

An adaptive social-ecological system management matrix for guiding ecosystem service improvements

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ABSTRACT

Social-ecological system (SES) management requires targets to move in a desirable direction. However, setting targets at the outset of a management program is challenging. People representing the demand side are not always aware of the benefits of nature that are desirable. Simultaneously, managers—who represent the supply side—have limited scientific information. Therefore, we propose an adaptive SES management matrix (ASESMM) using soft targets that are temporary and hypothetical because such targets cannot be fixed at the outset. By compiling both demand- and supply-side perspectives, the ASESMM helps managers choose feasible and desirable management practices. Ecosystem services' (ESs) classifications were adopted to capture the benefits and used as soft targets that can change over time. This ASESMM was developed by applying it to a Japanese coastal zone in consultation with the relevant stakeholders to maintain its practical value. A narrative analysis substantiated the lack of peoples' recognition of nature's benefits and the influence of ES information on that recognition. It also substantiated the comprehensiveness of the ESs' classifications. Moreover, the application revealed its usefulness for realizing *satoumi*, a Japanese concept of social-ecological production seascapes, as it might help managers enhance synergies as well as minimize the trade-offs associated with prioritized ESs. Although it was applied to a seascape in this study, the ASESMM can be applied to any SES management site in general, including landscapes.

1. Introduction

The social-ecological systems (SESs) perspective, of which human–nature interactions are an integral part, has gained increasing attention because it could lead to the sustainable use and conservation of nature (Berkes and Folke, 1998; de Groot et al., 2010; Folke et al., 2005). The term “social-ecological production landscapes and seascapes” (SEPLS) has been coined to refer to SESs wherein human–nature interactions succeed in maintaining sustainable ecosystem use and biodiversity conservation (Gu and Subramanian, 2014; UNU-IAS et al., 2014). Sound SES management is key to SEPLS and providing various ecosystem services (ESs); it provides multiple benefits while conserving nature (Arias-Arévalo et al., 2018; Bastian et al., 2013; Costanza et al., 2014; Reyers et al., 2013).

Articulating management targets is a prerequisite for sound SES

management guidance (Abson et al., 2014; Uehara et al., 2016; Uehara and Mineo, 2017). A “rule of thumb” such as “the more ES, the better” cannot always be adopted because maximizing ESs is not always desirable (Schröter et al., 2017) for both demand- and supply-side reasons. First, ESs are not equally demanded or desired. Each individual may have different preferences for ESs (Arias-Arévalo et al., 2017; Uehara et al., 2019b), and the demand for some ESs is not always beyond the current supply (Cord et al., 2017). Such preferences may also change over time (Skourtos et al., 2010; Uehara et al., 2018). Second, it is not always possible to supply ESs that meet peoples' demands because of trade-offs between ESs (Cord et al., 2017; Ellis et al., 2019; Wright et al., 2017) and the feasibility of supplying them owing to, for example, budget, time, and human resource constraints. Thus, it is critical to set management targets by understanding what is “desired,” articulating what is “desirable,” and reflecting what is desired (demand side) and what is feasible (supply side).

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Nomenclature

ASESMM	Adaptive social-ecological system management matrix
BIBD	Balanced incomplete block design
BWS	Best–worst scaling
ES	Ecosystem service
SEPLS	Social-ecological production landscapes and seascapes
SES	Social-ecological system
SI	Supplementary information

Although such normative information is undoubtedly essential, research that explicitly engages with normative issues remains scarce (Abson et al., 2014; Schröter et al., 2017). Abson et al. (2014) noted that there were no accepted normative frameworks in the literature. Schröter et al. (2017) formulated a concept of sufficiency to increase the potential risk of an implicit assumption that maximizing ESs is deemed “good.” Uehara et al. (2016) and Uehara and Mineo (2017) proposed the *satoumi* concept as a desired state of SEPLS. *Satoumi* is a Japanese word that captures the SEPLS concept in which active human–nature interactions enhance the productivity and biodiversity of seascapes (Uehara et al., 2019a). However, none of these authors presented an operational framework upon which management targets could be based.

However, in reality, it is challenging—if not impossible—to articulate fixed targets at the outset, which is complicated by ignorance and dynamics. It is difficult to say that, for example, a 20% increase in the area of seagrass beds is optimal as it meets residents’ demand for ESs. There are at least four reasons for this difficulty. First, peoples’ recognition of the types of ESs that they receive and what ESs they desire may be inaccurate (Avelino et al., 2019; Costanza, 2015). Second, ESs’ knowledge is limited because ESs are products of complex SES (Blythe et al., 2019; Boerema et al., 2016; Mehring et al., 2018). As demonstrated herein, ES information does not meet the demand of practicality despite being conceptually well developed (Wright et al., 2017). Third, peoples’ preferences may change over time; the same is true for targets (Blythe et al., 2019; Folke et al., 2010; Uehara et al., 2018). Lastly, ESs’ supply often changes over time owing to the dynamic nature of the SES as a complex, adaptive system (Holland, 1992; Schlüter et al., 2014). This fact might also influence demand (Mehring et al., 2018).

Given the importance of articulated management targets and the initial difficulties in setting them, we adopt the soft targets inspired by Norton (2015). Soft targets are temporal, hypothetical, and not pre-determined. In the complex dynamics of an SES, targets may change over time as an SES is learned through iterative testing, monitoring, and reevaluation (Folke et al., 2005). This calls for an adaptive or incremental learning strategy (“Adapt”) instead of an optimization strategy (or “Optim”) (Norton, 2015).

An approach to elicit soft targets should be instrumental to encourage its adoption by practitioners. It should provide information on its instrumental use in concrete management decisions rather than conceptual or strategic uses (Wright et al., 2017). However, few studies exist on instrumental use (Wright et al., 2017) and the rapid advancement of ES science and its potential, mainstreaming, and use in decision-making remain a challenge (Chaudhary et al., 2015; Potschin-Young et al., 2018). The approach should be accessible enough for use with all science-based management decisions and limited local technical capacities (Ruckelshaus et al., 2015).

This study aimed to develop an instrumental management tool with which soft management targets can be identified. Accordingly, we developed an adaptive social-ecological management matrix (ASESMM) that is accessible and can be updated periodically to reflect systemic changes in social-ecological management decisions. We developed the ASESMM by applying it to the Harima Sea, a coastal zone in western Japan, to verify its development and usefulness in practice.

The remainder of this paper is as follows. Section 2 introduces the study site and the ASESMM’s developmental steps. Section 3 reports the results obtained from its application to the study site. Section 4 addresses its management implications and practicality. Finally, Section 5 concludes the paper.

2. Material and methods

We used STATA 16.0 (StataCorp LLC, <http://www.stata.com>) software for all analyses except for the best–worst scaling (BWS), which was calculated using Nlogit 6 (Econometric Software, Inc., <http://www.li.mddep.com/>) and Microsoft Excel.

2.1. Study site

The Harima Sea is part of the Seto Inland Sea, the largest enclosed sea in Japan, with an area of 3,426 square kilometers (km²) and a mean depth of 25.9 meters (m) (Ministry of the Environment Japan, 2019). The Harima Sea is known for its fisheries (e.g., Japanese sand lance (*Ammodytes personatus*)), oysters (*Crassostrea*), and laver (*Pyropia*) aquaculture. However, over the past two decades, the catch has been declining (Ministry of Agriculture, Forestry and Fisheries, 2019). The environment has degraded (e.g., red tides and undesirable levels of chemical oxygen demand) during rapid economic development (Ministry of the Environment Japan, 2019).

In response, the Japanese government enforced the Act on Special Measures concerning the Conservation of the Environment of the Seto Inland Sea in 1973. Its focus was on improving water quality, but the Act was revised in 2015 to also provide diverse values from which people could benefit. It also requires prefectures to design a plan suitable for the characteristics of each sea or bay. Hyogo prefecture enforced an action plan for managing the Harima Sea (Hyogo Prefecture, 2016) that intends to realize *satoumi*, a Japanese concept of SEPLS (Uehara et al., 2019a; Uehara and Mineo, 2017; Yanagi, 2012). However, because *satoumi* refers to a desirable coastal zone state, it is context specific (Uehara and Mineo, 2017); therefore, its general description and management indices are insufficient for managers seeking to implement it. In response to residents’ unfamiliarity with ESs and the dynamic nature of the SES, soft targets tailored to a specific context could assist in creating an action plan for managing the Harima Sea (Hyogo Prefecture, 2016).

2.2. ASESMM

The ASESMM is a matrix that integrates demand- and supply-side perspectives. It helps managers choose ES management practices that meet residents’ preferences while avoiding trade-offs that are critical of the demand-side viewpoint. It has four developmental steps that are iterated periodically to reflect changes in the SES (Fig. 1). Several decision-making support tools share characteristics with the ASESMM. For example, structured decision-making defines objectives and measures and identifies and evaluates alternatives for making choices by integrating diverse stakeholder values in the face of ecological uncertainty (Failing et al., 2013; Guerrero et al., 2017; Martin et al., 2018). However, such tools do not share other key characteristics of the ASESMM, including the notion of soft targets, a comprehensive use of ESs’ classifications, and a combination of supply and demand analyses.

2.2.1. Step 1

Step 1 compiles the key states and benefits obtained from the SES. These ideally concern matters that benefit residents. However, residents are not always fully aware of what they want and actually receive (Costanza, 2015). Moreover, management targets in use may not always comprehensively capture key states and benefits for residents. Therefore, the ASESMM adopts the ES concept (Costanza et al., 2017) to capture these aspects as comprehensively as possible. The ES concept has gradually gained support in the policy arena (Bouwma et al., 2018).

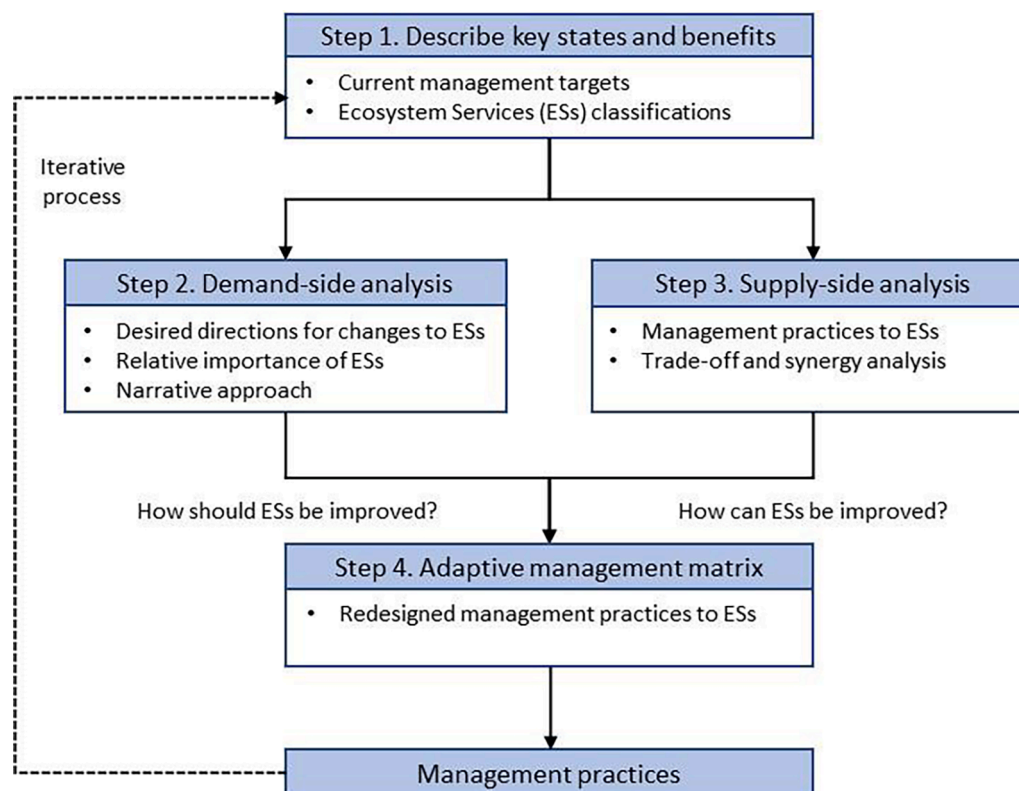


Fig. 1. ASesMM procedure. The ASesMM is expected to be iterated periodically.

Table 1 exhibits a list of marine ESs. We adopted 18 generic marine ESs' classifications (Böhnke-Henrichs et al., 2013; Hattam et al., 2015) to capture the benefits from the Harima Sea. Further, we added the benefit of the “relationship between people and the sea,” given the growing recognition of the importance of relational values (Chan et al., 2018; Uehara et al., 2019a, 2018). This relationship, or human–nature connection, is critical given that human disconnection from nature is a fundamental cause of the current ecological crisis and lack of sustainability (Ives et al., 2017; Restall and Conrad, 2015; Zylstra et al., 2014). Relational values consider the relationship itself as a valuable end rather than as merely a means to an end (Chan et al., 2018). While they can be perceived as a third class of values, adding to previously established constructs of instrumental and intrinsic values (Chan et al., 2016), relational values have been adopted for the valuation of ES (Himes and Muraca, 2018). Relational values may share cultural values with conventional cultural ESs but are not exactly the same (Chan et al., 2018);

relational values differ from cultural ESs listed in generic marine ESs classifications because these treat the relationship as a means to an end. Therefore, relational values offer an expansion of current constructs of cultural ESs (Stålhammar and Thorén, 2019). In this study, relational values were categorized—albeit, not typically—as cultural services (i.e., the “relationship between people and the sea” in Table 1) for the sake of the analysis. We are aware of the debate regarding whether noninstrumental values, such as relational values, are part of ESs (Braat, 2018; Díaz et al., 2018; Stålhammar and Thorén, 2019); however, this concern is beyond the scope of this study, making space for future considerations of relational values being placed in a category that is separate from cultural services. Because we did not present the ES category (Table 1) to the respondents, our choice of categorizing relational values into cultural services did not affect their answers. Another notable point that requires articulation is that while respondents were provided the description of relational values rather than simply asking about “the relationship between people and the sea” (see the Supplementary Information (SI)), it may not sufficiently capture all aspects of the concept of relational values. We intended to explain the distinction between means and ends as it is a core notion of relational values (Chan et al., 2018). Relational values have typically been measured using multiple items to develop a construct based on environmental psychology (Klain et al., 2017; Kleespies and Dierkes, 2020; Schulz and Martin-ortega, 2018; Uehara et al., 2020). However, See et al. (2020) showed that relational values using multiple items are nearly indistinguishable from instrumental values. Therefore, while room to further investigate the measurement of relational values remains, it is certain that the description of relational values requires careful attention to capture the key aspects of the concept in each context.

Moreover, while ESs and benefits such as human wellbeing may not be considered similar, the distinction is not always clear (Blythe et al., 2019). In this analysis, we focused on ESs as a proxy for benefits rather than on the dimensions to which each ES contributes in terms of human wellbeing.

Table 1
Nineteen marine ecosystem services (ESs).

Category of ES	ES Type No.	Type of ES
Provisioning services	1	Food production
	2	Biotic raw materials (non-food)
Regulating services	3	Air purification
	4	Climate regulation
	5	Disturbance prevention or moderation
	6	Regulation of water flows
	7	Waste treatment and assimilation
	8	Coastal erosion prevention
	9	Biological control
Habitat services	10	Migratory and nursery habitat
	11	Gene pool protection
Cultural services	12	Leisure, recreation, and tourism
	13	Aesthetic experience
	14	Inspiration for culture, art, and design
	15	Cultural heritage
	16	Cultural diversity
	17	Spiritual experience
	18	Information for cognitive development
	19	Relationship between people and the sea

In some studies, residents have been asked directly as to what ESs they received and how valuable they considered these ESs (Oteros-Rozas et al., 2014). However, we assumed that residents did not know much about the ESs that they received (Costanza, 2015); we compiled and verified the 19 ESs of the Harima Sea and their descriptions using various sources—academic literature, government reports, statistics, and consultations with managers and experts, including a consultation with coastal zone managers of the Harima Sea in October 2018. The quality of ES information was assessed through the following criteria: salience, credibility, and legitimacy (Cash et al., 2003; Wright et al., 2017). By adopting generic marine ESs' classifications with relational values, the ESs can be said to be comprehensive (a sub-criterion of salience) and legitimate because the list was created in an unbiased manner. The ES information does not, however, satisfy performance—a sub-criterion of salience measured by the outcome and irreversible change (Wright et al., 2017). Because a clear and predetermined goal cannot be set in an adaptive view, ESs were not chosen based on or targeted at a specific goal. Finally, we attempted to maintain credibility; however, certain limitations remained owing to the limited information available.

Given the paucity of ES information about the study site, we collected information by proposing the following rules. First, some ESs were provided with examples or a general description not specific to the study site. Second, while the flow of ESs should ideally be explained, the state of the natural capital (e.g., a tidal flat) was used as a proxy owing to the lack of information. Third, quantitative information was desirable because it produces a more concrete result. Fourth, information on changes in ESs might help with decision-making. Fifth, visual aids could assist people in obtaining a clearer image of an ES (Boyle, 2017). Addressing the uncertainty or inaccuracy of ES information is essential; therefore, we explained the uncertainty clearly to the respondents.

2.2.2. Step 2

Step 2 answers the question “how should ESs be improved?” (Fig. 1). Accordingly, we proposed two measurements: the desired direction for change in each ES compared to its current state (Measurement 1) and the relative importance of each ES compared directly to others (Measurement 2). The former asks residents for incremental or marginal changes rather than desirable (or optimal) levels of an ES. This measure is necessary but insufficient. Improvements in one ES may involve trade-offs with another (Cord et al., 2017). If residents prefer, for example, improving the migratory and nursery habitat and food provisioning by the same degree, managers must ascertain which ES should be prioritized when a trade-off is inevitable. Therefore, managers also need to understand the relative importance of the ES in question. Following a narrative approach, we asked the residents about the benefits via open-ended questions (Arias-Arévalo et al., 2017). Because this is a suitable method for capturing multiple values, including nonmaterial benefits (Arias-Arévalo et al., 2017; Ladle et al., 2016), it also verifies if the ES concept captures key benefits comprehensively.

We conducted an online survey involving the residents of the Hyogo and Kagawa Prefectures, which surround the Harima Sea, to collect data for the demand-side analysis (see SI for the questionnaire). We recruited participants through an Internet survey company; the company announced the survey and collected responses until the number of respondents reached the target volume. We asked that the sample follow the target population (i.e., residents in the Hyogo and Kagawa Prefectures) in terms of gender ratio, age composition ratios, and the size of the population in each prefecture. Prior to the main survey conducted during March 14–19, 2019, a pretest was conducted during February 8–13, 2019. The sample sizes were 2047 and 189, respectively.

2.2.2.1. Measurement 1. We asked the respondents how much they wanted the amount of each ES to improve with options ranging from “1. Needs significant improvement,” “2. Needs some improvement,” “3.

Fine in current condition,” “4. Conditions could decline,” and “5. Service could be potentially lost.” The items corresponded to the direction of change and its intensity to the amount of an ES compared to its current amount (i.e., “3. Fine in current condition”), namely, how much management effort should be put on the supply of each ES. We consulted the managers of the study site regarding the validity of the options. These options were also tested in a pretest; in practice, the options can be revised because the ASESM is an iterative process. Improvement can be qualitative, quantitative, or both, as clarified in the survey. Although the differentiation between quality and quantity may be critical for management (Uehara and Mineo, 2017), we did not ask the respondents about this because it might have been difficult for them to answer.

Although we are aware of the ongoing controversy on this topic, we treat the data as comprising interval, rather than ordinal, values by following an argument based on the empirical findings regarding their appropriateness (Allen and Seaman, 2007; Brown, 2011; Carifio and Perla, 2008; Willits et al., 2016). Specifically, we computed the mean value for each ES. An interval treatment was applied to the ESs (Bryce et al., 2016; Langemeyer et al., 2015). However, we have also provided the median values and bar charts to allow readers to further interpret the results. Either treatment is suitable because the ASESM requires ESs to be ranked in terms of the direction of change to an ES compared to its current state. If those who apply the ASESM to their cases do not agree with the interval treatment, an ordinal treatment (e.g., median values rather than mean values) can be used instead.

After sorting the ESs according to the requests for desired management directions as measured by the mean value for each ES, we grouped the results into four categories. The first was given the highest priority, the second the secondary priority, and so on. We grouped the ESs rather than adopt a ranking because mean values do not always differ significantly and are therefore not always directly comparable. Furthermore, it can be more intuitive and practical for policymakers and residents to see the priority according to the group. We presumed that, overall, the respondents would prefer improving all the ESs because ESs are beneficial; the respondents were not asked to consider the costs of improvements and trade-offs.

2.2.2.2. Measurement 2. While the direction of improvement explains how much each ES should be improved, it does not explain their relative importance. We adopted the BWS method (Finn and Louviere, 1992) because it enables a direct comparison of all ESs' improvements instead of between individual improvements, as in previous studies. For example, choice experiments, a type of nonmarket stated-preference valuation method, consider several scenarios but struggle to manage large numbers of attributes at once (Holmes et al., 2017). Alternatively, some studies have asked respondents to pick several important ESs (Lopes and Videira, 2016; Oteros-Rozas et al., 2014). The BWS method is becoming more widely used in measuring the importance of ESs (Soto et al., 2018; Tyner and Boyer, 2020; Uehara et al., 2019b).

Balanced incomplete block design (BIBD) was used to construct 57 choice sets (SI). In the BIBD, each alternative appears the same number of times and is paired equally with each of the other alternatives across all choice sets (Louviere et al., 2015). To reduce the number of questions per respondent, we divided 57 choice sets into seven groups. Answering 57 choice sets can be psychologically demanding (Aizaki et al., 2015); thus, each respondent was presented with eight or nine choice sets. Following the common practice in choice experiments that divides choice sets into blocks (Aizaki et al., 2015; Holmes et al., 2017), the data obtained from seven groups were pooled for analysis. Table 2 presents an example of a choice set. Each set contains different combinations of three ESs' improvements. Each respondent was asked to choose the most and least important ES from a series of such sets.

We analyzed the data obtained from the BWS questions using counting and econometric analyses. In the former, we noted the number of times each ES was chosen as being the most or least important for the

Table 2
Example of a choice set.

Ecosystem Services (ESs)	Most important	Least important
Disturbance prevention or moderation	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Leisure, recreation, and tourism	<input type="checkbox"/>	<input type="checkbox"/>
Cultural diversity	<input type="checkbox"/>	<input checked="" type="checkbox"/>

total-best (ΣB_i) and total-worst (ΣW_i) numbers, respectively. The best–worst (B–W) score of ES_i was calculated by subtracting the ΣW_i of ES_i from the ΣB_i of ES_i . The standardized B–W score of an ES_i was calculated by dividing the B–W score of ES_i by the number of times ES_i appears in all questions (T_i) (Eq. (1)). The standardized B–W adjusts the influence owing to the differences in the number of respondents between groups. A higher standardized B–W score implies that an ES is evaluated as being more important.

$$\text{std B – Wscore}_i = \frac{\Sigma B_i - \Sigma W_i}{T_i} \quad (1)$$

In the econometric analysis, we employed the maxdiff model—a variant of the conventional multinomial logit model (Louviere et al., 2015). In this model, respondents are assumed to examine all the possible pairs of ESs in a choice set (in this case, $3 \times 2 = 6$ pairs) and choose the pair that maximizes the difference in importance between the two most and least important ESs, respectively. Difference_{ij} in Eq. (2) represents the difference in the importance of ES_i and ES_j ; ε_{ij} is an error term (Lusk and Briggeman, 2009).

$$\text{Difference}_{ij} = \beta_i - \beta_j + \varepsilon_{ij} \quad (2)$$

The probability P_{ij} that the respondent chooses ES_i and ES_j as the most and least important ESs out of J (in this case, $J = 3$) ESs in the set is equal to the probability that the difference in importance between the two ESs is largest among all of the differences in the importance of every possible pair in the choice set. Assuming that ε_{ij} is distributed independently and identically with a type I extreme value distribution, the multinomial logit model can then be derived (McFadden, 1973). P_{ij} is described using Eq. (3) (Lusk and Briggeman, 2009). The parameters can be estimated using the maximum likelihood method.

$$P_{ij} = \frac{\exp(\beta_i - \beta_j)}{\sum_{k=1}^J \sum_{l=1}^J \exp(\beta_k - \beta_l) - J} \quad (3)$$

We randomized the order of the 19 ESs' questions, which measure the desired directions for the changes in an ES compared to its current states and the order of the ES presented in each subset in BWS. In the pretest, the order of the 19 ESs and the ranks of their mean values were correlated (rank correlation coefficients (tau-b) = 0.4971, $p < 0.01$), implying a possibility that the order of the ESs influenced their ranks. Therefore, we randomized the order of the ESs in the main survey.

2.2.2.3. Narratives. In addition to Measurements 1 and 2, we adopted the narrative approach and asked people about the benefits of the SES using an open-ended questionnaire that included nonmaterial values (Arias-Arévalo et al., 2017; Ladle et al., 2016).

The respondents were asked to answer the same open-ended question twice—before and after the introduction of marine ESs in the Harima Sea—"The Harima Sea offers a variety of benefits. From those of which you are aware, which would you like to enjoy? Please be as specific as possible." By comparing the "before" and "after" responses, we assessed how the ES information (i.e., the description of 19 ESs listed in Table 1; see SI for the case of the Harima Sea) changed the respondents' understanding of the benefits.

The lead author coded the answers for the 19 ESs (by following the descriptions of 18 ESs (Böhnke-Henrichs et al., 2013; Hattam et al., 2015) and relational values (Chan et al., 2018)) as follows: "don't know," "don't want," and "benefits do not fit into these categories." An answer could include and therefore be classified into multiple ESs. The coding was validated by a coauthor and corrected accordingly.

2.2.3. Step 3

Step 3 included the supply-side analysis. Stakeholders (e.g., coastal zone managers and experts) were asked to complete a matrix (Table 3) that listed management practices and the corresponding trade-offs and synergies between ESs. During this analysis, coastal zone managers and experts answered the question "How can ESs be improved?" (Fig. 1). Assuming that residents did not have an accurate knowledge of ESs, including how they are coproduced (i.e., their trade-offs and synergies) (Avelino et al., 2019; Costanza, 2015), we asked only managers and suppliers this question. Although the answer depends on how residents receive and perceive them, it is the suppliers who control the amount of ES.

In a meeting held in August 2019, we invited three experts and three coastal zone managers of the Harima Sea. Prior to the meeting, we consulted the managers to verify the practicality of the trade-off and synergy matrix (Table 3) through meetings and email communications. In the meeting, we explained the findings from the demand-side analysis. The attendees were asked to complete the matrix together in the meeting. For example, the improvement of ES_2 through management practice M_2 (e.g., the restoration of seagrass) had a positive impact on ES_1 ("↗" in the cell ES_2XES_1). The improvement of ES_{19} by implementing M_{19} (e.g., prohibiting fishing to secure places for the arts) had a negative impact on ES_2 ("↘" in the cell, $ES_{19}XES_2$). "→" indicates no impact. To finalize the matrix, we discussed it with the attendees via email.

2.2.4. Step 4

Step 4 combines the demand-side analysis (Step 2) with the supply-side analysis (Step 3) to create the finalized ASSESMM. Thus, the ESs in the trade-off and synergy matrix (Table 3) are reordered according to the management preferences elicited from the residents in the demand-side analysis. The ASSESMM illustrates the trade-offs caused by each management practice to improve targeted ES needs that must be considered. Using a matrix for ES information is not new (Wright et al., 2017). However, the matrices used in previous studies are less comprehensive and less focused on their practical use. For example, Baral et al. (2014) developed a matrix showing the relationships between various future land uses and their impact on ESs; Oteros-Rozas et al. (2014) developed a matrix demonstrating the relationships between ESs and their social and personal importance. The ASSESMM, by contrast, shows the relationships between ESs ascribed to specific management practices ordered by residents' ES demands.

3. Results

3.1. Key benefits of the Harima Sea

We compiled site-specific ES information by following the five rules previously specified (see SI). Because the availability of information varied, the degree of information about each ES also varied, as shown in Table 4. In some cases, we had to provide a general description that was not specific to the Harima Sea. In others, we provided a source of the ES, such as tidal flats or seagrass beds (i.e., biophysical structures or functions (Haines-Young and Potschin, 2010)). Quantitative information and changes were provided when available. In addition, we provided pictures and figures, if available, that helped respondents imagine an ES.

Table 3

An example of the trade-off and synergy matrix showing the trade-offs and synergies between ES improvements.

	Management Approach	ES1	ES2	...	ES19
ES1	M1				
ES2	M2	↗			
...	...	→	↗		
ES19	M19	↗	↘	→	

↗: synergy, →: no relation, ↘: trade-off.

↗: synergy, →: no relation, ↘: trade-off.

Table 4

Types of information collected for the ESs.

ES Type No.	ES Type	Overall Evaluation	ES or ES Source	Quantitative	Change	Visual Aid
1	Food production	Comprehensive	ES	Yes	Mixed	Yes
2	Biotic raw materials (non-food)	General description	–	–	–	–
3	Air purification	General description	–	–	–	–
4	Climate regulation	Example(s)	ES source	Yes	Increase	Yes
5	Disturbance prevention or moderation	Comprehensive	ES source	Yes	Mixed	Yes
6	Regulation of water flows	Comprehensive	ES source	Yes	Mixed	Yes
7	Waste treatment and assimilation	Comprehensive	ES source	Yes	Decrease	Yes
8	Coastal erosion prevention	Comprehensive	ES source	Yes	Mixed	Yes
9	Biological control	Example(s)	ES source	Yes	Decrease	Yes
10	Migratory and nursery habitat	Example(s)	ES	Yes	Decrease	Yes
11	Gene pool protection	General description	–	–	–	–
12	Leisure, recreation, and tourism	Example(s)	ES	Yes	–	Yes
13	Aesthetic experience	Example(s)	ES	Yes	Decrease	Yes
14	Inspiration for culture, art, and design	Example(s)	ES	Yes	–	–
15	Cultural heritage	Example(s)	ES	–	–	Yes
16	Cultural diversity	Example(s)	ES	Yes	–	Yes
17	Spiritual experience	Example(s)	ES source	–	–	Yes
18	Information for cognitive development	Example(s)	ES	–	–	–
19	Relationship between people and the sea	Example(s)	ES	Yes	–	–

3.2. Demand for ES improvement

We asked the respondents the following question: “Do you live in the vicinity of the Harima Sea?” We did not clarify if “vicinity” meant physical or psychological distance; we assumed that this depended on their individual perceptions. Less than half (40.4%) responded affirmatively. Approximately half of them (52.72%) had no contact with the Harima Sea; most lived elsewhere (82.87%). As for voluntary participation in activities related to the preservation of the Harima Sea (e.g., bird-watching and shore clean-ups), only 2% of the respondents living in the vicinity periodically participated in such activities; the participation of respondents living elsewhere was much lower (0.08%). Only 5.08% of the respondents were previously acquainted with the ES concept.

Fig. 2 shows the respondents’ preferences for the direction of change to the ES compared to its current condition. Overall, the respondents advocated more improvement. There were two types of frequency distributions; “2. Needs some improvement” (ES 1–10, 12, 13, and 19) and “3. Fine in current condition” (ES 11, 14–18) were dominant. There were two medians: “2. Needs some improvement” for ES 1–10, 12, 13, 16, and 19 and “3. Fine in current condition” for ES 11, 14, 15, 17, and 18.

Table 5 shows the mean value of the respondents’ requirement for improving an ES according to their residency. The smaller the mean value was, the more the improvement was desired. The order of preferred change did not differ considerably across the origins of the participants. Kendall’s rank correlation coefficients (tau-b), a nonparametric test, were high (0.9649, 0.9766, 0.9415 for Pooled vs. Close, Pooled vs. Distant, and Close vs. Distant, respectively, with a significance level of $p < 0.01$). Overall, the respondents living close to the sea demanded more improvements than those living far away from the sea.

Although differences existed according to the respondents’ location of residence, improvement was desired for all ESs (i.e., less than 3.00 of the mean). Overall, regulating and provisioning services were preferred over habitat and cultural services. Although the ESs were ordered by their mean values, the difference between two services in a sequence was not necessarily significant (see SI for the paired t -test results); thus, they were grouped into four ranks as shown below.

The ES number corresponds to that in Table 1. “Pooled” includes all respondents (i.e., “Living close to the Harima Sea” and “Living far away from the Harima Sea”).

Fig. 3 shows the relative preference for each ES over other ESs measured according to their standardized B–W scores (Eq. (1)) based on a counting analysis by region. No significant differences in their relative importance by region were found. Similar to their desired direction for changes to ESs (Table 5), the respondents tended to prioritize regulating services over cultural services. Kendall’s rank correlation coefficients (tau-b) between these two measures was high (0.731, $p < 0.01$) for all respondents, but the measures were not perfectly correlated.

We confirmed the validity of the results by comparing them with more sophisticated econometric estimates using the maxdiff model (Finn and Louviere, 1992) (see SI). The Pearson’s correlation coefficient for these two estimates was $r = 0.9997$ ($p < 0.01$).

Using these two measures for ES management preferences, we grouped the desired directions for changes to ESs into four rank groups and then reordered them within each according to the relative importance of each ES in its category (Table 6).

3.3. Supply-side analysis and compiling the ASESMM

The supply-side analysis elicits trade-offs and synergies between ESs



Fig. 2. Preferred directions of changes to the amount of an ES compared to its current condition: 1. Needs significant improvement; 2. Needs some improvement; 3. Fine in current condition; 4. Conditions could decline, and 5. Service could be potentially lost.

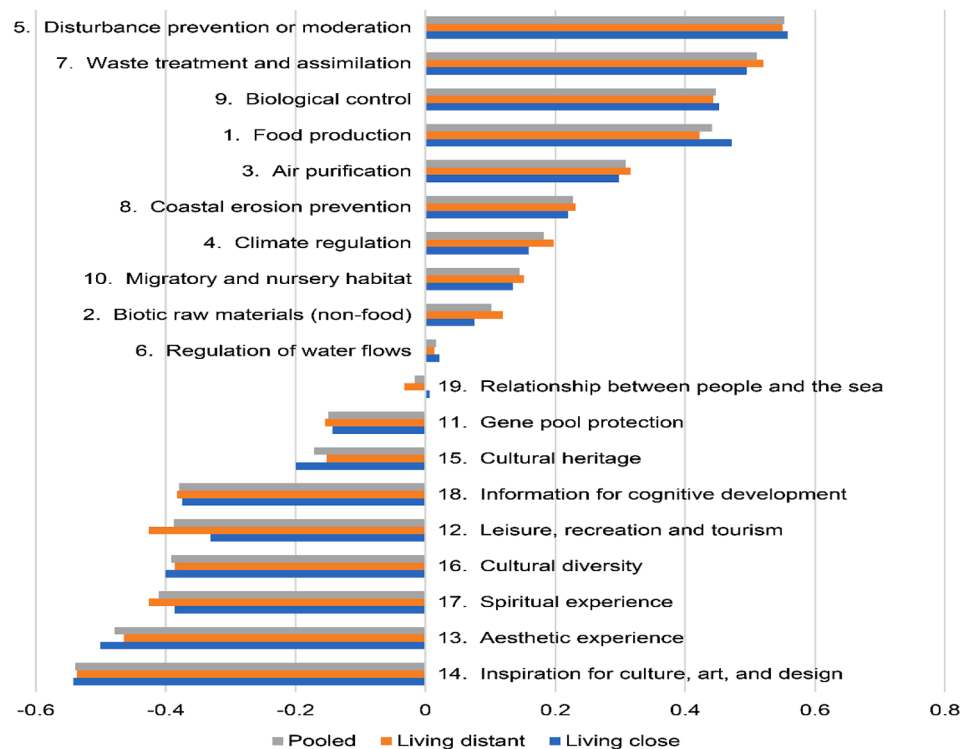
owing to ES improvements. Prior to this analysis, we held a meeting in July 2019 and had email communications with governmental officials involved in the management of the Harima Sea to test the validity of the ASESMM and correct it accordingly. In August 2019, another meeting with coastal zone managers of the Harima Sea and experts involved in coastal zone management took place. In the meeting in August, we asked the stakeholders about management practices to improve ESs.

Fig. 4 shows the matrix, which combines the results from the demand- and supply-side analyses. “↗,” “→,” and “↘” indicate synergy, no relation, and trade-offs, respectively.

Because disturbance prevention or moderation is the most highly prioritized, its improvement is preferred even when this involves trade-offs with other ESs. Biological control through the conservation of ecosystems has a trade-off with waste treatment and assimilation, which

Table 5Desired directions for change to an ES. $N = 2,047$, 827, and 1,220.

Pooled			Living Close to the Harima Sea			Living Far Away from the Harima Sea		
ES No.	ES Category	Mean	ES No.	ES Category	Mean	ES No.	ES Category	Mean
7	Regulating	1.98	7	Regulating	1.89	7	Regulating	2.04
9	Regulating	2.07	9	Regulating	1.97	9	Regulating	2.14
1	Provisioning	2.08	1	Provisioning	1.98	1	Provisioning	2.15
5	Regulating	2.25	5	Regulating	2.18	5	Regulating	2.29
8	Regulating	2.27	8	Regulating	2.21	8	Regulating	2.32
3	Regulating	2.29	3	Regulating	2.23	4	Regulating	2.34
4	Regulating	2.3	4	Regulating	2.25	3	Regulating	2.34
13	Cultural	2.34	13	Cultural	2.26	6	Regulating	2.38
6	Regulating	2.35	2	Provisioning	2.29	13	Cultural	2.39
2	Provisioning	2.36	6	Regulating	2.30	2	Provisioning	2.40
10	Habitat	2.39	19	Cultural	2.35	10	Habitat	2.42
12	Cultural	2.41	10	Habitat	2.36	12	Cultural	2.45
19	Cultural	2.41	12	Cultural	2.36	19	Cultural	2.46
11	Habitat	2.48	11	Habitat	2.42	11	Habitat	2.52
18	Cultural	2.52	18	Cultural	2.47	18	Cultural	2.55
16	Cultural	2.57	16	Cultural	2.54	16	Cultural	2.59
15	Cultural	2.65	15	Cultural	2.61	15	Cultural	2.68
17	Cultural	2.71	17	Cultural	2.65	17	Cultural	2.74
14	Cultural	2.76	14	Cultural	2.74	14	Cultural	2.77

**Fig. 3.** The relative importance of an ES to other ESs, measured in B-W scores.

is more highly prioritized. Therefore, the improvement of biological control should consider the trade-offs involved. It is worth reiterating that the managers and experts asserted that whether an improvement involves trade-offs and synergies depends on what management applies in practice. The list of management practices is merely an example to demonstrate the potential trade-offs and synergies so that other

practices can also be implemented.

Notably, there is no management applicable to improving air purification and climate regulation in the Harima Sea. Further, coastal erosion prevention, migratory and nursery habitats, the relationship between people and the sea, and gene pool protection involve various trade-offs with other ESs. Overall, cultural ESs are synergetic within

Table 6
Demand for ES improvement.

Rank	ES Category	ES Type No	ES Type	Std BW score
1st Rank	Regulating	5	Disturbance prevention or moderation	0.553
	Regulating	7	Waste treatment and assimilation	0.510
	Regulating	9	Biological control	0.447
	Provisioning	1	Food production	0.442
	Regulating	8	Coastal erosion prevention	0.227
2nd Rank	Regulating	3	Air purification	0.309
	Regulating	4	Climate regulation	0.182
	Provisioning	2	Biotic raw materials (non-food)	0.102
	Regulating	6	Regulation of water flows	0.017
	Cultural	13	Aesthetic experience	−0.479
3rd Rank	Habitat	10	Migratory and nursery habitat	0.145
	Cultural	19	Relationship between people and the sea	−0.016
	Habitat	11	Gene pool protection	−0.150
	Cultural	18	Information for cognitive development	−0.379
	Cultural	12	Leisure, recreation, and tourism	−0.388
4th Rank	Cultural	15	Cultural heritage	−0.171
	Cultural	16	Cultural diversity	−0.391
	Cultural	17	Spiritual experience	−0.410
	Cultural	14	Inspiration for culture, art, and design	−0.539

Management Priority	ES Category	ES Type	Management Practice (example)	Disturbance prevention or moderation	Waste treatment and assimilation	Biological control	Food production	Coastal erosion prevention	Air purification	Climate regulation	Biotic raw materials (non-food)	Regulation of water flows	Aesthetic experience	Migratory and nursery habitat	Relationship between people and the sea	Gene pool protection	Information for cognitive development	Leisure, recreation and tourism	Cultural heritage	Cultural diversity	Spiritual experience	Inspiration for culture, art and design
1	Regulating	Disturbance prevention or moderation	Maintaining coastal levee and defense																			
2	Regulating	Waste treatment and assimilation	Maintaining seagrass bed and mudflat	→																		
3	Regulating	Biological control	Conservation of ecosystems	→	↘																	
4	Provisioning	Food production	Natural resource management	→	→	↗																
5	Regulating	Coastal erosion prevention	Maintaining dikes and defense	↗	↘	↘	↘															
6	Regulating	Air purification	-	-	-	-	-	-														
7	Regulating	Climate regulation	-	-	-	-	-	-	-													
8	Provisioning	Biotic raw materials (non-food)	Conservation of ecosystems	→	→	↗	↘	→	→	→												
9	Regulating	Regulation of water flows	Maintaining moving levee	↗	→	→	→	↗	→	→	→											
10	Cultural	Aesthetic experience	Conservation of natural scenery	→	→	→	→	→	→	→	→	→										
11	Habitat	Migratory and nursery habitat	Conservation of migratory and nursery habitat	↘	↘	→	↘	→	→	→	→	→	↗									
12	Cultural	Relationship between people and the sea	Improvement of public access	↘	↗	↘	→	↘	→	→	→	→	↗	↘								
13	Habitat	Gene pool protection	Conservation of biodiversity	→	→	↗	↘	→	→	→	↘	→	↗	↗	↘							
14	Cultural	Information for cognitive development	Environmental education	→	→	→	→	→	→	→	→	→	↗	→	↗	↗						
15	Cultural	Leisure, recreation and tourism	Maintaining areas for water activities	↘	↗	→	→	↗	→	→	→	→	↗	↗	↗	→	↗					
16	Cultural	Cultural heritage	Designation of cultural heritage	→	→	→	→	→	→	→	→	→	↗	→	↗	→	↗	↗				
17	Cultural	Cultural diversity	Conservation of culture and promotion of new cultural activities	→	→	→	→	→	→	→	→	→	↗	→	↗	→	↗	↗	↗			
18	Cultural	Spiritual experience	Provisioning places for historical and cultural activities	→	→	→	→	→	→	→	→	→	↗	→	↗	→	↗	↗	↗	↗		
19	Cultural	Inspiration for culture, art and design	Sea related projects and events	→	→	→	→	→	→	→	→	→	↗	→	↗	→	↗	↗	↗	↗	↗	

Fig. 4. Adaptive Social-Ecological System Management Matrix (ASESMM) for the Harima Sea. The ASESMM was developed through consultations with Harima Sea coastal zone managers and coastal zone management experts. ↗: synergy, →: no relation, ↘: trade-offs.

themselves.

3.4. Narratives

Table 7 shows the number of ESs and other keywords mentioned in the open-ended questionnaire before and after explaining the ESs obtained from the Harima Sea. Before the ES information was provided, the respondents almost exclusively discussed food production (ES₁, 1107 respondents); Leisure, recreation, and tourism (ES₁₂, 197 respondents); and Aesthetic experience (ES₁₃, 122 respondents). Several people said, “I do not want to benefit from the Harima Sea” (291 respondents) and “I do not know what benefits I obtain from the Harima Sea” (114 respondents). Some respondents mentioned “healing (*iyashi* in Japanese)” (24 before and 62 after the ES information was provided). According to a Japanese dictionary, this means “[t]o heal illnesses and injuries. Also, to eliminate mental worries and anxieties” (Kitahara, 2010, p.133). Healing does not fit into the ESs’ classification as it may be considered a type of human wellbeing (Millennium Ecosystem Assessment, 2005), but there seems to be a strong link between ESs and human health, including healing (Karjalainen et al., 2010; Sandifer et al., 2015).

Comparing the answers before and after the provision of the ES information, the number of ESs mentioned in total increased by 16.7%. Fifteen of the ESs were mentioned more often; all ESs were appreciated after the information was provided. Four ESs had not been mentioned at all before. Interestingly, the number of respondents mentioning intrinsic values (i.e., not for the sake of humans but for that of nature) increased from 1 to 62. Both “Don’t want” and “Don’t know” decreased by 10.0 % and 43.9%, respectively. The mention of benefits that did not fit into the

ESs’ classification system increased from 67 to 276. These included, for example, “I receive natural gifts from the Harima Sea” and did not specify the kind of ES they stood for.

4. Discussion

4.1. Management implications

4.1.1. Current state and key benefits of the Harima Sea

The quality of ES information required for the instrumental use of the ASESMM, as in this study, is high (Wright et al., 2017). The respondents’ demand may be sensitive to the information provided. In addition, the respondents may not be well acquainted with the benefits that they receive from nature (Costanza, 2015). The narrative analysis substantiated these points in that the residents were unaware of the Harima Sea’s benefits; their recognition changed significantly after the ES information was provided (Table 7).

As shown in Table 7, the degree of information quality varies from generic descriptions (e.g., “Gene pool protection”) to detailed time-series data on the ES (e.g., “Food production”). However, we must provide ES information regardless of its limitations. Owing to the complex and dynamic nature of the SES, we cannot expect to glean complete information. In addition, information about the limited data availability (Table 7) along with people’s preferences over ESs obtained from demand-side analyses help managers identify what ES information should be emphasized. Because the ASESMM is an iterative process, this could help managers incorporate updated information in management decisions over time.

Table 7

The number of occurrences of benefits from the Harima Sea mentioned before and after ES information was provided.

ES Category	ES type No.	ES Type	Information about the ESs from Harima Sea	
			Before	After
Provisioning	1	Food production	1107	853
	2	Biotic raw materials (non-food)	18	20
Regulating	3	Air purification	19	63
	4	Climate regulation	23	21
	5	Disturbance prevention or moderation	3	84
	6	Regulation of water flows	8	4
	7	Waste treatment and assimilation	21	95
	8	Coastal erosion prevention	0	5
	9	Biological control	0	66
Habitat	10	Migratory and nursery habitat	2	43
	11	Gene pool protection	0	26
Cultural	12	Leisure, recreation and tourism	197	166
	13	Aesthetic experience	122	160
	14	Inspiration for culture, art and design	2	14
	15	Cultural heritage	5	63
	16	Cultural diversity	0	34
	17	Spiritual experience	5	22
	18	Information for cognitive development	13	48
	19	Relationship between people and the sea	8	26
Sub-total			1553	1813
-	-	Benefits not fitting into the ES classification	67	276
-	-	Intrinsic (i.e., for nature's sake)	1	62
-	-	Healing	24	42
-	-	Don't want	291	262
-	-	Don't know	114	64
Total			2050	2519

$N = 2,047$. The subtotal is the summation of ES Type Nos. 1–19.

$N = 2047$. The subtotal is the summation of ES Type Nos. 1–19.

4.1.2. Demand-side analysis

First, because all ESs are “beneficial” and we did not explicitly ask the respondents to consider the costs of improvement and the corresponding trade-offs among ES improvements, the respondents on average preferred to improve all ESs, as expected (i.e., the mean values in Table 5). Although we treated the data as interval, it can also be treated as ordinal (e.g., using median values).

Second, distance matters for people’s requests for improvement but not for their order. In the survey, we asked “Do you live in the vicinity of the Harima Sea?” without providing a clear definition of what “vicinity” means. Therefore, we presume that the respondents answered this question based on their physical and psychological distance, i.e., “vicinity” could be a physical and psychological construct. For future research, differentiating between these constructs would be informative; for example, if the psychological aspect matters, appealing to people’s psychology might change their answers.

Third, we applied two distinct measures to the demand for ES improvement (i.e., ES improvements and their relative importance) because they differ conceptually and can capture the various aspects of ES demand. The measures were correlated albeit imperfectly, thereby implying the meaningfulness of using both.

Fourth, the simple counting analysis using spreadsheets provided almost identical results as those from the sophisticated econometric analysis (e.g., the maxdiff model). The list of the choice sets for BWS satisfying BIBD is readily available (Louviere et al., 2015). While other stated preference methods—including the contingent valuation method and choice experiments using statistical analysis—have sample size requirements (e.g., de Bekker-Grob et al. (2015) as an example of such a choice experiment), the calculation analysis does not have a strict requirement. The questionnaire for the demand analysis takes the general form of a social survey with the addition of questions regarding BWS, asking respondents to choose the best and worst from a choice set. Keeping the method as simple as possible is critical in making it accessible to the average practitioner (Ruckelshaus et al., 2015).

Fifth, the demand for ES improvements (Table 6) raises a concern regarding the relationship between people and nature (Ives et al., 2017; Restall and Conrad, 2015; Zylstra et al., 2014). The respondents preferred ESs with less interaction with the Harima Sea (e.g., disturbance prevention or moderation and food production) in receiving benefits than ESs with more interaction, such as cultural ESs (Table 6). For example, people do not need to interact with nature to benefit from disturbance prevention, which is improved by civil engineering or moderation, and can eat fish that is available at a supermarket far away from the Harima Sea. Most seafood is cut and packaged, and people may not be aware of its origin. However, the lack of a human–nature connection is a root cause of ecological crises and unsustainability (Uehara et al., 2019a). Therefore, managers should encourage residents to interact with the Harima Sea to improve its ESs in the long term.

Sixth, overall, the narrative analysis substantiated the usefulness of the ESs’ classification (Table 7). It captured most of the benefits from nature. Most benefits were captured by the ESs’ classification; however, the narrative analysis elucidated the potential importance of “healing,” which cannot be categorized into the ESs’ classification. The relationship between the state of coastal zones and healing is worth investigating. It highlights the importance of considering cultural ESs (e.g., spiritual services) that are specific to individual countries. Although we placed intrinsic values outside the ESs by following the ESs’ classification adopted (Böhnke-Henrichs et al., 2013; Hattam et al., 2015), such values could be part of or consistent with common ES approaches (Ruckelshaus et al., 2015; Stålhammar and Thorén, 2019).

Seventh, the comparison of the narratives before and after the ES information was provided is instructive for management. The residents’ recognition of ESs increased and was diversified (Table 7). The mention of some ESs increased in the open-ended questions, implying that providing such information is effective in improving the residents’ recognition of ESs.

Finally, the managers observed that the respondents seemed to misunderstand the current conditions of the Harima Sea. For example, while the respondents indicated that waste treatment and assimilation (ES₇) was the second most important target for improvement, the managers argued that the Harima Sea was too clean, lacking nutrient salts, to cultivate fish. The Hyogo Prefectural government set a new water quality standard that allows sewage plants and factories to drain nitrogen (Kobe Shinbun, 2019). The demand analysis should be updated by promoting the residents’ understanding of the Harima Sea.

4.1.3. Supply-side analysis

The supply-side ES trade-off and synergy combinations were compiled based on the meetings and email communications with coastal zone managers of the Harima Sea and coastal zone management experts. Similar to Cord et al.’s (2017) argument, the stakeholders herein claimed that whether the relationships between ES improvements are trade-offs or synergy depends on the management practices that occur. Moreover, this relationship is location specific. When asked to picture the entire Harima Sea, the stakeholders said that the relationship depended on which part we were targeting. Moreover, “Air purification” (ES₆) and “Climate regulation” (ES₇) are not manageable at the local level, necessitating multilevel governance on an international level (Saarikoski et al., 2018).

The procedure of the supply-side analysis should be further developed. One weakness herein is the limited involvement of scientists (particularly natural scientists). To continue updating the information, scientists should be involved in a systematic manner—for example, by applying the Delphi method (Linstone and Turoff, 1975).

4.1.4. Asemm

Per the managers and experts, the ASESMM has five main benefits. First, it reveals how SESs should be managed from the demand side (how should ESs be improved?) and supply side (how can ESs be improved?). Second, the prioritization of ES improvement suggests what kind of ES information should be collected specifically. This prioritization is critical given resource constraints (e.g., budgets and scientists). Third, among the trade-offs involved in ES improvement, the ASESMM identifies the trade-offs that should be especially avoided or considered. It enables managers to focus on the trade-offs between ESs that are more prioritized than the targeted ESs. There is no need to consider all the combinations of trade-offs; however, a certain trade-off cannot always be ignored to improve a certain ES. The order of ES management (Fig. 4) could change as the provisions of ESs change as a result of ES management. Notably, the managers, experts, and literature claim that a management practice that could avoid such trade-offs might exist. Thus, *satoumi*, a Japanese concept of SEPLS, could be realized in the Harima Sea. Fourth, the ASESMM provides a platform for all stakeholders across different organizations at multiple scales to discuss ES improvement in a comprehensive manner and on the same grounds. Linking a broad range of stakeholders is challenging (Folke et al., 2005). Because ES improvement involves multiple sections (e.g., the division of fisheries, education, or the environment) on multiple scales (e.g., municipal, prefectural, national, or international), a platform that everyone can share, such as the ASESMM, is both integral and effective. Finally, the ASESMM is a practical tool for adaptive management because it is accessible and updateable. As previously mentioned, given the changes in demand for the richness (e.g., for fisheries) and cleanliness (e.g., for the transparency) of water quality, the Hyogo Prefectural government established a new water quality standard to increase the catch of fish in the Harima Sea. The ASESMM could help managers adapt management practices to such changes.

Nevertheless, there are three caveats. First, the ASESMM does not aim to replace the complex decision-making process of SES management (Saarikoski et al., 2018) but to aid the process with additional information. The managers noted that a decision involves multiple factors, such as budgets and politics and their interactions, rather than a lucid

Pareto improvement process. Second, the ASESMM is not perfect; it includes a demand-side analysis based on residents' inaccurate recognition of benefits and lack of knowledge about ESs, which is expected to improve through the iterative process of the ASESMM. For example, it can be iterated periodically (e.g., every five years) and simultaneously to when the management plan is revised. Finally, as indicated by the experts and managers, the ASESMM varies depending on the target area. In our experimental application, we asked the stakeholders to picture the entire Harima Sea. However, in reality, a management practice must target a smaller, more specific area.

4.2. Does the ASESMM contribute to sustainability?

The ASESMM is founded on Norton (2015) in that there is no single sustainability and that the path to sustainability is open to various possibilities. The ASESMM poses soft objectives that are adaptive to SES changes to achieve sustainability. Therefore, an SES can remain sustainable while continuously learning and adapting to changes.

Although we agree with Norton (2015), explicitly reflecting information regarding the irreversibility of the ASESMM is essential. If human and natural disturbances let an SES cross its threshold, ecosystems may be lost or become expensive and physically difficult to restore (Walker et al., 2004; Wright et al., 2017). Management practices changing an SES could also cross thresholds if they reflect peoples' demands without considering them. Irreversible changes are critical but not well reflected in the ES information available for instrumental use (Wright et al., 2017). For instance, seagrass (*Zostera marina*) in the Seto Inland Sea, which includes the Harima Sea, decreased by 72% during the 1960–1990 period of rapid economic growth (Ministry of the Environment, n.d.). Although no solid scientific data are available, an expert in the Seto Inland Sea suggested that there may be a minimum area of seagrass required to sustain the population and grow independently (personal communication, 2015). A loss of seagrass beds leads to the loss of various ESs (Himes-Cornell et al., 2018). In the ASESMM, information regarding irreversibility could be reflected in management choices that avoid crossing certain identified thresholds.

5. Conclusions

We developed the ASESMM as an instrumental tool for adaptive SES management that adopts the notion of soft targets and sustainability proposed by Norton (2015). The iterative application of the ASESMM updates soft targets via learning and incremental processes. By reflecting demand- and supply-side perspectives, the ASESMM helps managers choose management practices for ESs' improvement by avoiding trade-offs with more prioritized ESs.

The ASESMM was developed and tested by applying it to a Japanese coastal zone. The narrative analysis substantiated the comprehensiveness of the ESs' classification in capturing the benefits of nature; most of the benefits that the respondents recognized were categorized into the ESs' classification system. Although it captured most of the benefits, the narrative analysis elucidated their intrinsic values and healing quality. Further research is required on the relationship between ESs' classifications and healing. Excluding monetary measures (Kelemen et al., 2014), the ASESMM enables diverse benefits to be captured on the same grounds. Using BWS as opposed to other commonly used methods, such as choice experiments (Kim et al., 2020), allows more flexibility for capturing soft targets comprising many ESs for its simplicity. BWS is technically more accessible than choice experiments comprising choice sets, including multiple attributes and attending levels. While designing choice sets in choice experiments requires sophisticated techniques (e.g., D-efficient optimal orthogonal design (Holmes et al., 2017)), validated choice sets for BWS are readily available from previous studies (Louviere et al., 2015).

We consulted the managers of the study site and coastal zone management experts to ensure the practicality of the ASESMM. The

consultation revealed the possibility of attaining *satoumi*, a Japanese SEPLS, involving active human–nature interactions that enhance the productivity and biodiversity of seascapes. In other words, management using the ASESMM can enhance synergies while minimizing trade-offs involving prioritized ESs in realizing a SEPLS, a desirable state of SES. Because of the complex interactions of SES, trade-offs and synergies among ESs are a critical concern in SEPLS management (Cord et al., 2017).

An ASESMM can be built using only spreadsheets and is expected to be updated periodically to adapt to changes in SES, preferences, and updated ES information. Although the managers and experts herein supported the ASESMM's practicality, more rigorous procedures for supply-side analysis must be developed. For example, the ASESMM should involve more diverse stakeholders including scientists with more formalized procedures such as the Delphi method (Linstone and Turoff, 1975). Overall, we believe that this approach is effective for adaptive SES management. Moreover, it can be generally applied to SESs to assess the management of both seascapes and landscapes.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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