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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).

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

184 highlighted the multiple scale issues causing nonlinear, complicated dynamics of ecosystems
185 (Peterson and Parker 1998; Noda 2004; Yamakita et al. 2011).

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

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

208 dynamics even in a small village. Thus, the analyses of regional research elucidating local
209 decision-making processes should be linked with global economic analyses.
210 As multi-spatial scale issues are prominent both in ecological and social studies, the
211 development of interdisciplinary and transdisciplinary science should also consider the nested,
212 hierarchical structures of processes as depicted in Fig. 1. During the three workshops of
213 TSUNAGARI, we discussed the most plausible ways of integration across different
214 disciplines and across different scales. Many pathways of integrated approaches were
215 discussed, depending on research interests of participants (arrows in the middle parts of Fig.
216 1) although we recognized that it is virtually impossible to include all the integration into one
217 single study. We thus decided to proceed with listing up partial integration of different
218 combination of interdisciplinary studies and tried to evaluate which approaches are most
219 effective to solve different types of environmental problems (Fig. 2). The integration of
220 social-ecological study both at global and local scales was firstly discussed to be practical and
221 useful (Areas 1 and 3 in Fig. 2, respectively). For the integration of spatial scales, studies can
222 be initiated for both social and ecological systems (Areas 2 and 4 in Fig. 2, respectively). We
223 then started partial collaboration on these subjects, which are explained in the case studies
224 below.
225
226 **TSUNAGARI Perspective 2: Evaluating the importance of ecosystem connectivity on**
227 **biodiversity and ecosystem services, and on interactions among different stakeholders**
228 **within a watershed**
229
230 The organisms living in natural ecosystems are affected not only by the processes generated
231 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).

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 ^oC 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

304 our perspective goals. In this section, we present four of these integration efforts via case
305 studies that link different disciplines of social-ecological studies over different scales (Fig. 2),
306 and different types of ecosystems within a region.
307
308 1. Linking global-scale analyses of biodiversity and economy
309
310 Expansion of human economic activities affect global biodiversity and ecosystem services
311 directly by destroying and altering habitats and indirectly by changing climate. For the latter,
312 many studies have been trying to forecast future changes in biodiversity and ecosystem
313 functions based on the climate scenarios by IPCC (Yara et al. 2012; Beaugrand et al. 2015;
314 Molinos et al. 2016). For the former, recent progress of the global footprint analysis enables
315 us to analyze the effects of global economic activities and trade on biodiversity and various
316 types of ecosystem services such as water, carbon and nitrogen (Hertwich and Peters 2009;
317 Hoekstra and Mekonnen 2012; Galloway et al. 2014; Oita et al. 2016).
318 Global footprint analysis provides a way to understand which countries are responsible
319 for greater or less environmental impacts in other world regions, such as carbon emissions,
320 nitrogen increase and biodiversity loss. This is based on a global scale analyses of world trade
321 (input-output) data. For the biodiversity footprint, Lenzen et al. (2012) and Moran et al.
322 (2016) showed how seriously the economic activities by the developed countries increase the
323 extinction risk of endangered species in developing countries through habitat loss.
324 Although an already powerful tool, the current global footprint analysis still has some
325 limitations. First, global analyses of footprints to date have been primarily based on data and
326 statistics collected at national and international levels (such as in world-trade statistics).
327 However, a large variation exists in the spatial patterns of biodiversity, the vulnerability of

328 species to change, available ecosystem services, and economic activities. A resolution at the
329 country-level analyses is thus not fine enough to fully understand the impact of economy on
330 biodiversity loss of each specific area or species. To overcome this point, it is promising to
331 utilize spatially-explicit GIS data of the distribution and abundance of species. A recent study
332 by Moran and Kanemoto (2017) extend their footprint analyses to include GIS data on IUCN
333 red listed species, and successfully depicted the footprints at very fine resolution over the
334 whole globe (Fig. 4). Their analyses clearly showed how much impacts are given to each
335 biodiversity hotspot of the world by which types of specific human activities. Another study
336 quantified the potential loss of species from several taxonomic groups for multiple impacts
337 (climate change, eutrophication, acidification, land and water use) from global trade (Verones
338 et al. 2017), thus showing the consequences of our resource consumption for ecosystems on a
339 global level.

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

351 This problem will be overcome by the collaboration between researchers on footprint
352 analyses and scientists studying species distribution models using the mega-database of
353 biodiversity such as GBIF (www.gbif.org) and OBIS (www.iobis.org). For the marine
354 biodiversity research, recent increase in biodiversity data, and the development of species
355 distribution models will enable us to estimate global biodiversity patterns and its future
356 changes in finer resolution. Indeed, the resolution of the species distribution models of some
357 marine taxa increased from 10 degree latitude/longitude grid in 2010 (Tittensor et al. 2010) to
358 0.5 degree in 2015 (Klein et al. 2015). By utilizing these fine-resolution data on biodiversity,
359 evaluation of important areas for selecting marine protected areas has already been conducted
360 (Yamakita et al. 2017). It is now ready to carry out spatially explicit analyses of global
361 footprint for more target species, which results will offer valuable information to various
362 stakeholders and decision makers.
363
364 2. Linking studies of local practices and global economic analyses
365
366 Collaboration of scientists with local stakeholders who actually manage the status of
367 ecosystems are essential to achieve effective conservation of biodiversity and ecosystem
368 services. The practical activities based on "co-design, co-production and co-management"
369 have been ongoing and the international research community promotes such efforts under the
370 name of "transdisciplinary research" (Lang et al. 2012; Brandt et al. 2013).
371 One such transdisciplinary research framework has been established to achieve
372 sustainable use of marine ecosystem services in coastal areas of Asia, named as "Area
373 Capability Cycle (ACC)" (Ishikawa and Watanabe 2015). In this study, scientists collaborate
374 with local stakeholders such as fishermen and managers in local governments first by

375 transferring knowledge on values of natural capitals and ecosystem services, and then discuss
376 and determine effective and efficient methods of economic activities for sustainable use of
377 ecosystem services by round-table meetings. Established plans are to be executed in the real
378 field with PDCA (plan-do-check-act) cycle, which will facilitate the conservation of
379 biodiversity and ecosystems, as well as the sustainable use of ecosystem services by the
380 stakeholders concurrently (Fig. 5).

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

390 However, it remained unknown whether the established sustainable fishery was in fact
391 "environmental-friendly" in terms of consumption of materials and energy. For example, if a
392 new fisheries practice uses more materials from the world and if it emits more CO_2 to the
393 atmosphere, it may not sustainable in terms of climate impacts and sustainable economy at
394 global level. To examine this point, Life Cycle Assessment (LCA) can be a powerful tool.
395 LCA examines how each economic activity consumes material and energy, and releases
396 emissions. It evaluates the environmental performance of a system throughout its global
397 supply chain, by taking several impacts on human health and ecosystem quality
398 simultaneously into account (e.g. climate change, resource depletion, eutrophication, human

399 and ecotoxicity, etc.) (ISO 2006). In the case of the Thai fisheries, LCAs of different types of
400 fisheries were carried out, including data on local fishing gear, fuel consumption of each
401 fishery expedition (estimated by a GIS-track of each fishing boat), yields and their market
402 price. Preliminary analyses showed that materials for constructing boats, engines and fishery
403 gears of Thai fisheries mostly came from EU through global supply chains. Furthermore, the
404 emission of CO_2 and other wastes did not only differ among different fishery practice, but
405 also among different seasons of the year due to changes in fishery grounds with monsoon
406 conditions, which made assessment of environmental impact complex (Verones et al. under
407 review).

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

417

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

420

421 As mentioned in the above section, good communication among scientists and stakeholders
422 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.

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

471 the necessity of strong enforcement of the regulatory regime in combination with voluntary
472 mechanisms for success.

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

482

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

485

486 A variety of tools, including remote sensing, GIS and simulation models are now available to
487 monitor, evaluate and forecast ecosystem functions and services at small spatial scales, such
488 as within a watershed as shown in the previous section. By establishing GIS-based ecological
489 databases, it is now possible to map the economic value of multiple ecosystem services
490 (Bateman et al. 2013). For example, methods of physical dimension measurement and
491 monetary evaluation were used to evaluate and map the spatial patterns of 11 ecosystem
492 services in the middle-lower Yangtze River watershed, China (Li et al. 2014). This research
493 confirms the irreplaceable role of wetlands in this watershed and identifies the core wetlands
494 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.

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

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

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

528 One of the prospect approaches for the integration of studies conducted at different
529 spatial scale have been proposed (e.g., Ghermandi and Nunes 2013), which should be carried
530 out by the following steps. First, select some representative sites covering in different
531 environmental and human socioeconomical conditions. Second, construct a database of
532 ecosystem service status in selected sites by a variety of methods, e.g., literature and report
533 surveys, field surveys of ecology and local human community. Third, conduct statistical
534 analyses to determine key relationships between ecosystem services and human activities
535 along some major environmental gradients. Fourth, extrapolate the focal ecosystem services
536 to broader-scale study area using the relationship obtained in the previous steps and the
537 broader scale spatial data built upon GIS. Finally, validate the extrapolated patterns by field
538 serveys in some unstudied sites, and feedback the results to improve the model prediction. By
539 repeating these processes, we can obtain clearer broad-scale, fine-resolution patterns of
540 biodiversity and ecosystem services with modest costs, which will offer more criteria for
541 decision making to enhance sustainable ecosystem serivce uses by multiple stakeholders and
542 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

567 islands will require adapted approaches. Basic integration, such as coupling of local data to
568 LCA studies and further upscaling to global impact studies via trade models work in principle
569 for all ecosystem types, however, the data required and the fine-tuning of the models needs to
570 be performed individually. Comparative approaches covering different types of ecosystems
571 are therefore worthwhile, in order to examine this further.

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

583 Finally and most importantly, there is still uncertainty in how we can link our
584 integrated approach to future scenario buildings. Our global economic analyses such as global
585 footprint analyses and LCA are very useful to elucidate the impacts of current human-induced
586 stresses on biodiversity and ecosystem services. However, by themselves, we cannot predict
587 any future changes. For the side of ecological study, future changes in biodiversity are
588 predicted for many types of organisms based on IPCC climate scenarios (Beaugrand et al.
589 2015; Molinos et al. 2016). Similarly, future scenarios on economy and governance have been
590 established and increasing (Hunt et al. 2012). These climate and economy scenarios can be

591 used jointly to predict future changes in biodiversity and ecosystem services although the
592 caution should be made about the difference in target times between most climate change
593 models (usually targeting 2100) and economy models (usually targeting 2030-50). As in
594 spatial-scale dependency of social-ecological systems discussed in our first perspective, target
595 temporal scales also vary among different subjects on environmental studies, which
596 integration should be investigated in future research.

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

602

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614 **References**

615 Abe S (1996) Meteorological characteristic of Kushiro region. Saihyo 42: 91-94

616 Bartley R, Bainbridge ZT, Lewis SE, Kroon FJ, Wilkinson SN, Brodie JE, Silburn DM (2014)
617 Relating sediment impacts on coral reefs to watershed sources, processes and
618 management: A review. Sci Total Environ 468-469: 1138-1153. doi:
619 10.1016/j.scitotenv.2013.09.030

620 Bateman IJ, Harwood AR, Mace GM, Watson RT, Abson DJ, Andrews B, Fezzi C (2013)
621 Bringing ecosystem services into economic decision-making: land use in the United
622 Kingdom. Science 341: 45-50. doi: 10.1126/science.1234379

623 Beaugrand G, Edwards M, Raybaud V, Goberville E, Kirby RR (2015) Future vulnerability of
624 marine biodiversity compared with contemporary and past changes. Nat Clim Chang 5:
625 695-701. doi: 10.1038/nclimate2650

626 Brandt P, Ernst A, Gralla F, Luederitz C, Lang DJ, Newig J, Reinert F, Abson DJ, von
627 Wehrden H (2013) A review of transdisciplinary research in sustainability science. Ecol
628 Econ 92: 1-15. doi: 10.1016/j.ecolecon.2013.04.008

629 Briggs JC (1995) Global biogeography. Elsevier, Amsterdam

630 Brodie JE, Kroon FJ, Schaffelke B, Wolanski EC, Lewis SE, Devlin MJ, Bohnet IC,
631 Bainbridge ZT, Waterhouse J, Davis AM (2012) Terrestrial pollutant runoff to the Great
632 Barrier Reef: an update of issues, priorities and management responses. Mar Pollut Bull
633 65: 81-100. doi: 10.1016/j.marpolbul.2011.12.012

634 Brodie J, Pearson RG (2016) Ecosystem health of the Great Barrier Reef: time for effective
635 management action based on evidence. Estuar Coast Shelf Sci 183: 438-451. doi:
636 10.1016/j.ecss.2016.05.008

637 Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries RS, Díaz S, Dietz T, Duraiappah
638 AK, Oteng-Yeboah A, Pereira HM, Perrings C, Reid WV, Sarukhan J, Scholes RJ,
639 Whyte A (2009) Science for managing ecosystem services: Beyond the Millennium
640 Ecosystem Assessment. Proc Natl Acad Sci USA 106: 1305-1312. doi:
641 10.1073/pnas.0808772106
642 Connell JH (1961) The influence of interspecific competition and other factors on the
643 distribution of the barnacle *ChtJzamalrts stellatus*. Ecology 142: 710-723. doi:
644 10.2307/1933500
645 Connell JH (1978) Diversity in tropical rain forests and coral reefs. Science 199: 1302-1310.
646 doi: 10.1126/science.199.4335.1302
647 Cumming GS (2007) Global biodiversity scenarios and landscape ecology. Landsc Ecol 22:
648 671-685. doi: 10.1007/s10980-006-9057-3
649 Cumming GS (2011) Spatial resilience: integrating landscape ecology, resilience, and
650 sustainability. Landsc Ecol 26: 899-909. doi: 10.1007/s10980-011-9623-1
651 Dayton PK (1971) Competition, disturbance and community organization: The provision and
652 subsequent utilization of space in a rocky intertidal community. Ecol Monogr 41: 351-
653 389. doi: 10.2307/1948498
654 Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, Larigauderie A, Adhikari JR,
655 Arico S, Báldi A, Bartuska A, Baste IA, Bilgin A, Brondizio E, Chan KMA, Figueroa
656 VE, Duraiappah A, Fischer M, Hill R, Koetz T, Leadley P, Lyver P, Mace GM, Martin-
657 Lopez B, Okumura M, Pacheco D, Pascual U, Pérez ES, Reyers B, Roth E, Saito O,
658 Scholes RJ, Sharma N, Tallis H, Thaman R, Watson R, Yahara T, Hamid ZA, Akosim
659 C, Al-Hafedh Y, Allahverdiyev R, Amankwah E, Asah ST, Asfaw Z, Bartus G, Brooks
660 LA, Caillaux J, Dalle G, Darnaedi D, Driver A, Erpul G, Escobar-Eyzaguirre P, Failler

661 P, Fouda AMM, Fu B, Gundimeda H, Hashimoto S, Homer F, Lavorel S, Lichtenstein
662 G, Mala WA, Mandivenyi W, Matczak P, Mbizvo C, Mehrdadi M, Metzger JP, Mikissa
663 JB, Moller H, Mooney HA, Mumby P, Nagendra H, Nesshover C, Oteng-Yeboah AA,
664 Pataki G, Roué M, Rubis J, Schultz M, Smith P, Sumaila R, Takeuchi K, Thomas S,
665 Verma M, Yeo-Chang Y, Zlatanova D (2015) The IPBES conceptual framework -
666 connecting nature and people. Curr Opin Environ Sustainability 14: 1-16. doi:
667 10.1016/j.cosust.2014.11.002
668 Diaz RJ, Rosenberg R (2009) Spreading dead zones and consequences for marine ecosystems.
669 Science 321: 926-929. doi: 10.1126/science.1156401
670 Dickson B, Blaney R, Miles L, Regan E, van Soesbergen A, Väänänen E, Blyth S, Harfoot M,
671 Martin CS, McOwen C, Newbold T, van Bochove J (2014) Towards a global map of
672 natural capital: key ecosystem assets. UNEP, Nairobi, Kenya
673 Dornelas M, Gotelli NJ, McGill B, Shimadzu H, Moyes F, Sievers C, Magurran AE (2014)
674 Assemblage time series reveal biodiversity change but not systematic loss. Science 344:
675 296-299. doi: 10.1126/science.1248484
676 Fang X, Hou X, Li X, Hou W, Nakaoka M, Yu X (in press) Ecological connectivity between
677 land and sea: a review. Ecological Research
678 Galloway JN, Winiwarter W, Leip A, Leach AM, Bleeker A, Erisman JW (2014) Nitrogen
679 footprints: past, present and future. Environ Res Lett 9: 115003. doi: 10.1088/1748-
680 9326/9/11/115003
681 Ghermandi A, Pald N (2013) A global map of coastal recreation values: results from a
682 spatially explicit meta-analysis. Ecol Econ 86: 1-15. doi:
683 10.1016/j.ecolecon.2012.11.006

684 Gregory SV, Swanson FJ, McKee WA, Cummins KW (1991) An ecosystem perspective of
685 riparian zones. BioScience 41: 540-551. doi: 10.2307/1311607
686 Harley CDG, Hughes AR, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF,
687 Tomanek L, Williams SL (2006) The impacts of climate change in coastal marine
688 systems. Ecol Lett 9: 228-241. doi: 10.1111/j.1461-0248.2005.00871.x
689 Harvey BP, Gwynn-Jones D, Moore PJ (2013) Meta-analysis reveals complex marine
690 biological responses to the interactive effects of ocean acidification and warming. Ecol
691 Evol 3: 1016-1030. doi: 10.1002/ece3.516
692 Hertwich EG, Peters GP (2009) Carbon footprint of nations: a global, trade-linked analysis.
693 Environ Sci Technol 43: 6414-6420. doi: 10.1021/es803496a
694 Hoekstra AY, Mekonnen MM (2012) The water footprint of humanity. Proc Natl Acad Sci
695 USA 109: 3232-3237. doi: 10.1073/pnas.1109936109
696 Honda K, Kagiwada H, Takahashi N, Miyashita K (2014) Movement patterns of adult
697 Sakhalin taimen, *Parahucho perryi*, between stream habitats of the Bekanbeushi River
698 system, eastern Hokkaido, Japan. Ichthyol Res 61: 142-151. doi: 10.1007/s10228-013-
699 0387-2
700 Hou XY, Wu T, Hou W, Chen Q, Wang YD, Yu LJ (2016a) Characteristics of coastline
701 changes in mainland China since the early 1940s. Sci China Earth Sci 59: 1791-1802.
702 doi: 10.1007/s11430-016-5317-5
703 Hou X, Xu X, Wu T, Li X (2016b) Change characteristics and scenario analysis of coastal
704 wetlands in China. Wetl Sci 14: 597-606. doi: 10.13248/j.cnki.wetlandsci.2016.05.001
705 Hughes TP, Baird AH, Bellwood DR, Card M, Connolly SR, Folke C, Grosberg RC, Hoegh-
706 Guldberg O, Jackson JBC, Kleypas J, Lough JM, Marshall P, Nyström N, Palumbi SR,

707 Pandolfi JM, Rosen B, Roughgarden J (2003). Climate change, human impacts, and the
708 resilience of coral reefs. Science, 301: 929-933. doi: 10.1126/science.1085046
709 Hunt DVL, Lombardi DR, Atkinson S, Barber ARG, Barnes M, Boyko CT, Brown J, Bryson
710 J, Butler D, Caputo S, Caserio M, Coles R, Cooper RFD, Farmani F, Gaterell M, Hale J,
711 Hales C, Hewitt CN, Jankovic L, Jefferson I, Leach J, MacKenzie AR, Memon FA,
712 Sadler JP, Weingaertner C, Whyatt JD, Rogers CDF (2012) Scenario archetypes:
713 converging rather than diverging themes. Sustainability 4: 740-772. doi:
714 10.3390/su4040740
715 IPCC (2014) Climate change 2014: synthesis report. Contribution of working groups I, II and
716 III to the fifth assessment report of the Intergovernmental Panel on Climate Change,
717 IPCC, Geneva
718 Ishikawa S, Watanabe K (2015) Area-capability - promoting the use of local resources.
719 Research Institute for Humanity and Nature, Kyoto
720 Ishikawa S, Watanabe K, Theparoonrat Y, Amornpiyakrit T, Manajit N, Yasook N,
721 Arnupapboon S (2015) Balancing fishery resource utilization and conservation for
722 environmental sustainability and socio-economic stability. Fish for the People 13: 13-20
723 ISO (2006) Environmental management - life cycle assessment - principles and framework.
724 International Standard ISO 14040. International Organisation for Standardisation.
725 Geneva
726 Iyobe T, Haraguchi A, Nishijima H, Tomizawa H, Nishio F (2003) Effect of fog on sea salt
727 deposition on peat soil in boreal *Picea glehnii* forests in Ochiishi, eastern Hokkaido.
728 Japan. Ecol Res 18: 587-597. doi: 10.1046/j.1440-1703.2003.00580.x

729 Jetz W, McPherson JM, Guralnick RP (2012) Integrating biodiversity distribution knowledge:
730 toward a global map of life. Trends Ecol Evol 27:151-159. doi:
731 10.1016/j.tree.2011.09.007
732 Just RE, Natanyahu S (2012) Conflict and cooperation on trans-boundary water resources.
733 Springer Science & Business Media, New York
734 Kamauchi H, Sato S, Hayashi D, Okabe Y, Katsuyama T, Fukushima K, Yoshioka A, Sato T,
735 Tokuchi N, Nakaoka M (2012) Consumer of salmon carcasses in early winter of Eastern
736 Hokkaido. Forest Research 78: 81-87.
737 Kim E-S, Trisurat Y, Muraoka H, Shibata H, Amoroso V, Boldgiv B, Hoshizaki K, Kassim
738 AR, Kim Y-S, Nguyen HQ, Ohte N, Ong PS, Wang C-P (in press) International Long-
739 Term Ecological Research East Asia-Pacific Regional Network (ILTER-EAP): History,
740 development and perspectives. Ecological Research
741 Klein CJ, Brown CJ, Halpern BS, Segan DB, McGowan J, Beger M, Watson JEM (2015)
742 Shortfalls in the global protected area network at representing marine biodiversity. Sci
743 Rep 5: 17539. doi: 10.1038/srep17539
744 Koch EW, Barbier EB, Silliman BR, Reed DJ, Perillo GM, Hacker SD, Granek EF,
745 Primavera JH, Muthiga N, Polasky S, Halpern BS, Kennedy CJ, Kappel CV, Wolanski
746 E (2009) Non-linearity in ecosystem services: temporal and spatial variability in coastal
747 protection. Front Ecol Environ 7: 29-37. doi: 10.1890/080126
748 Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ
749 (2012) Transdisciplinary research in sustainability science: practice, principles, and
750 challenges. Sustain Sci 7 (supplement 1): 25-43. doi: 10.1007/s11625-011-0149-x

751 Lange K, Townsend CR, Gabrielsson R, Chanut PCM, Matthaei CD (2014) Responses of
752 stream fish populations to farming intensity and water abstraction in an agricultural
753 catchment. Freshw Biol 59: 286-299. doi: 10.1111/fwb.12264
754 Lenz M, da Gama BAP, Gerner NV, Gobin J, Gröner F, Harry A, Jenkins SR, Kraufvelin P,
755 Mummelthei C, Sareyka J, Xavier EA, Wahl M (2011) Non-native marine invertebrates
756 are more tolerant towards environmental stress than taxonomically related native
757 species: Results from a globally replicated study. Environ Res 111: 943-529. doi:
758 10.1016/j.envres.2011.05.001
759 Lenzen M, Moran D, Kanemoto K, Foran1 B, Lobefaro L, Geschke A (2012) International
760 trade drives biodiversity threats in developing nations. Nature 486: 109-112. doi:
761 10.1038/nature11145
762 Li X, Xiubo Y, Jiang L, Li W, Liu Yu, Hou X (2014) How important are the wetlands in the
763 middle-lower Yangtze River region: an ecosystem service valuation approach. Ecosyst
764 Serv 10: 54-60. doi: 10.1016/j.ecoser.2014.09.004
765 Li X, Hou X, Xianghong D, Su H (2016) Effects of land use change on imbalance in
766 ecosystem services: a case study of Laizhou Bay Coastal Zone. Scientia Geographica
767 Sinica 36: 1197-1204. doi: 10.13249/j.cnki.sgs.2016.08.010
768 Maass M, Balvanera P, Baudry J, Bourgeron P, Dick J, Equihua M, Forsius M, Halada L,
769 Krauze K, Nakaoka M, Orenstein DE, Parr T, Redman CL, Rozzi R, Santos-Reis M,
770 Swemmer T,, Vădineanu A (2016) Changes in biodiversity and trade-offs among
771 ecosystem services, stakeholders and components of well-being: the contribution of the
772 International Long-Term Ecological Research network (ILTER) to Programme on
773 Ecosystem Change and Society (PECS). Ecol Soc 21: 31. doi: 10.5751/ES-08587-
774 210331

775 Meyer C, Kreft H, Guralnick R, Jetz W. (2015) Global priorities for an effective information
776 basis of biodiversity distributions. Nat Commun 6: 8221. doi: 10.1038/ncomms9221
777 Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: our human
778 planet. Island Press, Washington
779 Molinos JG, Halpern BS, Schoeman DS, Brown CJ, Kiessling W, Moore PJ, Pandolfi JM,
780 Poloczanska ES, Richardson AJ, Burrows MT (2016) Climate velocity and the future
781 global redistribution of marine biodiversity. Nat Clim Chang 6: 83-88. doi:
782 10.1038/nclimate2769
783 Moran D, Kanemoto K (2017) Identifying the species threat hotspots from global supply
784 chains. Nat Ecol Evol 1: 23. doi: 10.1038/s41559-016-0023
785 Moran D, Petersone M, Verones F (2016) On the suitability of input-output analysis for
786 calculating product-specific biodiversity footprints. Ecol Indic 60: 192-201. doi:
787 10.1016/j.ecolind.2015.06.015
788 Mukai H (2005) Seagrass bed ecosystem in a total system of land-and coastal marine
789 ecosystems. Gekkan Kaiyo 37: 148-155
790 Mukai H, Iizumi H, Kishi M (2002) Material input from terrestrial areas under regular and
791 irregular conditions in Akkeshi watershed: a case study linking forest and sea. Gekkan
792 Kaiyo 34: 449-457
793 Nakamura F, Kameyama S, Mizugaki S (2004) Rapid shrinkage of Kushiro Mire, the largest
794 mire in Japan, due to increased sedimentation associated with land-use development in
795 the catchment. Catena 55: 213-229. doi: 10.1016/S0341-8162(03)00119-X
796 Nakaoka M, Lee K-S, Huang X, Almonte T, Sidik Bujang J, Kiswara W, Ambo Rappe R,
797 Maryam Yaakub S, Prabhakaran MP, Abu Hena MK, Hori M, Zhang P, Prathep A,
798 Fortes MD (2014) Regional comparison of the ecosystem services from seagrass beds in

799 Asia. In: (S. Nakano et al. eds.) Asia-Pacific Biodiversity Observation Network:
800 Integrative Observations and Assessments. Ecological Research Monographs, Springer
801 Japan, Tokyo, pp. 367-391
802 Noda T (2004) Spatial hierarchal approach in community ecology: a way beyond a low
803 predictability in local phenomenon. Popul Ecol 46: 105-117. doi: 10.1007/s10144-004-
804 0184-x
805 Nordlund LM, Koch EW, Barbier EB, Creed JC (2016) Seagrass ecosystem services and their
806 variability across genera and geographical regions. PLoS ONE 11: e0163091. doi:
807 10.1371/journal.pone.0163091
808 Oita A, Malik A, Kanemoto K, Geschke A, Nishijima S, Lenzen M (2016) Substantial
809 nitrogen pollution embedded in international trade. Nat Geosci 9: 111-115. doi:
810 10.1038/ngeo2635
811 Omija T (2004) Terrestrial inflow of soils and nutrients. In: Ministry of the Environment,
812 Japanese Coral Reef Society (eds) Coral reefs of Japan. Ministry of the Environment,
813 Tokyo, pp. 64-68
814 Ostrom E (2009) A general framework for analyzing sustainability of social-ecological
815 systems. Science 325: 419-422. doi: 10.1126/science.1172133
816 Palumbi SR, Pinsky ML (2014) Marine dispersal, ecology and conservation. In: (Bertness
817 MD, Bruno JF, Silliman BR, Stachowics JJ, eds.) Marine community ecology and
818 conservation, Sinauer, Sunderland, pp. 57-83
819 Paine RT (1966) Food web complexity and species diversity. Am Nat 100: 65-75. doi:
820 10.1086/282400

821 Paerl HW, Hall NS, Peierls BL, Rossignol KL (2014) Evolving paradigms and challenges in
822 estuarine and coastal eutrophication dynamics in a culturally and climatically stressed
823 world. Estuar Coast 37: 243-258. doi: 10.1007/s12237-014-9773-x
824 Pereira HM, Leadley PW, Proença V, Alkemade R, Scharlemann JPW, Fernandez-Manjarrés
825 JF, Araújo MB, Balvanera P, Biggs R, Cheung WWL, Chini L, Cooper HD, Gilman EL,
826 Guénette S, Hurtt GC, Huntington HP, Mace GM, Oberdorff T, Revenga C, Rodrigues
827 P, Scholes RJ, Sumaila UR, Walpole M (2010) Scenarios for global biodiversity in the
828 21st century. Science 330: 1496-1501. doi: 10.1126/science.1196624
829 Peterson DL, Parker VT (1998) Ecological scale. Columbia University Press, New York
830 Polis GA, Wendy B. Anderson1, and Robert D. Holt (1997) Toward an integration of
831 landscape and food web ecology: the dynamics of spatially subsidized food webs. Annu
832 Rev Ecol Syst 28: 289-316. doi: 10.1146/annurev.ecolsys.28.1.289
833 Pörtner HO, Langenbuch M (2005) Synergistic effects of temperature extremes, hypoxia, and
834 increases in CO_2 on marine animals: from Earth history to global change. J Geophys
835 Res 110: C09S10. doi: 10.1029/2004JC002561
836 Qiu J, Turner MG (2013) Spatial interactions among ecosystem services in an urbanizing
837 agricultural watershed. Proc Natl Acad Sci USA 110: 12149-12154. doi:
838 10.1073/pnas.1310539110
839 Roughgarden J, Gaines S, Possingham H (1988) Recruitment dynamics in complex life
840 cycles. Science 241: 1460-1466. doi: 10.1126/science.11538249
841 Sawai T (1988) Sea fog in Kushiro District. Tenki 35: 555-566
842 Stachowicz JJ, Terwin JR, Whitlatch RB, Osman RW (2002). Linking climate change and
843 biological invasions: ocean warming facilitates nonindigenous species invasions. Proc
844 Natl Acad Sci USA 99: 15497-15500. doi: 10.1073/pnas.242437499

Stuart-Smith RD, Bates AE, Lefcheck JS, Duffy JE, Baker SC, Thomson RJ, Stuart-Smith JF, Hill NA, Kininmonth SJ, Airoldi L, Becerro MA, Campbell SJ, Dawson TP, Navarrete SA, Soler GA, Strain EMA, Willis TJ, Edgar GJ (2013) Integrating abundance and functional traits reveals new global hotspots of fish diversity. Nature 501: 539-542. doi: 10.1038/nature12529

Tajima H, Tamaru O, Makino M (2015) Stakeholder Analysis for the comparison of the interests structures around seagrass beds. Journal of Coastal Zone Studies 27: 77-88.

Takeuchi N, Okubo M, Furumoto H, Omaki H (1982) Meteorology of Shibecha. Reports on University Forest, Faculty of Agriculture, Kyoto University 15: 35-42

Tanaka Y, Go GA, Watanabe A, Miyajima T, Nakaoka M, Uy WH, Nadaoka K, Watanabe S, Fortes MD (2014) 17-year change in species composition of mixed seagrass beds around Santiago Island, Bolinao, the northwestern Philippines. Marine Pollution Bulletin 88: 81-85. doi: 10.1016/j.marpolbul.2014.09.024

Thorburn PJ, Wilkinson SN, Silburn DM (2013) Water quality in agricultural lands draining to the Great Barrier Reef: a review of causes, management and priorities. Agric, Ecosyst Environ 180: 4-20. doi: 10.1016/j.agee.2013.07.006

Tittensor DP, Mora C, Jetz W, Lotze HK, Ricard D, Berghe EV, Worm B (2010) Global patterns and predictors of marine biodiversity across taxa. Nature 466: 1098-1102. doi: 10.1038/nature09329

Ueno Y, Hori M, Noda T, Mukai H (2006) Effects of material inputs by the Grey Heron *Ardea cinerea* on forest-floor necrophagous insects and understory plants in the breeding colony. Ornithol Sci 5:199-209. doi: 10.2326/1347-0558(2006)5[199:EOMIBT]2.0.CO;2

868 United Nations (2015) Transforming our world: the 2030 agenda for sustainable development.
869 (GA A/RES/70/1). https://sustainabledevelopment.un.org. Accessed 11 July 2017
870 Verones, F, Moran D, Stadler K, Kanemoto K, Wood R (2017) Resource footprints and their
871 ecosystem consequences. Sci Rep 7: 40743. doi: 10.1038/srep40743
872 Vitousek PM, Naylor R, David MB, Drinkwater LE, Holland E, Johnes PJ, Katzenberger J,
873 Martinelli LA, Matson PA, Nziguheba G, Ojima D, Palm CA, Robertson GP, Sanchez
874 PA, Townsend AR, Zhang FS (2009) Nutrient imbalances in agricultural development.
875 Science 324: 1519-1520. doi: 10.1126/science.1170261
876 Waterhouse J, Brodie J, Lewis S, Audas DM (2016) Land-sea connectivity, ecohydrology and
877 holistic management of the Great Barrier Reef and its catchments: time for a change.
878 Ecohydrol Hydrobiol 16: 45-57. doi: 10.1016/j.ecohyd.2015.08.005
879 Weinzettel J, Hertwich EG, Peters GP, Steen-Olsen K, Galli A (2013) Affluence drives the
880 global displacement of land use. Glob Environ Chang 23: 433-438. doi:
881 10.1016/j.gloenvcha.2012.12.010
882 Yamakita T, Wanatabe K, Nakaoka M (2011) Asynchronous local dynamics contributes to
883 stability of a seagrass bed in Tokyo Bay. Ecography 34: 519-528. doi: 10.1111/j.1600-
884 0587.2010.06490.x
885 Yamakita T, Sudo K, Jintsu-Uchifune Y, Yamamoto H, Shirayama Y (2017) Identification of
886 important marine areas using ecologically or biologically significant areas (EBSAs)
887 criteria in the east to southeast Asia region and comparison with existing registered
888 areas for the purpose of conservation. Mar Policy, in press. doi:
889 10.1016/j.marpol.2017.03.040
890 Yamano H, Satake K, Inoue T, Kadoya T, Hayashi S, Kinjo K, Nakajima D, Oguma H,
891 Ishiguro S, Okagawa A, Suga S, Horie T, Nohara K, Fukayama N, Hibiki A (2015) An

892 integrated approach to tropical and subtropical island conservation. J Ecol Environ 38:
893 271-279. doi: 10.5141/ecoenv.2015.028
894 Yara Y, Vogt M, Fujii M, Yamano H, Hauri C, Steinacher Mm Gruber N, Yamanaka Y
895 (2012) Ocean acidification limits temperature-induced poleward expansion of coral
896 habitats around Japan. Biogeosciences 9: 4955-4968. doi: 10.5194/bg-9-4955-2012
897

898 **Figure captions**

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

901

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

904

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

908

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

913

914 **Fig. 5** Diagram showing Area Capability Cycle (ACC) for the case of community-based set-
915 net fisheries in Thailand local fishery village. A new fishery practice (starting the set-net
916 fishery by the local community SEAFDC, indicated by the yellow box), which was more
917 effective in utilization of the resources than traditional fisheries, was established by the more
918 concern and care for ecosystem health by the local community (indicated by yellow thick
919 lines). The initial interaction between resources and local community was motivated and
920 driven by the hopes and prides of local community (indicated by a red box and black allows),
921 which brought positive feedbacks for the expansion of better practices, new skills and

922 industries (indicated by blue arrows and while boxes). Figure redrawn from Ishikawa et al.
923 (2015) with permission.
924
925 **Fig. 6** Diagram showing relationships among ecosystem functions (in round shape),
926 ecosystem services, and their use by different sectors of stakeholders for an eelgrass bed in
927 Japan. P: Provisioning services, R: regulating services, C: cultural services and S: Supporting
928 services. See text for more detailed information about how this diagram was made. Diagram
929 modified based on Tajima et al. (2015).
930
931 **Fig. 7** Changes in economic value of ecosystem services between 2000 and 2014 analyzed for
932 Laizhou Bay Coastal Zone, China. See Li et al. (2016) for the details.
933

Fig. 1

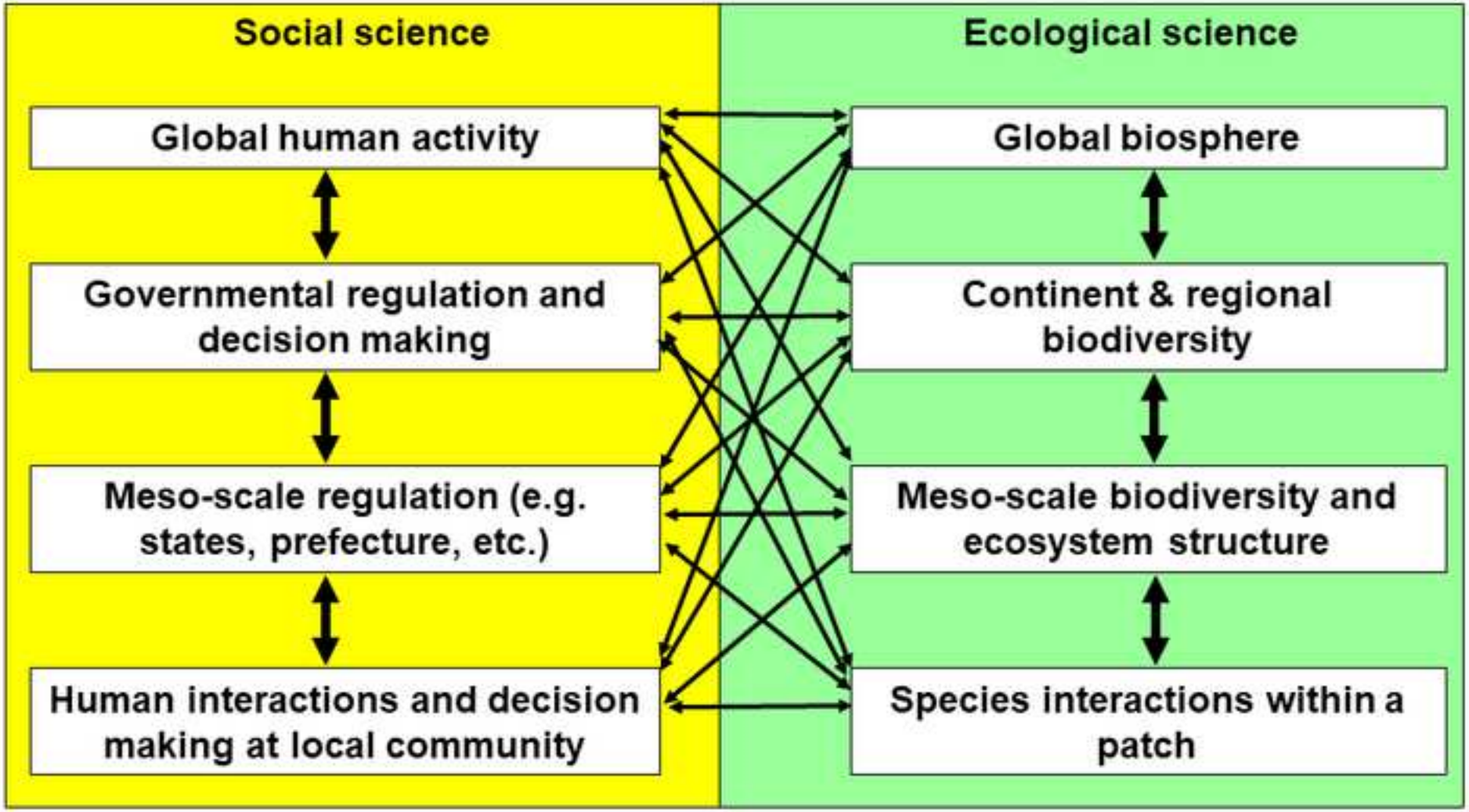
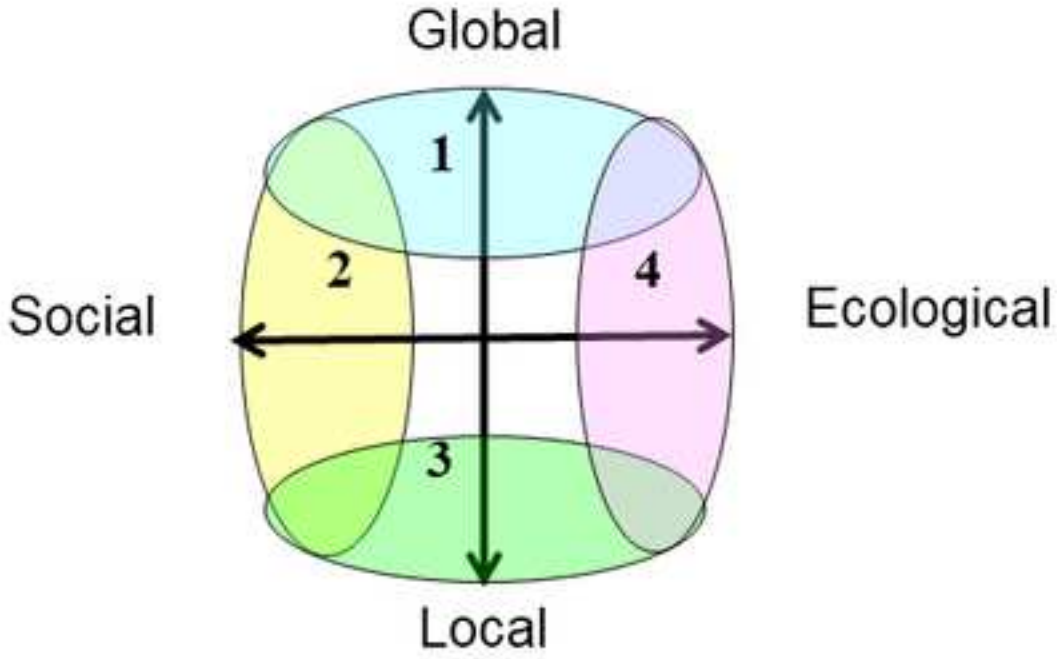


Fig. 1 (Nakaoka et al.)

Fig. 2



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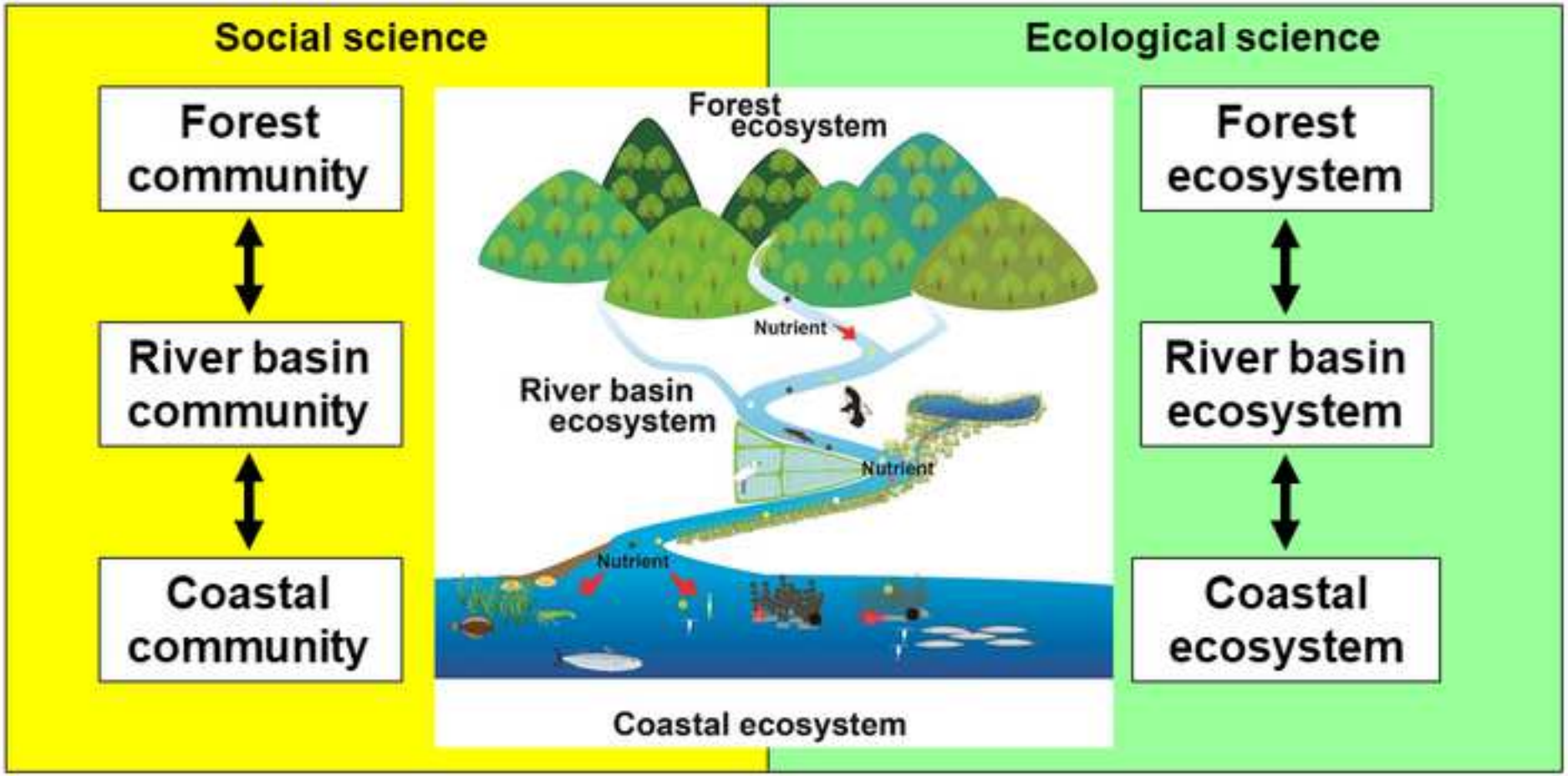

Fig. 3 (Nakaoka et al.)

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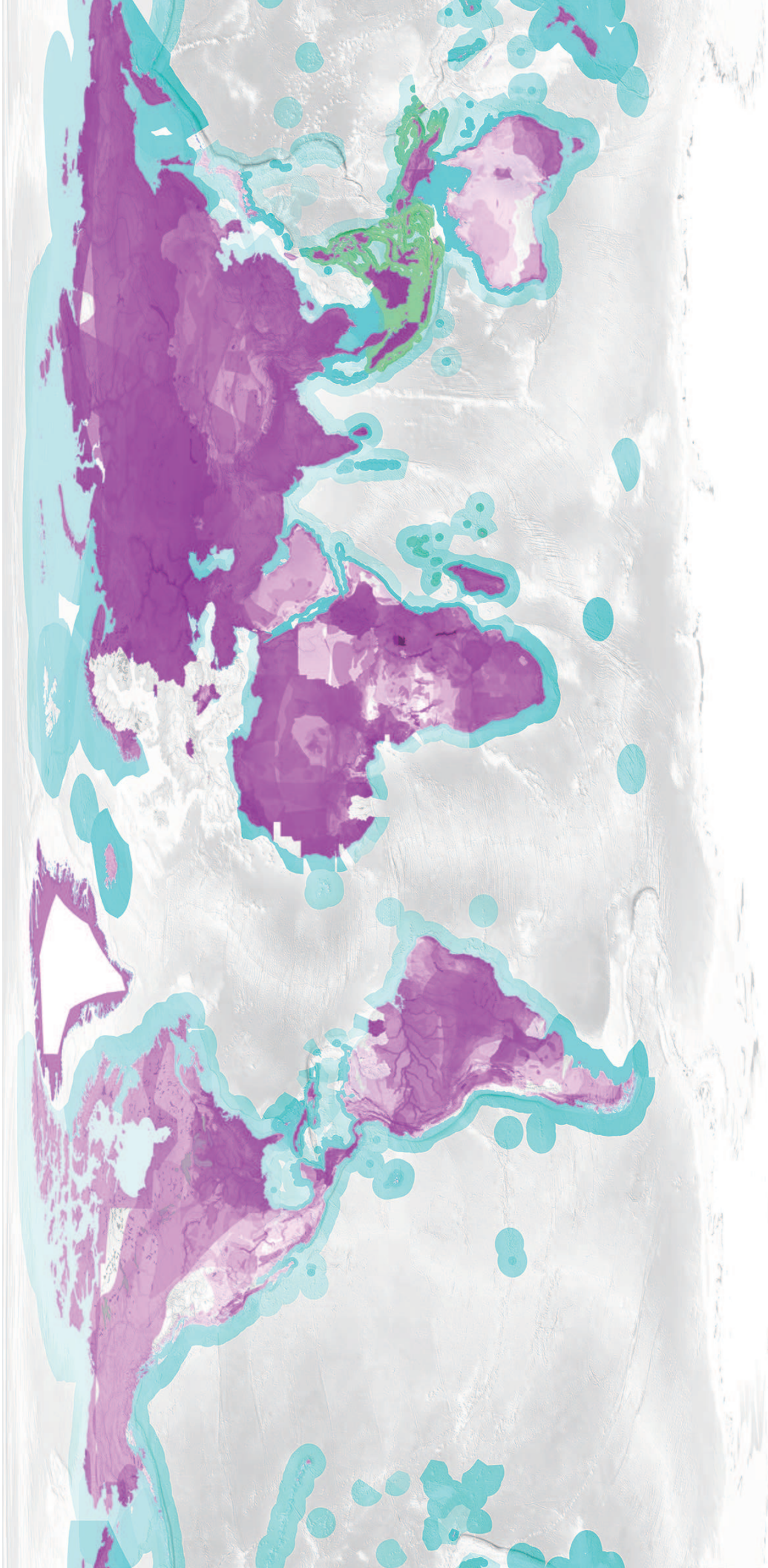

Fig. 5

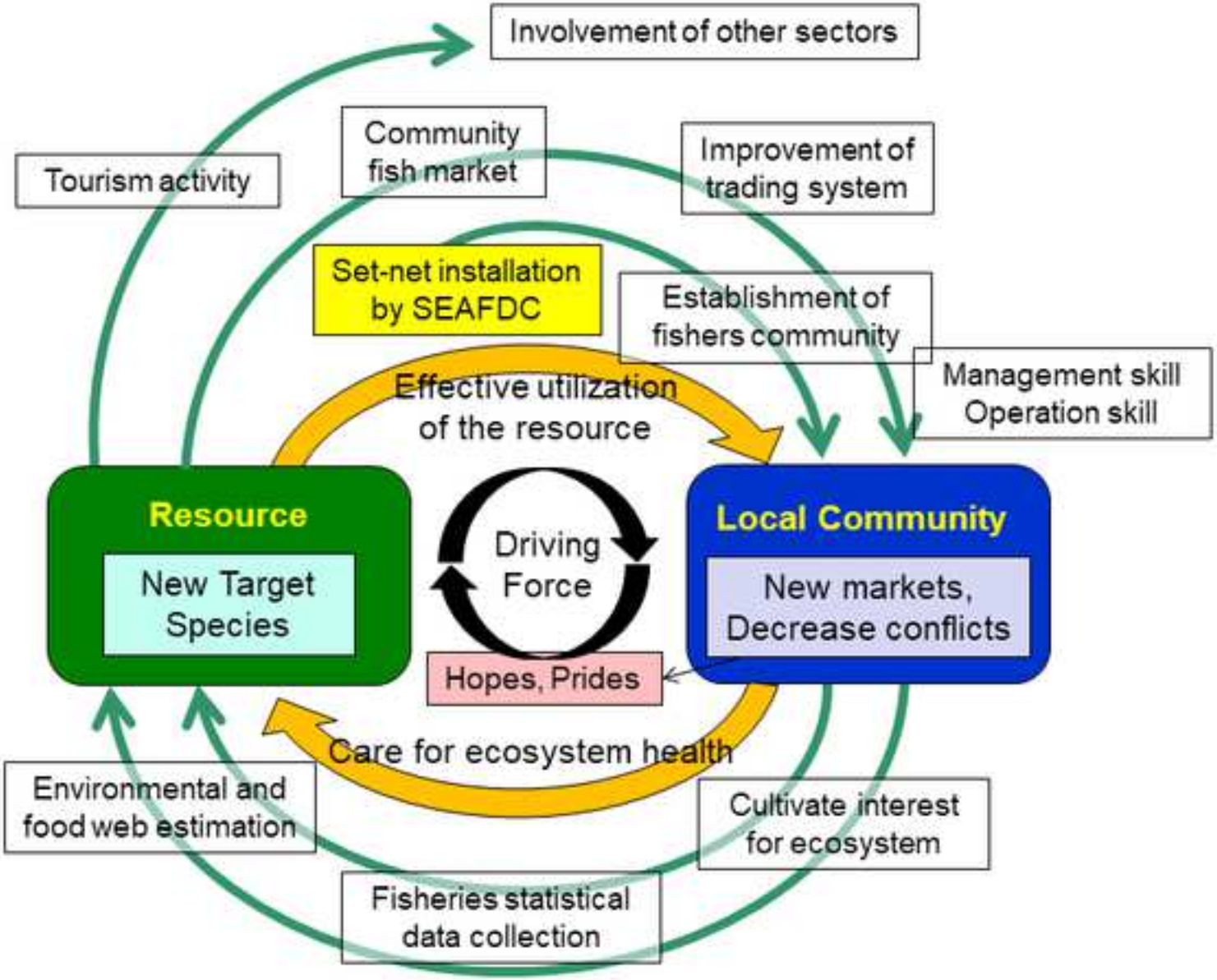

Fig. 5 (Nakaoka et al.)

Fig. 6

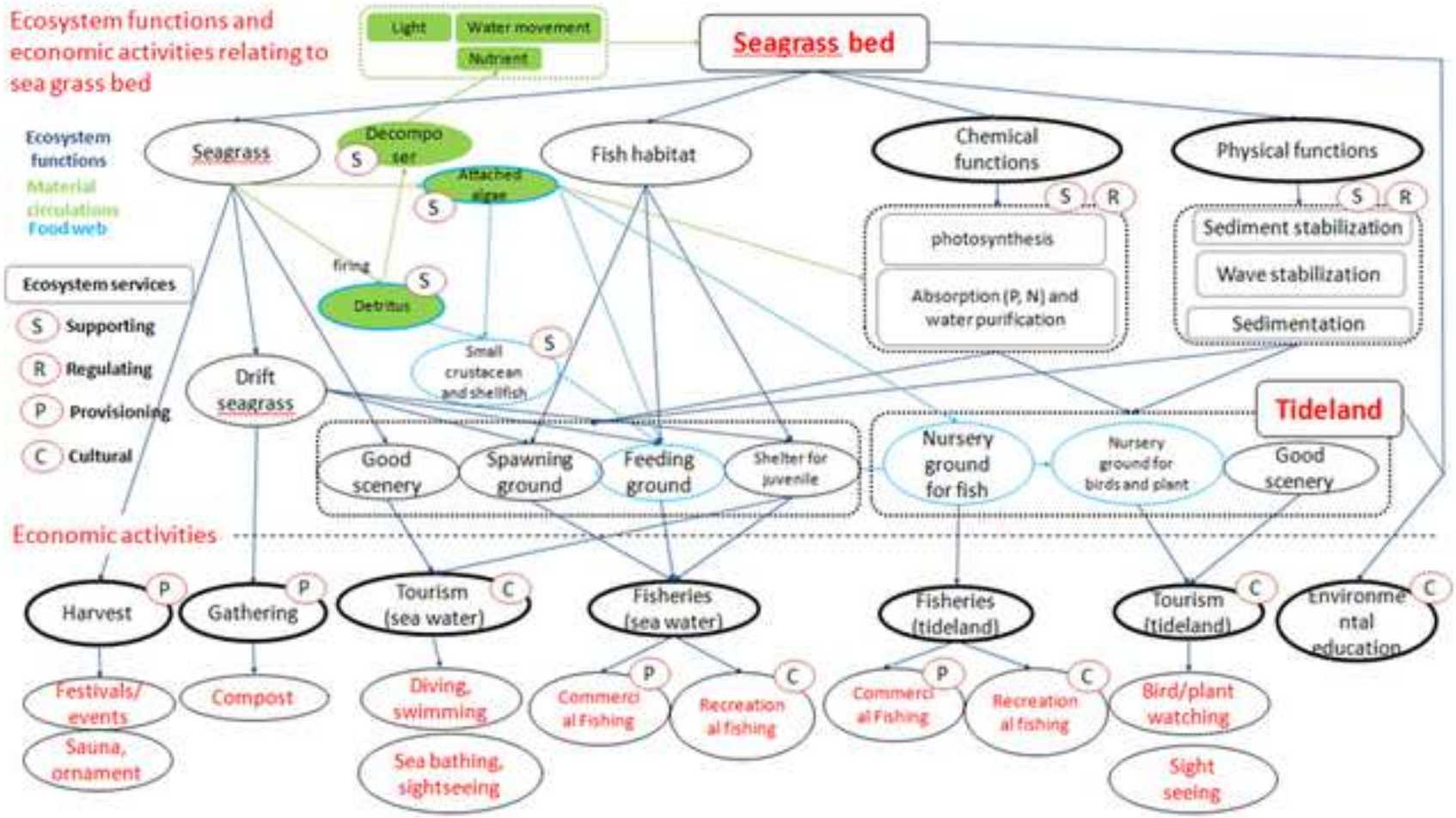

Fig. 6 (Nakaoka et al.)

Fig. 7

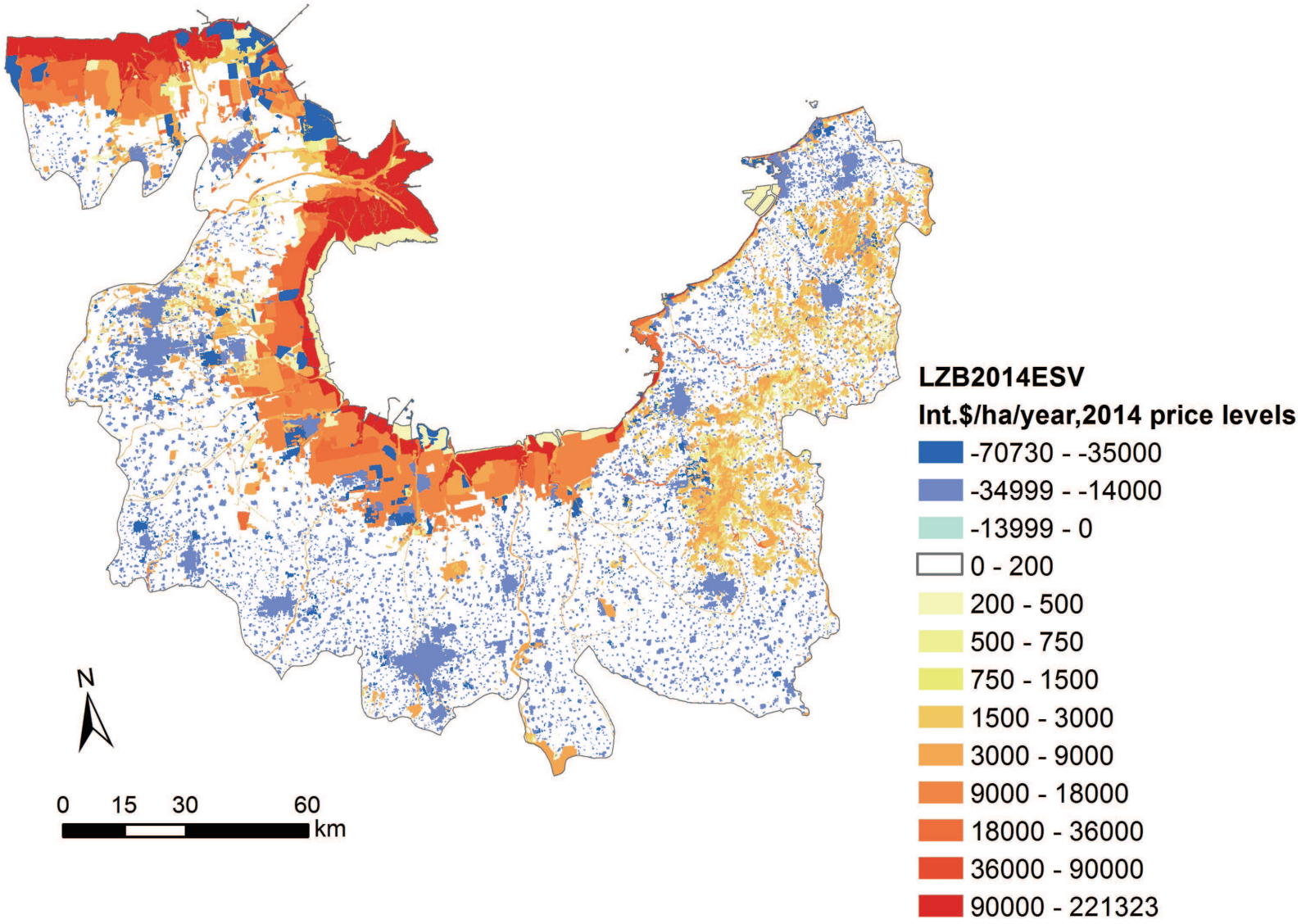

Fig. 7 (Nakaoka et al.)