Effects of harvest restraint periods and fluctuation tolerances of profits and harvests on sustainable timber supply levels from private forests in a district

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ABSTRACT
The current age class distribution of plantation forests in Japan is bell-shaped, with the peak at 50 years. This offers opportunities to increase domestic timber supplies, but confidence in the long-term stability of supplies must be established. For this, greater knowledge of sustainable harvest levels starting from current stocks is required. Thus, this study analyzed effects on harvest levels of varying harvest restraint periods and fluctuation tolerances of both harvest and profit levels, focusing on privately owned Cryptomeria japonica plantations in the Sampoku district of Murakami City, Niigata Prefecture, Japan. A 0-1 integer programming model was formulated to predict maximum sustainable harvest levels from the forests that could provide stable profits. Permutations of five harvest restraint period cases and three fluctuation tolerance cases were simulated to assess effects on the volume of total harvests. A 10-year harvest restraint period dramatically increased the sustainable harvest level, but extending it further had weaker effects. Varying the fluctuation tolerances substantially affected sustainable harvest levels in the absence of harvest restraints, but not in their presence. Thus, imposing a 10-year harvest restraint period enabled maximal sustainable timber production in the study area.

Introduction
The current age class distribution of plantation forests in Japan is bell-shaped, with the peak at 50 years. This is because numerous forests that were clearcut and devastated during World War II were planted in the 1950s, numerous hardwood forests were replaced with coniferous plantations in the 1960s to meet dramatic increases in wood demand caused by economic recovery and growth, and such afforestation declined in the 1970s due to rapid increases in wood imports (Forestry Agency of Japan 2014). Thus, forests covering large areas are ready to harvest or approaching harvest maturity, and potential domestic timber supplies are increasing, even though the age class distribution is far from that of fully regulated forest. However, the demand for domestic timber is generally low because of distribution far from that of fully regulated forest. However, the Gentan probability method and similar approaches have several problems; notably some private forests are not actively used for timber production (Noda 1999), and may not even be suitable for profitable timber production (Tatsuhara and Dobashi 2006). Yamada and Tatsuhara (2012) attempted to counter this problem by calculating the maximum sustainable timber supply from a district by simulating timber production through iterative binary searches, assuming that only potentially profitable forests would be harvested for timber production.

In a further refinement, Moriya and Tatsuhara (2014) predicted maximum sustainable timber supply levels from a district considering the profitability of timber production and reductions of profit fluctuations over a planning horizon. However, they assumed that harvests could be rapidly doubled to maximum levels, which may not be realistic because of the accompanying need for rapid expansion of both timber production and wood processing capacities. Moreover, it is difficult to supply timber at constant rates from forests with bell-shaped age class distributions. Thus, it would be more realistic for both sectors to plan to increase timber supplies to the maximum levels gradually.

It is also unrealistic to expect timber supplies to be completely constant, especially in districts with numerous small-scale forest owners, and there is a possibility to trade logs with other districts, so it is essential to allow some variation in harvests. Fluctuation tolerances under even-flow volume constraints have been set by given values of absolute bounds of harvest, absolute bounds on the change of harvest, and relative bounds on the change of harvest (Gassmann 1989). The
fluctuation tolerances may clearly affect harvest and profit levels, so adjustments of the tolerances may be required as elements of policies to increase or reduce timber supply levels. However, effects of fluctuation tolerances on harvest levels have not been clarified.

The objective of the study reported here was to analyze effects on maximum sustainable harvest levels in a specific district of varying the harvest restraint period in early parts of the planning horizon and fluctuation tolerances of both harvest and profit levels. In the focal district there are numerous small-scale privately owned plantation forests, the age class distribution is far from that of fully regulated forest, and some plantation forests are not suitable for profitable timber production. The outcome of the study is intended to support forest resource management in districts with such characteristics. Candidate prescribed silvicultural regimes (hereafter prescriptions) were determined, incorporating subcompartments’ geographical attributes into calculations of profitability and decisions regarding final cutting age. Then, maximum sustainable harvest levels allowing a certain fluctuation among planning periods were predicted, considering the harvest level under a given scenario to be the mid-point between lower and upper bounds and setting it as the objective function of a harvest scheduling problem rather than the total harvest or revenue of an entire planning horizon.

**Materials and methods**

**Study site**

The study focused on privately owned forests in the Sampoku district (38°21’–33° N, 139°27’–34° E) of Murakami City in the northernmost part of Niigata Prefecture, Japan. The district (formerly Sampoku Town, before merger with Murakami City in 2008) is one of the prefecture’s most active forestry regions. The studied forests were composed of sugi (*Cryptomeria japonica* D. Don) stands covering at least 0.1 ha. Smaller stands were excluded because harvesting them is not profitable (Yamada and Tatsuhara 2012), and a 441-year-old sugi stand in forest around the Hakogata-Hachimangu shrine was excluded because it is not commercially harvested. Subcompartments whose distance to the road was equal to the maximum yarding distance were also excluded because it was impossible to calculate the yarding distance for them. In total, this left 13,792 subcompartments covering 8701.5 ha. The current age class distribution of these subcompartments is bell-shaped, like the overall distribution of Japanese plantation forests (Figure 1). Current timber production in Sampoku district amounts to about 20,000 m³/year according to interviews with local experts reported by Yamada and Tatsuhara (2012). The Northern Niigata Wood Processing Cooperative (“Sugitopia Iwafune”) in the district produces sawn and laminated wood from domestic medium-diameter logs, and has a log processing capacity of 24,000 m³/year. The silvicultural system applied in the sugi plantations is summarized in Table 1 (regeneration treatments) and Table 2 (commercial thinning and final cutting regime).

**Data**

We used forest inventory and map data for 2010 provided by the Niigata prefectural government, contour and elevation point data provided by the Geospatial Information Authority of Japan (2012), and road data digitized from 1:5000 scale forest maps (Tatsuhara and Dobashi 2006). We also used information from interviews reported in Moriya and Tatsuhara (2014) with representatives of the forest owners’ cooperative in Murakami City about the current status of forests and silvicultural operations in the study area, Niigata prefectural government about current subsidies in the prefecture, and both Sugitopia Iwafune and Niigata timber market about relevant standards and prices of logs.

**Predicting yield and calculating profit**

Yield and profit were calculated for each subcompartment under each prescription according to the methodology of Moriya and Tatsuhara (2014), as summarized below. ArcGIS 9.3.1 was used as GIS software to obtain spatial information.

The average height of dominant and codominant trees in each subcompartment was calculated from stand age and site class entries in the forest inventory data using height/age curves published by the Niigata Prefectural Government (1980). The yield from each subcompartment under each prescription was predicted using the stand density control diagram published by the Forestry Agency of Japan (1981).
The height of trees in each diameter class was estimated using a dimensionless height curve (Nagumo et al. 1981). The stem form of the trees in each diameter class was estimated using a relative taper curve, again with parameters determined from the stand density control diagram. The volumes of logs obtained from stands were predicted under each prescription by simulating cross-cutting logs of three sizes from 1 m above the ground from each harvested tree according to the cutting prescription (Table 3). A third of the large- and medium-diameter logs was assumed to be A-grade (and the others B-grade), while all the small-diameter logs were treated as C-grade.

Eight prescriptions were applied in the simulations: seven for regeneration and logging (thinning and felling) and one for the regeneration treatment from Niigata Prefectural Government subsidies for the maintenance of main customers (Table 3). Subsidies for the medians of daily middle prices on the timber market and predicted log production and log prices. Log prices were set at Table 4.

The cost of managing the stands was estimated by summing the regeneration and logging (thinning and cutting) costs for final cutting and thinning harvests.

The revenue from sale of logs was estimated from the predicted log production and log prices. Log prices were set at medians of daily middle prices on the timber market and purchase prices of main customers (Table 3). Subsidies for regeneration treatments from Niigata Prefectural Government were considered when calculating profits (Table 4).

The cost of managing the stands was estimated by summing the regeneration and logging (thinning and cutting) costs for final cutting and commercial thinning, the following logging system was assumed:

Felling with a chain saw → tree-length cable yarding → bucking with a chain saw.

Whether a thinning was commercial or a thinning-to-waste was selected for each simulated thinning by comparing the potential revenue minus the cost of a commercial thinning plus subsidy from the prefectural government to the cost of thinning-to-waste. The area, initial age, and site class of subcompartments were obtained from the inventory data, while slope and distance to a road were calculated using GIS. Maximum and average yarding distances were also calculated using GIS by calculating each 10 × 10 m cell’s distance to a road then obtaining the maximum and average distances for cells in each subcompartment. The regeneration cost was estimated with adjustment for the person-days required for regeneration treatments listed in Toyama et al. (2009) according to each stand’s slope and distance to road (Takahashi et al. 1996). The logging cost was estimated by summing felling, bucking, yarding, and log transportation costs (Suzuki and Tatsuhara 2016).

The profit over a rotation was calculated for each subcompartment under each prescription from the corresponding revenue, subsidy, and cost estimates. Only prescriptions with a rotation age that did not exceed the initial age and yielded a positive profit per ha per year were considered as possible prescriptions for each subcompartment. These prescriptions were treated as candidate prescriptions which can be assigned to the subcompartment in harvest scheduling.

### Predicting maximum sustainable harvest levels

The following harvest scheduling model was formulated using 0-1 integer programming (Greenberg 1971). Both the length of a planning period and width of an age class were set at 10 years, and the length of the planning horizon at 150 years (15 planning periods).

Maximize

$$z = V$$  \hspace{1cm} (1)

subject to

$$\sum_{i=1}^{I} \sum_{j=1}^{J} v_{ij} x_{ij} \geq (1 - r_v) \forall t \in \{ T_r + 1 , \ldots , T \}$$  \hspace{1cm} (2)

$$\sum_{i=1}^{I} \sum_{j=1}^{J} v_{ij} x_{ij} \leq (1 + r_v) \forall t \in \{ T_r + 1 , \ldots , T \}$$  \hspace{1cm} (3)

$$\sum_{i=1}^{I} \sum_{j=1}^{J} v_{ij} x_{ij} \leq (1 - r_v) \forall t \in \{ 1 , \ldots , T_r \}$$  \hspace{1cm} (4)

$$\sum_{i=1}^{I} \sum_{j=1}^{J} p_{ij} x_{ij} \geq (1 - r_p) P \forall t \in \{ T_r + 1 , \ldots , T \}$$  \hspace{1cm} (5)

$$\sum_{i=1}^{I} \sum_{j=1}^{J} p_{ij} x_{ij} \leq (1 + r_p) P \forall t \in \{ T_r + 1 , \ldots , T \}$$  \hspace{1cm} (6)

$$\sum_{i=1}^{I} \sum_{j=1}^{J} p_{ij} x_{ij} \geq (1 - r_p) P \forall t \in \{ 1 , \ldots , T_r \}$$  \hspace{1cm} (7)

$$\sum_{i=1}^{I} \sum_{j=1}^{J} p_{ij} x_{ij} \leq 0 \forall t \in \{ 1 , \ldots , T_r \}$$  \hspace{1cm} (8)

$$\sum_{i=1}^{I} S_0 \leq \sum_{i=1}^{I} \sum_{j=1}^{J} ST_{ij} x_{ij}$$  \hspace{1cm} (9)

### Table 3. Assumed cutting priority of logs and log prices, from Moriya and Tatsuhara (2014), with revisions.

| Cutting priority | Log length (m) | Top end diameter (cm) | Grade | Customer | Price (yen/m³) |
|------------------|---------------|----------------------|-------|----------|----------------|
| 1                | 4.0           | 30+                  | A     | Niigata timber market | 18,000         |
|                  |               |                      | B     | Plywood manufacturer  | 8,600          |
| 2                | 4.0           | 16–28                | A     | Sawmill and laminated wood manufacturing complex | 10,500         |
|                  |               |                      | B     | Plywood manufacturer  | 8,600          |
| 3                | 2.0           | 6–14                 | C     | Supplier of fuel wood chips to a biomass power station | 3,645          |

### Table 4. Subsidies from the prefectural government.

| Treatment                | Subsidy (yen/ha) |
|--------------------------|------------------|
| Planting                 | 466,936          |
| Weeding                  | 57,161           |
| Pre-commercial thinning  | 110,390          |
| Commercial thinning      |                  |
| Harvested volume (m³/ha) |                  |
| 0–10                     | 82,462           |
| 10–20                    | 87,521           |
| 20–30                    | 113,689          |
| 30–40                    | 139,832          |
| 40–50                    | 160,020          |
| 50–60                    | 192,183          |
| 60–70                    | 218,351          |
| 70–80                    | 244,514          |
| 80–90                    | 270,683          |
| 90+                      | 296,846          |

Note: Values calculated from standard unit costs published by Niigata Prefectural Government (2012) multiplied by the assessment coefficient of 1.7 and subsidy rate of 0.3. The standard wage of regular workers was 14,700 yen/person-day (Niigata Prefectural Government 2012).
where $z$ is the objective function; $V$ is the sustainable harvest level during the planning horizon; $P$ is the profit level during the planning horizon; $I$ is the number of subcompartments (1372); $J$ is the number of alternative prescriptions (8); $T$ is the number of planning periods (15); $T_r$ is the number of planning periods with a harvest restraint; $x_{ij}$ is 1 when subcompartment $i$ is assigned to prescription $j$, and otherwise 0; $v_{ij,t}$ is the harvest volume in the $t$-th planning period when subcompartment $i$ is assigned to prescription $j$; $p_{ij,t}$ is the profit in the $t$-th planning period when subcompartment $i$ is assigned to prescription $j$; $S_0$ is the stand volume of subcompartment $i$ at the beginning of the planning horizon; $S_{I,j}$ is the stand volume of subcompartment $i$ at the end of the planning horizon when subcompartment $i$ is assigned to prescription $j$; $r_f$ and $r_p$ are the fluctuation tolerances in the periodic harvest and periodic profit, respectively; $y_{ij}$ is 1 when prescription $j$ is a candidate for subcompartment $i$, and otherwise 0.

Objective function, Equation (1): in order to predict the maximal sustainable harvest level during the planning horizon we maximized it as the objective function.

Harvest constraints, Equations (2)–(4): the harvest in each planning period should be smaller than the minimum of the tolerable fluctuation range during the harvest restraint period, and within the tolerable fluctuation range after the harvest restraint period.

Profit constraints, Equations (5)–(8): the profit in each planning period should also be smaller than the minimum of the tolerable fluctuation range during the harvest restraint period, and within the tolerable fluctuation range after the harvest restraint period. In addition, it should be $\geq 0$ because management with negative profit is not realistic.

Growing stock constraints, Equation (9): the quantity of growing stock at the end of the planning horizon should be larger than or equal to that at the beginning of the planning horizon to ensure sustainable forest management.

Constraints for assignment of a single prescription, Equation (10): the sum of $x_{ij}$ over $i$ should be 1, so that each subcompartment can be assigned only one of the prescriptions.

Constraints for possible prescriptions, Equation (11): only possible prescriptions for selection (determined in the previous section) are assigned as candidate prescriptions for each subcompartment.

Constraints for binary integers, Equation (12): the variables $x_{ij}$ and $y_{ij}$ can take a value of 0 or 1.

Using the model we simulated all permutations of five cases for the harvest restraint period (no period and the first one, two, three, or four planning periods; i.e. setting $T_r$ at 0, 1, 2, 3, and 4, respectively) and three cases for the fluctuation tolerance (5%, 10%, and 20%, i.e. setting both $r_f$ and $r_p$ at 0.05, 0.1, and 0.2, respectively). Thus, we simulated 15 cases in total. The model was solved using IBM ILOG CPLEX Optimization Studio v12.5.1 on a personal computer. The objective was not to obtain exact solutions but to analyze the fluctuation of the harvest level during the planning horizon. Thus, we rounded $V$ and $p_{ij,t}$ to 100 and 1000, respectively, then obtained approximate solutions by applying the branch-and-cut method with a relative gap tolerance of 0.5%.

Results

Harvest and profit levels

Harvest levels strongly increased when the first planning period was set as the harvest restraint period, but further increases in the harvest restraint period had little additional effect under all tested fluctuation tolerances (Figure 2A). A 10-year harvest restraint increased harvests by 41%, 29%, and 18% under fluctuation tolerances of 5%, 10%, and 20%, respectively. Moreover, the harvest level increased with increases in the fluctuation tolerance (Figure 2A). The profit level also increased with increases in the fluctuation tolerance (Figure 2B). However, it was affected very little by the presence or absence of harvest restraint (or length of the harvest restraint period), although it displayed a small peak when harvest was restrained for two planning periods.

Proportions of stands assigned to the prescriptions

Proportions of the total area of the subcompartments assigned to each of the prescriptions with no harvest restraint and 10-year harvest restraint were 100% and 97%, respectively. The proportion of harvested stands was around 80%, whereas the proportion of stands assigned to prescription 1 (harvest period) was 100%, 97%, and 85% in the no-restraint, 10-year-restraint, and 20-year-restraint periods, respectively.
harvest restraint for two planning periods (Figure 3) show that setting a harvest restraint period and/or increasing the fluctuation tolerances reduced the areas assigned to prescription 8 (no operations), although they did not change the area-weighted average rotation age of about 105 years. Proportions of the total area allocated to the four site classes and harvested (i.e., subjected to final cutting in the simulations) or unharvested, with no harvest restraint and harvest restraint for two planning periods (Figure 4) show that, as the fluctuation tolerances increased, proportions of the area harvested and allocated to site classes 2 and 3 increased, while setting a harvest restraint period sharply increased the proportion of harvested site class 3 relative to the proportion of harvested site class 2.

**Periodic harvest and profit**

The periodic harvest varied substantially under all the tested fluctuation tolerances with no harvest restraint, but when harvest was restrained for two planning periods the periodic harvest was much more stable after the restraint, and almost constant after planning period 5 under all tested fluctuation tolerances (Figure 5A). In contrast, there were large differences in periodic profit between planning periods 1–2 and after planning period 4 with no harvest restraint, and between planning periods 3–4 and after planning period 6 with harvest restraint for two planning periods (Figure 5B). However, the periodic profit was stable after these times, regardless of the presence or absence of harvest restraint. The fluctuation tolerances substantially affected the periodic profit in early planning periods, but after planning period 6 there were minor differences in periodic profits among the six permutations of no harvest restraint and two planning period harvest restraint with fluctuation tolerance of 5%, and virtually no differences with fluctuation tolerances of 10% and 20%. Varying the harvest restraint period also led to considerable differences in early harvest and profit levels, but minor differences in periodic harvests and periodic profits after planning period 6, which were also stable.

**Age class distribution**

At the end of the simulations, age class distributions of subcompartments assigned to prescriptions 1 to 7 were similar to uniform, while those of subcompartments assigned to prescription 8 were bell-shaped (Figure 6). The peak of the bell-shaped distribution (at age classes 20 and 21) was reduced by setting a harvest restraint and/or increasing the fluctuation tolerances.

**Discussion**

**Effect of harvest restraint periods**

Setting harvest restraint periods dramatically increased the harvest levels (Figure 2A), although it had considerably less
effect on profit levels (Figure 2B). It dramatically increased the areal proportions of harvested stands (Figure 3), especially the areal proportion of harvested site class 3 stands (Figure 4). According to findings by Moriya and Tatsuhara (2014) subcompartments covering 78% of the total study area could be harvested with net profits at ages up to 120 years, and almost all of these stands were assigned to harvesting prescriptions when a harvest restraint period was set. These results suggest that it shifted some marginally profitable stands from non-harvesting to harvesting prescriptions, thereby repressing any enhancement of profit per unit harvest volume. Moreover, the periodic harvest dropped at the allowable lower limit in planning period 1 with no harvest restraint (Figure 5A), although the periodic profits reached the allowable upper limit in the planning period (Figure 5B). To sustain both even-flow harvest and profit, more profitable stands were assigned to harvest in early planning periods and less profitable stands were assigned to harvest in subsequent planning periods. With a harvest restraint period, some of the more profitable stands did not have to be harvested quickly. Consequently, the area of stands that could be assigned to harvest prescriptions substantially increased as stands currently in the 6th age class (the peak of the current age class distribution) moved to the 7th age class, and more stands currently in the 5th and 6th age classes were assigned to harvest prescriptions (Figure 6). Therefore, setting a harvest restraint period enabled more stands (including less profitable stands mainly in the peak age classes, especially current 5th and 6th age classes) to be assigned to harvest prescriptions with various rotation ages.

However, extending the length of the harvest restraint period beyond two planning periods did not increase the harvest level. This is because there are some old plantation forests (Figure 1), and the maximum rotation in the clearcutting prescriptions was 120 years. Thus, greater extension of the harvest restraint period caused some of the stands currently in old age classes (particularly 10th and 11th), to pass beyond the assumed range of rotation lengths (Table 2) and thus avoid harvest.

Nelson et al (1991) combined 30-year, area-based logging plans with 150-year, strata-based harvest plans, and found that lower harvests in the first 30 years led to higher long-term harvest levels in later periods, because more profitable stands were harvested and immature stands were allowed to grow in the early periods under even-flow volume and net revenue constraints. In contrast, the increases in harvest levels associated with harvest restraints in this study were mainly due to increases in the proportion of stands assigned to harvesting prescriptions under even-flow constraints. This was because sustainable harvest levels were predicted for forests with a current bell-shaped age class distribution, and subcompartments under profitable prescriptions, rather than entire stands, were assigned to harvest.

**Effect of fluctuation tolerances**

Increasing the fluctuation tolerances increased both profit and harvest levels (Figure 2). Notably, it increased

![Figure 5. Changes in levels in each planning period depending on the harvest restraint period and fluctuation tolerances of harvest and price level. A, Harvest level; B, profit level.](image)

![Figure 6. Predicted age class distributions, in 10-year classes, of the studied stands after 150 years. A, No or two planning period harvest restraint and 5% fluctuation tolerances; B, no or two planning period harvest restraint and 10% fluctuation tolerances; C, no or two planning period harvest restraint and 20% fluctuation tolerances.](image)
proportions of the total area covered by harvested stands of both site classes 2 and 3 (Figure 4), by shifting the assignment of some profitable stands that were left unharvested with a low fluctuation tolerance (in order to sustain harvest levels during the planning horizon) to a harvesting prescription with a high fluctuation tolerance. Strict profit or harvest levels lead to increases in unharvested areas.

When a harvest restraint period was set, the following periodic harvests were almost constant, regardless of the fluctuation tolerance (Figure 5A). On the other hand, the periodic profits varied substantially during early planning periods, but were constant after the middle planning periods (Figure 5B). Stands currently in the 6th age class (the peak of the current age class distribution) passed beyond the range of possible rotation ages in the 8th planning period, but both periodic harvest and periodic profit became stable before this point. Thus, in practice the fluctuation tolerance in our scenarios corresponds to the rate of maximal increase of the profit level during early parts of the planning horizon, and with no harvest restraint period it governs the harvest level.

Sustainable timber supply

Diaz-Balteiro et al. (2009) simulated optimal harvest scheduling with an even-flow harvest area or volume constraint under various ranges of rotation ages to obtain fully regulated pure eucalyptus forests from Monterey pine stands and mixed eucalyptus-pine stands in community-owned forests in Galicia, Spain. The first half of age class distributions at the end of the simulations reported here were similar to those of fully regulated forest (Figure 6). This is because similar areas were harvested and planted in each planning period as a result of periodic harvests that met criteria set by the fluctuation tolerances. The results (especially the data presented in Figure 3) indicate that, in order to supply timber from the studied plantations sustainably, the forest owners will have to adjust the final cutting age and harvest stands at various ages rather than at the same rotation length.

Conclusions

We have analyzed effects of imposing harvest restraints in early planning periods, and varying fluctuation tolerances of the harvest and profit levels, on the maximal sustainable harvest level of privately owned plantation forests in a specific district with a bell-shaped age class distribution. Setting a 10-year harvest restraint dramatically increased the sustainable harvest level, although it did not change the profit level, and further extension of the harvest restraint period had weaker effects on the harvest level. Varying the fluctuation tolerances also substantially affected the sustainable harvest level, with no harvest restraint, but had minor effects on harvest level when a harvest restraint period was set. Therefore, imposing a 10-year harvest restraint enabled close-to-maximal timber production, and determined values of the harvest levels. The outcome of the study should facilitate management of forest resources in regions with similar characteristics to the study site.

The simulation model in this study incorporated two features. First, an even harvest level was set as the objective function, rather than total harvest over the entire planning horizon. In contrast to general long-term harvest schedules, the total harvest volume was not necessarily maximized here because the objective was to determine sustainable timber harvest levels with a given range of fluctuation. Second, subcompartments’ attributes such as site quality, yarding distance, and slope were determined using a GIS to reflect geographical differences among them in profitability calculations. A decision support system for long-term planning using linear programming and a GIS has been previously developed (Næsset 1997). However, in the approach presented here the candidate prescriptions provide links between subcompartments’ data in the GIS and integer programming that reduce calculation loads for harvest scheduling simulations.

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Disclosure statement

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