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Determining subsidised forest stands to satisfy required annual wood yield with minimum governmental expense

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ABSTRACT

There are regions where forestry is required for wood production but the profitability is so low that many forest stands cannot be managed without subsidisation. Hence, the policymakers should design an efficient subsidising system involving the selection of subsidised forest stands. In this paper, we present an analytical framework for the proposition through the construction of a normal forest (a forest state such that the age distribution of stands is uniform) that consists of only stands that need to be subsidised for regeneration. The normal forest is constructed so that it supplies the required annual wood yield with minimum governmental expense for the subsidy. The rotation age of the normal forest is set to an optimal rotation age based on the soil expectation value of the stands under the minimum subsidy rates. The normal forest can be derived without numerical integration when the dominant tree height distribution follows a generalised gamma distribution. We present an application of the framework for four tree species in the Nagano Prefecture, Japan. The result of the application shows that the framework enables us to select the subsidised stands for efficient governmental funding, implying the practical conditions of the stands and requirements of wood demands, by using optimisation functions in a commercial spreadsheet program.

1. Introduction

The production of wood requires a longer time than other agricultural produces. Hence, the forest policies need to be designed based on long-term perspectives so as to avoid failure of sustainable wood yield and unbalanced wood demand and supply in the future. The sustainability of wood production may be assured by the ability to supply the required wood demand without irreversible deforestation. However, the global state of forest management is far from being sustainable. In a worldwide study by FAO (2015) during 2010–2015, around 3308 thousand ha of forest area were lost annually. This deforestation is considered as the main cause for climate change. Therefore, the policies for preventing deforestation are devised through the Reduced Emissions from Deforestation and Degradation (REDD/REDD +) programme (Leventon et al., 2014; Miles and Kapos, 2008; Newton et al., 2015).

However, since the present wood market is global, promoting wood production at regions having a climate suitable for reforestation and altering woods produced by deforestation with woods produced in such regions may be also necessary. Japan is one of such region, where the forest area accounts for 67% of the total area, and 41% of the total forest area (10,269,734 ha) is comprised of artificial forest (Japan Forestry Agency, 2012). In contrast, because of steep slopes, crumbly geological features and undulated topography, profitability in wood production is very low. For example, average yielding cost for clear cutting and commercial thinning at 2011 are 7888 yen/m^3 and 11,837 yen/m^3 respectively (Policy Planning Division of Japan Forestry Agency, 2013). Furthermore, Japan's climate also allows diverse flora to flourish that competes with the artificially planted seedlings. From the ecological perspective, reforestation in Japan is easy (i.e., after clearcutting, forests consisting of any species are regenerated naturally); it might seem that regeneration for wood production is easy. However, because diverse undesired flora also grows easily and beats the commercial seedlings, intensive weeding and other silviculture works are required in early years from the regeneration. Furthermore, the steep slope requires intensive stand preparation to prevent falling of objects and high load work to planting. As a result, the required silviculture cost until 10 years from regeneration is estimated to be 1560 thousand yen/ha and the subsidies for regeneration are mandatory (Japan Forestry Agency, 2015a).

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Due to such conditions, forest owners tend to avoid clearcutting so as to prevent paying high regeneration cost from few profits obtained by clearcutting. The clearcutting areas in 2013 accounted for 67,257 ha (Japan Forestry Agency, 2015b), which is 0.65% area of artificial forests. As a result, the self–sufficient rate of wood production was 31.2% at fiscal 2014 (Japanese Ministry of Agriculture, Forestry and Fisheries, 2015a). Thus, although Japan's climate is suitable for reforestation, raising commercial trees is difficult because of the climate and high regeneration cost (Nagaike, 2015); this mandates the provision of subsidies for regeneration (Japan Forestry Agency, 2015a).

From the perspective of free-market economy, excessive government intervention in the wood market should be avoided where the profitability of forestry stands is sufficiently guaranteed, unless the high demand leads to over-exploitation of the forests. Forestry should be discontinued in regions having low profitability such that stands cannot be managed without subsidisation. However, from the global and environmental perspective, forestry for wood production should rather be done in regions where reforestation is easy, even if there is a requirement of a certain amount of subsidies. Such subsidisation increases the annual wood yield of these regions but adds to the government expenditure. Most of the defrayers of the expense are the public of the country, who are not the forest owners. The objective stands of the subsidisation should be, therefore, determined so that the expenses for the subsidy is minimised while satisfying the required annual yield. Furthermore, the equality of the subsidisation between the subsidised owners should also be taken into account. The subsidisation system should be designed in such a way that it neither allows the owners to gain profit from the subsidisation nor forces them to pay the unreasonable cost to accord the policy target. For designing such a subsidisation policy, we need to take into account that the expenses for the subsidisation and subsidy system such as the scope stands of the subsidy and subsidy rates have interactive relationships.

Some researchers assumed to subsidise forest stands as a compensation of public utilities, e.g., biodiversity (Kurttila et al., 2006) and carbon services (Kooten et al., 1995), and examined appropriate amount of the subsidy. However, it seems that no framework has been proposed for designing a subsidisation policy for log production in low profitability regions satisfying those requirements. The absence of such a framework restricts the rationalisation of subsidy systems in practice. For example, the Japanese government has set a target of increasing self–sufficiency of wood production to 50% by 2025 (Japan Forestry Agency, 2016a). On the other hand, the subsidy rate for standard regeneration cost is fixed at 70% regardless of the species and site quality (Japan Forestry Agency, 2016b). The present tool to regional forest management of the government comprises of "Gentan" method (Suzuki, 2003, 1963, 1961), which predicts the yield amount of a region. Since the method is a "prediction" method based on past regeneration or thinning area, it does not connect the yield amount and subsidising system explicitly. Other predictions of yield amount based on the current government's subsidy system using Geographic Information System (GIS) have been executed (Kawata and Matsumura, 2006; Nakajima et al., 2011; Taki and Takata, 2015; Yamada and Tatsuhara, 2012). Except for the subsidisation for log production, several optimisation methods for the classifications of forest use using GIS have also been proposed (Gustafson et al., 2006; Radeloff et al., 2006; Sheppard and Meitner, 2005). In principle, by iterating the selection of subsidised stands, the prediction of yield from the stands, adjusting subsidy rate for each stand, and estimating the necessary governmental expense, the optimisation of the subsidy system seems to be done numerically during designing of the subsidisation policy. However, each protocol of the iteration needs numerous time for determining the subsidising policy of a large area, if we adopt numerical calculation using GIS. The objective area must be a large area on the regional or national scale when determining subsidising policy. Therefore, we should consider a framework that enables us to determine the subsidisation policy that meets all the requirements.

In addition, the framework should be based on a forest state that ensures sustainable wood yield. One such traditional forest state is the ordinary normal forest (ONF), in which a working class (WC; an aggregation of stands in which rotation ages, species of trees and working system are common) has an age distribution such that the stand area of each age (from one year to the rotation age) is uniform. It has been proven that ONF is also an optimal convergence state when regeneration is controlled to maximise eternal net present value (Heaps, 2015, 1984; Mitra and Wan, 1986, 1985). The extended normal forest (ENF; Suzuki, 2003, 1979), which allows variation in the rotation age in a WC, also ensures a constant annual yield of wood. Based on these states, the framework is assured to be sustainable.

In this paper, we propose a framework to determine forest stands to be subsidised for wood production in regions where the profitability of forestry is low, but the possibility of reforestation is high, satisfying those requirements. The determination is conducted through identifying an ONF that satisfies a given required annual yield. It will be proven that the state that satisfies the requirement for subsidy adjustment of each stand is not ENF but ONF. The ONF is derived analytically without using GIS, for the availability to use at regional or national scale.

In the framework, the stands conditions to be subsidised, annual yield from the ONF, and the governmental expenses are determined interactively with analytical relationships. Hence, the related factors can be calculated from another factor interactively with a small calculation. Such framework seems to be natural assuming the subsidisation for forestry and may be useful in the practical policymaking of the subsidisation in the objective regions.

2. Materials and methods

We showed two analyses concerned with the framework. One is the analytical derivation of the ONF and the method used for the determination of forest area to be subsidised. The derivation is based on a discussion of optimal rotation age implying usual growth model of forest yield (Moriguchi et al., 2016). The second analysis deals with the application of the framework in a given region.

2.1. Growth of clearcutting profit of a stand and the optimal rotation age

In this section, we explain the growth of clearcutting profit of a stand, and the optimal rotation age based on the net present value in a single rotation (NPVS; from regeneration to clearcutting) as discussed by Moriguchi et al. (2016). Firstly, the height growth of the dominant trees can be simulated by using Bertalanffy's (1957) growth function (Hong-bing et al., 2001; Kurinobu and Toda, 2000):

$$\mathrm{H}(a) = H_\infty[1 - L_\mathrm{H}\exp(-k_\mathrm{H}a)]^{n_\mathrm{H}} \tag{1}$$

where a is the age of a stand (year), $\mathrm{H}(a)$ is the mean height of dominant trees at a years old (m), H_∞ is the upper limit of the height (i.e., the height at $a \to \infty$), and L_H, k_H and n_H are parameters. Only H_∞ varies with site quality, and the tree height is independent of stand density (Skovsgaard and Vanclay, 2008). At full-density conditions, the mean height of the dominant trees, stand volume per area and mean diameter of the trees have exponential relationships with the number of trees. This is referred to as the power-law at full-density conditions (Burkhart, 2013; Yoda et al., 1963). Through these relationships, the stand volume per area at full-density conditions can be calculated using the mean height of the dominant trees as follows (Ando, 1968; Tadaki, 1963):

$$\mathrm{V_f}(a) = \eta\mathrm{H}(a)^\beta \tag{2}$$

where $\mathrm{V_f}(a)$ is the stand volume per area (m^3/ha) at the full–density when the mean height of dominant trees is $\mathrm{H}(a)$, and η and β are positive parameters. $\mathrm{V_f}(a)$ represents the maximum stand volume per area, and a density index called relative yield (RY) is defined as follows (Ando, 1968):