Title

Spatially Explicit Residential and Working Population Assumptions for Projecting and Assessing Natural Capital and Ecosystem Services in Japan

Author names and affiliations

Takanori Matsui[1], Chihiro Haga[1], Osamu Saito[2], Shizuka Hashimoto[3]

[1] Division of Sustainable Energy & Environmental Engineering,
Graduate School of Engineering, Osaka University
2-1, Yamadaoka, Suita, Osaka 565-0871, Japan
TEL/FAX +81 (0)6-6879-7407

[2] United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS)
5-53-70, Jingumae, Shibuya-ku, Tokyo 150-8925, Japan
TEL +81 (0)3-5467-1212 FAX +81 (0)3-3499-2828

[3] Graduate School of Agricultural and Life Sciences, The University of Tokyo 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657, Japan
TEL +81-3-5841-5049

E-mails

Takanori Matsui: matsui@see.eng.osaka-u.ac.jp
Chihiro Haga: chihiro.haga@ge.see.eng.osaka-u.ac.jp
Osamu Saito: saito@unu.edu
Shizuka Hashimoto: ahash@mail.ecc.u-tokyo.ac.jp

Corresponding author

Takanori Matsui (Ph.D.)
Rm# 405, M3 Building of Sustainable Energy & Environmental Engineering, Osaka University, 2-1, Yamadaoka, Suita, Osaka, 565-0871, Japan
TEL/FAX +81 (0)6-6879-7407
matsui@see.eng.osaka-u.ac.jp

Abstract

In scenario studies of biodiversity and ecosystem services, the population distribution is one of the key driving forces. In this study, we developed a coupling method for narrative scenarios and spatially explicit residential and working population designs for all of Japan as a common data set for ecosystem scenario analysis implemented by 5-year project entitled "Predicting and Assessing Natural Capital and Ecosystem Services (PANCES)". Four narrative scenarios were proposed by the PANCES project by using two axes as major uncertainties: the population distribution and the capital preference. The residential population and the working population in primary industries were calculated using a gravity-based allocation algorithm in a manner consistent with the storylines of the PANCES scenarios. By using the population distribution assumption by scenario, the population was overlaid with the natural capital and the supply potential of ecosystem services. The results supported to understand the gaps between natural capital and maintainability, the potential of ecosystem services and realizability. The spatially explicit population distribution data products are expected to help design the nature conservation strategy and governance option in terms of both social system and ecological system.

keywords: ecosystem services, natural capital, scenario analysis, population distribution, spatially explicit

Introduction

Population is one of the most important indirect drivers of change that ultimately cause environmental change through shaping direct drivers such as land use change and agricultural expansion (e.g. IPCC 2000; MA 2005a), thereby playing important roles in exploring possible impacts on the environmental futures caused by alternative development trajectories. While existing global scale scenarios such as IPCC-SRES and Shared Socioeconomic Pathways (SSP) develops and distribute their population data for the use by wider audience, the spatial resolution of the such data is too often coarse and thus needs to be downscaled to an appropriate spatial scale for regional and local assessments (IPBES 2016). Also, assumptions embedded in global scenarios in the form of storylines do not necessarily capture local realities and uncertainties. This is one of the central reasons why the Millennium Ecosystem Assessment (MA) conducted Sub-Regional Assessments around the world at different spatial scales to better capture local conditions while hearing voices of local stakeholders (MA 2005b). Similarly, European countries developed their own scenarios to meet local policy needs such as land use and agricultural policy (Westhoek et al. 2006; Volkery et al. 2008).

Against this background, we are conducting a joint development project called "PANCES (**P**redicting and **A**ssessing **N**atural **C**apital and **E**cosystem **S**ervices)" to forecast the prospects of changing Japanese ecosystems under climate change, the fate of Japanese natural resources, and the transformation of Japanese social wellbeing (PANCES 2016). In this project, the entire system including natural ecosystems and social ecosystems are viewed as "Socio-Ecological Systems" and an integrated simulation model is being developed to project future scenarios for Japan. Japanese socio-ecological systems are now thought to face four types of crises (MOE 2012): the degradation of natural ecosystems due to human overuse, the decline in the quality of natural ecosystems caused by the underuse of *Satoyama* (Takeuchi et al. 2006), the disturbance by invasive species, and the transformation of natural ecosystems evoked by global environment change.

Of these four crises, the Japan Biodiversity Outlook warned that impacts of underuse (the second crisis) and global environmental change (the fourth crisis) on biodiversity and ecosystem services will increase in Japan into the future (JBO 2010). The main mission of the PANCES project is to better forecast these impacts, incorporating indirect driving forces such as low economic growth, population decline, and climate change on social wellbeing, and to backcast effective governance options proactively. The design of future scenarios and the development of simulation models are keys to quantitatively projecting and visualizing plausible futures. Figure 1 shows all the components of the integrated simulation system of socio-ecological systems in Japan under development (PANCES 2016). The module configuration consists of five modules (from the left side of Fig. 1):

(i) describing future scenarios and parameterizing the direct and indirect driving forces that impact socio-ecological systems;

(ii) developing the basic framework (demography, industry, land use, and natural capital) that respond to the indirect driving forces;

(iii) modeling the dynamics of the terrestrial and ocean ecosystems and developing logics to quantify the flow of ecosystem services under direct driving forces,

(iv) establishing a quantitative evaluation framework of the economic value of natural capital and ecosystem services and social wellbeing; and

(v) designing governance structures and policy intervention options for all Japanese socio-ecological systems.

Especially for (ii), it has been pointed out that indirect drivers, such as population size, distribution, and age structure, exert significant anthropomorphic pressure on the environment, such as biodiversity and ecosystem (IPBES 2016). In the field of climate change research, the development of spatially explicit population projection is progressing. Grübler et al. (2007) reported spatially explicit scenario interpretations for population and economic activity for the time period of 1990–2100 based on scenarios from the IPCC Special Report on Emissions Scenarios (SRES). The finest spatial resolution in this study was 0.5° × 0.5°. Using the downscaled indirect drivers, Kindermann et al. (2008) estimated the forest-cover change. Jones and O'Neill (2013) presented spatially explicit 100-year projections for the continental United States consistent with two different SRES scenarios. Jones and O'Neill (2016) presented a new set of globally and spatially explicit population scenarios, as did Jones and O'Neill (2013), that are consistent with the new Shared Socioeconomic Pathways (SSPs) developed to facilitate global change research. Jones and O'Neill (2016) demonstrated vulnerable populations existing in low-elevation coastal zones under alternative scenarios. And recently, Reimann et al. (2018) interpreted global SSP scenarios in local scenarios in the specific context of the Mediterranean region and estimated the plausible population distribution by region under different scenarios.

Developing region-specific scenarios and interpreting qualitative storylines for quantitative population distributions consistent with these scenarios is important not only in the field of climate change but also for biodiversity and ecosystem services studies. For example, Thorn et al. (2017) developed spatially explicit future scenarios for land cover, population density, and impervious cover in New Hampshire for the period of 2020–2100. This population projection made it possible to evaluate environmental indicators such as agricultural cover (agricultural land available per capita), water shortfalls (population duration of water supply stress), and flood risk (population duration of potential flood impact) (Samal et al. 2017).

In this paper, we developed a coupling method for (i) narrative scenarios and (ii) spatially explicit residential and working population distributions. In the next section, we introduce the Japanese population projection that is the basis of our development of population assumptions. In the methods section, the design processes of the residential and working population assumptions are presented. In the results section, we show the results of the population distributions and sample analyses using the quantitative data of the population assumptions. Finally, the discussion section includes conclusions, caveats, and directions for future work.

Methods

Outline of the population in 2010 and the BaU projection in 2050

Figure 2 shows the observed residential population distribution in 2010 (Fig. 2a) and the residential population distribution in 2050 (Fig. 2b) estimated by MLIT (2014a). This forecasting was estimated in grid cells with a 1-km^2 grid resolution using the cohort component method conducted by NIPSSR (2014). This estimation was based on the assumption of a middle level future birth rate. In the designing process of population assumptions, the residential population in 2050 projected by MLIT (2014a) was selected as the BaU (Business as Usual) projection. As a baseline trend, Japan is a highly aging society with fewer children (CAO 2016; Muramatsu and Akiyama 2011). The population is expected to decrease from 128 million in 2010 to 97 million in 2050. According to the shrinking population, the inhabited areas will decrease from 180,219 km^2 to 145,516 km^2, which means that, according to the BaU projection, the residential population will disappear from 20% of the current living area over 40 years (the yellow grids in Fig. 2b). This severe depopulation will cause large impacts on the management of Japanese natural ecosystems.

Figure 3 shows the working population distribution in 2010 according to SBJ (2010) and ZGI (2018). The working population in 2010 is 63 million. However, the proportion of aged population (over 65 years old) will be more than 40% of the residential population and the proportion of the working population (15–64 years old) will decline to 50% in 2050 (NIPSSR 2014). The working population decline will also affect the labor forces of primary industries such as agriculture, forestry, and fishery. The proportion of the working population in primary industries in Japan against the total workers was 33.9% in 1953. However the decrease was continuing exponentially and the proportion was 3.4% in 2017. And the proportion of aged population (over 65 years old) in primary industries was 11.9% in 1968 and dramatically increased to 49.3% in 2017 (MIAC 2018). Japan is expected to enter a serious situation of underusing nature. The decline in the working population and worker aging will significantly affect the fate and the sustainability of both the Japanese society and its ecosystems.

Population assumptions development

Based on the residential population in 2010 and the BaU projection, four alternative population distribution assumptions were designed in this study consistent with the storylines of the PANCES scenarios. The PANCES project developed future scenarios for all of Japan to the 2050 time horizon (Saito et al. 2018). The future scenarios were designed based on the scenario axis method (van’t Klooster and van Asselt 2006) extending the future scenarios developed in the Japan *Satoyama Satoumi* Assessment (JSSA 2010) more systematically and quantitatively. In the scenario developing process, an intensive expert workshop to extract the candidates of driving forces and two repeated surveys asked a hundred experts and policy makers to judge the likelihood and impact of these drivers based on the manner of Delphi method (Dalkey and Helmer 1963). The direct and indirect drivers affecting the natural capital and ecosystem services in the 2050 future Japanese society were identified in the expert workshop, and the impact and likelihood level of the driving forces were evaluated via web surveys. As a result of a consistency check test, "low economic growth" and "population decline", which were evaluated as high impact and high consensus of likelihood, were set as the baseline-trends. And two axes, which were high impact but low consensus of likelihood, were extracted as major uncertainties in the future society: the population distribution (urban compactification or dispersed population) and the capital preference (natural capital basis or produced capital basis). For the first axis, an urban compactification society promotes compact cities and rewilding/greening of underutilized land, while in a dispersed population society, rural communities will be maintained and people live in harmony with nature. For the second axis, the natural capital basis type promotes ecosystem-based infrastructure development, disaster risk reduction, land management, and ecotourism, while the produced capital basis type relies more on conventional man-made infrastructure and technologies. Detailed information is available in Saito et al. (2018).

Residential population distribution assumption

Two types of residential population assumptions were developed by reallocating the residential population distribution in the BaU projection based on the storylines of the PANCES scenarios. According to the BaU projection, the total population in Japan in 2050 was assumed to be 97 million. Population decline was set as the baseline trend and precondition, so the uncertainty of population distribution and capital preference was assumed as dependent drivers and not to affect the total population. Therefore, in all scenarios, the total population size was same but the population distributions were different in response to the storylines of whether Japanese society heads in the urban compactification or dispersed population directions (abbreviated as Cmp and Dsp, respectively). In the allocation calculation process, a simple gravity-based algorithm was employed in this study. Gravity models can easily expand or alter parameters to generate population distribution assumptions in exploratory research (Tamura and Masuda 2017; Jones and O'Neill 2013); therefore, this will be the basis for additional analyses to further investigate scenarios. The details are shown below.

In the Cmp scenario, people are assumed to abandon rural areas and move to the centers of cities. Therefore, to express urban compactification, the number of zero residential population grid cells in 2050 was set to double that of the BaU projection in the Cmp scenario. First, the grid cell with the highest residential population density was selected as the center of a city and then the Euclidean distances between the city center and all the grid cells were calculated. Second, the population was assumed to move from the low population density areas far from the city centers to the dense urban areas. In the BaU projection, 34,703 km^2 were estimated to be vacant in 2050; therefore, an additional 34,703 grid cells were selected as additional vacant areas in the Cmp society using the following optimization calculation. Note that the reallocated population was confined within each prefecture. The objective function to decide the zero residential population grid cells is

$$\min \sum_{i=1}^{N_j} \frac{C_{ij} \cdot pop2050bau_{ij}}{(dst_{ij}+1)}; \text{ for } j = 1, 2, \dots, N_{pref}, \quad \text{(eq. 1)}$$

which is subject to

$$Ncmp_j = \beta_p \cdot Nbau_j, \quad \text{(eq. 2)}$$

$$\sum_i^{N_j} C_{ij} = Ncmp_j; \text{ for } j = 1, 2, \dots, N_{pref}, \quad \text{(eq. 3)}$$

where C_{ij} is the binary design variable of whether the residential population in the grid cell *i* in the prefecture *j* in 2050 will be zero or not (1: zero , 0: non-zero), N_j is the total number of grid cells in the prefecture j, $pop2050bau_{ij}$ is the residential population in the grid cell *i* in the prefecture *j* in 2050 of the BaU projection, dst_{ij} is the distance from the grid cell *i* to the city center in the prefecture *j*, N_{pref} is the total number of prefectures in Japan, $Nbau_j$ and $Ncmp_j$ denote the numbers of grid cells where the residential population will be zero in the prefecture *j* in 2050 of the BaU projection and the Cmp scenario, respectively, and β_p is the urban compactification parameter to determine the residential population distribution in scenario *p* ($\beta_p > 1{:}\,compactified, 0 \leq \beta_s \leq 1{:}\,dispersed$). β_p was set to two in the Cmp scenario in this study. After C_{ij} was decided via the optimization calculation, the residential population of grid cell *i* in the prefecture j ($C_{ij} = 1$) in the Cmp scenario ($pop2050cmp_{ij}$) was allocated to the grid cells ($C_{ij} = 0$) via the following equation:

if $C_{ij} = 1$ then $pop2050cmp_{ij} = 0$,

else if $C_{ij} = 0$ then $pop2050cmp_{ij} = pop2050bau_{ij} + \Delta pop_{ij}$;

for $i = 1, 2, \ldots, N_j$ and $j = 1, 2, \ldots, N_{pref}$, (eq. 4)

where Δpop_{ij} is the increased/decreased residential population in the grid cell *i* in the prefecture *j* calculated by

$$\Delta pop_{ij} = \frac{pop2050bau_{ij}}{\sum_{i=1}^{N_j} pop2050bau_{ij}} \cdot \sum_{i=1}^{N_j} C_{ij} \cdot pop2050bau_{ij}. \quad \text{(eq. 5)}$$

In the Dsp scenario, the local people are assumed to remain in the rural area to manage natural areas that are familiar to them. A total of 34,703 km^2 would be vacant from 2010 to 2050 in the BaU projection; however, it was assumed that this vacancy would not occur in the Dsp scenario. The residential population in 2010 was preserved by means of people moving from the cities to the rural areas. It was assumed that the areas that are far from the city center but easy to live in would be preferentially preserved. Therefore, the grid cells that had high population density in 2010 despite being far from a city center were selected as preserved areas by Eq. (6). The objective function to select the grid cells where the residential population were preserved at the 2010 level in 2050 is

$$\max \sum_{i=1}^{N_j} C_{ij} \cdot pop2010_{ij} \cdot dst_{ij} \text{ for } j = 1, 2, \ldots, N_{pref}, \quad \text{(eq. 6)}$$

which is subject to

$$Ndsp_j = \beta_p \cdot Nbau_j, \quad \text{(eq. 7)}$$

$$\sum_{i}^{N_j} C_{ij} = Ndsp_j \text{ for } j = 1, 2, \dots, N_{pref}, \quad \text{(eq. 8)}$$

where C_{ij} is the binary design valuable (1: preserved, 0: not preserved), $pop2010_{ij}$ is the residential population in the grid cell i in the prefecture j, $Ndsp_j$ is the number of grid cells where the residential population is preserved at the 2010 level in the prefecture j in 2050, and β_p is the same parameter as in Eq. (2). β_p was set to one in this study. dst_{ij}, N_j, and $Nbau_j$ have the same definitions as in the Cmp scenario above. After the values of C_{ij} were decided, the residential population of the grid cell i in the prefecture j in the Dsp scenario ($pop2050dsp_{ij}$) was reallocated using the following equation:

$$\text{if } C_{ij} = 1 \text{ then } pop2050dsp_{ij} = pop2010_{ij},$$

$$\text{else if } C_{ij} = 0 \text{ then } pop2050dsp_{ij} = pop2050bau_{ij} - \Delta pop_{ij};$$

$$\text{for } i = 1, 2, \dots, N_j \text{ and } j = 1, 2, \dots, N_{pref}, \quad \text{(eq. 9)}$$

where Δpop_{ij} is the same as in Eq. (5).

Working population distribution assumption

It is very important to divide the service potential and the realized services and to identify the demand and supply structure (Jones et al. 2016). The residential population distribution is the basic proxy to arise the demand of ecosystem services. Conversely, the working population in primary industries is absolutely necessary to manage the natural capital and its ecosystem functions and to realize a supply of ecosystem services. The distribution assumptions of the working population in primary industries provide essential information concerning the supply potential. Consequently, it enables to analyze spatially explicit demand and supply gaps of ecosystem services. In this study, the working population distribution was first based on the residential population distribution and then adjusted by the capital preference: natural capital or produced capital based societies (abbreviated as Ntr and Prd, respectively). First, the workers engaged in agriculture and forestry were designated according to

$$FAWP_{2050,i,s} = P_{2050,i,s} \cdot WPR_{2050,i} \cdot PWPR_{2050,i,s} \cdot FAWPR_{2050,i}, \qquad \text{(eq. 10)}$$

where $FAWP_{2050,i,s}$, $P_{2050,i,s}$, and $PWPR_{2050,i,s}$ are the working population in agriculture and forestry, the residential population, and the proportion of the working population in primary industries in the grid cell *i* in 2050 under scenario *s*, respectively and $WPR_{2050,i}$ and $FAWPR_{2050,i}$ denote the proportion of the working population and the working population in agriculture and forestry in 2050 in the grid cell *i*, respectively. The first item $P_{2050,i,s}$ on the right side of Eq. (10) was decided by the residential population distribution assumptions explained in the previous section. Here, the second item $WPR_{2050,i}$ on the right side of Eq. (10) was calculated as

$$WPR_{2050,i} = WPR_{2010,i} + 4(WPR_{2010,i} - WPR_{2000,i}), \qquad \text{(eq. 11)}$$

where $WPR_{2000,i}$ and $WPR_{2010,i}$ are the observed proportions of the working population in 2000 and 2010 in the grid cell *i*, respectively. Aging is the baseline-trend of the PANCES scenarios; therefore, the second item ($WPR_{2010,i} - WPR_{2000,i}$) is basically assumed to be negative. Then, the third item $PWPR_{2050,i,s}$ in Eq. (10) is calculated as

$$\text{if } (PWPR_{2010,i,s} - PWPR_{2000,i,s}) < 0 \text{ then}$$
$$PWPR_{2050,i,s} = PWPR_{2010,i} + \gamma_c \cdot 4(PWPR_{2010,i} - PWPR_{2000,i}), \qquad \text{(eq. 12a)}$$
$$\text{else if } (PWPR_{2010,i,s} - PWPR_{2000,i,s}) \geq 0 \text{ then}$$
$$PWPR_{2050,i,s} = PWPR_{2010,i}, \qquad \text{(eq. 12b)}$$

where γ_c is a parameter in accordance with the primary industry activity level depending on the capital preference *c* ($0 \leq \gamma_c < 1$: Natural capital basis, $\gamma_c \geq 1$: produced capital basis). Japan is a representative developed country; therefore, the industrial structure has shifted to tertiary industries such as commerce, communication, finance, and services (MIAC 2018). According to this background, the difference between $PWPR_{2010,i}$ and $PWPR_{2000,i}$ in Eq. (12) is assumed to be negative. In a Ntr society, the domestic primary industry is assumed to be active in order to maintain the self-sufficiency of natural resources such as food and timber. Therefore,

γ_c was set to zero in the Ntr scenario, which means that the activity level of the primary industries was maintained at the 2010 level. Meanwhile in the Prd scenario, the domestic primary industries were assumed to have shrunk because Japan will be highly dependent on external natural resources via the global market in this scenario. Therefore, the parameter γ_c was set to two, which means that the primary industries shrink at twice the rate of the current tendency. The fourth item, $FPWPR_{2050,i}$, is generally characterized by the geographical and environmental conditions of the grid cell *i*; therefore, $FPWPR_{2050,i}$ was calculated as

$$FAWPR_{2050,i} = mean(FAWPR_{2000,i}, FAWPR_{2010,i}). \quad \text{(eq. 13)}$$

Finally, $FSWPR_{2050,i}$ was calculated using the equation

$$FSWPR_{2050,i} = 1 - FAWPR_{2050,i}. \quad \text{(eq. 14)}$$

Results

Residential population distribution by scenario

Figure 4 shows the residential population distributions under the different scenarios. The inhabited areas in the Cmp and Dsp scenarios were 110,813 km^2 and 180,219 km^2, respectively. As shown on the map, the change to compact cities in the Cmp scenario and the preservation of the residential populations in the rural areas in the Dsp scenario were observed, which means that the optimization calculation worked successfully and that the results were consistent with the storylines of the PANCES scenarios. The characteristics of compactification and dispersion were different for each prefecture. In the Cmp scenario, the most depopulated area was Hokkaido, the most northernmost prefecture in Japan. The residential population was disappeared in 93% of the grid cells in the Hokkaido Prefecture. The climate zone of Hokkaido is subarctic, and boreal forests cover approximately 70% of the land (Hokkaido Prefecture 2018). The Shiretoko Peninsula in northeastern Hokkaido is a natural world heritage site (UNESCO 2018a). Forestry, fisheries, and dairy farming flourish in this region. Compared to the Dsp scenario, the depopulation in the Cmp scenario could cause a lack of ecosystem management and have a large impact on the maintenance of the natural capital and regulating ecosystem services. Severe depopulation, a more than 50% decrease, was also observed in western Japan, especially Shikoku inland and Chugoku region. Between Shikoku island and Chugoku region, there is a national park, the "Setonaikai sea," which includes a cultural world heritage site, the "Itsukushima Shinto Shrine" (UNESCO 2018a). It is suggested that depopulation could affect not only cultural ecosystem services but also indigenous traditional culture.

Figure 5 shows the distribution of the residential population and the land area by population density class. The horizontal axis represents the residential population density classes, and the vertical axis represents the proportion of the grid cells and residential population in each residential population density class. Concerning the proportions of the residential population (dotted lines in Fig. 5), 70% of Japanese people live in the 2,000–20,000-person/km^2 density class in both the Cmp and Dsp scenarios. This means that Japanese society is still highly urbanized regardless of the future scenario. Conversely, the proportion of grid cells (solid lines in Fig. 5) by residential population density class is different within the scenarios. In particular, there is a large difference in the low population density areas, e.g., 0–100 person/km^2, which are generally local areas. The low residential population density area was 40% of the total inhabitable area in 2010, while the proportion of low residential population density area in the Cmp scenario decreased to 27% in 2050. This suggests that depopulation will progress strongly and that the low residential population density area will disappear by 2050. Japanese society will withdraw from the management of local areas and will not be able to maintain the rural natural capital. Conversely, the low residential population density area increases to 53% in the Dsp scenario and this population can be expected to sustain the connection to nature and the realization of ecosystem services.

Working population distribution in primary industries by scenario

Figure 6 shows the working population distribution in primary industries consisting of agriculture, forestry, and fisheries under the different scenarios. The vertical category represents the population distribution assumptions and the horizontal category represents the capital preference directions. Overall, there were no large differences between the population distribution directions; however, there was a large difference between the directions of the capital preference.

As shown in Fig. 4, the total number of the residential population is the same and most of the people live in the high population density urban areas in both the Cmp and Dsp scenarios. The change in the proportion of the working population was −9% in the dense grid cells with more than 2,000 person/km^2 in 2010. Therefore, urban working people decreased at roughly the same level in both scenarios. In addition, the change in the proportion of working population was −13% in the sparse grid cells with less than 2,000 person/km^2 in 2010. In the Dsp scenario, People remained in rural areas with low population density; however, the total number is not very large. Therefore, the working populations were approximately 39 million and nearly the same between the Dsp and Cmp scenarios shown in Fig. 6 (left). Compared to the difference in the population distribution assumptions, the direction of the capital preference (the Prd and Ntr scenarios) and the regional characteristics of the primary industries strongly affected the working population in primary industries, as shown in Fig. 6 (right). The change in the proportion of the working population in primary industries was dramatically different between scenarios due to the second term on the right side of Eq. (12a). The change in the proportion of the working population in primary industries in the grid cells with high residential population density (>2,000 person/km^2) and low population density (<2,000 person/km^2) in 2010 were −1.3% and −29%, respectively. This difference caused a severe decrease in the primary industry workers in the under-populated regions. In addition, the parameter γ_s in Eq. (12a) was two in the Prd scenario; therefore, primary industry workers especially disappeared in most of the low residential population density areas even if the natural capital and resources were rich.

Figure 7 shows the proportion of grid cells by working population in primary industries. The difference of scenarios affected the small agribusinesses with sizes of less than 200 employees. Especially in the CmpPrd scenario, most of the small-scale primary industries disappeared from rural areas and concentrated in urban areas. Therefore, the primary industries will become inactive and people will strongly depend on imported ecosystem services. In addition, rewilding will occur in local areas due to depopulation. Conversely, in the DspNtr scenario, people sustain their contact with neighboring natural capital and benefit from ecosystem services at small scales. At the same time, they risk disservices resulting from natural ecosystems such as natural disasters and animal injuries. Therefore, the difference in the population distribution assumptions has a large effect on people's lifestyles.

Sample analysis: Natural capital, Provisioning and Cultural Ecosystem Services

In this section, we introduce sample analyses using our spatially explicit population distribution assumptions in terms of natural capital, provisioning and cultural services. The case study site is the Ishikawa Prefecture, which is in north central Japan and includes the biosphere reserve site "Mt. Hakusan" (UNESCO 2018b).

Figure 8 shows the land cover in the Ishikawa Prefecture and the correlation between the working population in agriculture and forestry and natural capital by scenario. The representative land cover type in 1-km^2 grid resolution is shown in Fig. 8 (left). In Fig. 8 (right), the X-axis shows the occupancy level of natural capital landscapes within each grid cell. Each grid cell (km^2) contains the information of the land use types within its grid (MLIT 2014b). The proportion of the natural capital landscapes in terrestrial ecosystems (forest, farmland, and cropland) was calculated and classified into three levels. The Y-axis shows the total number of the working population in agriculture and forestry within a 10-km radius of each grid cell. The colors represent the CmpPrd and DspNtr scenarios, which had the largest and smallest working population in primary industries, respectively. As seen in the distributions of the natural capital level, the richer the natural capital landscapes were in the grid cell, the more agriculture and forestry workers were allocated in the DspNtr scenario. Conversely, few people remained in areas with rich natural capital in the CmpPrd scenario. This result is consistent with the storylines of the PANCES scenario (Saito et al. (2018)). As shown in Fig. 7, the conservation policies in the low working population density areas will be a key determinant for future natural capital and ecosystem services. Our dataset can help evaluate the sustainability of natural capital management using population distribution assumptions.

Figure 9 shows the total number of the working population in fisheries within a 10-km radius of each fishing port in the Ishikawa Prefecture by scenario. The number of the working population in fisheries strongly depends on the direction of the capital preference. In the Dsp scenario, fisheries remained in the areas with low population density comparing to the situation in the Cmp scenario series. In the storyline of the PANCES scenario, fisheries are assumed to expand aquaculture and enhance the food self-sufficient rate under fishery resource management in the DspNtr scenario. Meanwhile, most people live in urban areas and have abandoned fishing ports and feeding aquaculture increases based on the ICT system near urban areas in the CmpPrd scenario. Our data of spatially explicit population distribution assumptions can express these storylines, and the working population distributions in primary industries can be used to assess and evaluate the future supply potential of provisioning services in more detail, e.g., active or vanishing fishing port identification and feeding aquaculture plant allocation planning.

Finally, Figure 10 shows the poorly accessible natural landscape resources in 2050 due to the accommodation limitations in the Ishikawa Prefecture. Fig. 10a shows the working population density in 2050, and the grid cells with no working population are shown in yellow. The number of no working population cells is increased in the Cmp scenario compared to that in the Dsp scenario. The working population distinction is seen especially on the Noto Peninsula in the northern Ishikawa Prefecture, which is famous for its rich *satoyama*/*satoumi* and traditional ecosystem management (FAO 2018). Fig. 10b shows the distribution of the natural landscape resources on the Noto Peninsula. The points show the locations of the famous natural landscape resources (MLIT 2014c). The grid cells in cyan and magenta indicate the available and disappeared accommodations in 2050, respectively. First, accommodation capacities in 2010 were obtained from MLIT (2010). Then, an accommodation was identified as disappeared if the working population estimated by Eq. (11) became zero in the grid cell. As a result, the red points represent the poorly accessible natural landscape resources where accommodations within a 10-km radius disappeared in 2050 due to the working population extinction. In both scenarios, the northwestern resources are expected to be poorly accessible due to accommodation capacity losses. In the Cmp scenario, more resources in the northeastern and middle parts of the peninsula become poorly accessible. This low accessibility can not only cause inactivity in the tourism industry but also disturb the succession of traditional local culture.

Discussion

In this study, we developed residential and working population distribution assumptions depending on the BaU projection by MLIT (2014a). MLIT (2014a) forecasted the future population in a prefecture, city and grid cell order and the migration rates were considered in each scale. On the other hand, people were assumed to move the center of prefecture in this study, and this algorism represented very strong centralized society. We need to express multi scale centralized society in city level resolution. Furthermore, the population projection itself has large uncertainties such as the fertility rate, mortality, and immigration. In the NIPSSR (2014), low, middle, and high levels of fertility and mortality rate were set and nine projections were conducted. The projected populations were distributed from 91 to 104 million depending on the assumption. In this study we adopted the middle case as the BaU scenario; however we need to evaluate the effect of the baseline trend selection to the result of population distribution. NIPSSR (2018) updated the latest Japanese population projection by region (modified as low population decreasing rate, highly aged population in mega cities, and low numbers of children compared to the dataset used in this study); however, this projection has not been spatially allocated. We need to modify the assumptions of the BaU projection to develop more plausible future scenarios.

Considering the population structure is also important from social and industrial viewpoints. For example, people remain in rural areas in the Dsp scenario, and whether a region can secure labor force in primary industries decides the sustainability of the natural capital and ecosystem services in a region. As described above, Japan is a highly aging society. From this backdrop, for instance, the Ministry of Agriculture, Forestry, and Fisheries is now promoting the opportunity to participate in agricultural works for elder people with the help of information and robot technology (MAFF 2017) and the technological growth will augment the capability of nature management per working population. The participation of retired people in ecosystem management is a key factor to sustain local natural capital. MLIT (2017) recently released the population forecasting data with age structure in in 500-m grid resolution. We need to improve working population design logic considering the age structure and express the potential of participation of the retired people for nature conservation.

Furthermore, we treated only the primary industries here; however, the tourism industry has large role in linking people to natural capital in terms of cultural services (JBO–2 2016). Therefore, we need to describe much more diverse and detailed storylines to support governance and policy system designs.

Concerning the population reallocation process in this study, the small number of people living in the vast rural areas moved to the urban centers in the Dsp scenario, while a few people living in dense cities were allocated to rural areas in the Cmp scenario. However, one plausible scenario could be a large-scale migration from urban areas into rural areas with rich nature or, conversely, more people could rush to megacities (more than ten million people, such as Tokyo, Osaka, and Nagoya) with very high population densities. Extreme scenarios should be constructed in the start of scenario analyses (Schoemaker 1993). We need to express more diverse, extreme, and plausible population distribution assumptions by adjusting the boundary and weight settings of the allocation calculation.

In the population allocation process, we need to take into account environmental factors such as climate change impacts and the availability of natural resources, which effect residence choices. Jones and O'Neill (2016) pointed out that climate change may lead to the movement of people away from potentially drought-ridden regions or coastal urban areas facing rising sea levels toward currently under-developed cooler areas. Especially in Japan, the rate of increase of extreme precipitation is expected to be higher in future climate conditions (Nayak et al. 2017) and the intensity of typhoons is likely to increase (Takami et al. 2016). This situation will increase serious disasters such as landslides and flooding, and people will avoid areas vulnerable to natural disasters and prefer rich natural environments that can provide good regulating ecosystem services. We need to implement a residence choice model in association with environmental factors in the allocation algorithm.

In addition to the residential and working population distribution assumptions, we need to consider impacts on the local region via visiting population from external areas. Now Japan aims to become a "Tourism Nation" (CAO 2012). It is possible that the floating population including international visitors largely increases the access to the natural resources and activates the local tourism economy. And also the nonresident population, who do not live the areas but have strong interests and social ties to the region, attracted an attention and be expected to play to maintain and revive the local areas (METI 2009). Recently, it is said that agricultural diversification has various types (Barbieri and Mahoney 2009). For example in Japan, sixth sector industrialization, which means the promotion of primary producer’s diversification into processing and distribution by coupling the primary, secondary and tertiary industries (METI 2012). From another perspective, non-market transaction has a large contribution to the realization of ecosystem services in local communities. For example, it was revealed that many types of food were obtained from household food production and traditional food sharing customs in typical local communities in Japan (e.g. Kamiyama et al. 2016, Tatebayashi et al. 2018). These activities can be interpreted that demand and supply of ecosystem services are matched by hidden primary industries. These activities can impact on the definition of working population and the logic of eq. (10). It will also be an important suggestion to deepen the narratives of the capital preference directions. We need to implement the scenarios in consideration of the emerging new manners of realizing ecosystem services.

Conclusion

The future population distribution is a key indirect driver for conducting plausible scenario analysis of the demand and supply of ecosystem services. In this study, population distribution assumptions under the future scenarios in 1-km grid resolution were developed based on the gravity-based models. The scenario axis of the population distribution decided the residential population and the scenario axis of the capital preference broke down the residential population into working population in primary industries. By using the population distribution assumption by scenario, the population was overlaid with the natural capital and the supply potential of ecosystem services. The results supported to understand the gaps between natural capital and maintainability, the potential of ecosystem services and realizability. Thus, the spatially explicit population distribution data products are expected to help design the nature conservation strategy and governance option in terms of both social system and ecological system.

Acknowledgement:

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REFERENCES

Barbieri C, Mahoney E (2009) Why is diversification an attractive farm adjustment strategy? Insights from Texas farmers and ranchers. Journal of Rural Studies 25:58–66. DOI: 10.1016/j.jrurstud.2008.06.001

Cabinet Office, Government Of Japan (CAO) (2012) Tourism Nation Promotion Basic Plan, Available from http://www.mlit.go.jp/common/000234920.pdf

Cabinet Office, Government Of Japan (CAO) (2016) A 2016 Declining Birthrate White Paper, Available from http://www8.cao.go.jp/shoushi/shoushika/whitepaper/measures/english/w-2016/index.html

Dalkey N, Helmer O (1963) An experimental application of the Delphi method to the use of experts, Manage Sci 9(3): 458-467. DOI: 10.1287/mnsc.9.3.458

Food and Agricultural Organization of the United Nations (FAO) (2018) Globally Important Agricultural Heritage Systems (GIAHS) Noto's Satoyama and Satoumi. http://www.fao.org/giahs/giahsaroundtheworld/designated-sites/asia-and-the-pacific/notos-satoyama-and-satoumi/en/

Grübler A, O'Neill B, Riahi K, Chirkov V, Goujon A, Kolp P, Prommer I, Scherbov S, Slentoe E (2007) Regional, national, and spatially explicit scenarios of demographic and economic change based on SRES. Technological Forecasting and Social Change, Greenhouse Gases - Integrated Assessment 74: 980-1029. DOI: 10.1016/j.techfore.2006.05.023

Hokkaido prefecture (2018) the forestry statistics (in Japanese). Available from http://www.pref.hokkaido.lg.jp/sr/sum/kcs/rin-toukei/rin-toukei-index.htm

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2016) The methodological assessment report on scenarios and models of biodiversity and ecosystem services. Available from https://www.ipbes.net/sites/default/files/downloads/pdf/2016.methodological_assessment_report_scenarios_models.pdf

Intergovernmental Panel on Climate Change (IPCC) (2000) Available from http://www.ipcc.ch/

Japan Biodiversity Outlook Science Committee (2010) Report of comprehensive assessment of biodiversity in Japan (Japan Biodiversity Outlook). Global Biodiversity Strategy Office, Biodiversity Policy Division, Nature Conservation Bureau, Ministry of the Environment, Japan, Tokyo

Japan Biodiversity Outlook Science Committee (2015) Report of comprehensive assessment of biodiversity and ecosystem services in Japan (Japan Biodiversity Outlook 2). Global Biodiversity Strategy Office, Biodiversity Policy Division, Nature Conservation Bureau, Ministry of the Environment, Japan, Tokyo

Japan Satoyama Satoumi Assessment (JSSA) (2010) Satoyama-satoumi ecosystems and human wellbeing: socio-ecological production landscapes of Japan (summary for decision makers). United Nations University, Tokyo.

Jones B, O'Neill BC (2013) Historically grounded spatial population projections for the continental United States. Environ Res Lett 8: 044021. DOI: 10.1088/1748-9326/8/4/044021

Jones B, O'Neill BC (2016) Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways. Environ Res Lett 11:084003. DOI: 10.1088/1748-9326/11/8/084003

Jones L, Norton L, Austin Z, Browne AL, Donovan D, Emmett BA, Grabowski ZJ, Howard DC, Jones JPG, Kenter JO, Manley W, Morris C, Robinson DA, Short C, Siriwardena GM, Stevens CJ, Storkey J, Waters RD, Willis GF (2016) Stocks and flows of natural and human-derived capital in ecosystem services, Land Use Policy, 52: 151-162. DOI: 10.1016/j.landusepol.2015.12.014

Kamiyama C, Hashimoto S, Kohsaka R, Saito O (2016) Non-market food provisioning services via homegardens and communal sharing in satoyama socio-ecological production landscapes on Japan’s Noto peninsula. Ecosyst Serv 17:185–196. https ://doi.org/10.1016/j.ecose r.2016.01.002

Kindermann G, McCallum I, Fritz S, Obersteiner M (2008) A global forest growing stock, biomass and carbon map based on FAO statistics. Silva Fenn 42: 387-396. DOI: 10.14214/sf.244

Millennium Ecosystem Assessment (MA) (2005a) Available from https://www.millenniumassessment.org/

Millennium Ecosystem Assessment (MA) (2005b) Sub-Global Assessments. Available from https://www.millenniumassessment.org/en/Multiscale.html

Ministry of Agriculture, Forestry and Fisheries (MAFF) (2017) FY2016 Summary of the Annual Report on Food, Agriculture and Rural Areas in Japan. Available from http://www.maff.go.jp/j/wpaper/w_maff/h28/attach/pdf/index-29.pdf

Ministry of Economy, Trade and Industry (METI) (2009) White Paper on International Economy and Trade 2009, Available from http://www.meti.go.jp/english/report/data/gWT2009fe.html

Ministry of Economy, Trade and Industry (METI) (2012) 2012 White Paper on Small and Medium Enterprises in Japan, Available from http://www.chusho.meti.go.jp/pamflet/hakusyo/H24/download/2012hakusho_eng.pdf

Ministry of Environment (MOE) (2012) The National Biodiversity Strategy of Japan 2012-2020 Roadmap towards the Establishment of an Enriching Society in Harmony with Nature. Available from www.env.go.jp/press/files/en/528.pdf

Ministry of Internal Affairs and Communications (MIAC) (2018) Labor Force Survey. Available from http://www.stat.go.jp/english/data/roudou/index.html

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (2010) National Land Numerical Information download service, Accommodation Capacity Data. Available from http://nlftp.mlit.go.jp/ksj/gmlold/meta/suikei.html

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (2014a) National Land Numerical Information download service, Population Projections for individual 1km mesh. Available from http://nlftp.mlit.go.jp/ksj/gmlold/meta/suikei.html

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (2014b) National Land Numerical Information download service, Land Use Tertiary Mesh Data. Available from http://nlftp.mlit.go.jp/ksj/gmlold/meta/suikei.html

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (2014c) National Land Numerical Information download service, Tourism Resource Data. Available from http://nlftp.mlit.go.jp/ksj/gmlold/meta/suikei.html

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (2017) National Land Numerical Information download service, Population Projections for individual 500m mesh. Available from http://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-mesh500.html

Muramatsu N, Akiyama H (2011) Japan: super-aging society preparing for the future. The Gerontologist, 51(4): 425-432. DOI: 10.1093/geront/gnr067

Nakićenoić N, Swart R (2000) Special report on emission scenarios. A special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press.

National Institute of Population and Social Security Research (NIPSSR) (2014) Household Projections by Prefecture in Japan: 2010-2035, Outline of Results and Methods. Available from http://www.ipss.go.jp/pp-ajsetai/e/hhprjpref2014/t-page_e.asp

National Institute of Population and Social Security Research (NIPSSR) (2018) Regional Population Projections for Japan: 2015-2045, Outline of Results and Methods (in Japanese). Available from http://www.ipss.go.jp/pp-shicyoson/j/shicyoson18/t-page.asp

Nayak S, Dairaku K, Takayabu I, Suzuki-Parker A, Ishizaki NN. (2017) Extreme precipitation linked to temperature over Japan: current evaluation and projected changes with multi-model ensemble downscaling, Clim Dyn 1-17. DOI: 10.1007/s00382-017-3866-8

Predicting and Assessing natural Capital and Ecosystem Services (PANCES) (2016) http://pances.net/eng/

Reimann L, Merkens JL, Vafeidis AT (2018) Regionalized Shared Socioeconomic Pathways: narratives and spatial population projections for the Mediterranean coastal zone. Reg Environ Change 18: 235-245. DOI: 10.1007/s10113-017-1189-2

Saito O, Kamiyama C, Hashimoto S, Matsui T, Shoyama K, Kabaya K, Uetake T, Taki H, Ishikawa Y, Matsushita K, Yamane F, Hori J, Ariga T, Takeuchi K (2018) Co-design of national-scale future scenarios in Japan to predict and assess natural capital and ecosystem services. Sustain Sci 1–17. DOI: 10.1007/s11625-018-0587-9

Samal NR, Wollheim WM, Zuidema S, Stewart RJ, Zhou Z, Mineau MM, Borsuk ME, Gardner KH, Glidden S, Huang T, Lutz DA, Mavrommati G, Thorn AM, Wake CP, Huber M (2017) A coupled terrestrial and aquatic biogeophysical model of the Upper Merrimack River watershed, New Hampshire, to inform ecosystem services evaluation and management under climate and land-cover change. Ecol Soc 22(4): 18. DOI: 10.5751/ES-09662-220418

Schoemaker PJH (1993) Multiple scenario development: its conceptual and behavioral foundation. Strateg Manage J 14: 193-213. DOI: 10.1002/smj.4250140304

Statistics Bureau of Japan (SBJ) (2010) The population census in Japan 2010. Available from http://www.stat.go.jp/english/data/kokusei/index.html

Takemi T, Okada Y, Ito R, Ishikawa H, Nakakita E (2016) Assessing the impacts of global warming on meteorological hazards and risks in Japan: Philosophy and achievements of the SOUSEI program, Hydrological Research Letters 10: 119-125. DOI: 10.3178/hrl.10.119

Takeuchi K, Brown RD, Washitani I, Tsunekawa A, Yokohari M eds.: Satoyama -The Traditional Rural Landscape of Japan. Springer Tokyo, 229pp.

Tamura K, Masuda N (2017) Effects of the distant population density on spatial patterns of demographic dynamics. R Soc open sci 4:170391. DOI: 10.1098/rsos.170391

Tatebayashi K, Kamiyama C, Matsui T, Saito O, Machimura T (2018) Accounting Shadow Benefits of Non-market Food through Food-Sharing Networks on Hachijo Island, Japan. Sustain Sci 1–18. DOI 10.1007/s11625-018-0580-3

Thorn AM, Wake CP, Grimm CD, Mitchell CR, Mineau MM, Ollinger SV (2017) Development of scenarios for land cover, population density, impervious cover, and conservation in New Hampshire, 2010-2100. Ecol Soc 22(4):19. DOI: 10.5751/ES-09733-220419

United Nations Educational, Scientific and Cultural Organization (UNESCO) (2018a) Biosphere Reserves, Mount Hakusan. Available from http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/asia-and-the-pacific/japan/mount-hakusan/

United Nations Educational, Scientific and Cultural Organization (UNESCO) (2018b) World Heritage List. Available from https://whc.unesco.org/en/list/

van't Klooster SA, van Asselt MBA (2006) Practising the scenario axes technique, Futures, 38, 15-30. DOI: 10.1016/j.futures.2005.04.019

Volkery A, Ribeiro T, Henrichs T, Hoogeveen Y (2008) Your Vision or My Model? Lessons from Participatory Land Use Scenario Development on a European Scale. Syst Pract Action Res 21:459–477. DOI: 10.1007/s11213-008-9104-x

Zenrin Geo Intelligence (ZGI) (2018) The population census regional mesh statistics. On sale via http://www.zgi.co.jp/database/statistics/h22kokucho.html

Westhoek HJ, van den Berg M, Bakkes JA (2006) Scenario development to explore the future of Europe’s rural areas. Agriculture, Ecosystems & Environment 114:7–20. DOI: 10.1016/j.agee.2005.11.005

Figures

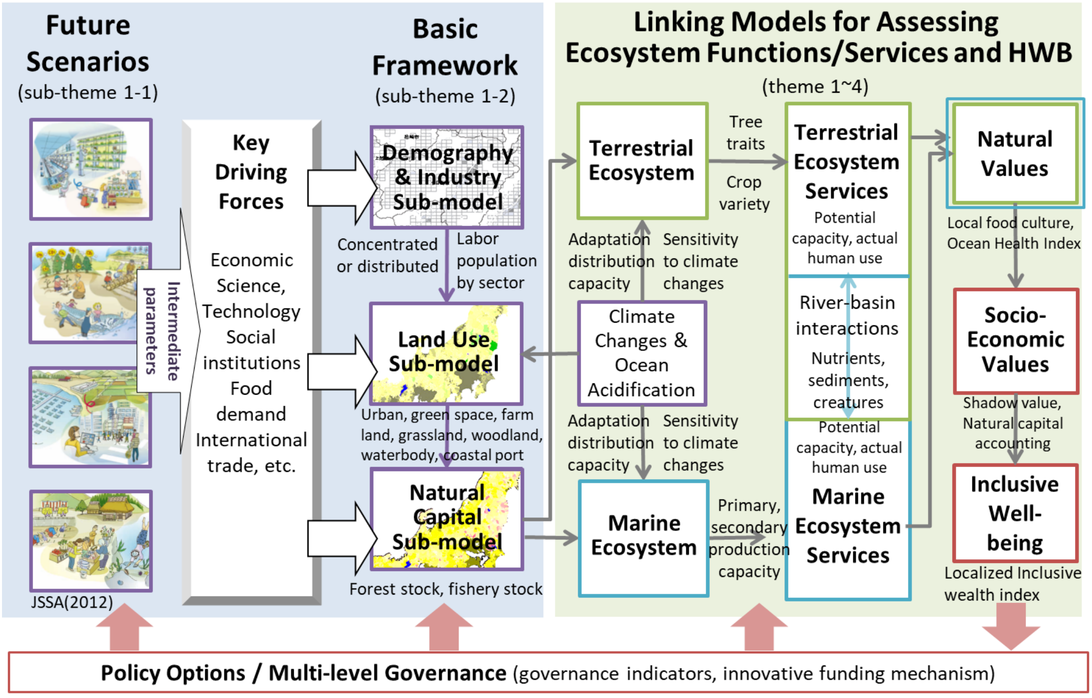
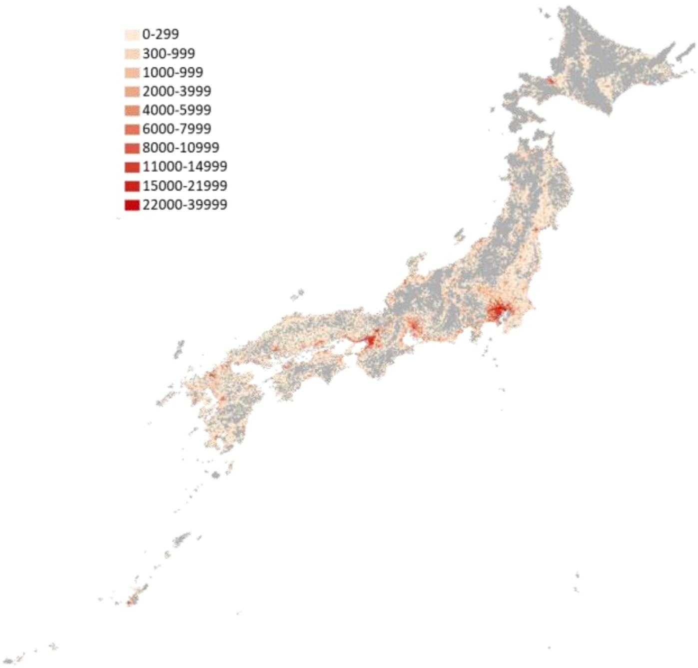
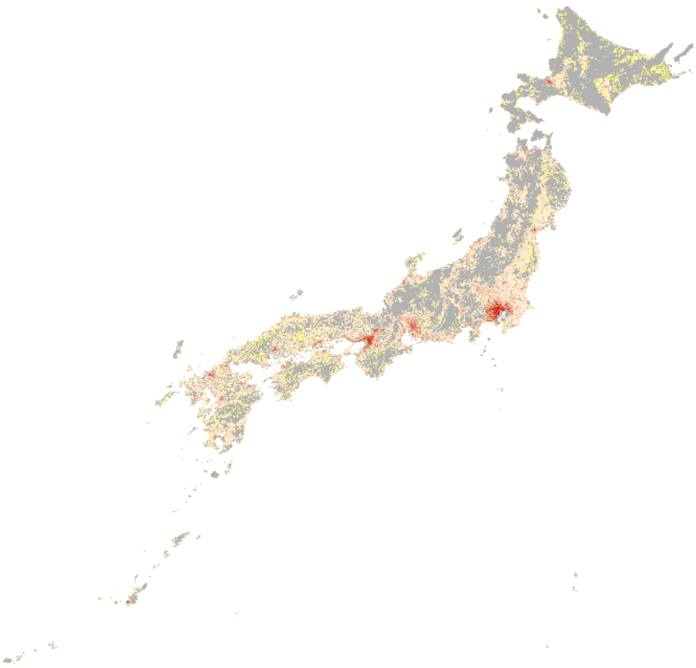


Fig. 1. Overview of the integrated simulation model of the socio-ecological systems in the PANCES project (PANCES 2016).

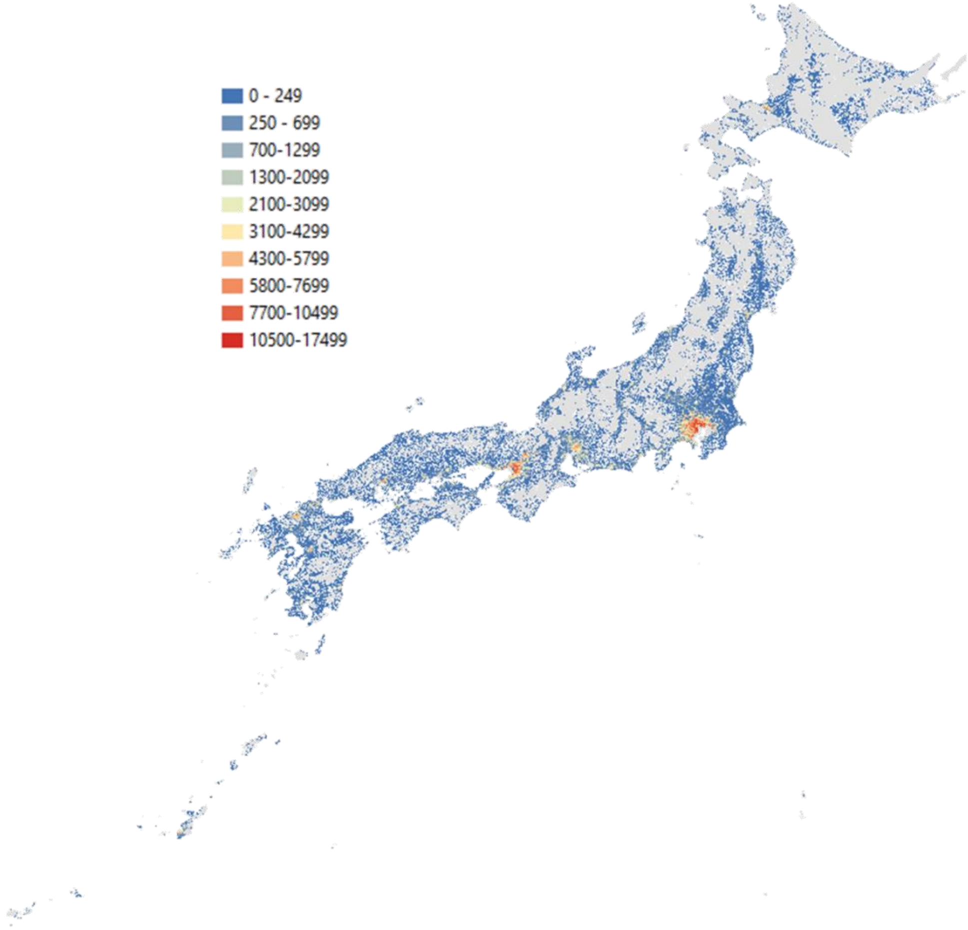


a) 2010 (n = 128,057,340)



b) 2050 in the BaU scenario (n = 97,074,889)

Fig. 2. Residential population distribution in (a) 2010 and (b) 2050 in the BaU projection. The population density [person/km^2] is shown in red, the uninhabitable areas are shown in gray, and the zero population areas are shown in yellow.



(n = 63,237,803)

Fig. 3. Working population distribution in 2010. The population density [worker/km^2] is shown in blue-red, and the uninhabitable areas are shown in gray.

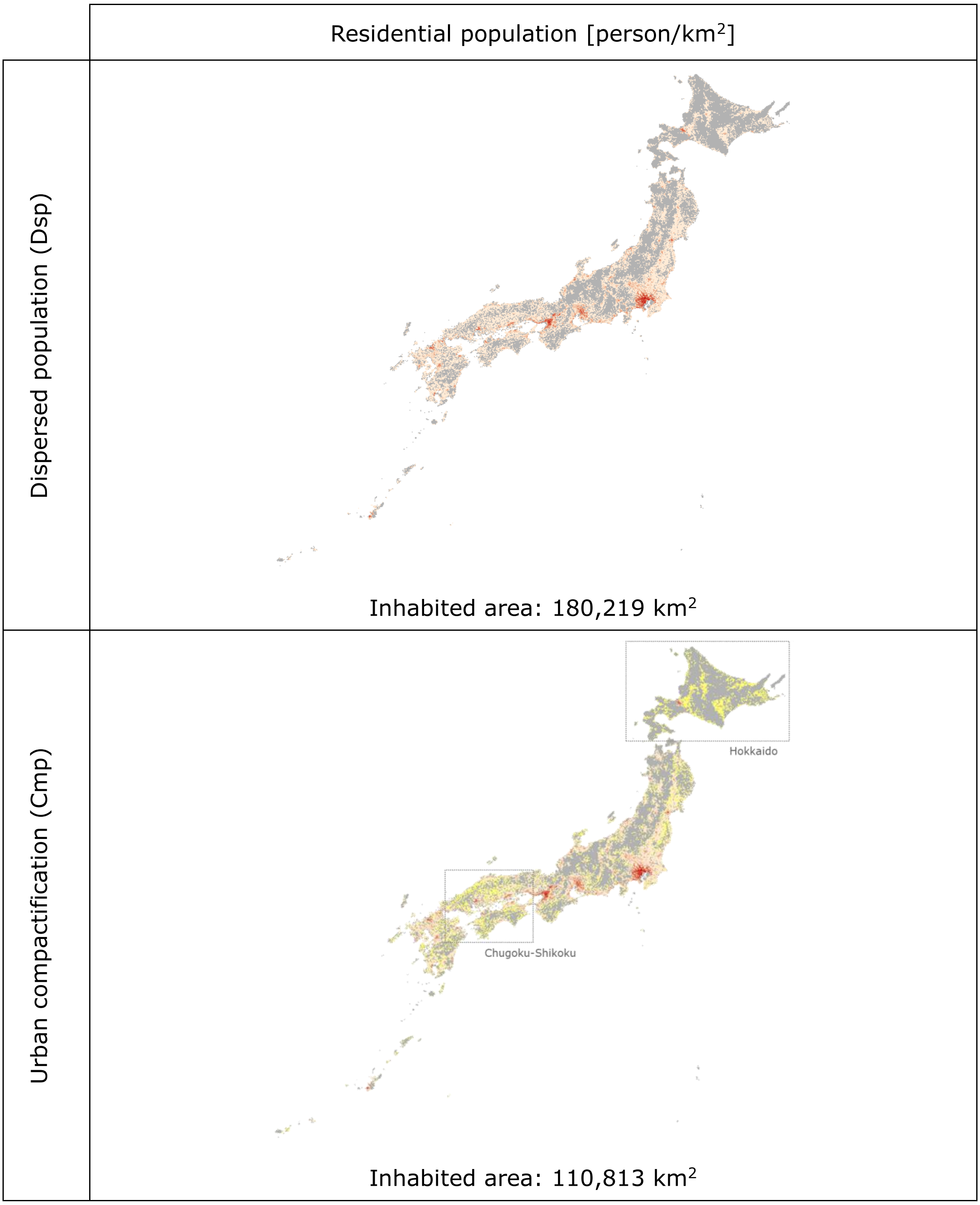


Fig. 4. Residential population distribution in 2050 by scenario (n = 97,074,889 in both scenarios). The population density [person/km^2] is shown in red, the uninhabitable areas are shown in gray, and the zero population areas are shown in yellow.

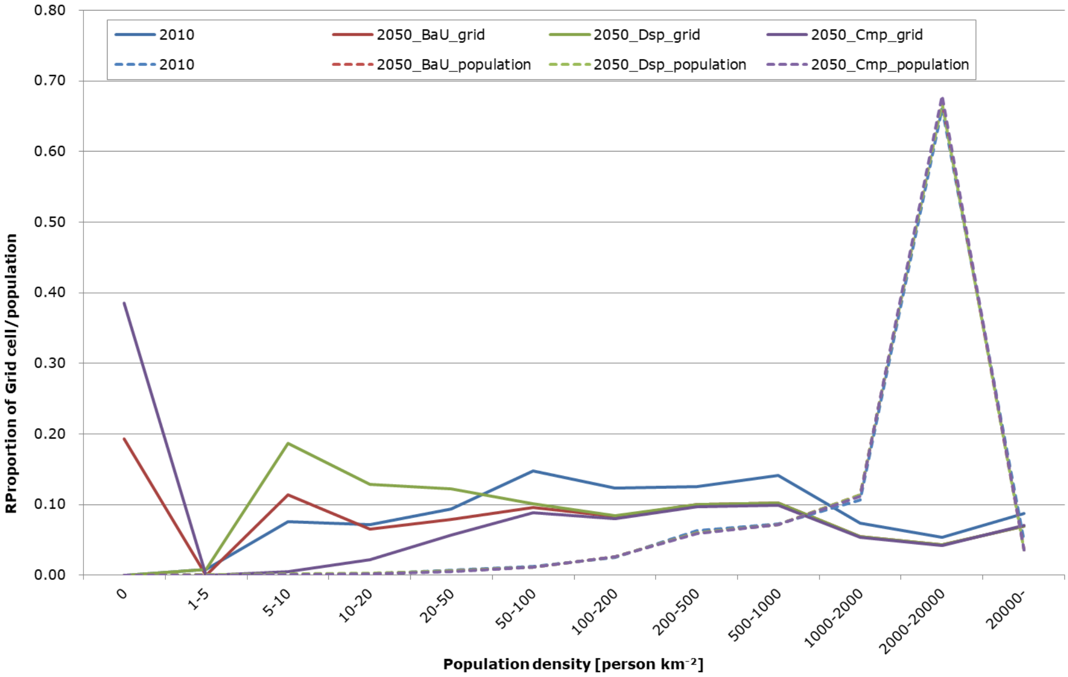


Fig. 5. Proportion of the residential population and the number of grid cells by residential population density.

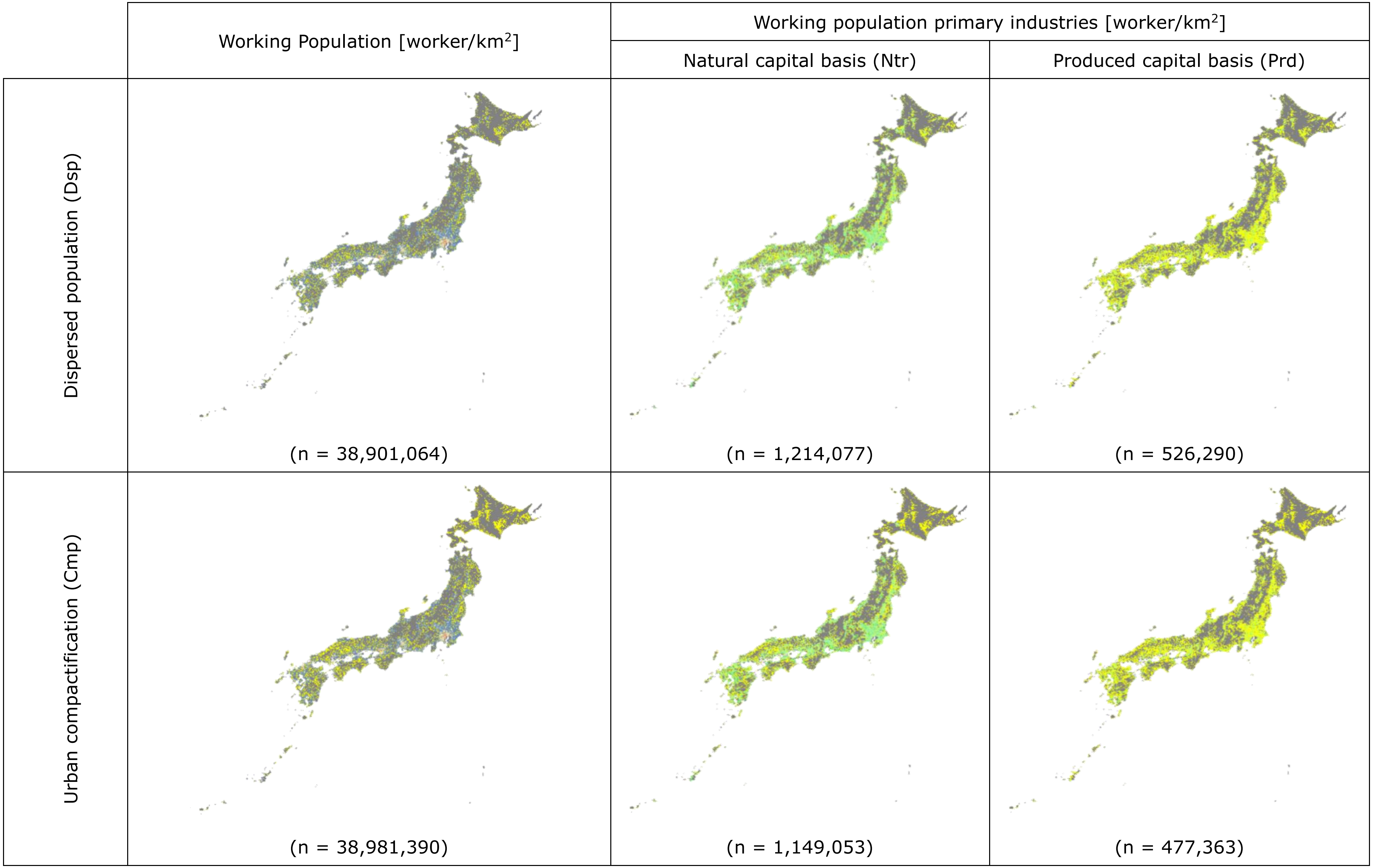


Fig. 6. Working population distribution in 2050 by scenario. The population density [worker/km^2] is shown in blue-red (working population) and green (working population in primary sectors), and the uninhabitable areas are shown in gray.

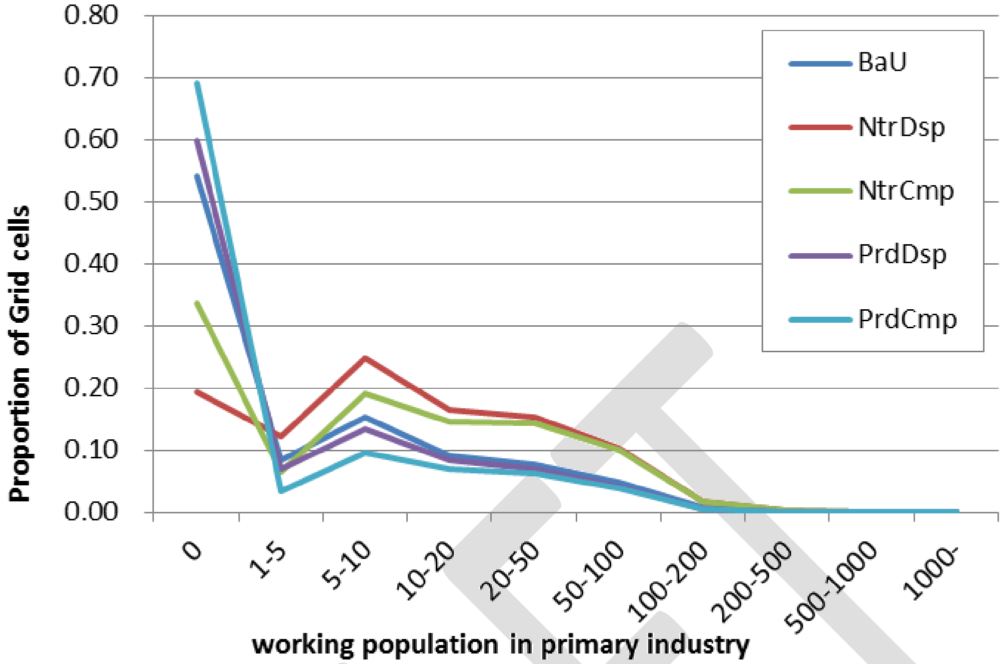


Fig. 7. Proportion of grid cells by working population in primary industries.

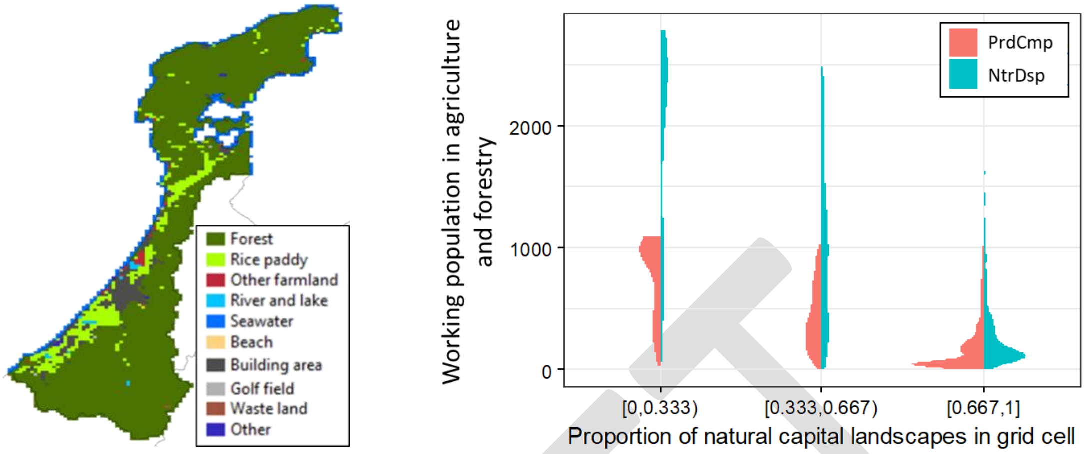


Fig. 8. Correlation between the working population in primary industries and the occupancy class of natural capital landscapes by scenario.

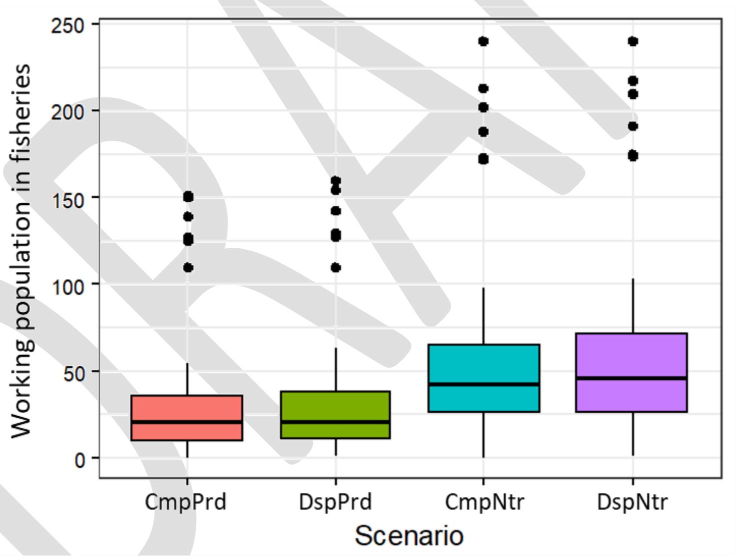
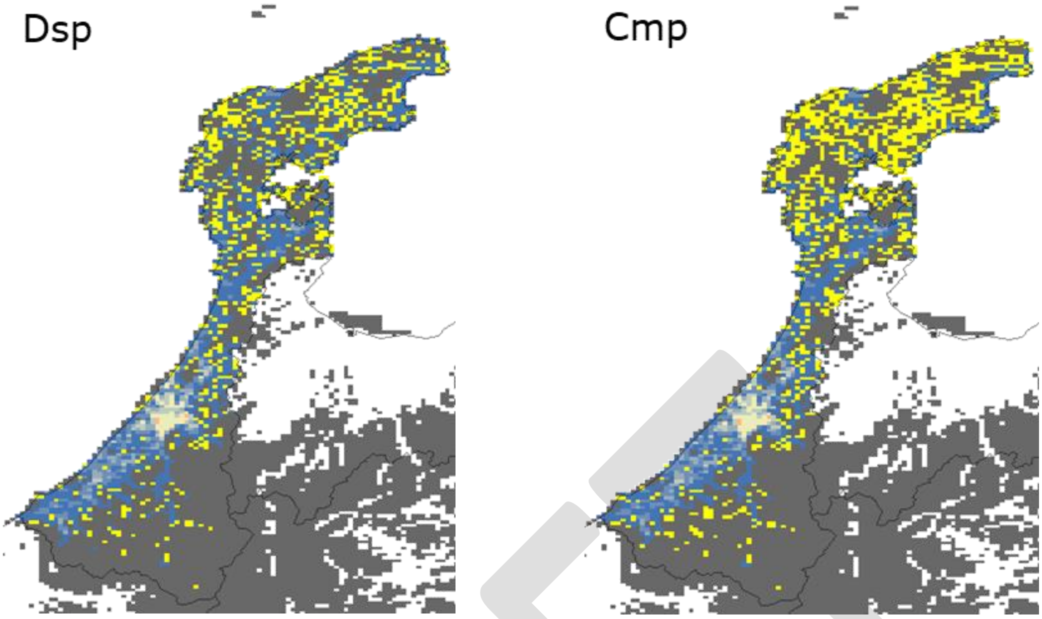
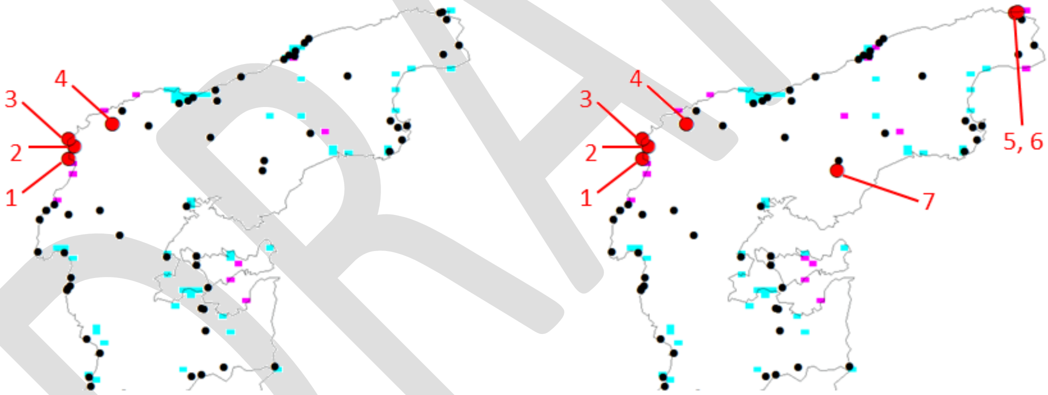


Fig. 9. Working population in fisheries by scenario (n = 73).



a) Working population in 2050 in the Ishikawa Prefecture. The worker population is shown in blue-red as in Fig. 3, the uninhabitable areas are shown in gray, and yellow indicates the zero working population in 2050.



b) Distribution of poorly accessible natural landscape resources in 2050 on the Noto Peninsula in the Ishikawa Prefecture. The grid cells in cyan and magenta indicate the available and disappeared accommodations in 2050, respectively. The black points indicate locations of natural landscape resources. The red points represent natural landscape resources where accommodations within a 10-km radius become difficult to maintain in 2050: **1**. the wave cut platforms in Kaiso, **2**. the Sakura Falls, **3**. the sea cliffs in Saruyama, **4**. the Name Falls, **5**. the sea cliffs in Noroshi, **6**. the wave cut platforms in Noroshi, and **7**. the columnar joint in Honki.

Fig. 10. Poorly accessible natural landscape resources in 2050 in the Ishikawa Prefecture.