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Optimal conservation planning of multiple hydrological ecosystem services under land use and climate changes in Teshio river watershed, northernmost of Japan

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ABSTRACT

Most anthropogenic activities impacted on water quality and quantity, and further impacted on ecosystem services (ESs) in watershed are related to land use and climate changes those may cause losses of ecosystem functions. Effective information regarding ESs and their optimal priority conservation planning responded to land use and climate changes provide useful support for diverse stakeholders in ESs planning, management and policies. This study integrated the approach of spatially explicit ESs (water yield, inorganic nutrient, organic nutrient and sediment retentions) by using hydrology and material flow model (Soil and Water Assessment Tools, SWAT model) into systematic conservation of hydrological ESs according to land use and climate changes in Teshio watershed located in the north of Hokkaido, Japan. We investigated the spatial patterns and the hotspots of ESs changes to determine the spatial pattern of changes in systematic conservation optimal area of ES protection in terms of ESs protection targets. Under the land use and climate change scenarios, the forest land use significantly affected on the water yield, sediment, organic-Nitrogen (N) and organic-Phosphorous (P) retentions. The agricultural land (paddy and farmland fields) impacted on the inorganic-N and inorganic-P retentions. We applied the systematic conservation model (MARXAN model) to optimize the area for management of hydrological ESs satisfied the protection targets (30% and 50% of potential maximum ESs values among all scenarios) in all and individual ecosystem services, respectively. The simulated results indicated that the areas of spatial optimal ESs protection for all hydrological ESs were totally different from those for individual ESs. For bundles of ESs, the optimal priority conservation areas concentrated in southwest, north, and southeast of this watershed, which are related to land use, topography and climate driving factors. These places could guarantee ESs sustainability from both environmental protection and agricultural development standpoints. The priority conservation area turned more compact under climate change because the increased precipitation and temperature increased ESs amount. For individual ESs, the optimal priority conservation areas of water yield, sediment retention and organic nutrient retention were traded off against those of inorganic nutrient retention (lower Jaccard's indexes and negative correlations of selection times). Especially, the negative correlation of selection times increased as the conservation target increased from 30% to 50%. The proposed approach provided useful information for assessing the responses of ESs and systematic conservation optimal planning to the land use and climate changes. The systematic conservation optimal areas of hydrological ESs provided an effective trade-off tool between environmental protection (sediment and organic nutrient retentions) and economic development (water yield and inorganic nutrient retention).

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1. Introduction

Ecosystem services (ESs) are benefits humans derive from ecosystems and could be direct (e.g. food supply) or indirect (e.g. climate regulation) (Millennium Ecosystem and Assessment, 2005). Many aspects of our planet are changing rapidly due to human activities and these changes are expected to accelerate during next decades (IPCC, 2007). For example, forest area in the tropics is declining, many species are threatened with extinction, and rising atmospheric carbon dioxide results in global warming (Bolstad and Swank, 1997; Geist and Lambin, 2002; Thomas et al., 2004). A global analysis of these changes revealed that 60% of the ESs provided by ecosystems has been diminished through human activities. These enormous impacts by grazing, fishing, timber, river diversion, water extraction and so forth are profound. These activities especially land use and climate changes disrupted ecosystem processes and diminished such a large fraction of ESs. It is recognized that the land use change would affect the hydrological cycle such as, infiltration, evapotranspiration, and groundwater (Lin et al., 2007). The land use change also can lead to decrease in soil nitrogen (N) storage. Loss of nitrate-nitrogen (NO_3-N) has particular implication for site fertility, and may also result in increased N loading in the hydrological ecosystem (Chaplot et al., 2003). Climate change is gaining momentum and will exacerbate many of the already existing adverse consequences of land use change impacts on water quality in the receiving water bodies (Millennium Ecosystem and Assessment, 2005). Climate change further amplifies the hydrological effects. There are changes in annual snow cover and the beginnings of vegetation changes that are influencing surface albedo with feedbacks to the climate system (Bouraoui et al., 2002). The water quality and quantity could be dramatically influenced by land use and climate changes and their negative consequence leads to decline in the ESs ecosystem provides (e.g. water supply and water purification). Therefore, it is necessary to implement spatial priority conservation planning of ESs for stakeholder to mitigate negative effect of land use and climate changes on ESs (Bu et al., 2014).

The principle challenges in managing ESs are that they are not independent of each other, and that the relationships between them may be highly non-linear (Tilman et al., 2002; Rodríguez et al., 2006). Individual ES can be through of as different elements of an interrelated whole. Attempts to optimize a single service often lead to reductions or losses of other services. For example, forested area provides a variety of extractive and non-extractive goods and services. If this region is managed for mining, this may decrease its value for carbon sequestration, flood control, or wilderness and biodiversity protection. Knowledge and awareness of the interactions between ESs under land use and climate changes are necessary for making sound decisions about how to manage natural systems appropriately (Chan et al., 2006). A spatial dimension incorporating biological conservation priorities and land use and climate changes is crucial for multiple ESs conservation. Systematic conservation planning has already been used extensively around the world to plan for ESs (Margules and Pressey, 2000; Sarkar et al., 2006; Butler et al., 2013). As emphasized in Egoh et al. (2007, 2010) and demonstrated by Chan et al. (2006), planning for ESs can benefit from the two decades of research and development that has included into the field of conservation planning, a sub-discipline of conservation biology which deals with identifying spatial priorities for conservation actions.

The benefits of enhancing the ecosystems to provide sustainable ESs at watershed scale, such as food, water purification and water supply for society have been remarkable and have supported agricultural expansion, population growing and urban development. This achievement often has been at the expense of each other ESs. These trade-offs of protected areas for sustaining and conserving each ESs under anthropogenic impacts (e.g. Land use and climate changes) have not been analyzed to full extent. In exploring ways to conserve areas to safeguard ESs, several studies have focused on assessing ESs by obtaining coarse statistic data from the public agencies (Chan et al., 2006; Turner et al., 2007; Naidoo et al., 2008; Egoh et al., 2009) without necessarily identifying priority areas for ESs by coupling the mechanism hydrology model with systematic conservation model under land use and climate change scenarios. Fresh water is one of the most important resources for humans, flora and fauna (Bu et al., 2014). Terrestrial watershed provides bundles of ESs such as water supply, sediment retention and nutrient retention. As land use and climate changes endanger sustainability of ecosystem at watershed scale, it is important to construct reserve networks that will have been focused on ESs hot issues. The optimal priority conservation areas of water supply and water purification are the directly critical indicators to assess the responses of ESs and environmental health to land use and climate changes. The priority conservation areas are used to show differences in spatial patterns between scenarios that have corresponding to ESs distribution under different land use and climate changes. Earlier studies have quantitatively assessed ESs and planned their priority conservation areas under land use or climate changes separately (e.g., Ferrier et al., 1995; Schröter et al., 2005; Nelson et al., 2009; Egoh et al., 2011). Few studies have analyzed and compared the impact of both land use and climate changes on protected area networks of individual or bundles of ESs in the watershed scale, even though those changes are simultaneously occurred in the same period (Gordon et al., 2009; Nelson et al., 2009; Carroll et al., 2010; Kujala et al., 2013). Therefore, modeling and understanding the responses of protected area networks of individual or bundles of ESs in the watershed scale to both land use and climate changes in the future are very useful and valuable toward optimizing land use planning, ESs management and policy in a watershed, particularly hotspot on priority conservation area of ESs. The priority areas would be the indicators of watershed management unit for conserving specific given ESs target in the watershed (Moilanen, 2007; Egoh et al., 2011).

Given above background, this study developed an analytical framework (integrating watershed-scale hydrology model into systematic conservation model) to identify and characterize the priority of the conservation areas for the spatial ESs patterns under land use and climate changes. This study used watershed-scale hydrology model to simulate ESs (water yield, inorganic nutrient retention, sediment retention, and organic nutrient retention) under multiple land use and climate changes at watershed scale, then constructed protected area networks of ESs by systematic conservation model. The optimal priority area is intended for the analysis of ESs data with aim of identifying spatial solution providing good conservation outcomes. The catchment-scale systematic conservation model could simulate the spatial variation in protected area networks and selection times of planning unit in the protected area networks under land use and climate changes. The model also could spatially explicitly explore the trade-offs of protected areas for ESs. It suggested that priority conservation area and its selection times could provide spatial extent and relative importance of ESs to fulfill conservation target, which is useful for functional ESs management and land use planning and further sustaining human benefits and health of nature system (Grantham et al., 2010; Weeks et al., 2010). The specific objectives of this study were (1) to identify areas where conservation efforts should be directed for individual ESs and for bundles of ESs under land use and climate changes at watershed scale, and to understand how changes in spatial patterns of ESs under land use and climate changes affect on priority conservation planning in the ESs; (2) to test the influence of different target levels of ESs used to identify priority areas, and to evaluate the trade-offs of individual ESs priorities under land use and climate changes.