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TSUNAGARI: A new interdisciplinary and transdisciplinary study toward conservation and sustainable use of biodiversity and ecosystem services

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Abstract

The expanding economical activities have accelerated losses of biodiversity and ecosystem services, which are especially pronounced in Asia. To find solutions to stop these losses, a group of scientists studying both ecological and social sciences has launched an interdisciplinary research network, entitled TSUNAGARI (Trans-System, UNified Approach for Global And Regional Integration of social-ecological study toward sustainable use of biodiversity and ecosystem services). The project is based on two main perspectives: (1) integrating different disciplines of environmental research across multiple spatial scales, and (2) evaluating the importance of ecosystem connectivity between land and ocean for biodiversity and ecosystem services. The integrative studies have been started as follows: (1) integrating global-scale analyses of biodiversity and economy by developing GIS-based footprint analysis, (2) establishing the link between the studies of local good practices of ecosystem management and life cycle assessment on ecosystem good and services, (3) linking local-scale ecosystem studies to decision making processes for sustainable society by multiple stakeholders, and (4) upscaling local analyses of ecosystem processes to broad-scale analyses of ecosystem patterns. The proposed approaches are considered effective to solve problems that impede conservation of biodiversity and sustainable use of multiple ecosystem services in various situations although we also find some gaps such as regional biases in biodiversity data and involvement of different types of stakeholders. By overcoming the major bottlenecks, we believe the new integrated approaches will promote conservation and sustainable management of biodiversity and ecosystem services research, and contribute to advance decision-making processes from local communities to international levels.

Keywords: Coastal ecosystem, Cross-scale integration, Eastern and southeastern Asia, Ecosystem connectivity, Social-ecological system

Introduction

The expanding economical activities by human have caused accelerated losses of biodiversity and multiple ecosystem services (i.e., provisioning, regulating, cultural and supporting services; Millennium Ecosystem Assessment 2005) through rapid land/sea use changes. This is aggravated by global climate change, which affects both terrestrial and marine ecosystems in multiple ways, not only by direct effects of temperature rise, but also by increase in intense stormy conditions, ocean acidification and sea level rise (Harley et al 2006; IPCC 2014). Meanwhile, analyses of ecological footprints have revealed that increasing economic demands by developed countries for provisioning services are among the main causes of biodiversity loss in developing countries (Lenzen et al.2012; Weinzettel et al. 2013). The combined effects of climate change and global economic activities can lead to further degradation both of terrestrial and marine ecosystems, and to economic disparity in local human communities. In order to reverse this trend, there is an urgent need to find better way to conserve and sustainably use biodiversity and ecosystem services. Some international efforts have been initiated, e.g., by setting Sustainable Development Goals (United Nations 2015), and by assessing the status of global biodiversity and ecosystem services by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al. 2015), although local activities such as establishing environmental stewardship cultivated through co-design, co-production and co-delivery activities are still not well-established in most regions of the world.

Since the publication of the Millennium Ecosystem Assessment (2005), the recognition and understanding of the global state of biodiversity and ecosystem services, their drivers, and their dependence on social and economic activities have improved. At the same time, the need for a more systematic approach for promoting interdisciplinary research on social-ecological systems has been highlighted (Cumming 2007; Carpenter et al. 2009; Ostrom 2009; Pereira et al. 2010). However, scientific knowledge is still limited for planning and executing effective management activities at both global and local scales. Major bottlenecks in the ecological sciences include the lack of fine-resolution information of the distribution of biodiversity at each locality (Jetz et al. 2012; Meyer et al. 2015), a great degree of variability in biodiversity and ecosystem services across multiple environmental gradients (Koch et al. 2009; Nakaoka et al. 2014; Nordlund et al. 2016), and interrelationships (trade-offs) among multiple ecosystem services (e.g., between provisioning and regulation services (Carpenter et al. 2009; Maas et al. 2016). As for social science, understanding for sustainable use of natural resources use are often limited due to the lack of scientific knowledge about the consequence of economic activities and consumption on the loss of biodiversity and ecosystem services, and due to insufficient communication among scientists, stakeholders and local citizens with different interests and demands (Dornelas et al. 2014).

Some of the above-mentioned problems share the same properties both in ecological and socioeconomic studies. Firstly, processes determining biodiversity and multiple ecosystem services, and decision making of their use are affected by nested, hierarchical structures; i.e. processes at broader spatial scales (e.g, climate variation and global economy) regulate processes at small spatial scales (e.g., species interaction in biological communities, and human interactions in local social communities), and vice versa (Peterson and Parker 1998; Noda 2004). Secondly, the connectivity of ecosystems between terrestrial and marine environments affects dynamics of biodiversity and multiple ecosystem services and decision-making processes at the community level (Polis et al. 1997; Waterhouse et al. 2016; Fang et al. in press). Previous studies on social-ecological systems cannot address these points sufficiently, although the importance of integration has been recognized recently (Cumming 2011). It is likely that those points are attributable to many reasons originated from various stakeholders. At this stage, we need to identify which problems should be solved first and which data and information scientists can appropriately provide decision makers. Thus, interdisciplinary and transdisciplinary collaboration between stakeholders and researchers are critically required for successful co-design, co-production and co-delivery of knowledge building. This is especially true in Asia where values of biodiversity and ecosystem functions of natural ecosystems are estimated to be the highest in the world (Stuart-Smith et al. 2013; Dickson et al. 2014), but where detailed information of biodiversity and ecosystem services, as well as social-ecological studies have not been well organized as yet (Nakaoka et al. 2014, Kim et al. in press).

The establishment of interdisciplinary and transdisciplinary research networks consisting of both ecological and social scientists, as well as stakeholders and decision-makers, are necessary to solve the environmental problems we are facing. As an attempt, a group of scientists from various fields of environmental studies, both in ecological and social sciences has launched a research network, entitled TSUNAGARI (Trans-System, UNified Approach for Global And Regional Integration of social-ecological study toward sustainable use of biodiversity and ecosystem services), with the support of the Belmont Forum (www.belmontforum.org). The Japanese word ‘tsunagari’ means connectivity, link and relationship, which we intend to build among scientists in different disciplines and among scientists, practitioners and stakeholders involving conservation of biodiversity and sustainable use of ecosystem services. The participants differ greatly in their background of expertise, ranging from ecologists studying community and ecosystem ecology, biogeochemists and geographers studying land/sea use changes, fisheries scientists studying local fisheries practices, fisheries management and policies, and to industrial ecologists studying global economy and sustainable sciences. Among various types of ecosystems, scientists studying coastal zones (e.g. wetlands and nearshore habitats) predominate in our group partly because one of our primary focuses is ecosystem connectivity between land and ocean for which most previous studies have been made in coastal zones.

During the two-year duration of TSUNAGARI project, we hold three workshops (at Ishigaki Island, Japan in May 2015, at Yantai and Yellow River Delta, China in April 2016 and at Kyoto, Japan in October 2016) to thoroughly discuss what types of interdisciplinary and transdisciplinary collaborations we could start to solve the above-mentioned problems. This concept paper is one of the outputs of TSUNAGARI activities. We first explain two main perspectives on the new interdisciplinary and transdisciplinary studies aiming to achieve (1) cross-scale, and (2) cross-ecosystem integrations. We then introduce ongoing case studies by TSUNAGARI participants demonstrating effective scientific approaches based on the integrated collaboration, specially focusing on coastal ecosystems in Asia and the world. Finally, we consider directions for future integrative studies by pointing out the gaps in our current knowledge. Our ultimate goals of the collaboration are to evaluate the current status and conditions of biodiversity, ecosystem services and their use by human communities in various types of ecosystems connected to each other, to establish which knowledge will be the baseline to predict future changes based on different scenarios on climate changes and development of human society, and to provide solutions to the problems of decision-making processes for sustainable use of biodiversity and multiple ecosystem services locally, regionally and globally.

TSUNAGARI Perspective 1: Integrating different disciplines of environmental research across multiple spatial scales

Various types of interdisciplinary studies linking ecological and social studies have been ongoing since the last decade (Cummings 2007, 2011; Carpenter et al. 2009; Maas et al. 2016). However, it is still least understood how integrated research should focus on the issue of multiple spatial-scale dependency which is important both in the natural ecosystems and human decision-making processes (Fig. 1).

<- Fig. 1

For the side of ecological studies, it has been acknowledged that processes affecting biodiversity and ecosystem services are determined by multiple factors operating at differential scales (the right side of Fig. 1). In both terrestrial and marine ecosystems, climate-driven abiotic factors shape global patterns of biodiversity and ecosystems through variation in temperature, precipitation and oceanic current regimes. For biotic factors, evolutionary and biogeographical processes such as restriction and release of certain types of organisms with changes in barriers (due to continental and oceanographic current shifts) determine global patterns of biodiversity over very long time-scales (Briggs 1995). At the intermediate scale (e.g., 10 to 1000 km scale), factors related to geographical settings of the regions, such as altitude, ocean depth, monsoon winds and coastal upwelling determine vegetation or biomass of dominant organisms in each ecosystem (Roughgarden et al. 1988; Palumbi and Pinsky 2014). At the small spatial scales (e.g. 1 to 1000 meter or smaller scales), classical studies in 1960-70’s already clarified that local disturbances such as wind and wave forces, as well as biological interactions among species such as predation and competition interfere with the processes determining biomass and productivity of organisms at different trophic levels (Connell 1961, 1978; Paine 1966; Dayton 1971). Previous studies on ecology already highlighted the multiple scale issues causing nonlinear, complicated dynamics of ecosystems (Peterson and Parker 1998; Noda 2004; Yamakita et al. 2011).

The same type of scale dependency is also important when we consider multiple effects of human-induced stresses to natural ecosystems. In coastal ecosystems for example, overexploitation of some specific resources, eutrophication and coastal development occur at relatively small spatial scales, whereas climate-related changes such as temperature rise and ocean acidification are ongoing at broader spatial scales. Most importantly, concurrent impacts of multiple drivers cause synergetic and unpredictable effects on biodiversity and ecosystem services (Hughes et a. 2003). Examples include the combined effect of temperature rise, ocean acidification and oxygen depletion on marine benthic animals in which the organisms impacted by multiple stresses suffer more severely than those exposed to only one type of stressor (Pörtner and Langenbuch 2005; Harvey et al. 2013). Likewise, interacting effects of temperature rise and alteration of coastlines by concrete walls and blocks may increase the invasion of non-native species, which are generally more resistant to heat and adapted to human-altered habitats (Stachowicz et al. 2002; Lenz et al. 2011).

Scale dependency is also important in social studies on environmental problems (the left side of Fig. 1). Firstly, decision making processes toward sustainable ecosystem management are affected by multiple sectors operating at different spatial and political scales. In the case of Japan, environmental policies are made and governed at three levels of organizations; i.e., local governmental units (LGU; cities, towns or villages; a total of 1718, as of April 2017; http://www.soumu.go.jp/kouiki/kouiki.html, as on April 9th, 2017), prefectures (a total of 47) and the national government. Decision making at the national government is also affected by international activities and treaties. Secondly, with the rapid expansion of international trade, local economic activities are more and more affected by global market dynamics even in a small village. Thus, the analyses of regional research elucidating local decision-making processes should be linked with global economic analyses.

As multi-spatial scale issues are prominent both in ecological and social studies, the development of interdisciplinary and transdisciplinary science should also consider the nested, hierarchical structures of processes as depicted in Fig. 1. During the three workshops of TSUNAGARI, we discussed the most plausible ways of integration across different disciplines and across different scales. Many pathways of integrated approaches were discussed, depending on research interests of participants (arrows in the middle parts of Fig. 1) although we recognized that it is virtually impossible to include all the integration into one single study. We thus decided to proceed with listing up partial integration of different combination of interdisciplinary studies and tried to evaluate which approaches are most effective to solve different types of environmental problems (Fig. 2). The integration of social-ecological study both at global and local scales was firstly discussed to be practical and useful (Areas 1 and 3 in Fig. 2, respectively). For the integration of spatial scales, studies can be initiated for both social and ecological systems (Areas 2 and 4 in Fig. 2, respectively). We then started partial collaboration on these subjects, which are explained in the case studies below.

<- Fig. 2

TSUNAGARI Perspective 2: Evaluating the importance of ecosystem connectivity on biodiversity and ecosystem services, and on interactions among different stakeholders within a watershed

The organisms living in natural ecosystems are affected not only by the processes generated within each ecosystem, but also by factors and drivers coming from outside the ecosystems, either by physical, chemical or biological processes (Gregory et al. 1991; Polis et al. 1997; Nakamura et al. 2004). Ecosystem connectivity is especially important for biodiversity in marginal habitats (ecotones) such as riparian forests/grasslands, saltmarshes and estuaries (Fig. 3).

<- Fig. 3

The effects of ecosystem interactions are quite diverse, and multiple types of interactions occur concurrently at different spatial scales (as discussed in the previous section). Along the coastal areas of eastern Hokkaido, Japan, for example, three types of ecosystem interactions are identified that are important in determining ecosystem functions and processes both on land and ocean. At the broadest spatial scale (10-100 km^2), summer sea fog caused by rapid cooling of warm southern monsoon by the cold Oyashio current cools coastal area which is ca. 5 °C cooler than in the inland. The cooling makes the types of forest vegetation and agriculture in this area very specific compared to other part of Hokkaido (Takeuchi et al. 1982; Sawai 1988; Abe 1996; Iyobe et al. 2003). At the medium scale (1-10 km^2), effects of terrestrial land use change from forest to agriculture affects water chemistry of rivers running each watershed, which can ultimately lead to changes in water quality at estuaries and nearshore sea (Mukai et al. 2002; Mukai 2005). Finally, at the smallest scale (< 1 km^2), waterfowl (herons) and fish (salmons) transport marine organic matters (their prey and themselves) to river and terrestrial areas, which locally affects community structure of forest and predatory bird behaviors (Ueno et al. 2006; Kamauchi et al. 2012; Honda et al. 2014). These examples show that land and ocean are ecologically connected by multiple (physical, chemical and biological) processes that operate at various spatial scales.

These interactions among ecosystems are affected by various stressors associated with human activities. One of the best known examples is the problem of sediment and nutrient discharge from watersheds that causes deterioration of marine ecosystems. This is particularly evident in tropical and subtropical regions. In Okinawa, after the reversion to Japan in 1972, extensive agricultural development resulted in a significant increase in sediment discharge to coastal waters, which has caused the degradation of freshwater and coastal ecosystems and biodiversity (Omija 2004). In the Great Barrier Reef (GBR) of Australia, sediment derived from increased erosion associated with beef cattle grazing and discharged via large rivers affect coral status (Bartley et al. 2014). In the northeastern Philippines, combined effects of sediment and nutrient runoff, and water pollution by excess fish aquaculture caused significant losses of seagrass bed and its biodiversity (Tanaka et al. 2014).

Compared to ecosystem connectivity, social connectivity of human communities among different parts of the watershed have been less studied and understood. The patterns of interrelationships among human communities within forest, river basin and coastal areas have been documented in some studies on environmental sociology, as represented by some examples such as the conflict among local communities over water resources in relation to land use change, impacts of intensified agriculture use of land on the water quality and fish catch in the downstream, and the negative effects of overexploitation of salmons in the coastal areas on the river fisheries in the upstream (Just and Natanyahu 2012; Qiu and Turner 2013; Lange et al. 2014). Such conflicts have led to minimal progress on managing sediment and nutrient discharge to the GBR from agriculture despite significant management expenditure (Brodie and Pearson 2016).

One of the difficulties in the study of interactions among different stakeholders in a watershed is that watershed boundaries do not always agree with that of local governmental units, making the co-design of decision-making processes and their co-management difficult to establish. Another problem lies in that fact that a lot of ecosystem goods and services are now transported over long distance regardless of local interactions within a watershed. Before the onset of globalization, it was a common practice by all human communities in coastal zones to carry out both agriculture on land and fisheries in rivers and nearshore seas. In such a case, solutions related to the conflict between land and sea uses could be brought under the consensus within each community. Nowadays, however, agriculture and fisheries (including aquacultures) have been more and more specialized and separated from each other, with different types of stakeholders getting involved in the use of terrestrial and coastal ecosystem services not only for provisioning services but also for cultural services such as leisure and ecotourism uses. Researchers and decision-makers alike still struggle with fully understanding of the implications of such intensified use of the connectivity and functioning of local ecosystems.

In the TSUNAGARI workshops, we discussed how we can plan and conduct studies on ecosystem connectivity taking both social and ecological systems into account. We considered and planned two types of researches with different approaches. The first study conducts social-ecological system surveys by incorporating all the ecological and social components within a local watershed consisting both of terrestrial and marine ecosystems. The second study examines and forecasts changes in ecosystem processes in a watershed based on different scenarios on land/sea use changes by multiple stakeholders. These integrated studies are explained in more detail in the third subsection of the case studies written below.

Case studies in integration

As mentioned above, we initiated several partial integrations between participants with different specialties to build new interdisciplinary and transdisciplinary sciences to achieve our perspective goals. In this section, we present four of these integration efforts via case studies that link different disciplines of social-ecological studies over different scales (Fig. 2), and different types of ecosystems within a region.

1. Linking global-scale analyses of biodiversity and economy

Expansion of human economic activities affect global biodiversity and ecosystem services directly by destroying and altering habitats and indirectly by changing climate. For the latter, many studies have been trying to forecast future changes in biodiversity and ecosystem functions based on the climate scenarios by IPCC (Yara et al. 2012; Beaugrand et al. 2015; Molinos et al. 2016). For the former, recent progress of the global footprint analysis enables us to analyze the effects of global economic activities and trade on biodiversity and various types of ecosystem services such as water, carbon and nitrogen (Hertwich and Peters 2009; Hoekstra and Mekonnen 2012; Galloway et al. 2014; Oita et al. 2016).

Global footprint analysis provides a way to understand which countries are responsible for greater or less environmental impacts in other world regions, such as carbon emissions, nitrogen increase and biodiversity loss. This is based on a global scale analyses of world trade (input-output) data. For the biodiversity footprint, Lenzen et al. (2012) and Moran et al. (2016) showed how seriously the economic activities by the developed countries increase the extinction risk of endangered species in developing countries through habitat loss.

Although an already powerful tool, the current global footprint analysis still has some limitations. First, global analyses of footprints to date have been primarily based on data and statistics collected at national and international levels (such as in world-trade statistics). However, a large variation exists in the spatial patterns of biodiversity, the vulnerability of species to change, available ecosystem services, and economic activities. A resolution at the country-level analyses is thus not fine enough to fully understand the impact of economy on biodiversity loss of each specific area or species. To overcome this point, it is promising to utilize spatially-explicit GIS data of the distribution and abundance of species. A recent study by Moran and Kanemoto (2017) extend their footprint analyses to include GIS data on IUCN red listed species, and successfully depicted the footprints at very fine resolution over the whole globe (Fig. 4). Their analyses clearly showed how much impacts are given to each biodiversity hotspot of the world by which types of specific human activities. Another study quantified the potential loss of species from several taxonomic groups for multiple impacts (climate change, eutrophication, acidification, land and water use) from global trade (Verones et al. 2017), thus showing the consequences of our resource consumption for ecosystems on a global level.

<- Fig. 4

The second problem, which is less appreciated by socioeconomic scientists, is the fact that the indicators useful in evaluating biodiversity and ecosystem service change at fine resolution are still limited in terms of the data type and accuracy for most species and ecosystems. In the studies of global biodiversity footprint mentioned above, the data used were on distribution range and status of threatened species given by IUCN database on red list species (Lenzen et al. 2012; Moran and Kanemoto 2017). Even though it is an excellent example for using the fine-resolution, but broad-extent data on biodiversity, such data are available only for relatively well-studied species (such as mammals and birds). Even for these species, some information is based on non-quantitative observation such as knowledge by local experts. It is especially true for marine species, where large information gaps still exist in the distribution and thus cannot be evaluated adequately by the red list categories.

This problem will be overcome by the collaboration between researchers on footprint analyses and scientists studying species distribution models using the mega-database of biodiversity such as GBIF (www.gbif.org) and OBIS (www.iobis.org). For the marine biodiversity research, recent increase in biodiversity data, and the development of species distribution models will enable us to estimate global biodiversity patterns and its future changes in finer resolution. Indeed, the resolution of the species distribution models of some marine taxa increased from 10 degree latitude/longitude grid in 2010 (Tittensor et al. 2010) to 0.5 degree in 2015 (Klein et al. 2015). By utilizing these fine-resolution data on biodiversity, evaluation of important areas for selecting marine protected areas has already been conducted (Yamakita et al. 2017). It is now ready to carry out spatially explicit analyses of global footprint for more target species, which results will offer valuable information to various stakeholders and decision makers.

2. Linking studies of local practices and global economic analyses

Collaboration of scientists with local stakeholders who actually manage the status of ecosystems are essential to achieve effective conservation of biodiversity and ecosystem services. The practical activities based on “co-design, co-production and co-management” have been ongoing and the international research community promotes such efforts under the name of “transdisciplinary research” (Lang et al. 2012; Brandt et al. 2013).

One such transdisciplinary research framework has been established to achieve sustainable use of marine ecosystem services in coastal areas of Asia, named as “Area Capability Cycle (ACC)” (Ishikawa and Watanabe 2015). In this study, scientists collaborate with local stakeholders such as fishermen and managers in local governments first by transferring knowledge on values of natural capitals and ecosystem services, and then discuss and determine effective and efficient methods of economic activities for sustainable use of ecosystem services by round-table meetings. Established plans are to be executed in the real field with PDCA (plan-do-check-act) cycle, which will facilitate the conservation of biodiversity and ecosystems, as well as the sustainable use of ecosystem services by the stakeholders concurrently (Fig. 5).

<- Fig. 5

One successful case study of ACC is found in a fishery community of Rayong, Gulf of Thailand. Here, traditional small-scale fisheries have long been conducted by individual fishers, which sometimes lead to overexploitation of some specific resources, and to low yield despite long operation time. However, after an ecological assessment of fish stocks (status of provisioning services) by scientists, local fishers changed their fishery practices to conduct a large stationary net fishery by group operation, which resulted in more yield in less operation time (i.e., more income in more sustainable way). The new practice also enhanced communication (good relationship) among fishers and their responsibility to manage the sustainable ecosystem services (Ishikawa et al. 2015).

However, it remained unknown whether the established sustainable fishery was in fact “environmental-friendly” in terms of consumption of materials and energy. For example, if a new fisheries practice uses more materials from the world and if it emits more CO_2 to the atmosphere, it may not sustainable in terms of climate impacts and sustainable economy at global level. To examine this point, Life Cycle Assessment (LCA) can be a powerful tool. LCA examines how each economic activity consumes material and energy, and releases emissions. It evaluates the environmental performance of a system throughout its global supply chain, by taking several impacts on human health and ecosystem quality simultaneously into account (e.g. climate change, resource depletion, eutrophication, human and ecotoxicity, etc.) (ISO 2006). In the case of the Thai fisheries, LCAs of different types of fisheries were carried out, including data on local fishing gear, fuel consumption of each fishery expedition (estimated by a GIS-track of each fishing boat), yields and their market price. Preliminary analyses showed that materials for constructing boats, engines and fishery gears of Thai fisheries mostly came from EU through global supply chains. Furthermore, the emission of CO_2 and other wastes did not only differ among different fishery practice, but also among different seasons of the year due to changes in fishery grounds with monsoon conditions, which made assessment of environmental impact complex (Verones et al. under review).

Use of combined ACC and LCA is thus found promising to evaluate whether good practices developed by stakeholders and scientists are not only sustainable within local community, but also environmentally less impacted in terms of global energy consumption and emission of wastes (including CO_2). If the investigated practices are judged as environmentally more sustainable, it will further enhance motivations of local community to promote more sustainable local economic activities, considering conservation of biodiversity and ecosystem services. In contrast, when LCA gives worse scores to current fishery practices, it may give the community an opportunity to reevaluate their current practices toward better decision making based on scientific data.

3. Linking local-scale ecosystem studies to decision making processes by multiple stakeholders

As mentioned in the above section, good communication among scientists and stakeholders based on precise scientific information is a key to achieve successful conservation of biodiversity and sustainable use of ecosystem services. A bigger challenge comes when different types of stakeholders co-exist who wish to use multiple ecosystem services in different ways, and when they are in conflict over the use of these services. In the cases of coastal ecosystems, for example, it is commonly observed that local commercial fishers who use marine habitats for their yield (provisioning services) have conflicts with tourism sectors who offer various types of leisure activities to holiday visitors such as angling, boating and SCUBA diving (cultural services).

The integration of ecological studies and sociological studies with participation of stakeholders can be a promising way to understand how the conflicts among stakeholders are generated based on different uses of multiple ecosystem services. One of such integrated studies has been recently initiated by linking ecosystem functions, ecosystem services and their use by multiple stakeholders for eelgrass beds in Japan (Tajima et al. 2015). In their approaches, they depicted the interrelationship among these components by listing up all the different types of ecosystem functions and services from eelgrass beds, and linking these categories with different types of stakeholders and their economic activities based on intensive social surveys (interviewing and questionnaire surveys to local scientists and different types of stakeholders) (Fig. 6, see Tajima et al. 2015 for the detailed methods). Through the comparisons among different regions of Japan, they found that types of stakeholders involved in the use of eelgrass beds, as well as the strength of their interactions were different, depending on the regional variation in fisheries and other economic activities (Tajima et al. 2015). Once the direction (either positive or negative) and the intensity of interrelationships between ecosystem services and stakeholders are clarified, it will help decision makers such as local governments and environmental committees to look for solutions to reduce conflicts among stakeholders.

<- Fig. 6

These approaches can be extended to the management of terrestrial and coastal ecosystems within a watershed by multiple stakeholders (in our second perspective). One of the most commonly observed cases is the conflict between farmers in the upper stream and fishers in coastal areas within the same watershed where the changes in land use for agriculture are claimed to be the causes for the reduction of marine resources through deterioration of water quality via input from rivers (Diaz and Rosenberg 2009; Vitousek et al. 2009; Paerl et al. 2014). To look for the solution by agreements of farmers and fishers, first requirement is to carry out quantitative assessment on the effects of land use changes on water quality of rivers and coastal areas.

In the case of sediment and nutrient discharge to coral reefs, relevant case studies for integrated environmental management based on a consideration for catchment-to-reef continua was conducted in Okinawa of Japan (Yamano et al. 2015) and in the Great Barrier Reef of Australia (Brodie et al. 2012; Thorburn et al., 2013; Waterhouse et al. 2016). In Okinawa, a framework to integrate biophysics and socioeconomics, by setting a conservation target and threshold, identifying the sources and processes, and examining cost-effectiveness and management priorities was established and applied to Kume Island (Yamano et al., 2015). The project resulted in initiating measures to prevent sediment discharge from sugarcane fields with local government, NPO and farmers. In the GBR, the series of the studies showed the Australian and Queensland governments responded to pollution concerns from watershed runoff by developing an integrated plan to address this issue in 2003. Incentive-based voluntary management initiatives were introduced in 2007, and a State regulatory approach was implemented in 2009 (Brodie et al. 2012). However inadequate funding and reluctance to enforce regulations led to limited progress in reducing loads of sediment and nutrients discharged to the GBR (Brodie and Pearson 2016). The partial failure of this initiative showed the necessity of strong enforcement of the regulatory regime in combination with voluntary mechanisms for success.

The recent development of computer-intensive modelling of the dynamics both for terrestrial and marine ecosystems can examine how the changes in land and sea uses and farming and fishery practices can alter ecosystem services. Linking these terrestrial and marine ecosystem models would be useful to evaluate quantitatively how the change in land can alter the status of coastal ecosystems and the provisioning services such as fish and aquaculture yield. The output from such combined models on the land-ocean connectivity will be helpful to understand where the critical problems are located, and to establish agreements among different types of stakeholders such as to set regulations on agriculture and fishery options to retain sustainable ecosystem services.

4. Linking local-scale analyses of ecosystem processes to broad-scale analyses of ecosystem patterns

A variety of tools, including remote sensing, GIS and simulation models are now available to monitor, evaluate and forecast ecosystem functions and services at small spatial scales, such as within a watershed as shown in the previous section. By establishing GIS-based ecological databases, it is now possible to map the economic value of multiple ecosystem services (Bateman et al. 2013). For example, methods of physical dimension measurement and monetary evaluation were used to evaluate and map the spatial patterns of 11 ecosystem services in the middle-lower Yangtze River watershed, China (Li et al. 2014). This research confirms the irreplaceable role of wetlands in this watershed and identifies the core wetlands and ecosystem services from a socio-economic perspective. The value of human-made wetlands is 48% lower than that from natural wetlands, which reflects that conversion of natural wetlands for aquaculture makes no sense from the sustainability perspective. In another study conducted at Laizhou Bay, a very typical coastal ecosystem in China, Li et al. (2016) analyzed the temporal and spatial changes in the value of 22 different types of ecosystem services (6 provisioning services, 9 regulating services, 5 cultural services and 2 supporting services) and found that 43% decrease in ecosystem services value in this region during 2000 to 2014 (Fig. 7). The ecosystem service values of water supply, waste treatment, nursery service, genetic diversity, disturbance moderation, erosion prevention were lost seriously due to the loss of coastal wetlands for the expansion of the construction land and urban land. Land use change may seem economically profitable. However, due to the losing of ecosystem services such as regulating or supporting services, the imbalance in ecosystem services would impact the human well-being and socio-economic development. Policy making should consider imbalance in ecosystem service, protect regional ecosystem services function and maintain its stability.

<- Fig. 7

Such GIS-based, fine-resolution analyses of ecosystem services can be applicable only for limited areas where enough information of ecology and economy is available. When we need to evaluate the ecosystem service values at broader-scale (e.g., along the whole coast of Japan and China), we still need to rely on coarse-grain remote sensing data that can cover wider area, and statistical data on economy and human population status summarized for each local governmental unit. For example, using large-scale multi-resource data along the mainland coasts of China (approximately 18,000 km) since the early 1940s, Hou et al. (2016a) showed that due to the significant coastline artificialization mainly driven by sea reclamation and coastal engineering, the remaining natural coastline accounts for less than one third in 2014. More thoroughly monitoring on recent changes of land use and wetland in coastal

China revealed that coastal land use and wetland changed acutely from 2000 to 2010, resulting in the decrease of natural coastal wetland from 9956 km^2 to 3288 km^2, whereas the increase of artificial wetland by 2592 km^2 (Hou et al. 2016b). Overall, the obtained results of these studies showed drastic changes in the coastal zone of China which can be used to set the baseline for the management purposes.

The integration of studies conducted at these two different spatial scales would be worthwhile to extrapolate our findings to unstudied area where fine-resolution data are insufficient, and to estimate the fine-scale processes at broader extent which is, in most cases, practically impossible due to limitation in financial supports and manpower.

One of the prospect approaches for the integration of studies conducted at different spatial scale have been proposed (e.g., Ghermandi and Nunes 2013), which should be carried out by the following steps. First, select some representative sites covering in different environmental and human socioeconomical conditions. Second, construct a database of ecosystem service status in selected sites by a variety of methods, e.g., literature and report surveys, field surveys of ecology and local human community. Third, conduct statistical analyses to determine key relationships between ecosystem services and human activities along some major environmental gradients. Fourth, extrapolate the focal ecosystem services to broader-scale study area using the relationship obtained in the previous steps and the broader scale spatial data built upon GIS. Finally, validate the extrapolated patterns by field serveys in some unstudied sites, and feedback the results to improve the model prediction. By repeating these processes, we can obtain clearer broad-scale, fine-resolution patterns of biodiversity and ecosystem services with modest costs, which will offer more criteria for decision making to enhance sustainable ecosystem serivce uses by multiple stakeholders and decision-makers in various parts of each country.

Concluding remarks: Major gaps and challenges

Based on our project perspectives, we introduced here some ongoing studies by new interdisciplinary and transdisciplinary collaborations toward conservation of biodiversity and sustainable use of ecosystem services that are threatened by various stressors operating at global and local scales. The integration of ecological and socioeconomic studies across various spatial scales is promising to produce fruitful outputs which will be useful to solve problems practitioners and stakeholders are facing. However, it is still unknown to what extent our proposed approaches can be applicable to various cases in the world.

During the three workshops in 2015 and 2016, we found many gaps which can inhibit to achieve our ultimate goals of collaboration. Firstly, biological and ecological data on biodiversity and ecosystem services, as well as data on human utilization and awareness of ecosystem services, are still lacking in many areas of Asia, especially in developing countries. Take marine biodiversity data, for example, species distribution models predict the hotspot of biodiversity in the coral triangle area (the Philippines, Indonesia and Papua New Guinea), whereas actual data in global databases like OBIS and GBIF from these countries are far less than those from other countries like Japan, Korea and China. More systematic approaches are needed to be established to fill the biological and socioeconomic information gap in Asia

Secondly, there may be a gap in our knowledge of the ecological and social processes among different types of ecosystems and habitats, e.g. among forests, plains, freshwater and marine systems. Our projects mainly focused on coastal zones, which are influenced by both terrestrial and marine ecosystem dynamics and where human is most densely populated in the world. However, other types of habitats like inland forests, arid areas and offshore oceanic islands will require adapted approaches. Basic integration, such as coupling of local data to LCA studies and further upscaling to global impact studies via trade models work in principle for all ecosystem types, however, the data required and the fine-tuning of the models needs to be performed individually. Comparative approaches covering different types of ecosystems are therefore worthwhile, in order to examine this further.

Thirdly, we still recognize gaps in types of stakeholders to be involved in the transdisciplinary studies. So far, stakeholders in local communities have been well considered such as the local fishers in Thailand of our ACC study. However, it is difficult to specify and invite broader-scale stakeholders such as governors in provinces and countries, as well as those responsible for international decision making. We already know that major stakeholders who are responsible for the decline in global biodiversity are consumers in developed countries (Lenzen et al. 2012). We still do not have any established methodologies to effectively collaborate with such indirect and remote stakeholders in the transdisciplinary science. Linking our sciences to the study on multigovernnance, i.e., nested, hierarchical structure of decision-making processes covering international, national and local politics, would be a next step to fill up these gaps.

Finally and most importantly, there is still uncertainty in how we can link our integrated approach to future scenario buildings. Our global economic analyses such as global footprint analyses and LCA are very useful to elucidate the impacts of current human-induced stresses on biodiversity and ecosystem services. However, by themselves, we cannot predict any future changes. For the side of ecological study, future changes in biodiversity are predicted for many types of organisms based on IPCC climate scenarios (Beaugrand et al. 2015; Molinos et al. 2016). Similarly, future scenarios on economy and governance have been established and increasing (Hunt et al. 2012). These climate and economy scenarios can be used jointly to predict future changes in biodiversity and ecosystem services although the caution should be made about the difference in target times between most climate change models (usually targeting 2100) and economy models (usually targeting 2030-50). As in spatial-scale dependency of social-ecological systems discussed in our first perspective, target temporal scales also vary among different subjects on environmental studies, which integration should be investigated in future research.

To fill such gaps by developing more effective approaches, we can move forward to establish new integration of solution-based scicences which are currently under development by various scientific and policy-making organizations in the world. We are hoping that our first attempts to link different fields of science and practitioners will lead to more intensive collaborations that are not only useful but also stimulative and exciting.

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Figure captions

Fig. 1 TSUNAGARI perspective 1. Integration in social-ecological studies at various spatial scales

Fig. 2 TSUNAGARI perspective 2. Cross-ecosystem integration in both ecological and socioeconomic studies

Fig. 3 Areas of case studies on partial integration of the TSUNAGARI perspectives. Horizontal and vertical axes showing the direction of integration presented in Fig. 1. Four areas of integration are explained in each subsection of the main text.

Fig. 4 Spatially explicit analysis of global biodiversity footprint showing global hotspots of species threat linked to consumption in the European Union. Darker colors (red on land, and blue to green in coastal sea) indicate areas of hotspots more threatened by EU consumption. See Moran and Kanemoto (2017) for the details.

Fig. 5 Diagram showing Area Capability Cycle (ACC) for the case of community-based set-net fisheries in Thailand local fishery village. A new fishery practice (starting the set-net fishery by the local community SEAFDC, indicated by the yellow box), which was more effective in utilization of the resources than traditional fisheries, was established by the more concern and care for ecosystem health by the local community (indicated by yellow thick lines). The initial interaction between resources and local community was motivated and driven by the hopes and prides of local community (indicated by a red box and black allows), which brought positive feedbacks for the expansion of better practices, new skills and industries (indicated by blue arrows and while boxes). Figure redrawn from Ishikawa et al. (2015) with permission.

Fig. 6 Diagram showing relationships among ecosystem functions (in round shape), ecosystem services, and their use by different sectors of stakeholders for an eelgrass bed in Japan. P: Provisioning services, R: regulating services, C: cultural services and S: Supporting services. See text for more detailed information about how this diagram was made. Diagram modified based on Tajima et al. (2015).

Fig. 7 Changes in economic value of ecosystem services between 2000 and 2014 analyzed for Laizhou Bay Coastal Zone, China. See Li et al. (2016) for the details.

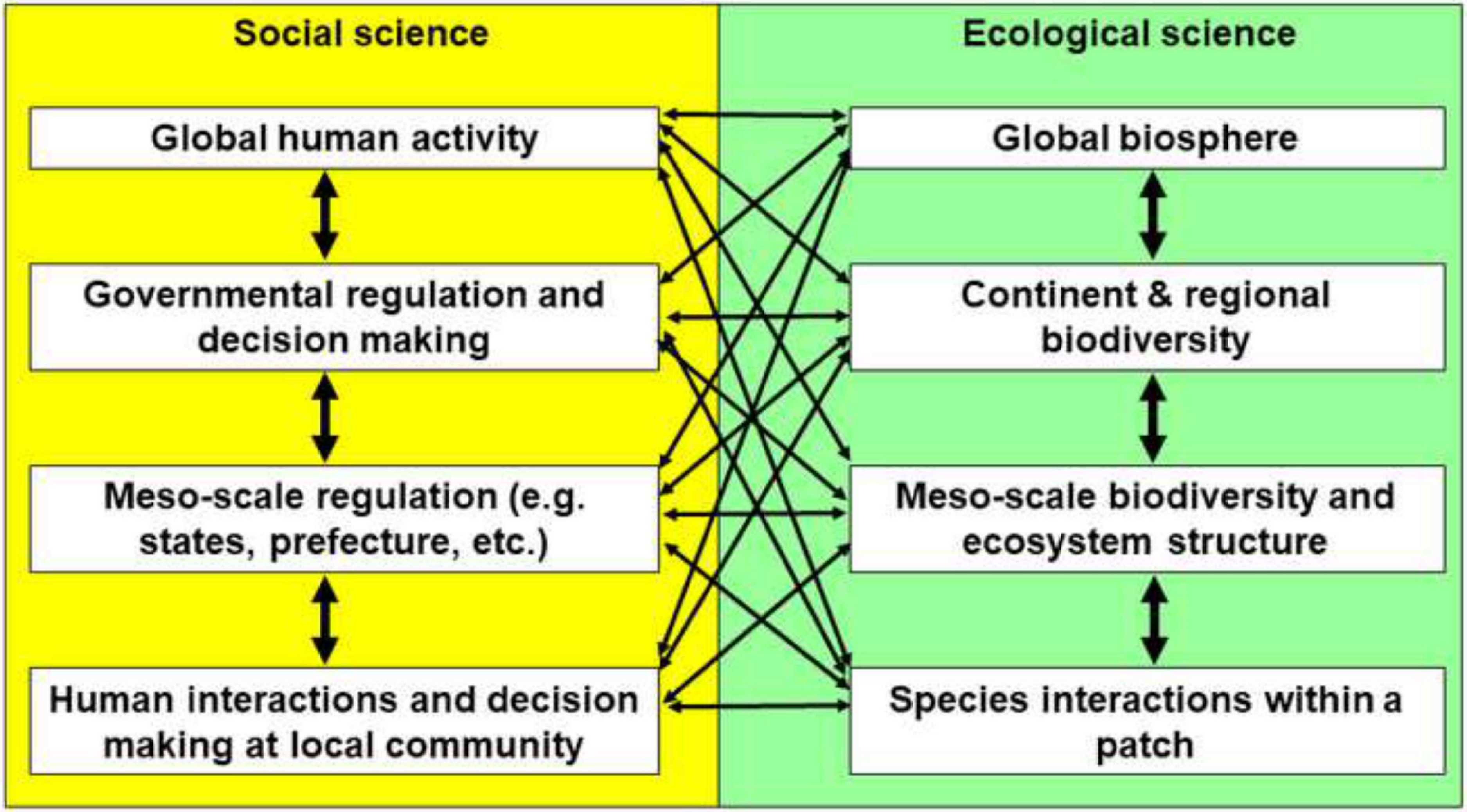
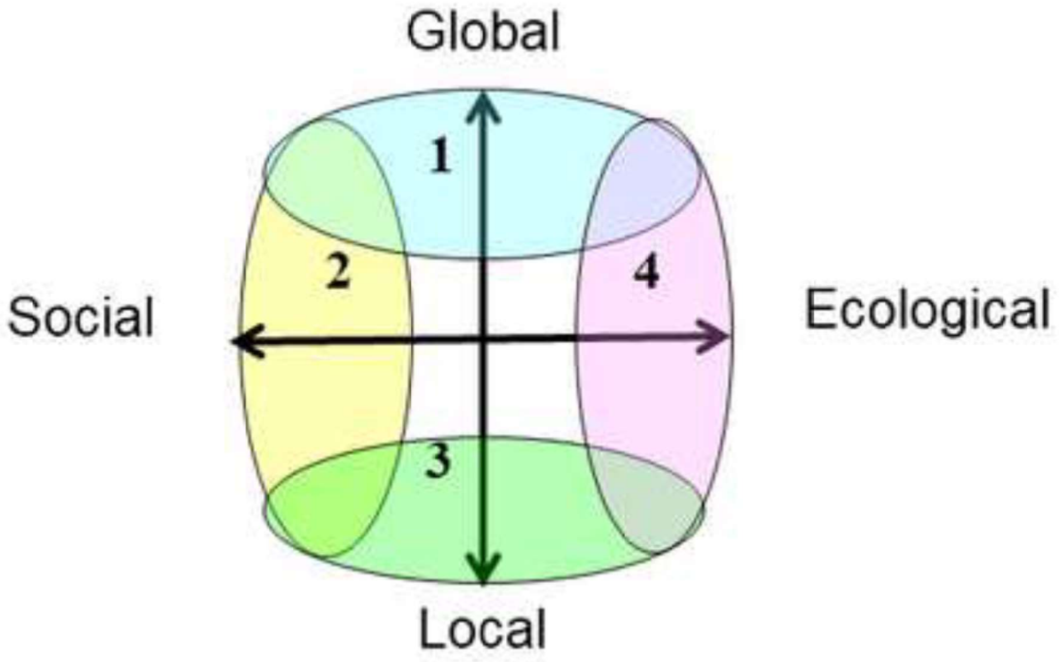


Fig. 1 (Nakaoka et al.)



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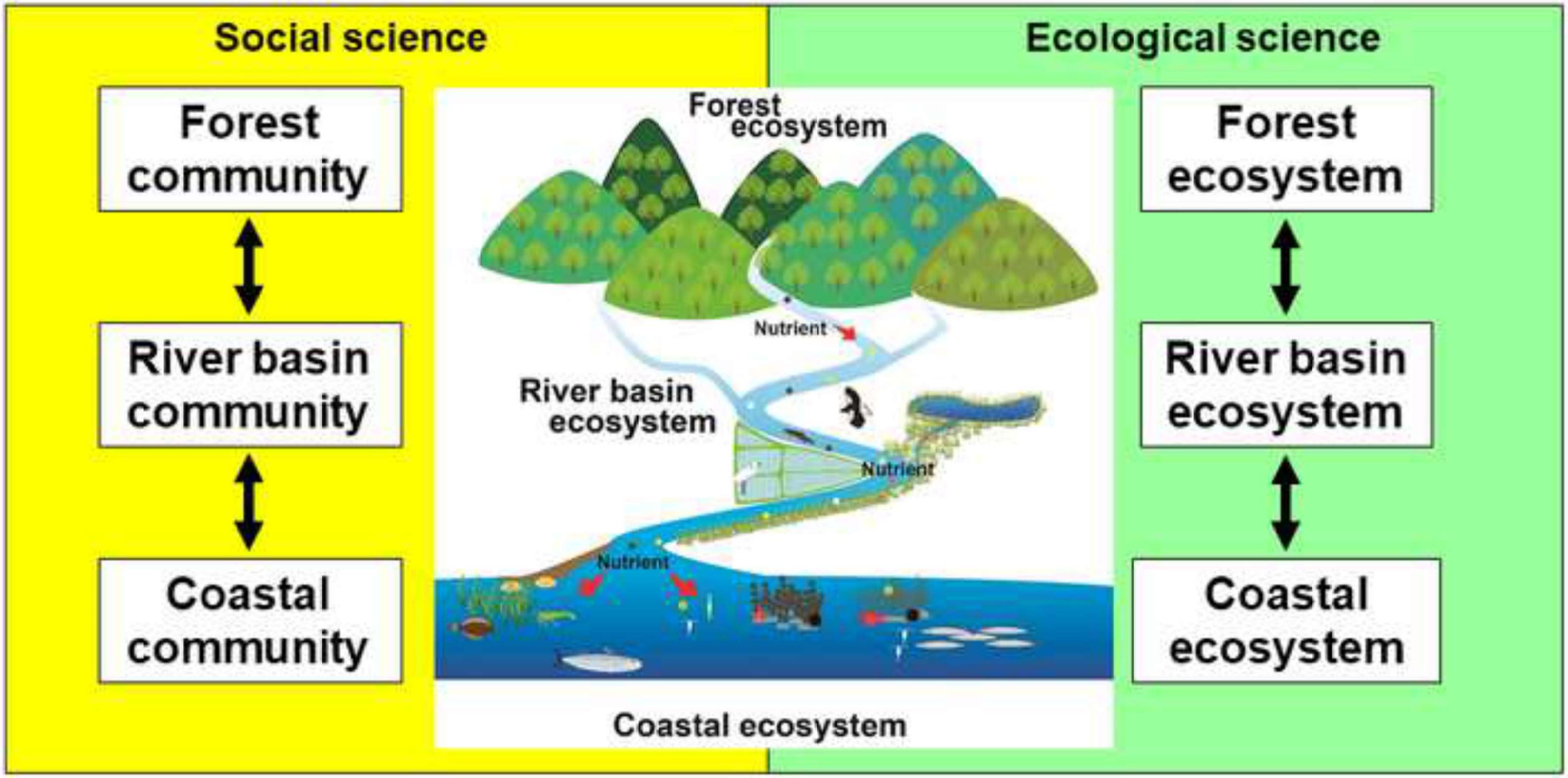
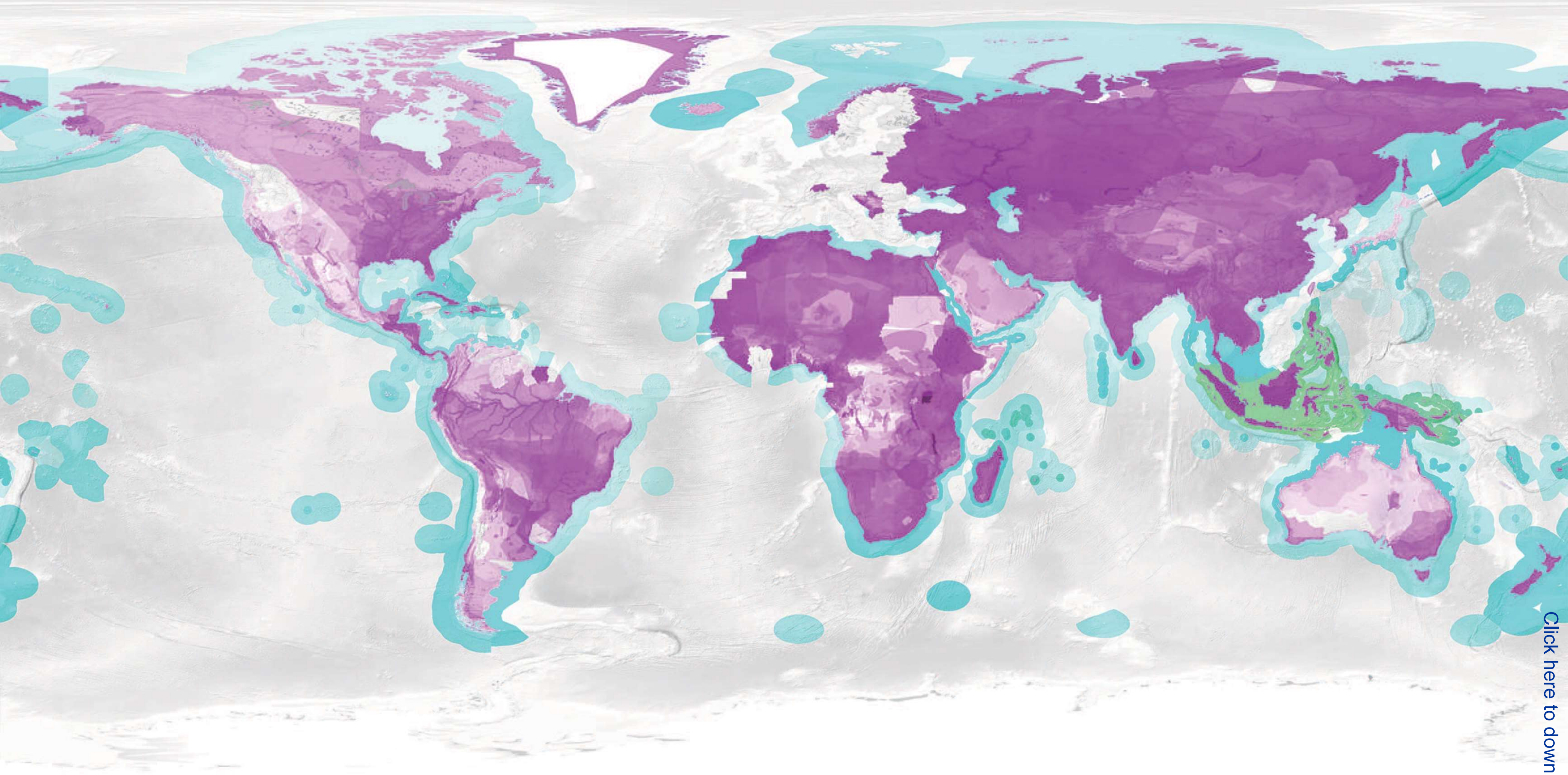


Fig. 3 (Nakaoka et al.)

Fig. 4



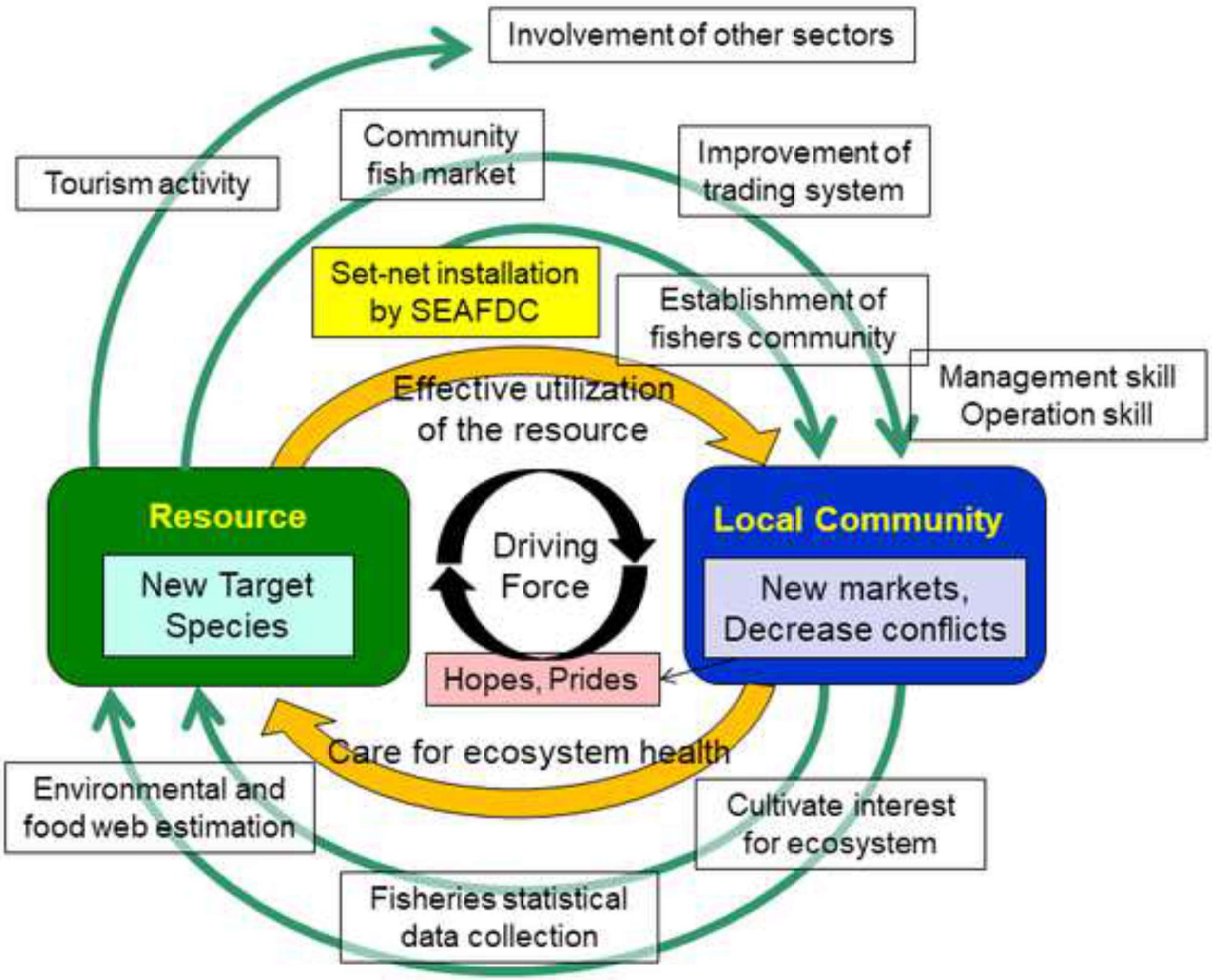


Fig. 5 (Nakaoka et al.)

Fig. 6

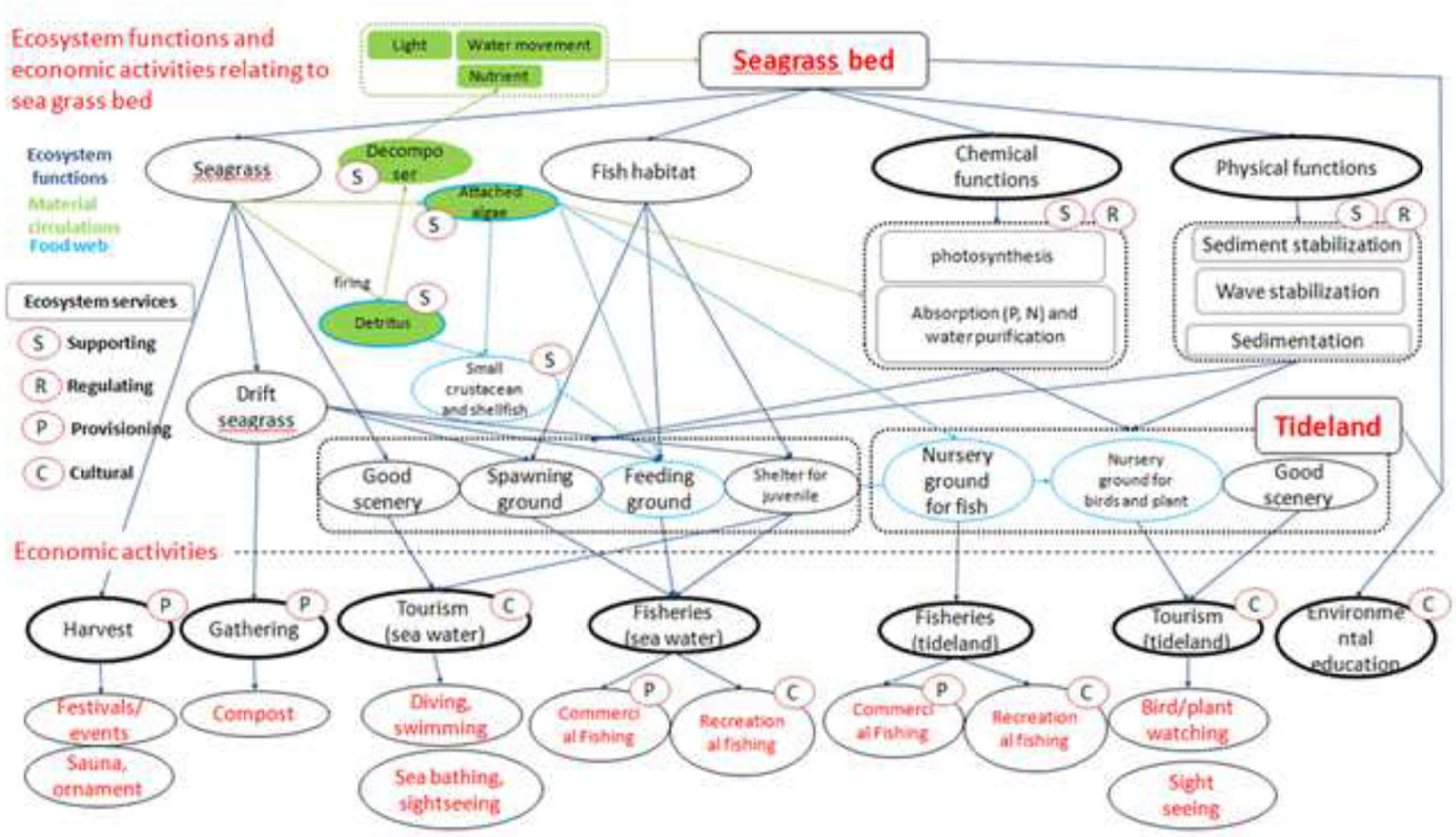


Fig. 6 (Nakaoka et al.)

Fig. 7

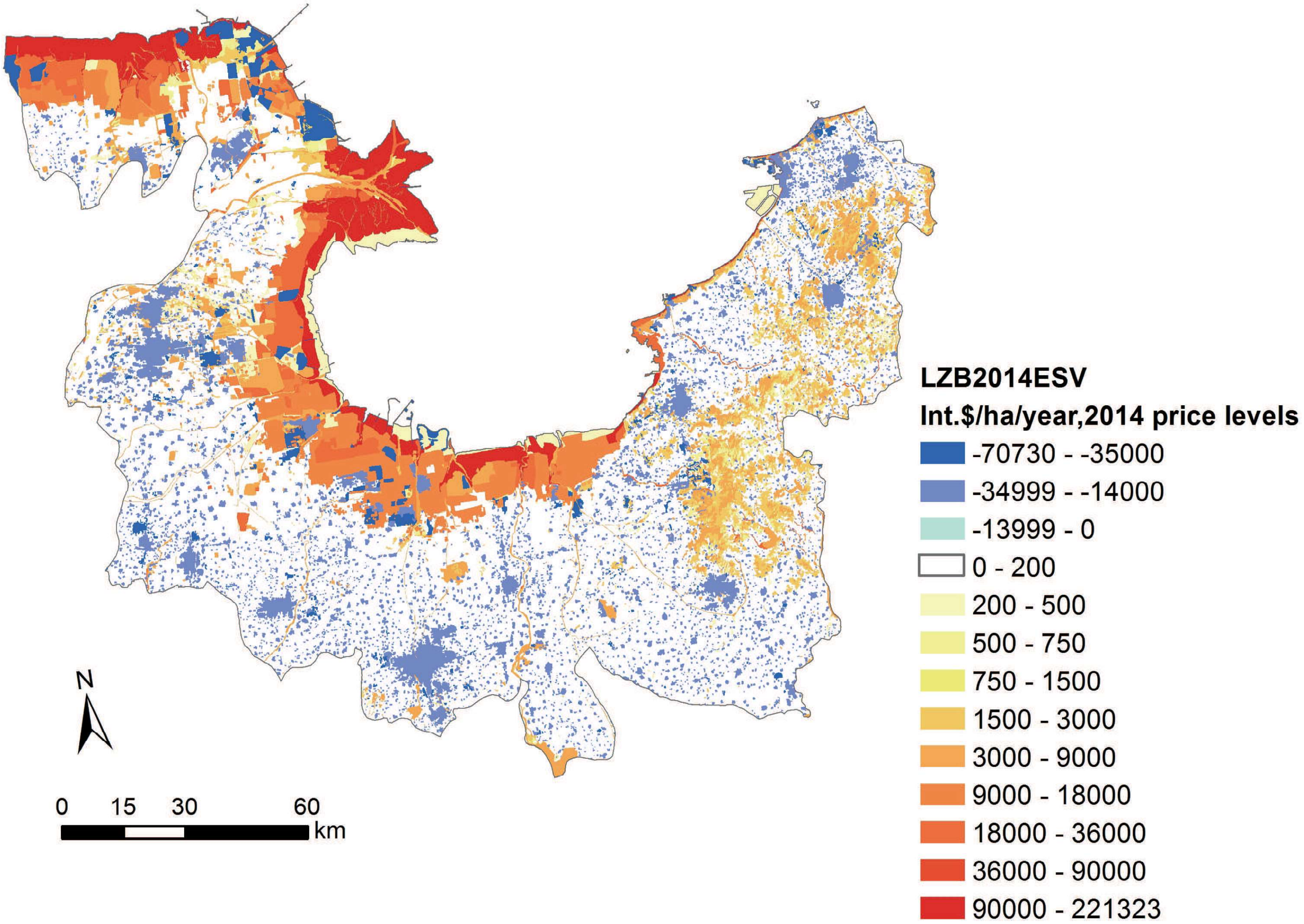


Fig. 7 (Nakaoka et al.)