear
	• Number of industrial factory in coast	factory
	• Number of national parks	park
	• Area of places for worship (shrines, temples)	ha
	• Hotel rooms in coast	room
	• Stock of habitats and places for the purpose of monitoring environment and studying	habitat
	• Number of school	school
	• Number of museum for the purpose of broadcasting nature conservation	museum
	• Number of riverway,	riverway
	• Number of deep channel, Number of artificial beaches	channel, beach
	• Area of vertical revetment	revetment
	• Area of slope revetment	revetment
	• Area of revetment made of stone	revetment
	• Length of pipe	km
	• Number and Area of “no fishing” zone	ha
Natural capital	• Stock of plankton • Number of species of plankton	plankton
	• Stocks of fish. E.g., ayu, amphidromous fish, finless porpoise, great white shark	fish

	• Stock of jellyfish	jellyfish
	• Stocks of Demersal fish (clams, shrimp, crab)	fish
	• Stock of oyster	oyster
	• Stock of salt	ton
	• Stocks of living organisms. E.g., sandeels, waterfowl.	living organism
	• Stocks of genetic material from marine flora and fauna	Genetic material
	• Stocks of material for decoration, fashion, handicrafts, souvenirs, etc.	material
	• Stocks of material for medicinal benefits;	material
	• Concentration of NOx, SOx	mg/L
	• Area of seaweed beds	ha
	• Area of low oxygen water and anoxic water	ha
	• Amount of sulfide	kg
	• Area of tidal flats	ha
	• Area of sediment	ha
	• Total Length of shoreline	km
	• Amount of waste	kg
	• Poisonous substance (heavy metals, dioxins, PCB)	kg
	• Stocks of sensitive species	species
	• Area of beach for bathing	ha
	• Area of forest	ha
	• Area of paddy field	ha
	• Area of kelp beds	ha
	• Abundance of species using the area for nursery	species

5 Conclusion and further research topics for implementing the framework

This study proposed a novel operational sustainable assessment framework for integrated coastal zone management (ICZM) at a regional scale by applying it to Seto inland sea, Japan. It is a combination of three separated developed concepts: IW, Satoumi, and ES science. IW is a technical base for creating sustainability indicators and is a stock-based assessment technique. Satoumi is the Japanese traditional knowledge and concept for coastal zone management and connotes multiple implications. ES science provides scientific knowledge which connects ecosystems to human well-being. With the combination, we believe that the framework could provide readily useful knowledge for a regional level ICZM in order to attain and sustain a desirable state of a coastal zone.

To fully implement the framework effectively, there are at least three research topics we need to further pursue.

System boundary is non-negligible issue especially for a regional level sustainability assessment (Bell and Morse, 2008). In practical sense, administrative boundary could be used as NOAA uses county level and/or state level boundary. However, it is not so simple. A region is an open system in which it relies on other regions. Even if the region depleted all the natural resources, it can import. Shrinking population may not be an issue if people commute to the region. It is also a challenge to set an ecological system boundary. The mobility of ES may cross the ecological system boundary. Fish, for example, are often consumed people far from the region. When a novel payment system such as payments for ecosystem services (PES) is introduced, it is important to take into account beneficiaries in addition to the suppliers. Management will add further complications to the system boundary issue. Because of the complex and spatially expansive nature of ICZM, the community involvement may not enough. In addition to local government, a national or even higher level involvement could be required (Cummins and McKenna, 2010).

To calculate shadow prices requires further work. This is not just about finding right prices but also requires theoretical discussion to estimate them. The complication is that ES is a joint production of social-ecological system; all the benefits may not be attributed to the ecosystem. Fish prices include contributions from other stocks. For example, the maintaining fish stock does not necessarily provide a larger amount of fish. To catch fish, fishermen with man-made capital such as boats are essential and the fishermen population has been declining to a great degree in Japan.

What further complicates the sustainability assessment of coastal zones is the non-convexity of ecosystems (Dasgupta and Mäler, 2004). Ecosystems may behave in non-linear way because of its non-convexity. For example, because of the existence of a threshold in an ecosystem, the system behaves in totally a different manner. For example, under a certain level of fish, they may not be able to sustain their population and go to extinct. Further, because of the interaction between ecosystems and economic systems, the dynamics become much more complex (e.g., Uehara (2013)). Therefore it is important to understand how stocks (i.e., natural, man-made, human capital) behave dynamically rather than simply adopting the projections of the past trends. System dynamics, a computational approach to nonlinear dynamical system (Sterman, 2000) could be an approach to this issue.

Acknowledgments

We would like to thank Dr. Yanagi at International Center for Environmental Management of Enclosed Coastal Seas, and Prof. Nakagami, Prof. Obata, and Dr. Yoshioka at Ritsumeikan University for their valuable comments. Our study was funded by the Japanese Ministry of the Environment.

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