博士論文

A Study on Decision Support Approaches for Regional-Level Forest Management

（地域レベル森林管理のための意思決定支援手法に関する研究）

山 田 祐 亮

A STUDY ON DECISION SUPPORT APPROACHES FOR REGIONAL-LEVEL FOREST MANAGEMENT

YUSUKE YAMADA

DOCTORAL THESIS

RESOURCE ANALYSIS LABORATORY,
DEPARTMENT OF FOREST MANAGEMENT
FORESTRY AND FOREST PRODUCTS RESEARCH INSTITUTE

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Human life occurs only once, and the reason we cannot determine which of our decisions are good and which bad is that in a given situation we can make only one decision; we are not granted a second, third, or fourth life in which to compare various decisions.

— Milan Kundera, "The Unbearable Lightness of Being"

ABSTRACT

This research developed a decision support approach (DSA) for local-level forest management. This DSA supports municipal governments to establish an effective forest zoning policy as a method for local-level forest management. It consists of indicators for forest multiple functions and a simulation model for a hierarchical forest management system. A case study showed the effectiveness of forest zoning and the DSA on sustainable regional forest management. This DSA would help to solve various problems municipalities suffer from and to adopt a hierarchical cyclic learning approach for forest planning.

Expectations on municipal governments managing regional forest with their own initiatives have been increasing since most forest functions fulfill themselves in local-level. However, municipalities generally have problems in insufficient manpower, difficulties in consensus buildings, and lacks of evaluation systems. As a result, forest plans established by municipal governments are not based on scientific analysis and ineffective. A new paradigm, instead of the current forest planning system, is needed for establishing a region-oriented master plan by each local government. A triple loop approach is one solution. This approach defines a whole system to apply adaptive management theory to actual forest management. A hierarchical structure of this approach enables to upper-scale governments to provide useful strategies or schemes to lower-scale by evaluating progresses of planning and projects of lower-scale governments. This research focused on development of indicators for forest functions and planning methods for a hierarchical management system; both of them are required for constructing the triple loop structure of forest management.

Many research reported the effectiveness of indicators for local-level sustainable forest management. Objective evaluations that can be achieved with indicators would improve sustainability by understanding the current situations and setting definite targets. Actual examples of indicators in forest planning is highly suggestive. In this research, processes of establishments and operations of forest master plan by advanced municipalities that utilize indicators were clarified by hearing investigations. Municipalities of Toyota, Shinshiro, Nagahama, and Tsushima were investigated. This research also have categorized processes of establishing indicators and have extracted general problems. As a results, each set of indicators have exhibited a current situation and problems of the locality significantly. The important issues for the regions such as insufficient human resources or preserving indigenous ecosystems are assessed with those sets of indicators. The committees, which consist of local forestry compa-

nies, experts, and other local participants evaluate the indicators periodically. Indicators have been established by Top-down/Bottom-up, Output/Outcome, Planning/Monitoring, Requirement/Current approaches. Because each approach has both strong and weak points, indicators with balancing both approaches should be developed. However, there are various obstacles to achieve it. Municipal governments generally have issues about comprehensiveness, consistency, dissemination, and verification. In order to heighten an effect of forest planning including local-level indicators, understanding the influence of a plan on changes of indicators and establishing systems to help motivated municipalities are important. Even though these problems exist, the advanced municipal governments suggested effectiveness of indicators on forest planning. Indicators improve understandings of the current and upcoming situations and make comparisons among management alternatives easier. Therefore DSA that are served for regional forest policy makings should contain indicators for forest multiple functions in an appropriate manner.

The DSA was developed in this research by integrating the simulation model and indicators for evaluating forest functions. While deliberating a regional-level forest management policy, one should note the probable existence of plural and independent decision-makers in the target region and the possibility that they may misunderstand or disobey the intent of the regional policy. To achieve sustainable forest management, the relationships between the policy and the decisions of individual decision-makers with respect to forestry activities (for example, thinning or clear-cutting) need to be considered; the relationships can also be called as uncertainties in controllability. This research designed a simulation model for forest zoning to simulate the changes in indicators of forest functions while reducing uncertainties in controllability of regional management on individual forestry activities. The model uses a Bayesian network model based on observed behavior (decision-making) by foresters, which simulates when and where zoned forestry activities are implemented. The Bayesian network model can reduce uncertainties by iterative learning. Verification with virtual forests and harvest tendencies indicated the high accuracy of the simulation model.

Forest functions including wood production, protection against soil erosion, preservation of biodiversity, conserving water resources, and carbon retention were evaluated in the DSA. These are vital functions for sustainable forest management; nevertheless the difficulties in evaluations have caused those functions to be ignored in municipal plans. Wood production was evaluated with the amounts of timber produced by forestry activities. For evaluating protection against soil erosion, area with high risk for soil erosion was estimated from geographical factors and forest age. A bayesian network model with National forest inventory (NFI) data was used for the estimation. The total area with high risk for the whole region was evaluated as the indicator. Preservation of biodiversity was evaluated with contributions of forest structures to biodiversity with the thought that the structures in old-growth forest make a better contribution to wildlife habitats. Contributions are estimated as old-growth index with a mathematical model based on NFI data. The average value of old growth-index in the target area was calculated as the indicator. As an indicator for conserving water resources, aggregating area of forest which is clearcut in a lower part of a slope was calculated, focusing on an outflow of nitrate nitrogen. A disturbance of forest may result an outflow of nitrate nitrogen that cause to eutrophication and contamination of river. Carbon retention was evaluated with the amount of carbon fixation of standing tree calculated by mathematical model used for a national reporting.

The DSA was applied to a study area, Ugo municipality, Akita, to held simulations under three zoning alternatives: (1) no zoning covering for wood production, (2) the current zoning that is actually used, and (3) zoning planned to emphasize wood production. Zoning designed to emphasize wood production was based on scientific analysis, such as geographical analysis, while the current zoning was not. The simulation predicted the changes of the forest functions for 100 years. The results indicated that alternative zoning based on science analysis could enhance forest functions. The zoning alternative to emphasize wood production could enhance wood production by 6–18%, but decrease protection against soil erosion by 2.1%, preservation of biodiversity by 3.8% and carbon stock by 1.5%. These results indicated forest zoning can improve sustainability of regional forest by influencing individual decision-makings. Establishing appropriate zoning to specific targets based on scientific analysis is important. Moreover, the DSA would allow to bring a wise choice when comparing zoning alternatives.

This research developed the simulation model to estimate the influences of a local-level forest plan on forestry activities occurred in lower-scales; in addition establishment and implementation of appropriate indicators for local-level forest management were discussed. The DSA that was developed by integrating the simulation model and indicators is able to achieve continuous improvement of sustainability in a hierarchical forest management system. The DSA developed in this research would enable to draw up regional forest plans while considering trade-offs of forest functions and building consensus among local stakeholders more efficiently. The new paradigm with appropriate indicators and DSA for local-level will definitely improve sustainability of regional forest management and planning.

PUBLICATIONS

Some ideas and figures have appeared previously in the following publications:

"Can a Regional-level Forest Management Policy Achieve Sustainable Forest Management?"
Yamada Yusuke In:Forest Policy and Economics 90. (2018), pp.82-89

"Decision Support System for Adaptive Regional-Scale Forest Management by Multiple Decision-Makers"
Yamada Yusuke, Yamaura Yuichi In:Forests 8.11 (2017), pp.453

"Applicability of adaptive management methods to municipality forest planning in Japan"
Yamada Yusuke In:Journal of the Japanese Forestry Society 99.2 (2017), pp.84-96

"Examination of Maximum Sustainable Timber Yield Based on a Profitability Simulation"
Yamada Yusuke, Tatsuhara Satoshi In:J For Plan 18.1 (2012), pp.1-11

Mancher Pfau verdeckt vor Aller Augen seinen Pfauenschweif
- und heisst es seinen Stolz.

— Friedrick Wilhelm Nietzsche

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ACRONYMS

SFM	Sustainable forest management
DSA	Decision support approach
C&I	Criteria and indicators
MPWG	Montréal process working group
BRI	Benefit relevant indicator
BN	Bayesian network model
CPT	Conditional probability table
FCP	Floor cover percentage
NFI	National Forest Inventory
EWP	Enhancing wood production

PREFACE

1

GENERAL INTRODUCTION

BACKGROUND AND OBJECTIVES

Japanese forest is now at the crossroads. There are enormous problems that hinder sustainable forest management (SFM): apathy for forest and forest management, aging of forest owners, indistinct boundaries of land properties, lack of precise and detail information, forest workers aging, and so on [23, 81]. Adding to that, more and more forest have been getting at harvesting age while the area of younger forest has become scarce [48].

Forestry activities including both thinning and clear-cutting have been encouraged in order to improve forest health and level age distribution. The Japanese government has designed a wide variety of policies from an improvement of productivity with using highly efficient forestry operating machines to an expansion of utilization ways of lumber such as wood fuel biomass or cross laminated timber [48]. Although these policies have been sometimes criticized for distorting sound economic activities [36, 98], they have attained some progress in activating forestry. Introduction of forestry machines has been progressing and new entries of forestry companies has been taking part therein. As a result, improvements of timber self-sufficiency ratio and lumber exportation have been seen for a decade. A huge number of biomass power generation plants that consume wood fuel biomass have been built all over Japan. The number of public buildings made of wood has increased.

However, such movements have possibilities to cause other problems. The area that is not planted after clear-cutting has been increasing [28]. Such area is in a risk to be a devastated land. A devastated land easily harms forest public functions and causes natural disasters including landslides. A flood of new wood fuel biomass energy plant has fostered this trend.

In order to avoid degrading forest public functions, timber production and other functions should be balanced. Some major functions of forests, such as their roles in biodiversity, water protection, or wood production, are fulfilled on a regional-level[1]; thus, regional-level forest management policy plays a significant role [24, 95, 99].

Municipal governments are called upon to play a key role to improve the sustainability of local forest management. Municipal governments are located in a position to transmit upper-scale policies

1 In this research, regional-level or local-level refer to municipal scale that is regulated by a single municipal government.

down to their region and establish plans that correspond to situations and problems of the regional forests; they are in the junction point between top-down and bottom-up. Policies decided by the upper-level government are modified to comply with demands of the region. The Japanese government has given a greater authority to municipal governments to manage forest from indigenous people's viewpoints.

Despite the fact that municipal governments have a greater role for SFM in the present situation, they as if have lost their arms and legs to do that. Their financial situations are generally getting worse and human resources are decreasing. A current system for planning has lost substances.

A novel paradigm for establishing effective policies and plans is needed to support municipal governments. The current planning system has not achieved efficient planning[2] due to insufficient human resources in most regions. Regardless of the fact that various kinds of forest planning methods such as zoning methods or harvest-regulation have been developed, those methods are scarcely used in the actual site. This shows that problems concerned with forest planning situate in systems or processes of the municipal governments rather than in planning methods. It is required to build an effective strategy for regional planning considering the whole planning system and actual procedures simultaneously.

This research aimed to theorize an applicable regional forest planning including DSA for municipal governments considering current situations and problems. Improvement of sustainability of multiple forest functions was situated as a top priority in this research.

Firstly, current situations and problems were outlined with preceding reports and studies (part.i). Grasping problems of municipal governments would help the development of efficient approaches to corresponding problems in forest planning of municipal governments. Then, requirements and schemes for improving regional planning efficacy were considered. This research proposed a triple loop learning approach as a novel paradigm to actualize adaptive forest management for Japanese municipal forest policy making. Indicators for forest functions and a planing method a hierarchical system are vital for building this structure. The DSA developed in this study is composed of evaluation methods for forest functions to define indicators and a simulation model for the hierarchical planning system. Indicators adopted to regional forest management were reviewed before developing the DSA (part.ii). They serve to rotate an adaptive management planning cycle smoothly by evaluating changes in forest functions objectively. Approaches for applying indicators were considered at hearing investigations on advanced municipalities. Hearing investigations revealed demands of municipal governments in

2 In this research, 'planning' refers to whole procedures containing establishment, implement, evaluation, and improvement of a plan.

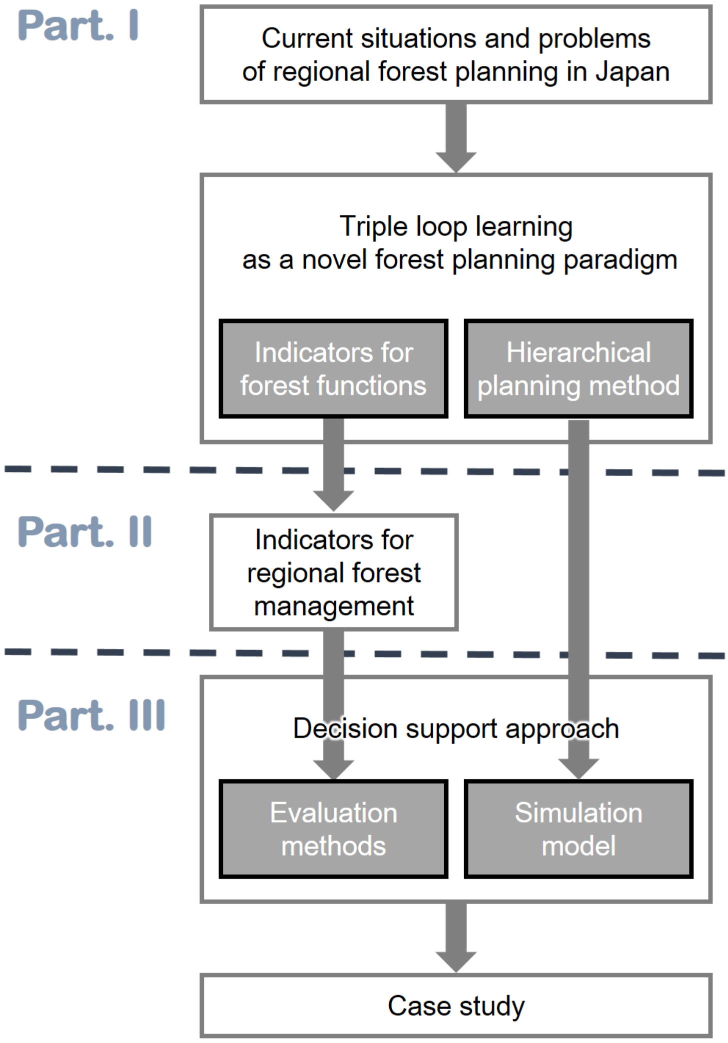

Figure 1.1: Structure of this research

regional management and requirements for applying indicators. Finally, a DSA was developed with a model to simulate influences of regional forest policy on individual forestry activities and evaluation methods for critical forest functions (part.iii). This approach supports in establishing forest zoning considering the sustainability of forest multiple functions with simulated changes of indicators. The DSA was developed to corresponding problems in forest planning of municipal governments in Japan. A case study was supplied with this DSA to reveal the effectiveness of the DSA on the development of local-level sustainable forest policies.

SIGNIFICANCE OF THIS STUDY

This research has revealed following points:

Part. I

- The current situations and problems of municipal forest planning in Japan,
- A suggestion of a new paradigm for efficient forest planning,

Part. II

- The outline of criteria and indicators for sustainable forest management,
- Classification of development methods for indicators,
- Sets of indicators and methods for establishing and implementing them in advanced municipal,
- General problems for developing indicators for regional-level forest management,

Part. III

- The efficacy of the decision support approach with indicators for forest functions and a simulation model with considering a hierarchical planning system,
- Influences of forest zoning as a regional-level forest policy on decision-making for individual forestry activities and changes of forest functions,
- And expressive power of Bayesian network model for describing effectiveness of upper-scale management in lower-scale management.

This research presents a new paradigm for sustainable forest planning with a DSA. This DSA helps to implement a cyclic planning scheme such as adaptive management approaches and establish regional oriented forest plans.

The details of adaptive management are explained in 2.3.

Part I

FOREST MANAGEMENT PLANS FOR MUNICIPALITIES

This part shows the current situations and problems of municipal forest planning in Japan from the literature review. Although municipal governments started to have a greater role in local forest management, most municipalities are not equipped to serve in this function because of shortages of manpower, difficulties in consensus building, and lack of evaluation systems. There is an urgent need to develop processes for establishing a municipal forest plan as a master plan of local-level forest management.

A novel paradigm for efficient forest planning is required. A triple loop planning system was introduced in this research. This system contains cyclic planning systems and a hierarchical structure for management scales. Criteria and indicators for sustainable forest management and planning methods for a hierarchical system would serve to apply the triple loop structure to actual forest management.

2

CURRENT SITUATIONS OF LOCAL-LEVEL FOREST PLANNING IN JAPAN

Before considering effective forest planning in regional forest management, current situations (2.1) and problems (2.2) were revealed by the literature review. Understanding specific problems would bring better solutions. Then an effective approach for forest planning corresponding to them was discussed in 2.3.

2.1 MUNICIPAL FOREST PLAN

Forest Planning System[1] has been changing its style from a top-down approach to a bottom-up approach. Initiating movements toward regional revitalization has begun since "Act on Overcoming Population Decline and Vitalizing Local Economy in Japan" was enacted in November 2014. Regional revitalization aims to overcome the reduction of population and the negative growth of the local economy, as well as to realize a positive cycle in the local economy and community. This movement has given local governments more discretionary power and made their role much heavier.

This tendency is particularly strong in forest management [46, 54, 63] because it is impractical to apply a unifying management method to all over the country due to the divergence of demands to forest services and relationships with inhabitants and local forest [63]. The framework defined in Forest Law for managing local-level forest by municipal governments is "Municipal Forest Planning". The central government instructs to establish this plan; all municipal governments have established a 10-year plan to be reviewed every five years since 1998. The Forest and Forestry Restructuring Plan enacted in 2011 aimed to build a stronger bottom-up structure for forest plan-

1 Forest Planning System is a system for forest management in Japan. The system constitutes a hierarchical structure with the Basic Law of Forest and Forestry situated at the top (Shiraishi 2012). Each plan corresponds to each scale. The Basic Plan for Forest and Forestry is established by the central government based on the Basic Law of Forest and Forestry. The Minister of Agriculture, Forestry and Fisheries formulates the National Forest Plan to make it agree with the Basic Plan on Forest and Forestry. Each planning unit of the National Forest Plan is distributed by the wide basin of the main rivers into 44 areas. In lower scales, for non-national forest, there are three hierarchical plans based on the Forest Law. Prefectural Governor establishes the Regional Forest Plan for each prefecture agreeing to the National Forest Plan. Head of Municipality establishes the Municipal Forest Plan for each municipality agreeing to the Regional Forest Plan. And the Forest Management Plan is established by the forest owner or the trustee asked for managing forest to agree to the Municipal Forest Plan.

ning; Municipal Forest Plan is supposed to be established as a master plan[2] for local forest since then. Bottom-up planning approach would be desirable for forest sustainability since forest functions are fulfilled in local scale.

However, there are few municipal governments that formulate such that can be called master plans on the contrary to the intention of the central government. Most municipal government officers just follow the proposals of their predecessors without any scientific basis when drawing up new management plans. Although various kinds of forest planning methods such as zoning methods or harvest-regulation have been developed, those methods are scarcely used in the actual site. This shows that problems concerned with forest planning situate in systems or processes of the municipal governments rather than in planning methods. Actually, many research pointed out vulnerable human resources and organizational structure of municipal government (e.g. [50, 51, 61]).

2.2 PROBLEMS IN PLANNING

The current situations and problems have been discussed actively (e.g. [54, 84]). In these discussions, three following subjects have been discussed very often; a shortage of manpower, difficulties in consensus building, and lack of evaluation systems.

2.2.1 *A Shortage of Manpower*

The most common issue concerned with local forest management in Japan is insufficient human resources, especially with a high specialty of forestry concerned knowledge [39, 50]. Kakizawa and Kawanishi [53] reported the current situations of manpower of municipal governments in Hokkaido with a questionnaire. The average number of staffs who worked for forest and forestry was 2.3 persons and 1.2 of them gave their whole time for forestry concerned work. Only 7.5% of them were educated in forest or forestry and more than a half of officers had worked in the current faculties for less than two years. These results have shown difficult situations of the municipal governments in human resource affairs. Most of them engaged in not only forestry concerned work but also a wide variety of work at the same time. It prevents them from focusing on forest planning. The lack of

2 A master plan for regional forest management is defined as a management policy to supply forest ecosystem services widely and permanently corresponding to demands of stake-holders [124]. This kind of plan must be determined from individual alternatives based on scientific analysis and evaluated periodically by a committee including regional inhabitants.

specialty is also to be an obstacle for establishing a regional oriented plan that needs reasonable grounds.[3]

Methods for achieving labor savings are needed for planning in such situations. Due to the financial difficulties, an increase in personnel is almost impossible. Municipal mergers that have been promoted in many regions might cause to weaken the organization for agriculture and forestry [44, 50]. To provide easy methods for forest planning and a whole system to support using them are rather reasonable solutions than improving personnel situations.

2.2.2 *Difficulties in Consensus Building*

Active participation of local residents is important in establishing and applying region-oriented forest plan [54, 110, 118]. Taking opinions from stakeholders about the municipal plans is needed because those plans would sometimes regulate economic activities in a private forest for maintaining public functions. Forestry law established in 2011 stipulates that Forest Management Plan developed by a forest owner must agree with Municipal Forest Plan; it raised demands and necessities to adopt opinions of local residents.

However, municipal plans often have been established by a small group consisting of the person such as governmental officers, a few forestry companies, and forest owners who have large amounts of forest land [29, 44, 49]. Adding to that, most forest owners in Japan are not interested in forestry and, therefore, forest plans. Although the original draft of the municipal plan is supposed to be inspected and collect public comments before publishing, no opinions are usually offered. Thus, the current opinion collecting system has lost its substance. Insufficient consensus building has a possibility to cause conflicts among the objectives of forest management [50, 101].

The importance of consensus building has been seen in a new light since local governments have come to play significant roles in forest management. Conventional Forest Planning system with a top-down approach has had no place for reflecting local residents opinions to plan. That's one reason why discussions among stakeholders had not been taken in planning process [49]. Incorporating of opinions and promoting multipurpose management is essential to achieve the establishment of the Municipal Forest Plan as a master plan. The process of planning is required to be open to all citizens. Advanced municipalities that have their own master plans have efficient systems to collect and reflect the opinions of various stakeholders [5]. A new planning paradigm that contains a process of a consensus building

This process is defined as a participatory planning.

3 A shortage of manpower tends to be facilitated due to lacks of software such as GIS or information systems [87]. In some municipal governments, integrated GIS systems that are designed to be used by every quarters of the municipal governments hindered officers in their works for forestry .

should be restructured considering the hierarchical structure of forest management.

2.2.3 *Lack of Evaluation Systems*

There have been no evaluation systems defined in conventional forest planning system [54]. The Basic Plan for Forest and Forestry established in 2016 devoted pages to evaluate the current situation based on the previous plan, however, that is criticized for its insufficiency [52, 117]. Such lacks of evaluations depress the effectiveness of the plan. Lower-scale governments have not evaluated their forest plans by their own initiatives except few local governments who have established evaluation systems with a committee organized by local residents.

Valuing results and applying it to the next plan is the only way to improve the efficacy of the plan [107]. Moreover, demands for local governments to show for what they use environmental taxes have been increasing [45]. It is indispensable to establish an evaluation system for planning.

2.3 ADAPTIVE MANAGEMENT APPROACH AND A NEW PARADIGM TO APPLY IT

Problems mentioned above depress the effectiveness of planning. Ineffective plans cause an obstruction of economic activities and degradation of forest functions. In this section, a novel paradigm for effective regional forest management planning is discussed.

Based on the problems, requirements for municipal governments to play a central role in regional forest management can be organized with a PDCA cycle approach[4]. At "Planning stage", it is required to select alternatives while building a consensus and setting targets that can be easily evaluated. At "Doing stage", it is required to implement the plan to achieve targets. Municipality governments have to keep watching appropriateness for each management activities to suit a plan. At "Checking stage", it is required to compare the actual state with the target value to evaluate the level of achievement and release information to the public. At "Acting stage", it is required to provide an improvement suggestion based on the evaluations of management results. A planning system with continuous improvement such as the PDCA cycle approach makes regional forest management more efficient [82].

Adaptive management is also a cyclic management approach that is well suited for natural resource management. Adaptive management improves management methods and policies for complex objects adaptively by a continuous monitoring process. A framework for AM has a two-phase process for both technical and social learning (Fig. 2.1 [121]); the framework comprises of a planning phase and an iterative decision phase.

A planning phase includes harmonization of the stakeholder's interests, the establishment of objectives, the suggestion of alternatives, construction of mathematical models, and the establishment of a monitoring plan [4]. This phase is not only a preliminary step but also an improvement step for the system and objectives.

An iterative phase includes decision making, implementing, monitoring, and assessment. These steps are iterated to improve management for achieving objectives established in a planning phase [121]. A planning phase and an iterative phase are also repeated periodically and buildf a double loop. The double loop structure heightens effects of management policies; an inner loop is referred as adaptive learning to revise actual activities and an outer loop is referred as creative learning to improve whole systems [107] .

Adaptive learning is also called a single loop learning and creative learning is also called a double loop learning.

Adaptive management can be a brilliant tool to enhance sustainability. Following three strategies would help to apply adaptive man-

4 PDCA cycle is a cyclic management approach for project management; it contains planning, doing, checking, and acting processes. This approach improve management by iterating those steps periodically.

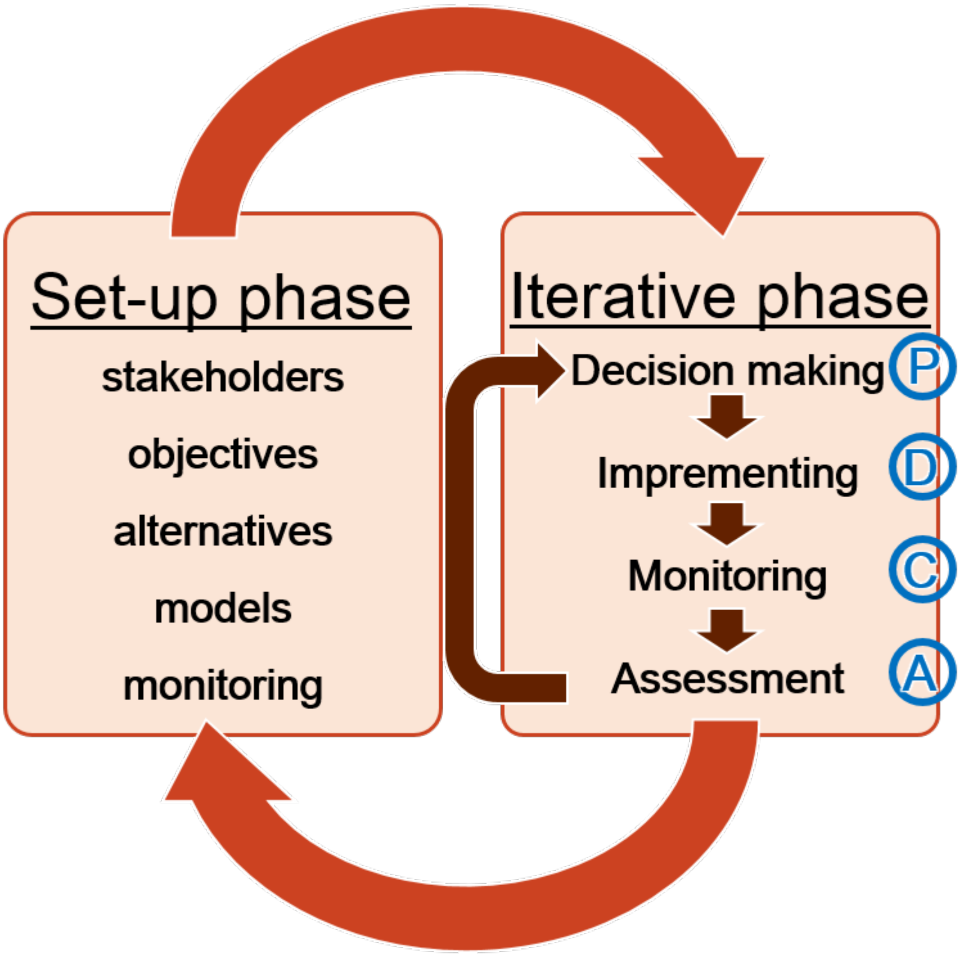

Figure 2.1: Two-phase learning in adaptive management (revised from Williams [121]).

agement to actual forest planning; a triple loop structure, a hierarchical planning system, and criteria and indicators (C&I)[5]. A triple loop structure refers to a whole system for applying adaptive management to actual forest management. What should be improved is identified in each loop. This triple loop can also be considered as corresponding to hierarchies of management scales. Engaging a hierarchical planning system would serve as a liaison among the multilayer structure. C&I can be a basis of objective assessment and give feedback to upper-scale planning.

2.3.1 *A Triple Loop Structure*

There are huge differences among municipalities in budgets for forestry, the area of private forest, and numbers of people who engage in forestry work [44]. Therefore, efforts carried out for forest planning are also uneven among different regions. A new paradigm with which even weak municipal governments can implement sound planning is needed.

A triple loop structure can be seen as a triple-loop learning system with single-loop learning for improving planning and activities, double-loop learning for reconsidering objectives and systems, and triple-loop learning for improving guidelines and methods (Fig 2.2). These loops correspond to three evaluation points of view: the appropriateness of procedures and methods, the suitability of objectives, and the effects of planning.

It can be considered that each loop corresponds to a scale of forest management; inner loops for lower-scale management, and outer loops for upper-scale management. Upper-scale governments provide guidelines and methods that are intended to help to proceed planning process even for weak municipals by instructing detail procedures for establishing plans. They also improve those methods by monitoring lower-scale management that have used the methods they have provided. This kind of iterating process is implemented in a multilayer structure, and hence, a whole management system would be improved.

Municipalities with sufficient personnel and budget can add their originality while establishing master plans as advanced examples outside the guideline. A central figure will play a major role here. Aikawa and Kakizawa [5] referred to the importance of a knowledge producer who facilitates adjustment of opinions and creating new knowledge. A forester is expected to play a role as a knowledge producer for region oriented forest planning. Furthermore, a guideline defined by upper-scale governments that instruct and support forest planning

5 Criteria display a list of major factors of forest soundness and productivity. Indicators are used for evaluating sustainability of forest management quantitative and qualitatively. Indicators are categorized into functions indicated by criteria.

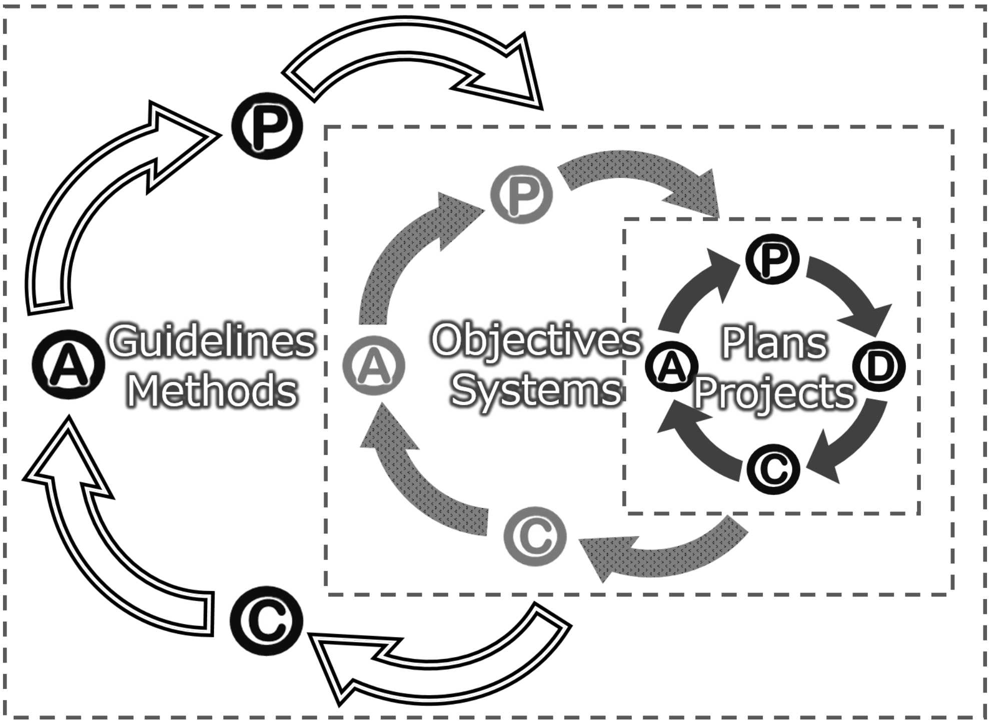

Figure 2.2: The structure of triple-loop learning

by lower-scale governments is expected to be improved by adopting advanced planning cases in this multiple loop structure.

2.3.2 *Planning in Hierarchical Systems*

The target scale for forest management by a municipal government is regional level rather than project level. The authority of municipal government would not go beyond the scope of governance. This limitation may cause two problems.

Firstly, the optimal allocation for management activities assumed by municipalities would be not applicable to the target region. Even if individual decision-makers apply optimal allocations of management activities to project level forest management, it does not mean optimal for regional level. Municipal governments cannot interfere with the allocation of activities in project level determined by forest owners or private forestry companies in order to optimize regional level forest management.

Secondary, there is a limitation of regulations enforced by municipal governments. In the current situation, every forestry activities are allowed as long as they keep regulations that are designed to protect public functions. For example, municipal governments have to give a permission for clear-cutting even if the location of it is adjacent to another clear-cutting as long as the area of each activity is smaller than the limitation area prescribed in the regulation.

Some solutions to these problems are suggested. A resource manager who engages in forest management for a basin area is one solution [108]. Some attempts to build unity of purpose such as getting forest certification for the whole municipal area or uniting private forest management can be seen in several areas [55, 64, 126]. These kinds of tight cooperation between management and governance will be required from this time forward.

On the other hand, understanding the influence of local-level plan on individual forestry activities is effective in the hierarchical system. Considerations of the influences provide the ability to predict the future of natural resources with regional plans. The effectiveness of plans can be revealed with analyzing the relationships between observed behavior of stakeholders and regional policy.

In the triple loop structure, the hierarchical planning method enables to bridge between different scale management. Upper-scale governments guide the direction of forest management in lower-scale by providing guidelines or objectives that are designed with considering influences with hierarchical planning models. Feedback from lower-scale should reduce uncertainties in the influences of governing.

2.3.3 *Criteria and Indicators for Regional Forest Management*

The effects of plans can be evaluated by observing the level of achievement of the goal. The level of achievement is indicated both qualitatively and quantitatively with ecological monitoring and social investigation. Evaluations of management results are used not only for improvement of planning for next term but also for being published to local residents.

C&I are used for establishing and checking objectives [69, 70, 73]. Indicators enable to provide common understanding easily and objective evaluations. Without indicators, the meaning of management plans can be lost since these plans do not have any targets and cannot be evaluated either. Generalized indicators are also useful to bring smooth consensus building.

Forest planning should be multipurpose and the range of evaluation needs to be wide. Hence, C&I should have comprehensiveness. Sustainability of forest is maintained by the mutual and hierarchical support of multiple functions. The suitability of objectives can be evaluated by validity verification considering temporal social situations and future demands. The objectives have to be amended periodically according to unstable social and environmental situations. The objectives are to be established by discussing in stakeholder's councils.

C&I also provide useful information to understand the effectiveness of forest plans in the triple loop learning. That enables upper-scale governments to update their plans to fit the current situations of lower-scales.

2.4 SUMMARY OF THIS PART

This part shows the current situations and problems in municipal governments for regional-level forest planning. Forest planning system of Japan has shifted from a top-down approach to a bottom-up approach. The responsibilities of municipal governments have been heavier. They have to establish master plans for their regional forest management. Any plannings without a master plan fall into being ad-hoc systems because long-term perspective is crucial for forest planning. The aims of municipal governments are to achieve the purpose of master plans by balancing between promotion and restraint of timber production with managing and governing methods such as zoning.

However, most municipal governments are incapable of planning on their own initiative. They suffer from many problems they can't solve by themselves. Due to insufficient human resources, they establish plans by following the proposals of their predecessors. On the other hand, these plans are often easily modified according to forest owner's wishes. Such a loss of robustness happens because those plans are not based on scientific analysis and consensus is not built with them. Besides, poor evaluation systems let the plans to be and remain in neanderthal states. These problems obstruct sound planning cycles.

A novel paradigm corresponding to these problems is required for sustainable forest planning. Adaptive management that makes natural resource management improved with iterative learning would be one solution. A triple loop structure, a hierarchical planning method, and C&I would support to apply adaptive management approach to actual forest management.

A triple loop structure is a multilayered cyclic planning system for multi-scale management. Directions or methods for forest planning are provided by upper-scale governments and improved by feedback from lower-scale governments. A hierarchical planning method and C&I reduce the friction in communication and planning interaction among multiple scales.

Following two parts of this research focused on these strategies. In part ii, indicators for local-level forest management were discussed. Methods for establishing effective indicators were sought based on hearing surveys to advance municipals. A decision support approach for regional-level forest management was developed with indicators of forest multiple functions in part iii. This approach contains a model to simulate influences of regional forest policy on lower-scale management. With this model, alternatives under the hierarchical management system are assessed in a long-term perspective.

Part II

INDICATORS FOR LOCAL-LEVEL FOREST MANAGEMENT

Criteria and indicators improve the effectiveness of forest planning. They define specific goals in the establishment of plans and enable to evaluate results of plans objectively. Means for adopting indicators in regional forest planning were discussed in this part.

Firstly, the outlines of criteria and indicators for sustainable management were literature reviewed. Various kinds of frameworks of indicators that are applied to individual scales exist all over the world. How indicators for national-level and local-level have been developed was introduced with the actual cases. Then, features of indicators were classified based on those processes.

Secondly, indicators adopted in some advanced municipal governments in Japan for their forest planning were reviewed based on hearing investigations. Each set of indicators displays the specific regional features. Finally, general problems for using indicators in regional forest planning were listed based on these cases.

3 INDICATORS FOR REGIONAL FOREST MANAGEMENT

3.1 CRITERIA AND INDICATORS FOR SUSTAINABLE FOREST MANAGEMENT

Unrelenting efforts have been made to actualize SFM. The Declaration of Forest Principle and Agenda 21 that were adopted in 1992 United Nations Conference on Environment and Development held in Rio de Janeiro called for the identification of C&I for evaluating progress in national efforts towards the management, conservation and sustainable developments of all types of forest [119]. This principle enhanced to establish the international C&I frameworks such as Helsinki process, Tarapoto process, or Central African Forest Observatory. Japan is a member of Montréal process in which the Pacific Rim community discuss C&I for managing temperate and boreal forest.

The details of Montréal process are referred in 3.2.

C&I for lower-scales have also been researched and developed[1]. Prabhu et al. [92] suggested the benefits of applying C&I to forest management unit level in actual forest management. Several local scale C&I have been established and implemented (see 3.3). C&I for regional, project, and stand level can make followings easier;

- Project management,
- Publishing policy evaluations,
- Cross-regional and cross-chronological evaluations,
- and Making next term policy.

These can be useful tools for each step of adaptive management. Regional governments should use C&I effectively in this era of decentralization.

In this chapter, Motréal process as an international framework for C&I (3.2) and applying examples outside Japan (3.3) are literature reviewed. Then, classification types for C&I are argued (3.4) based on those actual C&I. The purpose of this chapter is to elucidate disputed points by outlining and organizing C&I actually used.

1 Mitsuda et al. [72] classified forest management scales into three; regional, project, and stand level. They sorted management methods by applying scales to help selecting an appropriate one for the management. Appropriate C&I can also be changed by applying scale in evaluation objects and units. Therefore, the upper scale C&I cannot apply to the lower scale management directly.

3.2 MONTRÉAL PROCESS

Montréal process working group (MPWG) started to discuss developing C&I in 1994 and agreed on Santiago Declaration including seven criteria and sixty-seven indicators in 1995. Since then, C&I has been updated in 2007, 2009, and 2014 to reflect the experience during reporting processes and continuous discussion. Seven criteria have been remained throughout these updating;

CRITERION 1: Conservation of biological diversity

CRITERION 2: Maintenance of productive capacity of forest ecosystems

CRITERION 3: Maintenance of forest ecosystem health and vitality

CRITERION 4: Conservation and maintenance of soil and water resources

CRITERION 5: Maintenance of forest contribution to global carbon cycles

CRITERION 6: Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies

CRITERION 7: Legal, institutional and economic framework for forest conservation and sustainable management.

These criteria have been established based on the idea of a mutual structure of forest and other related resources. Maintaining forest ecosystem health and vitality (Criterion 3) can be considered as a synonym for solidifying a foundation of forest multiple functions. With sound ecosystem, forest functions such as biodiversity, productivity, soil and water conservation, or carbon retention (Criteria 1, 2, 4, and 5) are expected to be fulfilled. As a result, we gain benefits from these functions (Criterion 6). These benefits have very similar viewpoints to ecological services. Social and economic systems to coordinate interests among stakeholders in the spatial and chronological view are needed to maintain ecosystem, functions, and benefits (Criterion 7). These factors are supported mutually to achieve SFM. Thus Montréal process holds comprehensiveness for evaluating forest.

Member countries have voluntarily published country reports once or several times. Summarizing processes of the reports in order to review the progress of SFM and C&I made them realize the importance of applying C&I to lower-scale [78]. MPWG officially stated to the continuous enhancement of the utility of C&I at local- to global-scales in Yanji Declaration. Actual forest management is usually implemented in local- or lower-scales, therefore, C&I for those scales are effective for evaluating practical sustainability. Some attempts to apply national-level C&I to local-level can be seen (e.g. [58, 62, 92, 104]).

3.3 INDICATORS FOR LOCAL-LEVEL FOREST MANAGEMENT

Appropriate C&I differ depending on scales and locations. National level C&I such as Motréal process can't be used in lower level management as it is. Evaluating subjects and units have to be arranged to agree on a target scale. Adding to that, C&I should cover the peculiarities of the region. Consensus-building is also important for establishing local-level C&I; whole management system would not persist without harmonizing stakeholder's opinions. These issues often make the development of C&I vexed.

On the other hand, these difficulties can be interpreted as benefits of adopting C&I to local level forest management. It can be easier to evaluate the sustainability of locality and build consensus by giving specific numeric values that provide information about the current and future situations of the local forest.

C&I have been developed to evaluate forest functions that are closely connected with human lives in U.S. Northwest Forest Plan in 1994; it has been well known for adopting ecosystem management at the first time in the world to protect ecosystems including spotted owl habitats while sustaining timber production. This management system has been intended to maintain forest conditions. This is the beginning of ecosystem management that stepped outside of anthropocentrism. However, this approach ignored some aspects of forest ecosystems; it only focused on the specific species habitats and forestry production.

In 2012, a new planning rule for managing national forest land was adopted by The United States Forest Service. This rule intends to sustain ecosystems that simultaneously contribute to social and economic sustainability and require plans to maintain ecosystem services and multiple uses. Ecosystem services are goods and services that benefit human lives and activities, provided by ecosystems. Ecosystem services are now recognized widely as a keyword for sustainable development. Forest ecosystem provides various ecosystem services including provisioning, regulating, cultural, and supporting services. Smith et al. [109] indicated the value of ecosystem services as follows;

- Describing to the public and to Congress the value of national forest to the people,
- Characterizing management activities in terms of ecosystem service outcomes to complement output-related targets required by Congress.

On the other hand, applying concepts of ecosystem services to establishing plans is difficult due to lacks of knowledge and methods for measuring them. It is required to assess the biological process and acknowledge the link between the process and human welfare at the same time. This link is important for deciding the direction of managing forest and improving understands of ordinary people.

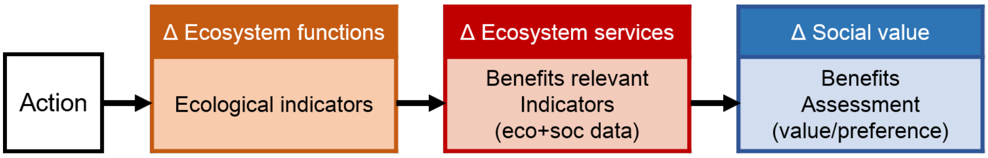

Figure 3.1: An ecosystem service causal chain [85].

The concept of Benefit-relevant indicators (BRIs) is one of the useful approaches to evaluate ecosystem services. BRIs are designed to measure benefits provided by ecosystems directly. Therefore, not only changes of ecosystem services but also benefits from these services are evaluated with BRIs. For example, changes in fish abundance as ecosystem services are measured by the amount of fish landed commercially as a BRI. BRIs are defined by describing ecosystem services causal chains, which show changes in ecosystem functions, ecosystem services, and social values; these are affected by actions, policies, or projects [85] (Fig 3.1). This causal chain enables to link social changes with those of ecosystems and improve detecting problems and solving them.

Although each ecosystem service indicated in the ecosystem services a causal chain can be a BRI, Olander et al. [86] recommends to adopting BRIs with the minimum standards for best practice (Fig 3.2). The assessment process can be promoted by simplifying indicators as possible.

In other regions, some attempts to develop sets of indicators by harmonizing top-down and bottom-up approaches are observed. The province of British Columbia, Canada, has adopted sets of indicators in multiple scales: from national-level C&I based on the Montréal process to forest management unit level with forest certification [42]. There has been an urgent need for participatory decision-making for designing indicators in British Columbia due to the continuing controversies over logging [103]. Hence some sets of indicators have been developed by integrating national C&I with aboriginal forest ecosystem values for regional level [3, 58, 104]. Center for International Forestry Research (CIFOR) developed a generic template for local-level C&I [14]. This template is widely used and modified to develop regionally specific C&I [60, 80].

3.4 CONFLICTS AMONG INDICATORS

Each set of indicators has each feature and procedure in the developing process. Understanding distinctiveness of individual sets of indicators would help to establish specific indicators for regional forest management. In this section, features of indicators and processes to develop them are classified with a form of contrast.

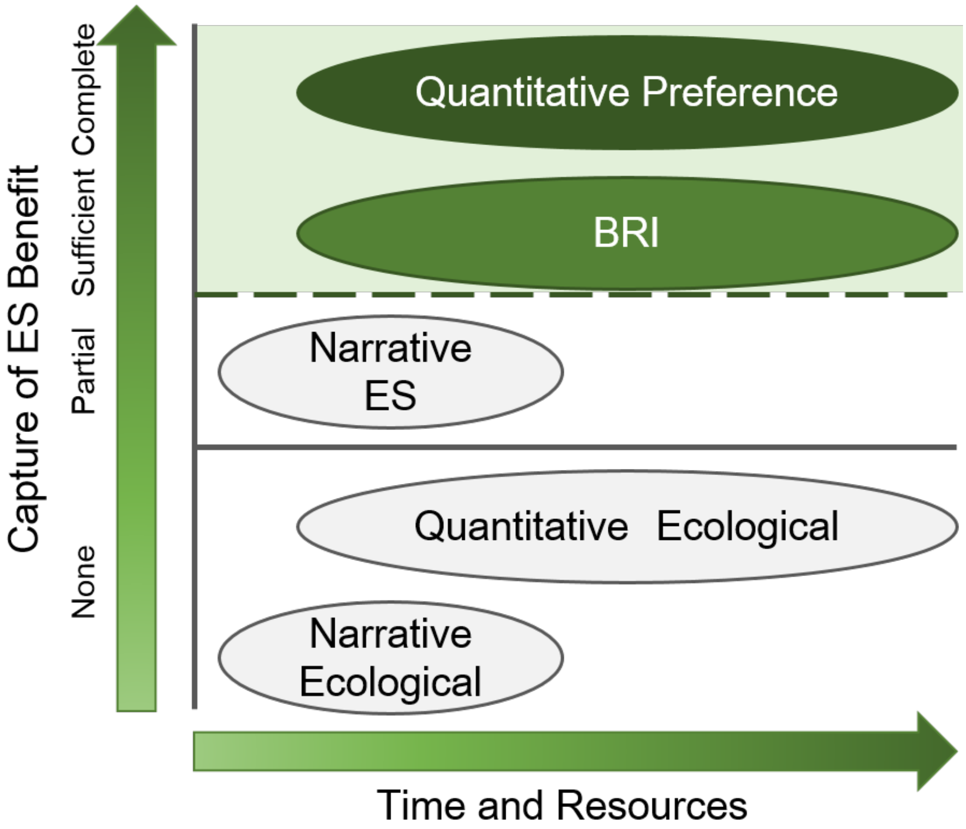

Figure 3.2: Minimum standard for best practice in using ecosystem services in decision making [86].

3.4.1 *Top-down versus Bottom-up approaches*

There are two ways of establishing a set of indicators: top-down and bottom-up approaches[26, 47, 60]. In top-down approaches, indicators are defined by a handful of officials or experts often based on upper-scale indicators. This approach generally makes a set of indicators to equip comprehensiveness. Covering a wide range of forest functions is vital for monitoring sustainability because they are tightly related with each other. A set of indicators with top-down approaches also enables a cross-bound evaluation that enhances the reliability of local forest sustainability. Such indicators can be easily aggregated in upper-scale.Adding to that, indicators can be established with relatively less time and resources. Despite these benefits, top-down approach run the risk of ignoring the locally important factors.

On the other hand, local community members engage in the development of indicators in a bottom-up approach. It allows to reflect locality in indicators. Fraser et al. [26] indicated key benefits of community participation: pragmatic and skill building. Indicators can be pragmatic by the discussion among communities to which those who are involved with forest activities in the local forest belong. Hence planning come to relevant to local situations and easily gain consensus. Moreover, as many case studies have reported, community member's skills and knowledge improve while continuous discussion. They reconfirm the importance of their local forest and deeply consider how to bequeath it to the next generation in good conditions. Their awareness is expected to have a ripple effect on the relationships with forest in the region. However, Indicators developed in bottom-up approaches may fall into an inclination to some specific functions, consuming huge costs, and holding contradictions for aggregation with other sets of indicators.

Providing a balance between top-down and bottom-up approach is needed to establish a wise set of indicators for sustainable management. Integration of these approaches will bring better benefits and more relevant results [93]. To do this, lively and intense discussions among stakeholders including researchers, governmental officers, and local communities are needed.

3.4.2 *Output versus Outcome*

Output and outcome indicators should be carefully separated to understand the effects of forest management precisely. Products and services directly provided by projects or economic activities are evaluated quantitatively and qualitatively with output indicators. Output indicators are generally easy to be developed and evaluated because the relationships with activities are tight.

By contrast, outcome indicators are used to evaluate more general results generated by projects or economic activities. They can be considered as changes in the real society resulted from outputs. Indicators for ecosystem services and BRIs can be assumed as outcome indicators. For example, it can be considered the number of newly introduced highly efficient forestry operating machine as an output indicator and the rise of timber productivity as an output indicator.

Outcome indicators are relatively difficult to be evaluated because the relationships with policy or projects are unclear. Advanced scientific knowledge is needed to establish outcome indicators. However, they are highly advantageous because they usually describe actual benefits for human society. Every effort should be made to adopt outcome indicators instead of output as far as circumstances allow [106].

3.4.3 *Planning Indicators versus Monitoring Indicators*

It is impossible to separate planning and monitoring indicators clearly; one indicator can be both according to its purpose.

Planning indicators aim to set goals of forest management. Indicators mostly discussed in this research are planning indicators. Monitoring indicators are used to estimate the value of forest that is influenced by the implementation of plans. Statistics are published periodically by governments of multiple scales as monitoring indicators. These values are often referred to grasp the present situation in forest planning.

Continuous planning cycles including establishment, implement, and reviewing while associating planning and monitoring indicators with each other is needed for SFM [62, 72]. The relationships between policies and indicators should be clarified for the robust associations between those kinds of indicators.

3.4.4 *Requirement base versus Current base*

Sets of indicators based on requirement are developed by clarifying the required level for achieving SFM in individual indicators. This work needs high scientific expertise and specific analysis. Achieving the targets of those indicators is usually difficult because current situations are not considered while setting targets. However, requirement based indicators are truly advantageous due to demonstrating the contribution to SFM clearly.

Indicators based on current situations correspond to achievable level or expected result of projects. These are similar to output indicators in treating direct results. Although it is relatively easy to establish, the relationships with SFM are generally unclear.

Requirement based indicators are desirable because of the agreement with the purpose of establishing indicators. On the other hand, research for required amounts or quality to achieve sustainability are still in progress in most fields.

4 INDICATORS FOR LOCAL-LEVEL FOREST MANAGEMENT IN JAPAN

4.1 APPLYING INDICATORS IN JAPAN

As mentioned in 3.2, Japan participates in Motréal process as a national level framework for C&I. Two reports have been published until now; the first one was published in 2003, and the second one in 2006. The government, researchers, and other related groups cooperated with each other to produce these reports. Various data including statistics, forest register data, and national forest inventory (NFI) were used. Knowledge and abilities were concentrated to unravel what the current situation of Japanese forest was like.

Regrettably, such efforts had been discontinued. One of the reasons is that Motréal process is based on voluntary intentions. It takes too much cost to make reports continuously. Another reason is that the government does not feel the necessity of the report. They believe their periodical reports, such as white papers or Forest Planning Systems, defined in the Forest Low are enough for monitoring health of Japanese forest.

Then, how indicators are applied in Japanese Forest Planning System? In Forest and Forestry Basic Plan, target values are defined for the area of forest types and annual timber supply. These values had not been evaluated officially until the plan established in 2016. Although Forest and Forestry Basic Plan in 2016 has a chapter for evaluation, it does not go beyond confirmation of the target numbers [117]. Other indicators are unclear or have not been indicated. Even though the idealized image is defined in the plan, the importance of setting concrete policies and goals have been ignored. It can't be said that indicators are used effectively at the national-level.

Municipal governments have been defined as leading actors of local forest management in Forest and Forestry Basic Plan. Therefore, municipal governments are expected to build master plans for local forest management. Although they have numerous problems such as lacks of human resources and knowledge, motivated municipalities have made efforts to lead their local forest sustainable. Corresponding to these situations, despite the slow progress of adopting indicators at the national-level, some advanced municipal governments establish plans with indicators successfully.

This research made hearing investigations on four municipalities including Toyota, Shinshiro, Nagahama, and Tsushima as advanced cases in which indicators have been applied to their forest planning.

Then, general problems for establishing and implementing sets of indicators in municipalities were discussed based on the investigations.

4.2 INDICATORS UTILIZED IN MUNICIPALITIES

Indicators and processes of developing them in the four advanced municipal governments were revealed by hearing investigations. The investigations were conducted for Toyota on September 15th, 2017, Shinshiro on September 15th, 2017, Nagahama on February 22nd, 2016, and Tsushima on December 14th, 2017.

4.2.1 *Toyota*

Toyota municipality is situated in the center of Aichi Prefecture and is famous for the automobile company having the same name. 68% of the total area is covered with forest, and 57% of the forest is artificial forest. Toyota formed as a result of a municipal merger, being led by Tokai torrential rain disaster in 2000. This disaster aroused citizen's interests in environmental problems and forest management. The municipality government enacted "Toyota Forest Development Act" in 2007, "Toyota Forest Development Conception for 100 Years" based on this act, and integrated policies and numerical targets for "Toyota Forest Development Basic Plan" to achieve the conception. The progress of the basic plan was reviewed in 2012, and the second term had begun in 2013. "Toyota Forest Development Council", composed of various groups such as forest union, academic experts, forest owners, NPO, or private companies, discuss and evaluate the progress regularly.

The conception declared the goal to let all of artificial forest to be thinned by 2027. A hierarchical structure of indicators has been constructed; other indicators were designed in order to achieve thinning area as an upper target (Table 4.1). Functions outside of the set of indicators are monitored with additional evaluation systems. Most of indicators have been designed based on requirement, not based on the current situation. Therefore, achievement level stays low.

"Forest Development Meeting" is used as a place to make the conception and the plan public and implement them. This meeting is organized by forest owners in the unit of larger sections of villages to promote thinning and consolidate project areas. Forest classification provides an example of the attempt in the meeting for improving effectiveness. The municipality has shown several types of forest and let forest owners choose one of them as future forms of their forest. The forest types include timber producing forest and neglect forest. Respecting forest owner's wishes, the government puts the choice into their hands. That has resulted in every private forest in the municipality stays for timber producing. Hence, the need for scientific analysis

Indicators	Target values for 2022
Thinning area	18000 ha
The number of Forest Development Meeting	170
Area of projects for consolidation	15750 ha
The number of green trainees	10
The number of students of forest school	10
Length of newly established road	28 km
Productivity for harvesting	8000 yen/m^3
Thinning area where timber is carried out	333 ha/year
Amount of lumber derived from thinning	38.3 thousand m^3/year
Amount of local limber used for public works	1000 m^3

Table 4.1: Indicators of Toyota Forest Development Basic Plan

for forest zoning has been aroused in order to persuade forest owners and promote forest classification. Policies such as enhancement of defying forest zoning with newly offered forest types to improve the achievement level are to be adopted in the next term plan.

This zoning is not concerned with forest zoning defined in Municipal Forest Plan.

4.2.2 *Shinshiro*

Shinshiro is a municipality adjacent to Toyota. Relatively large area (83%) is covered with forest, and 74.8% of it is artificial forest. Shinshiro municipal government enacted "Shinshiro Forest Development Basic Act" in 2009 promoted by policymakers. Corresponding to this act, "Shinshiro Forest Development Basic Plan" was established in 2010 to embody this act. "Shinshiro Forest Development Council", consisted of forest union, academic experts, market participants, a forestry development center, NPO, forest instructors, and forest owners, evaluate the progress of the plan in about twice a year.

The structure of the plan that is similar to Toyota's plan, has a hierarchical structure with the mid-to-long term goal of thinning area. However, the relationships between thinning area and other indicators are relatively weak. Indicators relating to people, such as human resources or volunteers characterize the plan (Table 4.2). These show that the municipal government needs the cooperation of diverse groups due to the lacks of financial and human resources. Tightening relationships with the Forest Development Basic Plan, the Municipal Forest Plan, and plans established by other departments is also important for them. For example, area of timber producing forest, which is referred in the basic plan correspond to forest zoning defined in the Forest Municipal Plan. However, the responsible officers feel difficulties in coordination with other plans.

Indicators	Target values for 2020
Thinning area	15700 ha
Area of reforestation after clear-cutting	80 ha/year
The number of projects for consolidation	15
Productivity for harvesting with forestry machine	15000 m^3/year
Amount of harvesting timber	44000 m^3/year
The number of training course for forest owners	45 per year
The number of forest practice planner	10
The number of people who join programs for human resources development	30
The number of people who join programs for learning with experience	500 per year
Area of municipality owned forest offered for volunteering activities	4 ha/year
The number of social gathering for local people	60
The number of projects for consolidation	15

Table 4.2: Indicators of Shinshiro Forest Development Basic Plan

They also recognize a need to show not only achievable level but also the effectiveness of the achievement. Because influences of the achievement on forest sustainability are unclear, objective and scientific data are important.

4.2.3 *Nagahama*

Citizens in Nagahama, which is facing the lake Biwa, have high environmental consciousness. The results of the satisfaction survey for Nagahama citizens in 2017 show great demands for administrative services such as wildlife damage control, forest management and forestry activation, global warming prevention, better environmental development, or sound material-cycle society creation. Both prefecture and municipal government establish environmentally concerned policy with great care. Corresponding these trends, "Nagahama Forest Municipal Plan" was established in 2012 as a master plan for forest management in the municipality. In order to bring the municipal plan into practice, "Nagahama Forest Action Plan" mentioning specific approaches was established in 2015. The action plan defines indicators for forest management in Nagahama. "Nagahama Forest Direction

Council" review and evaluate the progress of the plans every year. The council consists of academic experts, a timber processing company, NPO, a forest union, and prefecture officers.

The action plan differs from the master plans of the other municipalities referred in this research; this plan is in the different position in the planning system. Other master plans are developed outside of the current forest planning system; those municipalities design their own forest concerned bylaw and own plans for forest management under them. Enacting a new own bylaw is time and labor consuming, so most municipal governments would not be willing to do so for establishing a master plan. On the other hand, Nagahama Forest Action Plan was established under Forest Municipal Plan that is defined in the Forest Law. Developing the master plan under the existing system would save labor. Hence, designing a planning system in which local governments can develop their plans with their own initiatives is important to support motivated municipalities with poor human resources.

The action plan defines forty-eight indicators in various categories. It has an overwhelmingly larger number of indicators than other municipals such as Toyota with ten indicators, Shinshiro with twelve indicators, or Tsushima with twenty-four indicators. This gap reflects recognition of local governments for the importance of indicators. About a half of indicators in the action plan are concerned with civil lives, corresponding to environmental consciousness. Shiga prefecture government promotes utilization of outcome indicators, and Nagahama also has intended to adopt outcome indicators positively. Timber production amount and productivity has been evaluated as outcome indicators to measure the progress of important projects such as a project for expanding forest resource use or a project for efficient timber production. However, the municipal government has been troubled with setting outcome indicators for other functions. Because of the limitations of human resources, the municipal government can't afford to evaluate outcome indicators that need extra work such as field surveys. Furthermore, the lack of academic knowledge of the municipal officers prevents the establishment of these indicators.

4.2.4 *Tsushima*

Tsushima is an island municipality. Because the distance from forest to the ocean is small, forest management influence directly to the major industry: fishery. One of the considerable reasons for the sea desertification[1] is insufficient forest management in the upper stream.

1 The sea desertification is a phenomenon in which a large amount of seaweeds die simultaneously. It causes decrease of a catch of major marine products such as abalones or turban shells.

Indicators	Target values for 2019
Timber production	20000 m^3
Timber productivity	4.3 m^3/day person
Inviting a forester from Germany	1
Dissemination of information thorough a PR brochure	4
Dissemination of information thorough internet	4
Dissemination of information thorough a event	1
Dissemination of information thorough a class for children	1
Providing toys made of regional timber	5
Number of delivery lessons	2
Number of trainee of Satoyama development	230 person/year
Area of projects concerned with Satoyama	20 ha/year
Number of appeals on citizen organizations	2
Number of newly supported citizen organizations	2
Number of appeals for projects to improve forest functions	2
Number of supported organizations that implement projects to conserve forest functions	12
Number of materials for raising seedlings given to citizens	800
Number of companies concluding an agreement for forest development	3
Number of lectures held in facilities concerned with forest	2
Number of work experience programs in forestry company	1
Number of members of a forestry research group	100

(continued.)

Indicators	Target values for 2019
Number of people who join self-employed forestry households	10
Number of lecture classes for self-employed forestry households	2
Timber production by self-employed forestry households	2000 t
Number of employed persons of Community Co-builders	3
Number of houses supported to be built with local timber	15
Number of public facilities built with local timber	10
Local timber used for building public facilities	2000 m^3
Number of wood-burning stoves	145
Number of woody fuel biomass boilers	2
Sales amount of firewood	300 t
Number of experience classes for forest products	2
Number of inquiries from resident's associations	1

Table 4.3: Indicators of Nagahama Forest Development Action Plan

For this reason, citizen's consciousness to forest is surprisingly high compared to other areas. The indigenous ecosystem in Tsushima including Tsushima wildcat also contributes to this high consciousness. The number of certified forestry companies has increased with the growing hinoki export. On the other hand, they have general problems of Japanese forestry such as unclear boundaries.

"Tsushima Forest Development Act" was enacted in 2012, proposed by the mayor who had a strong motivation for environmental conservation. Based on this act, "Tsushima Forest Development Basic Plan" was established in 2013. First 6 pages of this plan, that is approximately 15% of the whole, is a story about a girl having moved to Tshima. In the story, the relationships and problems between people and forest are shown. This reflects the conscious towards citizens including children as readers. Indicators and policies referred in the plan were also established considering citizen's lives. As a result, most indicators are tightly related to industries (Table 4.4). Wildlife damage, for example, is evaluated by new industries using harmful mammals or the monetary amount of damage, instead of the number of captured mammals. The plan was established and has been evaluated by "Tsushima Forest Development Council". This council, that consists of academic experts, government officers, forestry companies, forest owners, NPO, public invited members, farmers, and fisheries, enables to adopt a wide range of citizen's opinions.

"Tsushima Logging Guideline" was published at the same time as Tsushima Forest Development Plan. These two are used to protect against deterioration of public functions caused by a huge area of logging. The guideline offers forestry methods such as a maximum area or buffer area of clear-cutting, to reduce influences on public functions. Forestry companies receive the individual municipal subsidy when they obey the guideline. Thus, Tsushima municipal government links the plan towards citizens and the guideline towards forestry companies to fulfill forest functions.

On the other hand, the government has a problem with methods of making the plan and the guideline known widely. The municipal official bulletin is used to inform but the effect is limited. Relatively new forestry companies do not know the guidelines. Adding to that, the guideline doesn't have any legal force; the effect of the guideline is unclear.

4.3 PROBLEMS FOR USING INDICATORS

4.3.1 *Comprehensiveness*

Because sets of indicators adopted in the municipalities referred in the above are established with bottom-up approaches, comprehensiveness might be lost. In the bottom-up approach, apparent or emer-

Indicators	Target values for 2017
The number of facilities built with local lumber	5
Amount of lumber production	24000 m^3
Utilization rate of biomass derived from industrial waste	93 %
Facilities with a wood fuel chip boiler	4
Dried shiitake mushroom production	150 t
The number of shiitake producers	360
The number of newly industrialization with utilizing harmful mammal.	5
Amount of sold J-VER credit	1206 t/CO_2
The number of commodities with J-VER credit	5
Area of thinning for municipality owned forest	30 ha
The number of experience programs for school children	5
The number of training programs for self-employed forestry household	5
Woody chip production	17750 m^3
Amount of timber exportation	3000 m^3
Amount of wood product exportation	500 m^3
The number of items approved as product from environment kingdom	10
The number of public meeting for forest owners	2
Area of approved forest management plan	20000 ha
Area of thinning in artificial forest	923 ha
Length of newly established road	50 km
Amount of damage by harmful mammal	250 million yen
The number of community models for developing forest for Tsushima Leopard Cat	3
Length of newly established guard fence for conserving endemic species	45000
The number of projects for improving environment of forest, river, village, and the ocean	1

Table 4.4: Indicators of Tsushima Forest Development Basic Plan

gent problems rather than unapparent but critical problems tend to be focused on. An unbalanced set of indicators has a possibility to harm forest functions that support each other. Comprehensiveness is impaired due to the difficulties of establishing and evaluating indicators. Adding to that, the need for it is not well understood.

4.3.2 *Consistency*

Each forest function has mutual relations with others. When local governments establish forest management plans, they have to consider the relationships among functions to improve one of them; they might be connected or in a trade-off. Although various plans are operated simultaneously in municipalities, the influence of plans on indicators is unfounded in many cases. The qualitative and quantitative contribution of plans and the relationships among indicators should be analyzed scientifically for achieving goals [12].

4.3.3 *Dissemination*

According to hearing investigations, municipal governments have problems in the methods to make their plans and sets of indicators to be known publicly. It is needed to inform stakeholders who directly operate local forest in order to make the plans progress steadily. Plans have a possibility to be desk theories if they misunderstand or are uncooperative. Effective methods for dissemination are required in this era of less motivation for forest management.

Forest Low prescribes that Forest Municipal Plan must be investigated publicly by being displayed in the municipal office. However, it is useless way; generally few people come to investigate the plan.

4.3.4 *Verification*

Verification processes are important to authorize the plan for local level forest management. Proving the effectiveness of achieving indicators on SFM promotes the progress of the plan. High expert knowledge for various categories is necessary to do that. Continuous observations and evaluations with monitoring indicators are useful for the present situation with lack of expertise in local governments.

4.3.5 *Concreteness*

Some municipal governments are not willing to adopt indicators due to their concreteness. The progress can be understood easily by defining the numerical goal. They are afraid of being accused of not achieving the plan. However, advanced municipals mentioned above have not always achieved their targets. They have not been accused of that because they explain reasons for the failure and solutions for the next term.

4.4 SUMMARY OF THIS PART

Sustainability of regional forest planning advances with indicators for forest functions by making assessment objectively. Various sets of indicators have been developed for multiple scale levels. For national level management, MPWG has developed and applied a set of indicators for temperate and boreal forest. Japan also has reported with the Motréal process indicators twice, however, these indicators have not been used for planning especially of regional-level forest. Because indicators for national-level cannot be applied directly to regional-level, a scheme to develop indicators well fitted to regional-level is required. The U.S. has adopted sets of indicators that were strongly related to human lives. These indicators are developed from various viewpoints such as human benefits provided by ecosystem services or top-down/bottom-up approaches.

Multilateral viewpoints are needed to establish a wise set of indicators. Some conflicts arise while developing indicators: top-down versus bottom-up, output versus outcome, planning versus monitoring, and requirement base versus current base. Ignoring either one side of these conflict degrades the efficacy of indicators and would make them meaningless.

Indicators actually implemented in Japan were generally developed with bottom-up approaches. Hearing investigations revealed how municipal governments establish and use forest management plans with indicators; a committee organized by local stakeholders has discussed and determined their plans with the future perspectives. As a result, the sets of indicators reflect current and historical situations of the regions very well.

However, municipal governments and the sets of indicators they use have some problems because they lack the viewpoints of the conflicts of indicators. These problems are similar among the municipalities although sets of indicators are totally different from each other; problems concerned with comprehensiveness, consistency, dissemination, verification, and concreteness were observed. Systems including scientific analysis that corresponds to these problems are required.

Efficient indicators can support decision-making on regional forest policies made by regional committees by clarifying objectives and progresses. Many researches have reported the usefulness of indicators for consensus building. Indicators improve understanding of current and upcoming situations for committee members and make comparisons among management alternatives easier. Therefore decision support approaches that are served for regional forest policy-making should contain indicators for forest multiple functions in an appropriate manner. In the following part, sets of indicators were developed for a decision support approach concerning the problems mentioned in this part.

Part III

DECISION SUPPORT APPROACHES FOR REGIONAL-LEVEL FOREST MANAGEMENT

This part shows the structure of a decision support approach (DSA) developed in this research and the results of applying it to a study area. The DSA consists of a simulation model and sets of indicators.

The simulation model was developed considering the hierarchical system of forest planning. The influences of a regional-level forest policy on lower-level forest management, or decision-making for individual forest activities have uncertainties. This kind of uncertainty was integrated into the simulation by using observed behavior of forestry activities. A Bayesian network model was used to reveal the influences of regional-level policy on forestry activities and the future allocation of forest resources. The future of forest with each zoning alternative is simulated with this model.

Sets of indicators were developed for evaluating alternatives. This research assessed functions for timber production, protection against soil erosion, preserving biodiversity, conserving water resources, and carbon retention. Scientific methods for evaluating these functions were developed using data from national forest inventory of Japan.

DSA was applied to a study area: Ugo, Akita. The results of the case study show the effects of zoning on changes of forest functions and sustainability of regional forest. Efficient plannings for local-level forest management can be obtained with this DSA.

5

DEVELOPING THE DECISION SUPPORT APPROACH

This research developed a DSA in order to support establishing regional-level forest management with appropriate indicators. This DSA was designed to integrate a simulation model for hierarchical forest management system and estimation methods for indicators of forest functions. This chapter describes the outline of the DSA (5.1) and the structure of the simulation model (5.2). Verification of the simulation model was conducted by applying it to virtual forests and virtual forestry activities (5.3).

5.1 THE APPROACH FOR FOREST PLANNING WITH MULTIPLE DECISION-MAKERS

5.1.1 *Uncertainties in Regional-level Forest Management Planning*

Williams [121] identified four forms of uncertainties concerned with natural resource management: environmental variation, partial observability, partial controllability, and structural or process uncertainty. Environmental variation is caused by such factors as climate variability and strongly affects natural resources. Partial observability arises from a lack of ability and finances to investigate a whole ecosystem, and it results in sampling variation. Partial controllability expresses the differences between the intent of a management plan and actual actions. Structural or process uncertainty refers to incomplete knowledge of the structure and processes of ecosystems, which can change during investigations. These uncertainties can be grouped as ecosystem uncertainties (such as environmental variations or structural uncertainties) and social uncertainties (such as partial controllability or economic changes).

The importance of uncertainties in controllability is acknowledged in natural resource management [2]. In particular, where multiple decision-makers or stakeholders are involved, it is necessary to consider the influence of broad-scale management (e.g., zoning; see [72]) on local-scale decision-making [11, 18]. What complicates considerations of regional-level forest management is that several individual decision-makers may be present in a target region. Each of these decision-makers might misunderstand or disobey the intent of the regional management policy [59, 100, 120]. A regional policy cannot always take into consideration where and when each forestry activity (for example, thinning or clear-cutting) is to be carried out; it is forest activities that produce direct changes in future forest resources. Thus a regional forest manager needs to understand the extent to which a regional management policy affects individual forestry activities [9, 100]. By doing so, the manager can truly know whether regional-level forest management can achieve SFM.

Decision support approaches (DSAs) for regional management planning have been developed over many years. Two approaches exist: one assumes a single decision-maker in the target region, and the other assumes multiple decision-makers. Linear programming methods or heuristic optimization programming methods are frequently used examples for decision supports assuming a single decision maker [19, 21]. To optimize wood production or other ecosystem services, the optimum schedules for management activities are determined for the target region and period. These kinds of methods can support decision-making when the management activities can be completely scheduled to follow a particular intention, although as mentioned above, they are impractical for regions where multiple decision-makers exist. Participatory planning approaches are methods for establishing forestry plans that involve various stakeholders or decision-makers, and participatory models are tools to support such an approach [25, 56]. The main objectives of these methods are to integrate knowledge and harmonize opinions among stakeholders. This idea means that adopting participatory planning is not necessarily the best way to manage a regional forest. Acceptance of the regional management plan among forest owners, sawmill companies, scientists, and other stakeholders is regarded as the most important matter. However, the ability of the plan to control stakeholders is not mentioned, and the effect of regional management policies on decision-making by those responsible for planning and carrying out individual forestry activities are generally not considered. Even though some DSAs designed to deal with social uncertainties related to economic change have been established (e.g., [68, 94]), no DSAs designed to apply adaptive management to regional forestry while reducing uncertainties of controllability, have been offered.

In this research, a DSA to support regional forest zoning plans was established by simulating changes in forest functions relevant to controllability and ecosystem uncertainties. The target scale of the DSA is the municipality, which is the minimum unit of governance and plays a central role in regional forest management in Japan. Most forest owners in Japan have only tiny forest areas, so each municipality usually includes many decision-makers for each forestry activity. Observed behavior of forestry activities was used for analysis since discordance between scales of management can be understood only by examining differences between the intentions and observed behaviors of decision-makers [38].

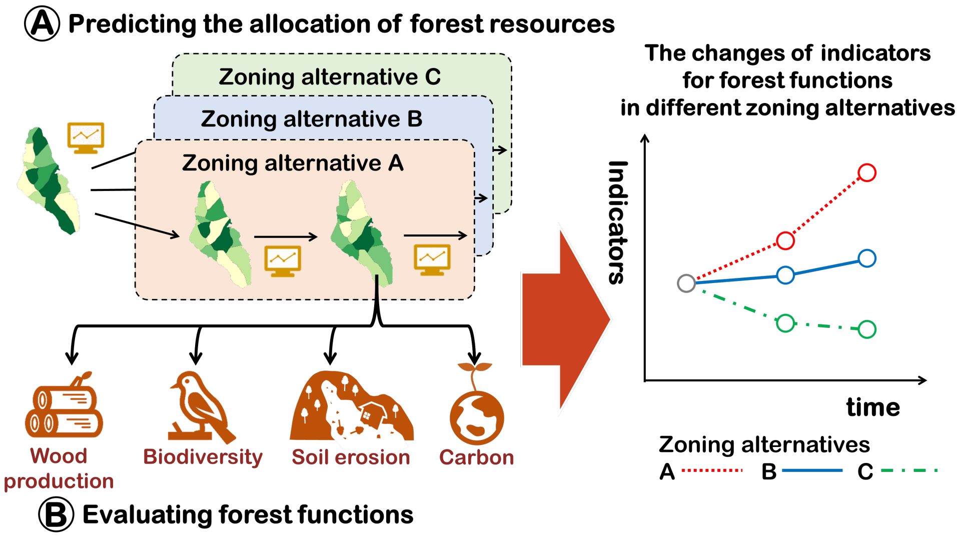

Figure 5.1: Structure of the decision support approach

5.1.2 *An Outline of the Decision Support Approach*

To consider decision-making by individual foresters, the DSA (1) simulates the allocation of future forest resources by predicting when and where forestry activities will be implemented on the basis of observed behavior; and (2) estimates indicators of forest ecological services in simulated forest scenarios (Fig 5.1). These results are integrated to predict the changes in forest functions that can be influenced by zoning policies. To improve the controllability and effectiveness of regional forest management, the DSA uses a Bayesian network (BN) model to reduce uncertainties through iterative learning.

Ecological services simulated by DSAs include uncertainties in controllability and ecosystem function. This study does not aim to interpret the consequences of individual uncertainties, which are often not important for forest managers, but to know the influences of their plans and management on the resultant ecosystem services. The DSA was designed to provide the basic information for a municipality to establish a regional plan with the points of spatial and time series view.

5.2 THE SIMULATION MODEL FOR ALLOCATIONS OF FOREST RESOURCES

A simulation model was constructed to reveal the relationships between zoning and individual forestry activities. The model also estimates the effects of zoning on future forest production and resources by means of a simulation using those relationships.

5.2.1 *An Outline of The Model*

The model in this research was constructed in four steps: (1) revealing the relationships between zoning and forestry activities, (2) creating conditional probability table (CPT), (3) deciding by means of random numbers in which stands forestry activities occurred according to the CPT, and (4) simulating forestry activities. In this model, a Bayesian belief network (BN) model was used to clarify the relationships and obtain the CPT. A BN model is a model of a selected real system that represents the system components and interrelationships in the form of a probabilistic causal network [20]. BN models are well-suited for use in long-term natural resource management because knowledge or belief about how a system functions can be updated to incorporate new understanding or data over time [97]. Such a trait enables models to adapt to changes in socioeconomic conditions. In this research, the BN model was implemented using Netica software 5.24 (Norsys Software Corp., https://www.norsys.com/).

5.2.1.1 *Revealing the relationships between zoning and forestry activities*

In this research, the relationships were modeled to understand the possible forestry activities that occur in each forest stand. The factors (nodes) used as inputs for BN model were categorized into three: biological factors (species, age, volume, and volume per area), geographical factors (area, slope degree, and distance from road), and social factors (zoning and whether forest owners live in the region or not) (Table 5.1). The factual existence of forestry activities in a certain period can be considered to connect to these nodes. The zoning types differ according to the region. Therefore, nodes have to be modified in accordance with the target region. The relationships between nodes (i.e., links) were determined from interviews with a government officer and a director of forest owners' cooperatives in Ugo, which was the region where the case study was conducted. The structure of BN is illustrated in Fig 5.2. Forestry activities dealt with were thinning and clear-cutting, which are the dominant forms of forest management in Japan.

5.2.1.2 *Creating a conditional probability table*

All input factors were summarized to genarate a single value that represented the probabilities of whether forestry activities occurred or not for each forest condition. Then, these probabilities were integrated to form a CPT. Each forest stand is assumed to be harvested according to those probabilities.

Biological factors	Geographical factors	Social factors
Species	Area (ha)	Zoning
Age (years)	Slope degree (°)	Forest owner does or does not live in the area
Volume (m^3)	Distance from road (m)	
Volume per unit area (m^3/ha)		

Table 5.1: Nodes of the model of the study area.

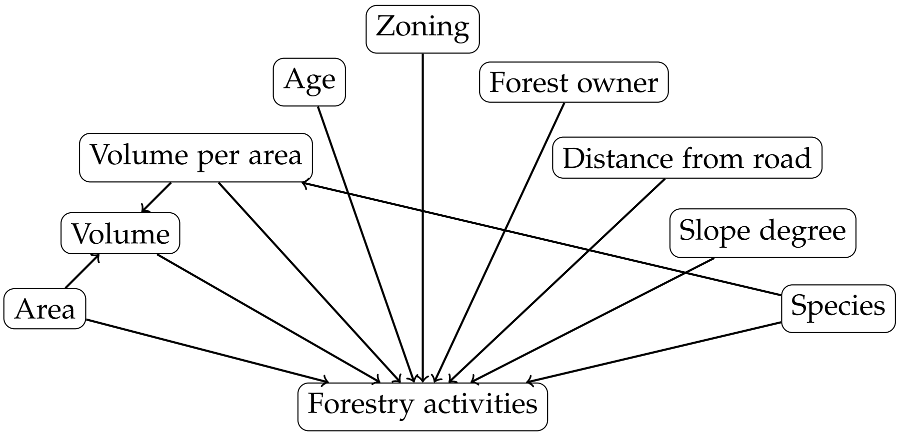

Figure 5.2: Structure of the Bayesian network model.

5.2.1.3 *Deciding in which stands forestry activities occurred*

Whether a particular forestry activity (clear-cutting, thinning, no operation) occurs is determined according to a flowchart (Fig 5.3). First, conditional probabilities of the occurrence of each forestry activity were assigned to each forest stand based on the forest inventory created by the government and geographical information calculated from the digital elevation model published by the Geospatial Information Authority of Japan by Quantum GIS 2.12.3 (Quantum GIS Development Team., http://qgis.osgeo.org). Forest conditions in each stand were compared against the CPT to decide which probability to apply. Second, the probabilities were compared with random numbers generated for each stand and time. If the random number was smaller than the probability, then that activity was deemed to be carried out in the relevant forest stand.

5.2.1.4 *Simulating forestry activities*

The state of the stands was adjusted to reflect the result of forestry activities. If a stand was to be clear-cut, then the age and the volume of the stand were set to 0 to reflect complete removal of the trees. Afterward, ages of all stands were incremented and the stand volume was simulated according to ages. After each iteration, the stand condition

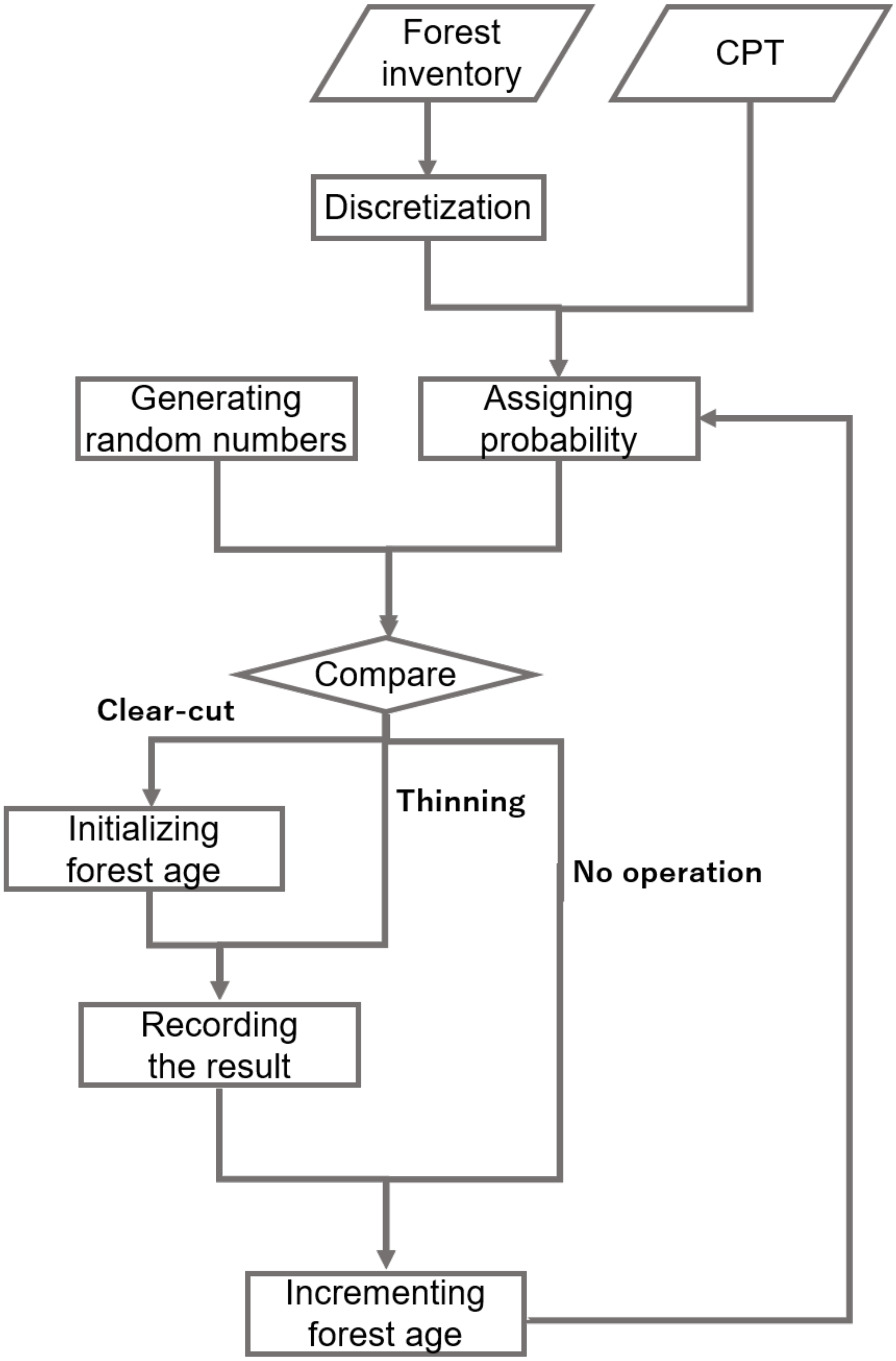

Figure 5.3: Flowchart of the model to decide which stands are harvested. compared.

was compared with the CPT to determine what activity would occur in that stand during the next iteration.

By iterating these steps, the model predicted future forestry activities and forest resources.

5.2.2 *Bayesian Network Model*

BN is a directed acylic graph with a set of variables and a set of directed edges between variables, which can factor the joint probability distribution for the variables [13, 27, 89]. For natural resource management problems, BN have many successful applications reported in literature as Bayesian networks classifier (see [20, 65, 67]).

BN was used in this research for two reasons. Firstly, data for guessing harvest tendencies are insufficient at least in the current situation. Available data concerned with harvest tendency is scarce in Japan. Although the amounts of timber appearing on the market can be acquired in statistics, amounts of timber harvested with thinning or clear-cutting are not distinguished in those statistics. Local governments receive applications for felling trees including methods, amounts, and locations, however, those data are usually not organized to be used. Hence, a process for grasping harvest tendencies has to be started with insufficient data. BN is a strong tool for guessing with relatively little data. It can conquer this problem by improving the accuracy of the inference with iterative learning and reflecting prior knowledge. Secondary, there is a need to make an inferring process to be clear. Consensus building is very important for regional oriented forest planning. To build a consensus easily, planning process must be open to stakeholders. BN, as a graphical model, displays a causal network that helps the model to be understood visually. It also can be the basis of discussion.

5.3 MODEL VERIFICATION

5.3.1 *Methods*

The model constructed with the procedure mentioned above was verified to confirm its reliability. Since long-term data about harvesting timber is generally unavailable, the verification was conducted with virtual forests and harvest tendencies.

The model was verified by the following four steps: (1) creating virtual forests and harvest tendencies, (2) deciding harvest schedules for the virtual forest, (3) predicting the harvest schedule using the BN model, and (4) assessing the accuracy.

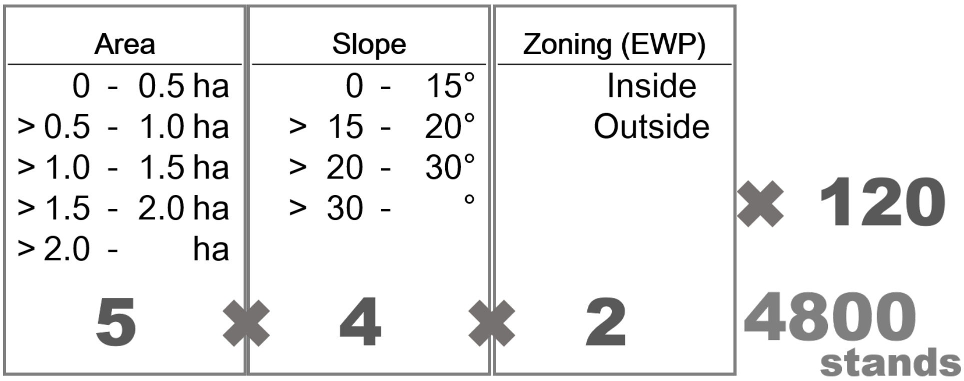

Figure 5.4: Characteristics of the stands of the virtual forests created for verification of the model. EWP: Enhancing wood production.

5.3.1.1 *Creating virtual forests and harvesting trends*

Virtual forests were created to verify the model. Each virtual forest was divided into 4,800 stands, each with a different set of parameters (Fig 5.4). Stands were divided into five classes by area at 0.5 ha intervals, and also divided into four classes by slope (0-15°, >15-20°, >20-30°, and >30°). Half of the stands were zoned as being inside Enhanced Wood Production (EWP) zone, and half were zoned as being outside the EWP. In EWP zones, forests are managed to ensure stable and profitable timber production. The age of the stands was allocated according to the age distribution of two types of forest: forest with normally distributed age classes (hereafter referred to as "ideal" forest) and forest with the age class distribution that is actually observed in Japanese plantation forests[48] (hereafter referred to as "real" forest) (Fig 5.5). The age distribution of the real forest forms a single peak due to a lack of clear-cutting and reforestation.

Harvest tendencies were also assumed to imitate the decision-making of individual forest owners in the region. Clear-cutting was assumed as the harvest method for the verification process. The stands to be harvested were determined according to the Gentan probability, which is the probability that a forest owner will harvest a stand at a certain age after regeneration [111, 127]. Figure 5.6 shows the Gentan probability distribution used to simulate the tendency. The probabilities were then weighted according to the stand's conditions as shown in Table 5.2, and each stand was assigned a harvest probability according to the weighted tendency.

5.3.1.2 *Deciding harvest schedules for the virtual forests*

With the use of the harvest tendencies defined above, virtual harvest schedules for 50 years were decided for the ideal forest and the real forest. If the assumptions of our model are accurate, then the accuracy

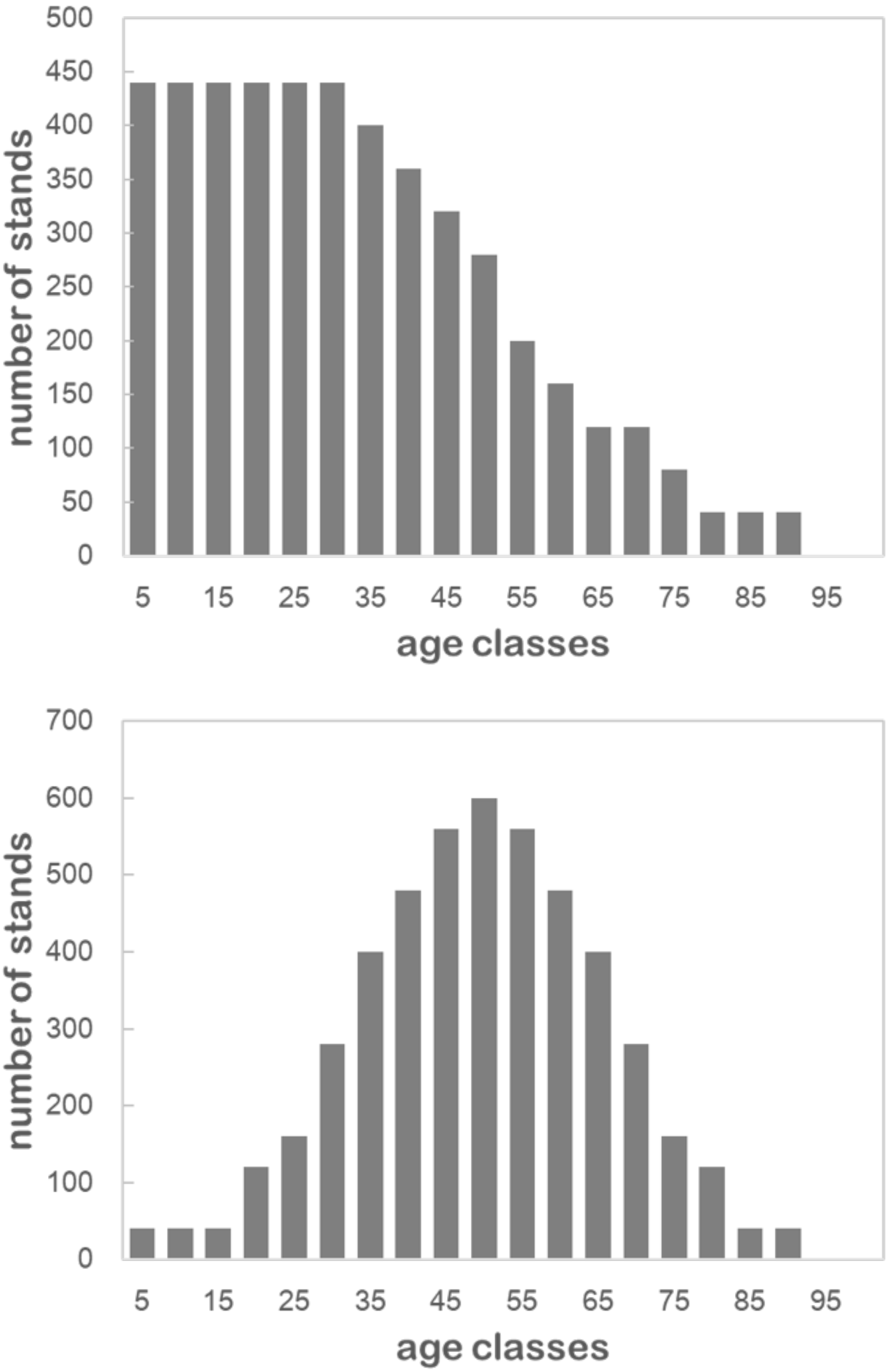

Figure 5.5: Age distribution of the virtual forests. Top: ideal forest, down: real forest.

Figure 5.6: Gentan probability distribution used as the harvest tendency for verification of the model.

Area	Weight	Slope	Weight	EWP	Weight
≤ 0.5 ha	0.6	≤15°	1.3	Inside	1.5
> 0.5-1 ha	0.8	> 15-20°	1.0	Outside	1.0
> 1-1.5 ha	1.0	> 20-30°	0.7		
> 1.5-2 ha	1.1	> 30°	0.5		
> 2ha	1.3				

Table 5.2: Weighting for the harvesting probability. Area

	Area			Slope			EWP	
Year	≤0.5 ha	>0.5-1 ha	...	≤ 15°	>15-20°	...	Inside	Outside
1st	87	77	...	103	106	...	203	205
2nd	85	88		81	116		209	191
3rd	75	64	...	102	98	...	185	202
...	...	...	...	...	...	...	...	...
50th	75	62	...	107	95	...	193	194

Table 5.3: Example of a predicted harvest schedule vectorized to compare with virtual harvest schedules.

with which the BN model predicts the harvest tendencies should improve as the model is trained.

5.3.1.3 *Predicting harvest schedules*

The model was trained on which stands were to be harvested and when based on the data for every fifth year in the virtual harvest schedule. Then, the model predicted the harvest schedules for the remaining periods. The trial was run 100 times.

5.3.1.4 *Assessing the accuracy*

The accuracy of the model was assessed by comparing the predicted harvest schedules with the virtual harvest schedules. Harvested stands were counted for each situation and year and then tabulated (Table 5.3). The similarity of the two tables was then calculated using Pearson's correlation coefficient. The mean of the coefficient of repeated trials was defined as the accuracy of the model. A coefficient closer to 1 corresponds to greater accuracy of the model.

5.3.2 *Verification Results*

The model was able to make accurate predictions; in both cases, the mean correlation coefficients were >0.92 throughout the simulations. Figure 5.7 shows that the accuracy improved with learning in both cases. The accuracy rose sharply in the first 10 years with the ideal forest, and then the increase became gradual. By contrast, the rise in accuracy was slight in the first 10 years with the real forest, and then it became relatively stable. This result was due to the shift in the age of harvested stands during the simulation because of the initial age distribution. The improvement of the accuracy was hindered by the shift of harvested age; however, the accuracy remained constant or improved as a result of adaptation by the model. These results show that the model developed in this study has high accuracy and can adapt to changing tendencies.

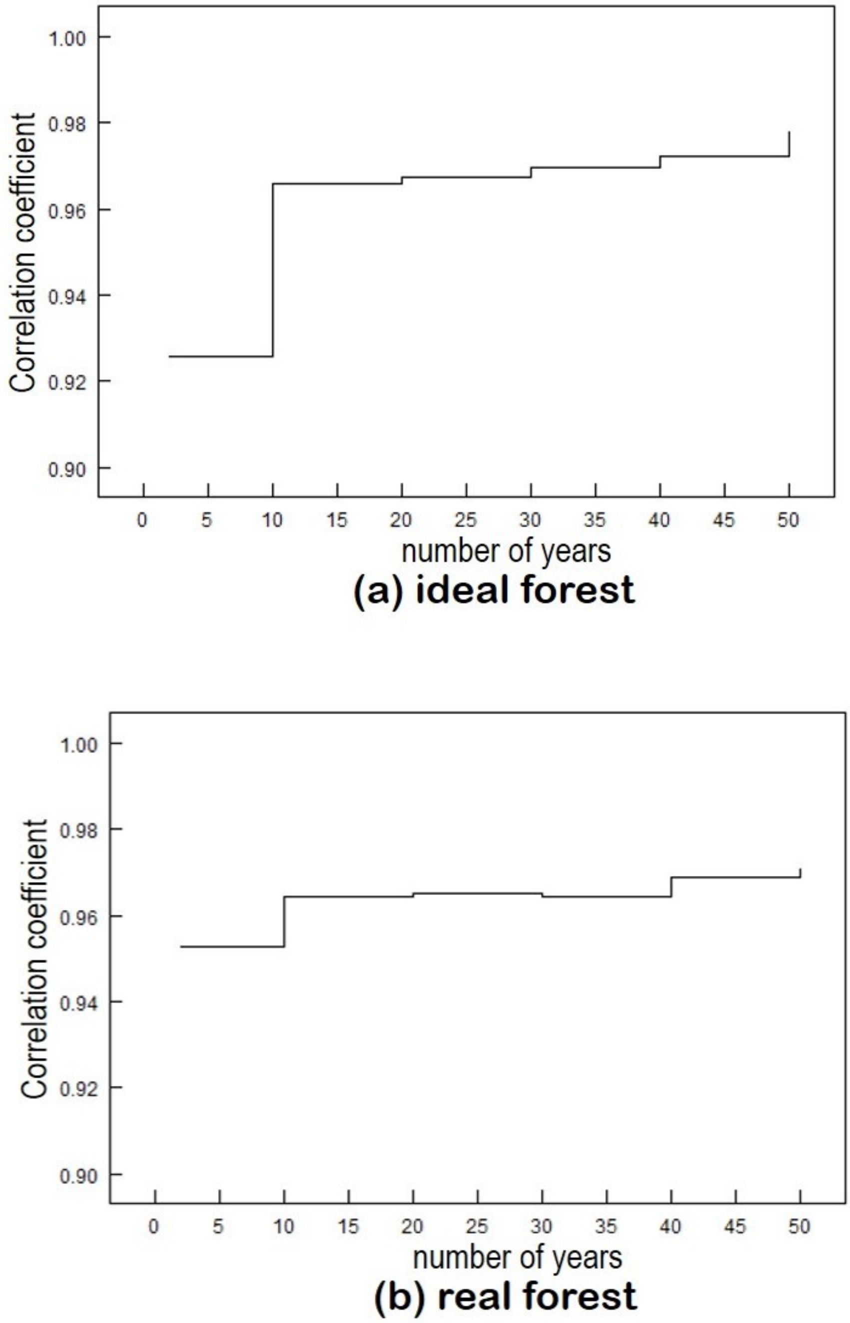

Figure 5.7: Values of Pearson's correlation coefficients between the predicted and virtual harvest schedules.

6

INDICATORS FOR THE DECISION SUPPORT APPROACH

6.1 EVALUATIONS FOR REGIONAL-LEVEL FOREST

As mentioned in 4, municipal governments have problems in establishing indicators; they tend to lack comprehensiveness, consistency, dissemination, verification, and concreteness. To support improving the sustainability of forest multiple functions, indicators corresponding to these problems must be developed. Such indicators should be developed in discussion among stakeholders with scientific bases.

This research attempted to develop indicators for functions, which are seldom applied to municipal plans but important for sustainability: timber production, protection against soil erosion, preserving biodiversity, conserving water resources, and carbon retention. These indicators designed as outcome indicators based on scientific analysis can be expected to complement comprehensiveness of municipal sets of indicators.

These scientifically based indicators can be a starting point for discussion to define better and more regional oriented indicators. Municipal governments in Japan establish individual sets of indicators with bottom-up approaches in the current situation. Indicators in this research were developed to provide them to municipal governments to lighten their burden of establishing own regional indicators.

6.2 TIMBER PRODUCTION

Policies and plans for improving timber production have drawn the greatest attention for considerable years in Japan. Forest owner's interests to forest have been decreasing because low timber price and productivity have attenuated forestry. It results in scarce forest activities and degradation of forest functions. Japanese government aims to improve forest functions by enhancing wood production.

Timber production was evaluated from the simulated amount of harvested timber in this research. Timber volume of each harvest was estimated from a yield table provided by the prefecture government.

6.3 PROTECTION AGAINST SOIL EROSION

Soil supplies ecological services such as water, clean air, and biodiversity [76], so the protection of soil against erosion is crucial [90, 113]. In forest, soil erosion is caused mainly by rain and by surface streams

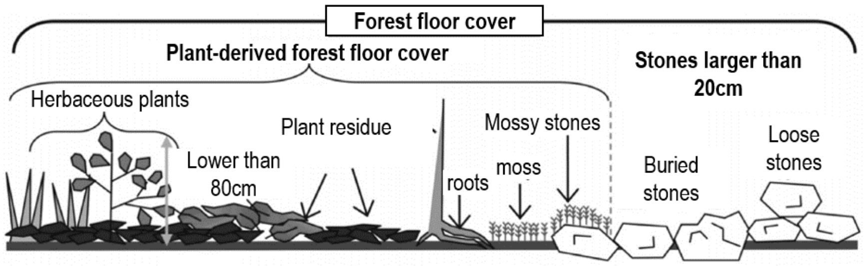

Figure 6.1: Criteria assessed in inspection of forest floor cover in National Forest Inventory of Japan, adapted from the NFI manual (unpublished).

[96], and pillar, rill, and gully erosion are typical [79, 112, 116]. The occurrence of erosion depends on the terrain and on objects on the forest floor [22, 75].

We evaluated the risk of soil erosion with a BN model to reveal the relationships with terrain factors and forest floor cover percentage (FCP). In general, steep slopes and poor FCP often contribute to erosion [37, 74]. The BN model was trained with data from the National Forest Inventory of Japan (NFI).

The NFI is based on a forest resource monitoring survey implemented every 5 years in permanent sampling plots on a 4-km grid [40]. Tree variables such as species and size, FCP, and degree of soil erosion are measured, as well as site conditions such as slope and surface features. The existence of pillar, rill, and gully erosion in every plot is recorded as a binary variable. FCP is measured by eye in increments of 10%. Vegetation cover and large stones are assessed from FCP (Fig 6.1). FCP is low in crowded forests because the understory vegetation is sparse [15, 75].

The structure of the BN model is shown in Figure 6.2. Slope and surface topography are used as terrain factors. Forest growth stage and dominant species, which determine the forest density, influence FCP. FCP is generally lower in young forest than in very young or older forest on account of crowding. Forest stage is determined by eye in the NFI. Elements of surface are integrated into two categories to reduce complexity, gentle and steep. We determined the structure of the BN model considering a mechanism of soil erosion, which occurs by raindrops and surface stream, and is protected by FCP. The BN model learned NFI of the third term (2009–2013), which contains 12,497 plots data for estimating parameters by Maximum-Likelihood with Netica. States of variables are shown in Table 6.1.

The area where the DSA is applied is divided into 10-m square cells, each of which is evaluated to determine probabilities of soil erosion. Then the probability of soil erosion is inferred for each cell by the forest conditions with CPT generated by the BN model. The forest conditions for each cell are determined based on Fundamen-

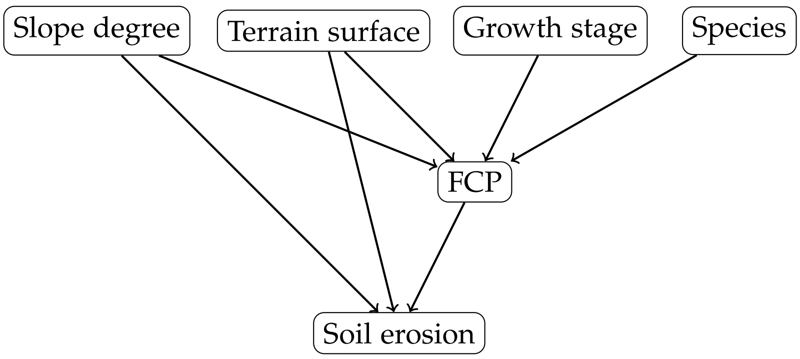

Figure 6.2: Structure of the Bayesian network model used to estimate the possibility of soil erosion.

Variables	States
Soil erosion	True
	False
FCP(%)	0 to <40
	40 to <70
	70 to <90
	90 to ≤100
Slope degree	0 to <10
	10 to <20
	20 to <30
	30 to <40
	≥40
Terrain surface	Gentle
	Steep
Forest growth stage	Young
	Others
Dominant species	Japanese ceder
	Japanese larch
	Others

Table 6.1: Variables and states used for the model to reveal the influence of regional forest management on individual forestry activities.

tal Geospatial Data [119] and forest inventory data provided by a local government. Slope degree, terrain surface, forest growth stage, and dominated species were used for inference as factors. FCP was inferred from those data because there is no direct information available about it. Cells with p > 15% (the proportion of plots with soil erosion in the NFI) are regarded as high-risk cells. The total high-risk area is treated as an indicator of the function of protection against soil erosion. If regional management has a good influence on the function, this indicator should be low.

6.4 PRESERVING BIODIVERSITY

The preservation of biodiversity is crucial owing to its relationships with other forest functions, as well as its own economic, ecological, spiritual, and aesthetic values [41]. Old-growth or primary forests have high biodiversity values because they provide habitat to many species (e.g., [32]). Studies suggest that the value of biodiversity can be maintained by certain management methods such as establishing unharvested nature reserves [8] and retaining trees during the harvest [35].

Functions for preserving biodiversity was evaluated with a old-growth index as a function of climate and topography in this study [66]. The old-growth index was developed with methods of Yamaura et al. [125]. Old-growth index was calculated from four key stand variables for natural forest: mean DBH of live trees with >5 cm DBH; densities of live trees with 40 cm DBH (large tree density / ha); SD of DBH for live trees with >5 cm DBH; densities of live trees with >5 cm DBH. The first three variables increase with stand age, whereas tree density declines with stand age. One single structure variable was used for plantation forest: BA of broad-leaved trees that is negatively correlated to BA of planted tree. Aggregation of these variables was defined as the old-growth index. To make the index tractable by logit-transformation, the old-growth index (I_{og}) was formulated to values between 0 and 1:

$$I_{og} = mean\left(I_{i,og}\right) = \frac{1}{4} \times \sum_{i=1}^{4} \left| \frac{x_i - x_{i,young}}{x_{i,old} - x_{i,young}} \right|$$

where x_i is the ith structural variable, $x_{i,young}$ is median values of x_i for young forests derived from the plot data of forests $\leq$10 to 20 years old, and $x_{i,old}$ is median values of x_i for qualified old-growth forests in Japan. This formulation means that I_{og} is a mean value of four sub-indices calculated from four structural variables ($I_{i,og}$). The effects of environmental heterogeneity on the development rates of I_{og} and four sub-indices ($I_{i,og}$) along with stand age were examined with the median values from 30 permanent plots registered as old-growth forests (>150 years old) throughout Japan in forest permanent plot data of the Forest and Grassland Survey of the Monitoring Sites 1000 Project[1] [43]:

$$\log\left(I_{og,j} / \left[1 - I_{og,j}\right]\right) = \beta_0 + coeff_j \times age_j + e_j$$

where $I_{og,j}$ is an old-growth index of jth plot, age_j is its stand age, β_0 is an intercept, and $coeff_j$ is a coefficient of stand age (can be specific to jth plot), which dictates the rate of structural development (Larson et al. 2008). The final term (e_j) is an unexplained error term with a normal distribution.

In this study, the key stand variables were modeled as a function of climate and topography. Maximum depth of snow cover and warmth index as climatic covariates. Climate data were cited from Climate Mesh Data 2000 published by the Japan Meteorological Agency storing the climate data during 1971 to 2000. Four covariates were used as topography: slope angle, topographic openness, catchment area, and solar radiation. These were calculated from a 20-m digital elevation model (DEM) based on '10-m' DEM published by Geospatial Information Authority of Japan with QGIS Desktop 2.12.3 (https://www.qgis.org) and SAGA GIS [16]. The effects of environmental covariates were examined on rates of structural development by modeling $coeff_j$ as the function of covariates:

$$coeff_j = \beta_1 + \sum_k \left(\beta_{k,1} x_{k,j} + \beta_{k,2} x_{k,j}^2\right)$$

where β_1 is an intercept, $x_{k,j}$ is kth covariates of jth site, and $\beta_{k,1}$ and $\beta_{k,2}$ are coefficients of $x_{k,j}$ and its squared term. The covariants were fit the Bayesian model with 5500 plots data from NFI.

Hence, the old-growth index increase as forest age gets bigger. Preventing forest from harvesting where old-growth index gets easily large is the efficient way for maintaining the forest for biodiversity. In this study, the mean value of the old-growth index in the target region was estimated as the indicator for biodiversity.

6.5 conserving water resources

Water resource is essential for our daily lives. Various kinds of usage such as agriculture and industry as well as domestic use need water with good quality. The relationship between water quality and riparian forest has a great importance since almost all water resource area is covered with forest in Japan.

Nitrogen flux is one of a major interest concerned with forest ecosystem and water conservation. A disturbance of forest may result in an

1 Monitoring sites 1000 project is a surveying system for Japanese ecosystems. The purpose of this project is to provide qualitative and quantitative information about the natural environment continuously. Core sites and sub-core sites are designed for forest ecosystem and surveyed every or every five years. Every standing tree is measured in each survey.

Species	BEF		R	D	CF
	Age $\leq$ 20	Age > 20			
Japanese ceder	1.57	1.23	0.25	0.314	0.51
Japanese larch	1.50	1.15	0.29	0.404	0.51
Others	1.40	1.26	0.26	0.624	0.48

Table 6.2: Parameters used for calculating carbon stock.

outflow of nitrate nitrogen [1, 115]. Nitrate nitrogen eutrophicates and contaminates river, moreover, it is known that intake of a large quantity of nitrate nitrogen harm human health [105].

It has been reported that amounts of nitrate nitrogen in river increase after clear-cutting occur at a lower part of slope [30]. Clear-cutting augments redundant nitrogen in soil by reducing nitrogen utilization of plant and increasing supply from foliage. Redundant nitrogen is nitrified and dissolves in soil water. Soil water with nitrate nitrogen outflows into river easily from a lower part of a slope. It takes approximately 10 to 15 years for soil nitrogen condition to recover to be ordinary in forest of Japan [31, 114].

This research evaluated a function for conserving water quality by aggregating area of forest which is clear-cut within 10 years in a lower part of a slope. Slope which was lower than one-third of the whole length of a slope was defined as a lower part of the slope.

6.6 CARBON RETENTION

The importance of forest as a carbon sink is likely incontrovertible in this era of climate change [88]. There is increased need to evaluate the effect of forest management on carbon stocks to contribute to the global warming prevention [10]. Regional forest management can prevent decrease of carbon retention by suppressing excessive logging. The function for carbon retention was evaluated by estimating living woody biomass with an equation provided by Greenhouse Gas Inventory Office of Japan [34]. The carbon stocks are calculated by multiplying the stand volume of each tree species by wood density, the biomass expansion factor, the root-to-shoot ratio and the carbon fraction of dry matter:

$$C = \sum_{j} \{ [V_j \times D_j \times BEF_j] \times (1 + R_j) \times CF \}$$

where C is carbon stock in living biomass [t-C] ,V is stem volume [m3], D is wood density [t-d.m./m3], BEF is biomass expansion factor for conversion of stem volume, R is root-to-shoot ratio, CF is carbon fraction of dry matter [t-C/t-d.m.]. The parameters for each tree species (j) are shown in Table 6.2.

7

APPLYING THE DECISION SUPPORT APPROACH TO THE STUDY AREA

The DSA was applied to a study area, Ugo municipality. Using data gathered in the study area, the model simulated the changes in indicators of forest functions among the three zoning alternatives. The results were discussed for revealing the influence of zoning on future forest functions. The ability to reduce uncertainties was not verified because not enough data for iterative learning were available.

7.1 AN OUTLINE OF THE STUDY AREA

We modeled alternative plans for forest zoning in Ugo municipality, Akita prefecture (Fig 7.1). Here, 90% of forest is privately owned (most by small-scale owners), of which half are plantation forest. The dominant species in most plantation forests is sugi (Japanese cedar, *Cryptomeria japonica*), which is the major forestry species in Japan. Forestry is one of the main pillars of the economy in the region; however, low timber prices have caused economic stagnation in forestry for several decades. This situation gives the age distribution of forests a peaked shape (Fig 7.2). Timber production must be enhanced to activate the regional economy. In this area, 61.2% of forest owners own less than 3 ha of forest. There are also various forestry companies which manage forests for the owners. The municipal officers currently responsible for planning have little knowledge about forestry, and as a result, current regional plans are nominal with little change in content since the previous revision of the plan and the revision before that.

In the study area, three zone types were made to cover the region; Enhancing Wood Production (EWP) zone, Preventing Landslides zone, and Conserving Water zone. Zoning influences individual decision-making through the following process: The forest planning system in Japan has several levels, and the upper-level plans govern the lower levels [71]. Individual forest owners make their own Forest Management Plan, and they receive preferential treatment if their plans follow the upper-level plan. Forest owners who want to receive preferential treatment follow the zoning that is defined in the Municipal Forest Improvement Plan to make plans and decisions about forestry activities. However, they may not obey the municipal plan if they do not feel the need for any government assistance.

Ugo municipal government designates 23% of privately owned forest as an EWP zone, which is intended to promote timber produc-

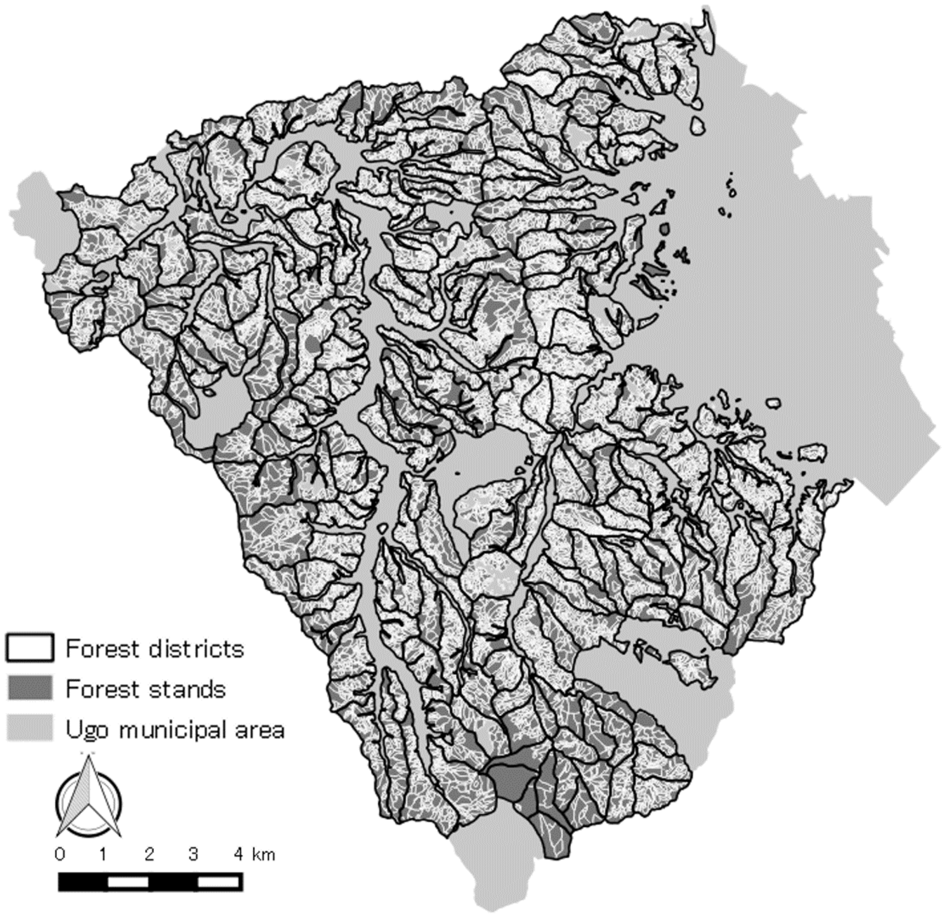

Figure 7.1: Forest districts and stands in Ugo. Forest districts separate the region by natural landscape features such as valleys, mountain ridges, and rivers, and were used to set zoning. Forest stands separate each forest district by natural landscape features, ownerships, forest age, and forestry activities that have occurred, and were used for the simulations.

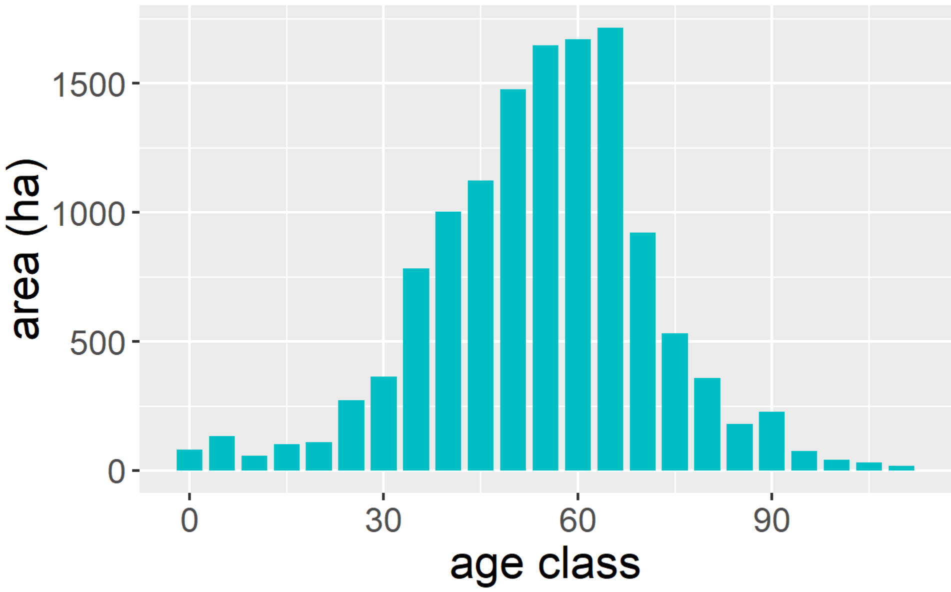

Figure 7.2: Current distribution of forest age classes in the study area: forest age was separated by every five years in each class.

tion by preferential treatments such as subsidies. The percentage and assignation of EWP zone were initially determined according to the distribution of mature plantation forest when the first municipality plan was established in 1999, and have not been varied since. The designation may not be efficient in terms of forestry promotion. Furthermore forest functions are significant in the region. Rice, which requires plentiful clean water, is extensively cropped, and thus relies on forest to provide clean water and to conserve soil.

7.2 zoning alternatives

Sustainable forest management depends on the application of scientific zoning methods. Three forms of zoning alternatives were considered: current zoning, zoning without EWP zone (NZ zoning), and zoning to enhance wood production (WP zoning) (Fig 7.3). If no differences in trends of forest functions were observed between NZ zoning and the other zonings, then zoning would appear to be meaningless.

Zoning was set in units of 280 districts in forests of the region separated by natural landscape features such as valleys, mountain ridges, and rivers (Fig. 7.1). In current zoning, according to the current municipal plan, the EWP zones covered areas that include large areas of old-growth forest. However, because zoning is originally set by considering the potential of the area, zoning only by forest age is illogical. WP zoning was set by considering slope degree, stand index, and area of plantation Japanese cedar. Each district was assigned a

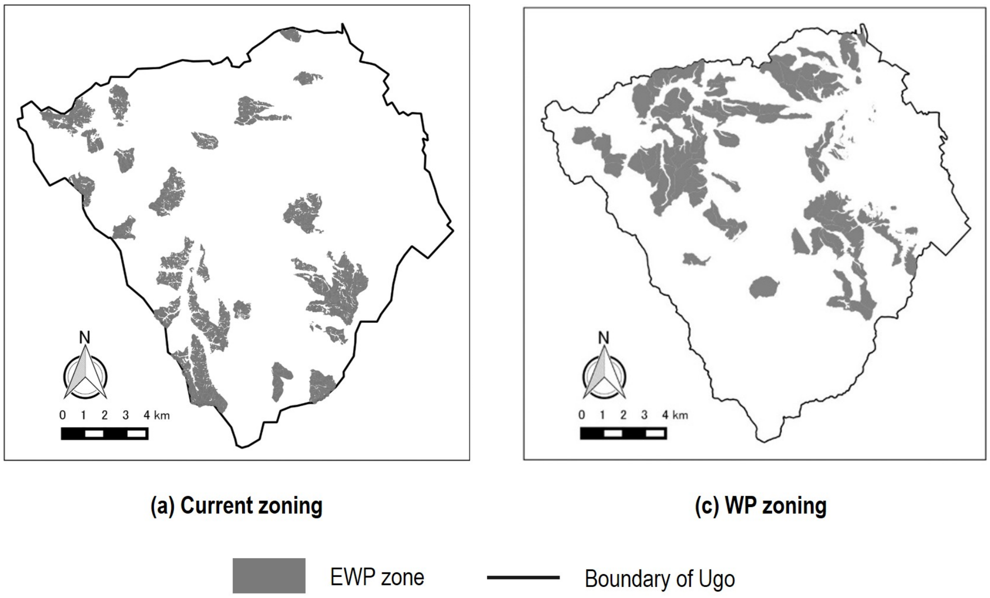

Figure 7.3: Three zoning alternatives compared in the case study

score of 1 to 5 for each condition such as ratio of area of less than 30° slope to the total area, the average stand index, or the ratio of sugi plantation area to the total area. As a final score for each district, individual parameter scores were summed. Then districts were converted to EWP zone according to their condition, starting with the stands that received the highest score until the total EWP zone area reached that of current zoning.

7.3 APPLICATION

Figure 7.4 shows a structure and variables of the BN model used to simulate the allocation of forestry activities in the case study, including the three zone types mentioned above. The structure of BN was estimated by the author, and the parameters were estimated by Maximum-Likelihood with Netica. To update the CPT, the model learned from data on which stands were to be thinned and which ones were to be clear-cut. The data were provided by prefecture and municipal governments for 2013, 2014, and 2015 (forest inventory and tree felling records supplied by the prefecture government), which contains 12,005 forest stands data for each year. Forest activities occurred in both plantations and natural forest in the study area. The probabilities of stands with conditions, which did not appear in training data, were inferred with evidence of species and age, although such stands were very few. Forest older than 150 years excluded from the list of clear-cutting because a sawmill in the region refuses to accept logs beyond a certain diameter. The prior probability of the occurrence of thinning and clear-cutting was set at 1% because these

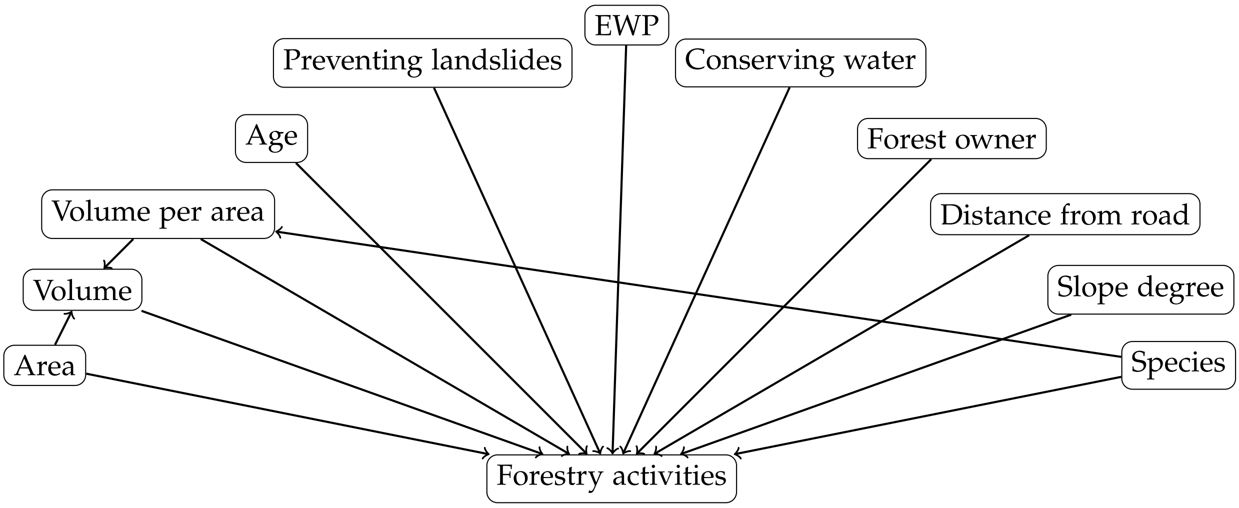

Figure 7.4: Structure of the Bayesian network model to estimate the probability of forestry activities.

forestry activities rarely occurred in the study area. Each factor was classified as shown in Table 7.1.

With the use of the CPT, forestry harvests were simulated for 100 years. Trials were repeated 100 times for each of the zoning alternative. The model simulated the forestry activities for each stand. The research area was separated into 12,005 stands according to natural landscape features, ownership, forest age, and forestry activities that have occurred (Fig. 7.1). The simulated allocations of forest resources in the study area were evaluated with the methods mentioned in 6.

7.4 RESULTS

7.4.1 *Clear-cutting Volume*

Figure 7.5 shows the predicted volume of clear-cut timber under each zoning. Given the age distribution of forests in the research area, wood production increases for the first 50 years and then gradually decreases.

Wood production under current zoning is higher than that under NZ zoning in the first 30 years. However, almost no differences were observed between the two zonings afterward possibly because of the old-growth forest covered by EWP under current zoning. The municipal government said they had set EWP to cover old-growth forest. After harvesting old-growth forest, any attractive forest may no longer exist for forest owners to clear-cut, so the value of current zoning becomes the same as that of NZ zoning. With regard to WP zoning, wood production is greater than that under NZ zoning over the whole period and also exceeds the value under current zoning after 30 years.

Variables	States
Forestry activities	No operations
	Thinning
	Clear-cutting
Volume (m^3)	0 to <100
	100 to<200
	200 to <300
	300 to <400
	400 to <500
	500 to <600
	≥600
Volume per unit area (m^3/ha)	0 to <100
	100 to <200
	200 to <300
	300 to <400
	400 to <500
	500 to <600
	≥600
Age	0 to <10
	10 to <20
	20 to <30
	30 to <40
	40 to <50
	50 to <60
	60 to <70
	70 to <80
	80 to <90
	≥90
Area (ha)	0.2 to <0.5
	0.5 to <1.0
	1.0 to <1.5
	1.5 to <2.0
	2.0 to <3.0
	≥3.0

(continued)

Variables	States
Species	Japanese ceder
	Japanese larch
	Others
Slope degree	0 to <15
	15 to <20
	20 to <30
	≥30
Distance from road (m)	0 to <25
	25 to <50
	50 to <100
	100 to <200
	≥200
Whether or not forest owners lives in DSA area	Absent
	Within the area
Zoning to enhance wood production	True
	False
Zoning to conserve water	True
	False
Zoning to prevent landslides	True
	False

Table 7.1: Variables and states used for the model to reveal the influence of regional forest management on individual forestry activities.

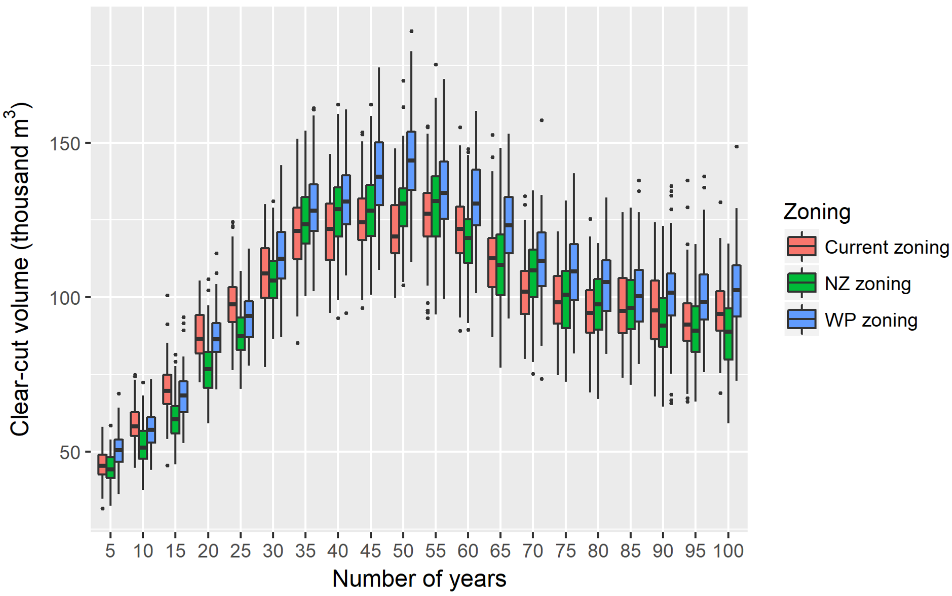

Figure 7.5: Simulated clear-cut volume. The boxplots signify the medians, the maximum and minimum values, and the quartiles of each trial.

The mean volume of wood production in WP zoning was 7500 to 22500 m^3 larger than in current zoning, or 6% to 18% of the total volume of clear-cutting after 30 years. These results can be interpreted as an indication of the efficacy of zoning. EWP in WP zoning should cover an area with relatively high profitability; such area becomes more attractive than other area for forestry activities with EWP. This finding means that zoning has the possibility to increase wood production by increasing the attractiveness of regional forests for harvesting. However, we can also say that inadequate zoning has relatively minor effects. The municipal government of the study area set the EWP to cover areas that contain abundant old-growth forest. The simulation results show that this policy has the effect of increasing wood production in the early stage, although this effect cannot be sustained for a long time.

7.4.2 *Thinning Volume*

Predicted thinning volumes differ from those of clear-cutting (Fig. 7.6). For the first 50 years, no noticeable differences in wood production were observed under any of the zonings. However, differences gradually increase thereafter. The volume of wood from thinning under NZ zoning exceeds that under other zonings, and that under current zoning is higher than under WP zoning. The mean volume of wood production in NZ zoning was 7000 to 15000 m^3 larger than in current zoning, or 8% to 18% of the total volume of thinning after 60

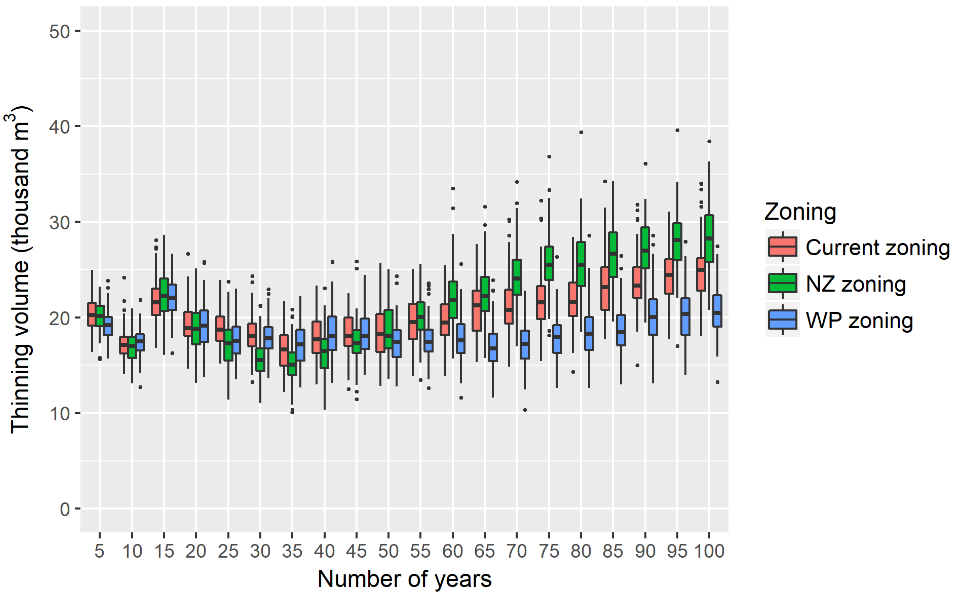

Figure 7.6: Simulated thinning volume

years; on the other hand, The mean volume of wood production in WP zoning was 7800 to 19000 m^3 smaller than in current zoning, or 11% to 25% of the total volume of thinning after 60 years

Subsidies may be the reason for these tendencies. The governments subsidize thinning in zones where thinning enhances the public functions of the forest. As a result, EWP zone decrease attractiveness of forest as a target of thinning. However, differences in wood production by thinning between the zonings were more slight than those from clear-cutting.

7.4.3 *Protection Against Soil Erosion*

Figure 7.7 shows a change in the ratio of area with high risk where the possibility of soil erosion was higher than 15%. On the whole, the ratio declined for the first 25 years, then it increased slightly until 65 to 75 years, and a slight reduction was observed in the last 25 years. The falls of the early years were also owing to the distribution of forest age. The area of young forest where the risk for soil erosion is relatively high dropped as time had gone by since forest in early, or very young, stage was scarce in the current situation.

Ratio of erosion risk was higher in WP zoning than other zonings after 30 years and the differences have increased gradually until the end of the simulations. The ratio of area with high risk of soil erosion in WP zoning was 1.0% to 1.8% higher than in current zoning, and 1.5% to 2.1% higher in NZ zoning after 60 years. This reason of this can be considered exceeding of clear-cutting area in WP zoning; it had increased area of early stage forest. Through the simulation, although

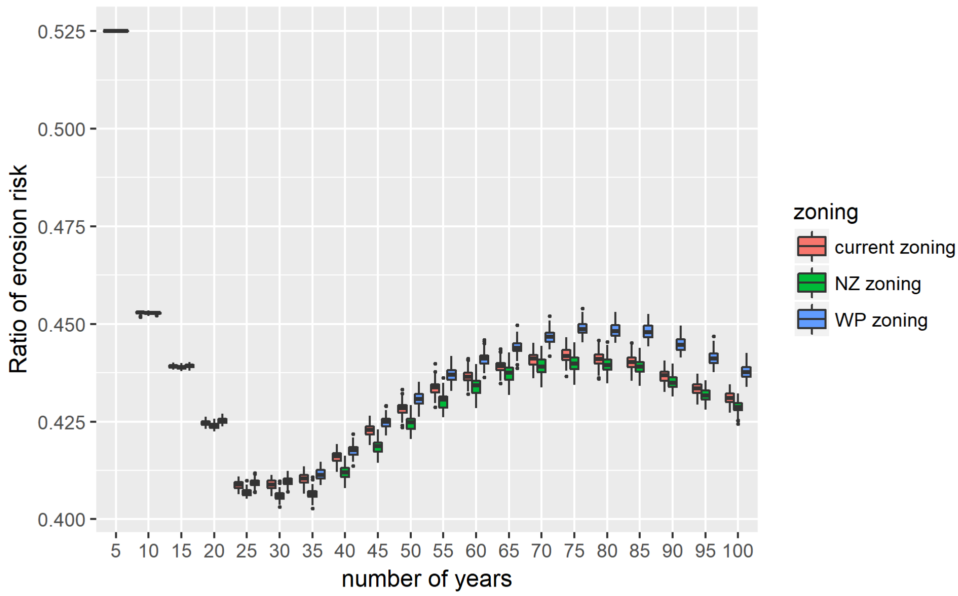

Figure 7.7: Change in area at >15% risk of soil erosion over 100 years simulated with the DSS. Boxes show median values, maximum and minimum values, and quartiles of each trial.

clear-cut area in NZ zoning had slight differences with current zoning, the ratio of risky area appeared to be lower. This result could account for the allocation of EWP zone of current zoning. Current zoning has been established without considering any geographical factors, therefore EWP zone might promote clear-cutting where erosion risk is high. It can be said that timber production and protection for soil erosion have a possibility to be compatible in this study.

7.4.4 *Preserving Biodiversity*

In general, the mean value of old-growth index increased through the simulation due to the rather small area of clear-cutting compared to total forest area (Fig 7.8). NZ zoning maximized the index; at 100 years, the index was 2.5% more than in current zoning and 3.8% more than in WP zoning. The smaller index in WP zoning could be explained by its greater clear-cut volume.

The old-growth index was relatively high in NZ zoning, although wood production was almost the same as in current zoning. EWP zone of current zoning covers south and west part of the study area, where old-growth index get easily high in younger age compared to other area (Fig 7.9). Forest in such area would remain young in the current zoning due to promoted clear-cutting. Hence, the mean value of old-growth index of current zoning would be lower than NZ zoning.

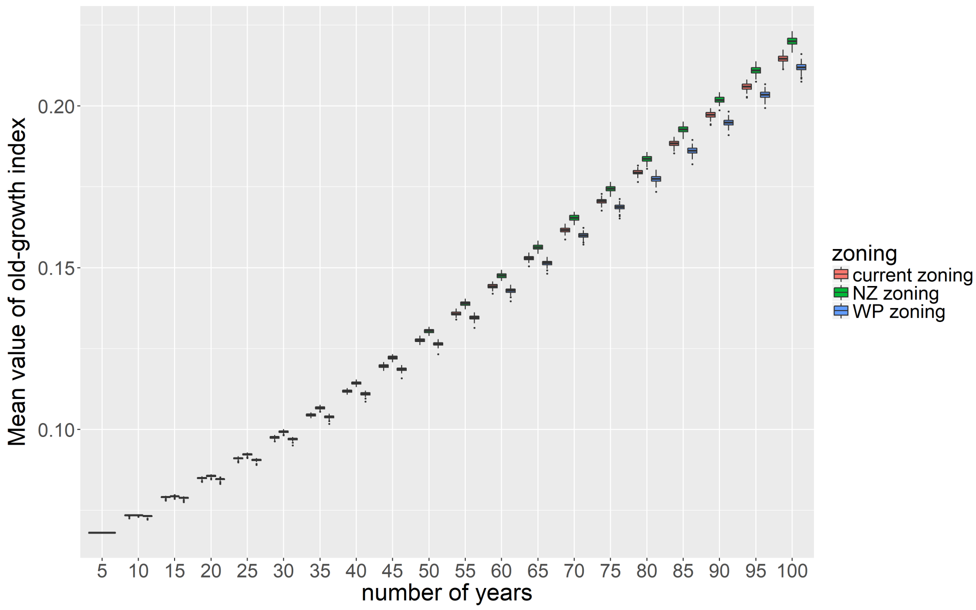

Figure 7.8: Change of mean value of old-growth index simulated with the DSA. Boxes show median values, maximum and minimum values, and quartiles of each trial

The differences between WP zoning and others indicate trade-offs between wood production and biodiversity. On the other hand, the results from current and NZ zoning indicate that zoning could enhance certain forest functions while maintaining wood production by considering terrain factors. Excluding important area for a specific function from EWP zone can improve the function.

7.4.5 *Conserving Water Resources*

Figure 7.10 shows a change in the area of lower part of slope that is clear-cut within 10 years. On the whole, the area increased for the first 40 years, then it decreased gradually. These trends and the differences of the area in the zoning alternatives correspond to clear-cutting volume.

The area of NZ zoning is lower than other zonings in the first 40 years and is the almost same with current zoning after that. On the other hand, the area of WP zoning had almost no differences with current zoning in the first 40 years and exceeded other zonings after that. Zoning alternatives in this study were not defined considering water resource conservation. Therefore the area of the lower part of slope that is clear-cut directly reflected the whole clear-cutting area. If water quality is a first priority in the region, zoning alternatives are required to be designed to reduce clear-cutting in the lower part of slope.

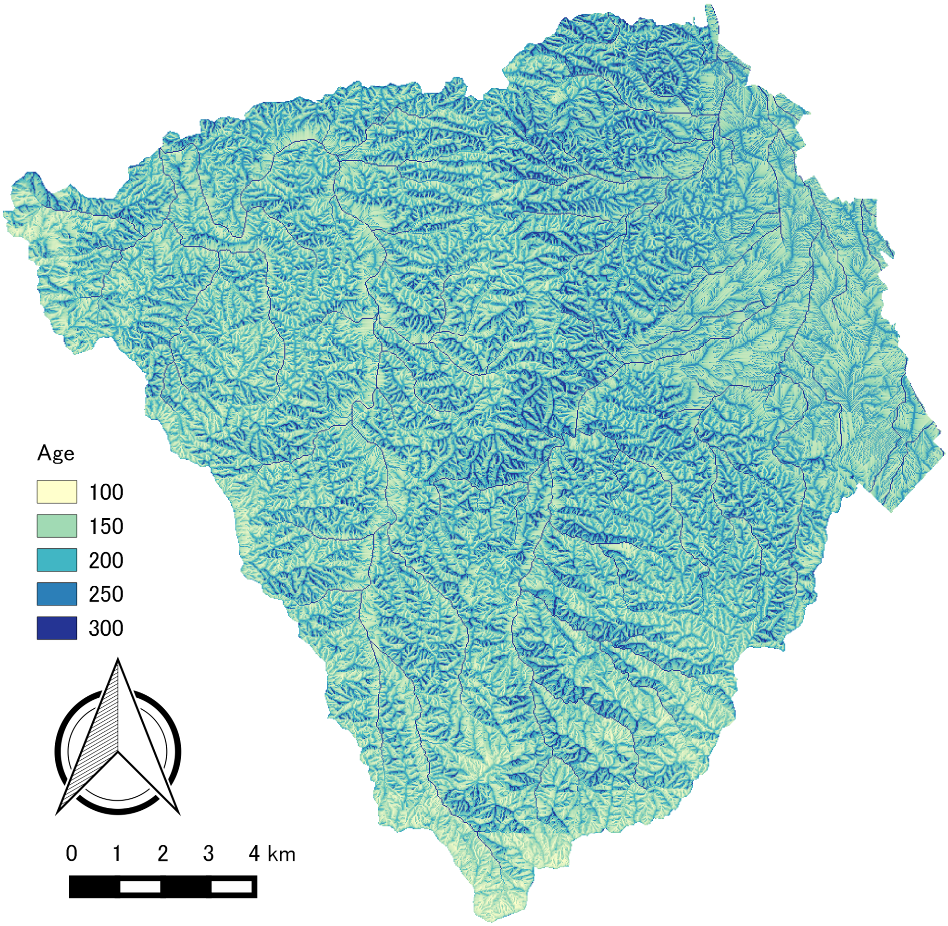

Figure 7.9: Required age for 0.5 I_{og}

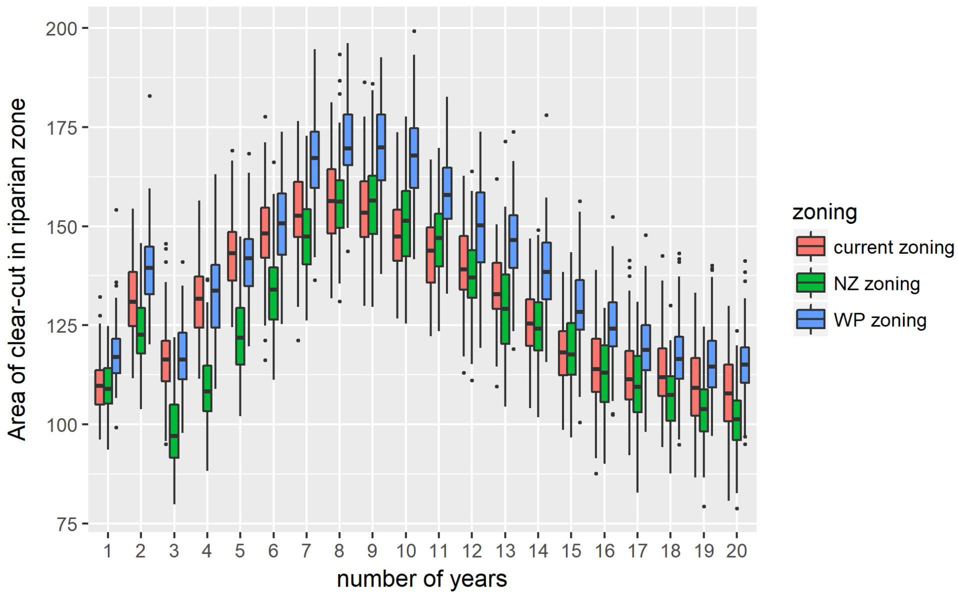

Figure 7.10: Change of area of lower part of slope that is clear-cut within 10 years simulated with the DSA. Boxes show median values, maximum and minimum values, and quartiles of each trial

7.4.6 *Carbon Retention*

Carbon stocks of living woody biomass increased during the simulation in every zoning alternatives (Fig 7.11). The rate of increase was gradually decreasing. The differential of attractions for forestry activities of forest stands location can be assumed as a cause of this trend. Forest stands with factors such as gentle slope or EWP zone, which makes them more attractive to forest owners, would be clear-cut repeatedly. On the other hand, forest owners would be not willing to clear-cut forest stands with less attractiveness. Less attractive stands got old at an early stage; that caused a rapid increase of carbon stock for the first decades. By contrast, trends in the latter decades had occurred because forest stands that are favorable for forest owners stay relatively young to the end due to clear-cutting and reforestation.

NZ zoning maximized the total carbon stock; at 100 years, the stock was 3400 tons or 0.2% more than in NZ zoning and 32000 or 1.5% more than in WP zoning. Carbon stock of living biomass was relatively high in NZ zoning. The relatively low wood production in NZ zoning can cause this trend. These results indicate the possibility of trade-offs between wood production and carbon retention.

7.4.7 *Discussion*

Prior works have developed various DSAs for adaptive forest management, which aim to achieve sustainability while improving man-

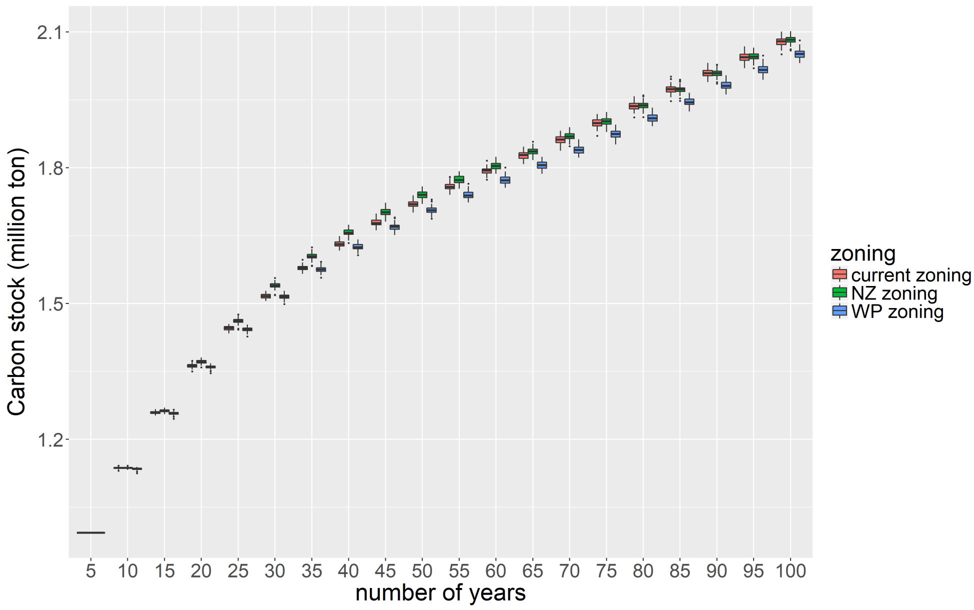

Figure 7.11: Change of carbon stock simulated with the DSA. Boxes show median values, maximum and minimum values, and quartiles of each trial.

agement and reducing uncertainties. Those DSAs tend to pay attention on uncertainties about ecosystems rather than controllability of management, which is important in regional scale management. This research established a DSA for zoning to manage regional forest coping with uncertainties of both controllability and ecosystem. A BN model based on observable behavior was constructed to estimate influences, or controllability of zoning on the allocation of forestry activities. Adding to that, models including BN were established to evaluate ecosystem services such as protecting soil erosion, preserving biodiversity, or carbon retention. The DSA in this research integrated these models to simulate future trends of forest functions.

The DSA was applied to the study area as a case study to assess efficiency. We compared three zoning alternatives that aimed to enhance different forest functions. The results of the simulation indicated that appropriate zoning allowed the possibility of improvement of multiple forest functions. According to the case study, WP zoning would increase wood production in the long-term by covering attractive stands for forest owners with EWP to enhance clear-cutting. On the other hand, this zoning condition might result in degradation of public functions. Considering how multiple criteria of forest functions can be balanced is important. Comparison of current and NZ zoning showed the possibility of maintaining multiple functions simultaneously. Clear-cutting volume was almost the same in those two alternatives, however, the indicator for biodiversity was better in NZ zoning. It revealed that zoning can be designed to improve multiple functions in an appropriate manner. Also, such a balance can be achieved and regional forest management can become sustainable by integrating the opinions and knowledge of various stakeholders and experts with the simulation results.

The results also argued that the effect of zoning might weaken if it is not adequately based on scientific analysis. The differences between the indicators of current zoning and NZ zoning were less than those of EWP zoning. Thus, a possible conclusion is that current zoning has a limited contribution to SFM. A regional-level forest management policy has the possibility to achieve SFM to some extent. However, if zoning is inappropriate, then the effect of zoning is expected to be limited. In Japan, most municipal government officials lack appropriate scientific knowledge and follow the proposals of their predecessors when drawing up new management plans. This approach results in ineffective planning with respect to SFM. Encouraging the use of models such as the one constructed in this research ensures that regional policies that can improve the sustainability of forest ecosystem services can be implemented.

The DSA supports establishing an efficient zoning by providing information about the effects of zoning on the target functions in the long-term perspectives. Simulated results of forest functions would bring a wise choice to a local committee that is organized for forest planning. Indicators based on scientific analysis and a hierarchical viewpoint would be integrated into municipal forest planning with this DSA.

7.5 SUMMARY OF THIS PART

This part demonstrated the structure of the DSA. The DSA consists of a simulation model and evaluation methods for forest functions. The simulation model was designed to simulate individual forestry activities in a hierarchical planning system. Simulated decision-making for forestry activities is influenced by a zoning alternative to be inspected. A verification proved the high accuracy of the model. The evaluation methods were developed to define indicators for critical forest functions based on scientific analysis. These indicators would help municipal governments to build their own sets of indicators. The developed DSA was applied to the study area in order to estimate the effectiveness of forest zoning on the sustainability and of the DSA on developing such zoning.

The results of the case study show the effects of zoning on ecosystem functions. Zoning is typically assigned without consideration of the effects on forest resources; two main approaches are used: comparing alternatives or functions with contemporary factors (e.g., [102, 123]) and comparing scenarios to impose fixed forestry activities (e.g., [17, 77]). The former cannot assess sustainability, and the latter can easily be idealistic. In contrast, a DSA designed for uncertainties in both controllability and ecosystem functions enables spatial planning such as zoning to be integrated with temporal planning. In addition, such a DSA adapts to observed behaviors to make the predicted results more realistic. This type of DSA accommodates trade-offs among forest functions during planning.

Although the DSA is designed to decrease uncertainties, the case study did not test this outcome, as continuous data collection and inspections are required to verify it: it has not been a long period since the municipal government began to collect data about forestry activities in the study area, so there is not enough data yet to allow iterative learning. In addition, FCP and the occurrence of soil erosion have been recorded only since 2009 and have been measured only once or twice in each plot. Neither was it possible to update the BN model to estimate the risk of soil erosion due to a lack of iterative survey data. But the ability of the DSA model to reduce uncertainties of controllability was verified by virtual forests and a virtual harvesting schedule. The scientific and adaptive management of local forest will need information gathered continuously and the use of such DSAs.

In spite of these problems, however, our results show how the DSA can benefit regional forest management by providing useful information for zoning to acquire sustainable ecosystem services while including partial controllability.

Participatory planning is one method used for managing regional forests where multiple decision-makers are involved [6, 56]. It promotes collaboration and consensus-building among various stakeholders in establishing plans, and has high affinity with AM [91, 122]. Its goal is to establish plans to fulfill forest functions by satisfying all needs through trade-offs. Plans based on common sense should have a degree of controllability [7]. Although decision-makers are involved in broad-scale planning in adaptive participatory planning, it is unlikely that every activity is totally suited to a plan [83], and they seldom know how far they can follow the plan in deciding activities. It is important to understand the degree of controllability by management to achieve sustainability. The DSA established in this study can provide a basis for decision-making in participatory planning considering uncertainties of controllability. The DSA improves the feasibility of a plan by simulating consequences of regional management at the local scale. Integrating both participatory planning and a DSA can efficiently reduce uncertainty about controllability. This kind of DSA will support adaptive participatory management of regional forests while reducing uncertainties.

Part IV

CONCLUSION

8

CONCLUSION

A PLANNING SYSTEM FOR SUSTAINABLE FOREST MANAGEMENT

Sustainability of local-level forest is greatly affected by municipal governments planning. They are entrusted with a mission to establish, implement, and check forest plans that are based on the current situations and problems of local forest and local resident's lives. Forest planning system in Japan has a hierarchical system from national level to forest management unit level. Municipal Forest Plan is situated in the position that need to integrate upper- and lower-scale plans. They use strong tools provided from upper stream in order to govern and manage local forest. However, problems such as a shortage of manpower, difficulties in consensus building, or lacks of evaluation systems hinder municipal governments to do so.

Adaptive management and its comprehensive process would help solving these problems with a iterative planning approach. A guideline that indicates detailed procedures defined in adaptive management makes planning smoother and easier. To apply adaptive management and improve efficacy of regional-level forest planning, a new paradigm for an entire system of forest planning is required.

A triple loop structure for planning with which adaptive management can be applied to actual forest management would be a system beyond previous systems with top-down or bottom-up approaches. Both top-down and bottom-up approaches have the strong and weak points. Although we have to balance two approaches to establish effective and specific plans, it is often difficult to do so because of repulsion of these approaches. The triple loop approach converts scales into schemes or systems; upper-level government don't govern lower-level but provide tools in this approach. Upper-scale managements revise guidelines or introduce new methods to achieve their goals. Monitoring or gathering information of lower-scale management is a foundation of these revisions. They attempt to give solutions for common problems from knowledge from advanced cases. Lower-scale governments use tools offered by upper-scale governments to manage local forest. Advanced municipals would develop their own strategies corresponding to requirements of their specific situations. Although the number of loop levels is defined three here, it might be changed according to the number of hierarchies for forest governance. Moreover, loop levels also describe the differences of time scales of planning. This kind of multiple loop structures would raise the standard of sustainability of forest planning for whole country by smoothing communications among different scale governments, increasing speed of applying better schemes in local-level forest management, preventing from compulsions by upper-scale governments, and lightning the burden of lower-scale governments.

Two kinds of schemes for constructing the triple loop structure have been discussed in this research: indicators and hierarchical planning methods. Indicators are very capable communication tools. An outsider can easily understand results or progresses of plannings. Therefore upper-scale governments can assess lower-scale plannings to reflect them to their plannings. When there are multiple scales for forest plannings, considering influence of upper-scale management on lower-scale is important to improve efficiency. Because previous planning methods have focused on a single scale, they have risks to be non-interactive and go in the wrong direction. Methods considering the relationships among different scales should be used. Furthermore, it would be preferable if these indicators and methods improve themselves while iterative planning processes.

INDICATORS FOR REGIONAL FOREST PLANNING

There have been two approaches for establishing sets of indicators: developing indicators well suited for forest in everywhere or in a specific region [33]. The aim of these approaches are different. The former ones are used for cross-regional evaluation. Multiple regions are compared for checking sustainability of their management. Intensive investments are sometimes brought to regions with poor results. The latter ones are designed to improve management actually for local management, so that the commonality is not important. Indicators are modified to correspond to the specific problems of the region. These indicators enable to compare forest functions in time directions, however, they cannot be used for cross-regional evaluations. Aims for developing indicators differ among individual situations. As a result, a huge number of sets of indicators have been developed for different scales and different regions in the current world. Each set of indicators have been developed based on each philosophy.

This research pointed out the importance of integrating multilateral view points for developing sets of indicators. Regional forest management requires a set of indicators that fits to the specific problems. On the other hand, benefits of common indicators are promoted in the triple loop management. The triple loop management encourage upper-scale governments to provide a comprehensive set of indicators and to collect results of monitoring lower-scale forest. Costs for lower-scale governments to establish their own indicators and for upper-scale governments to integrate indicators of different regions are expected to decrease with common indicators. Balancing approaches is required for developing indicators for efficient forest planning. However, only a few attempts to harmonize top-down and bottom-up approaches are observed (c.f. [60]).

Sets of indicators currently used in municipals of Japan are designed with bottom-up approaches. Committees that consist of stakeholders such as local governments, experts, forestry companies, environmental protection groups, or local habitats develop and evaluate them. These indicators show the current situation and problems of each region very well. However, ignoring benefits of top-down approaches has caused separations from scientific perspectives and lacks of comprehensiveness [12, 78]. Forestry Agency of Japan has little interests in using indicators for forest management in individual locations. A proposition of general sets of indicators that are scientifically developed is needed.

DECISION SUPPORT APPROACHES WITH MULTIPLE DECISION-MAKERS

Forestry activities are major measures for managing forest. Regardless of forest functions that are focused on, what human can only do is cutting trees; the question is where and when trees should be cut down. These allocations of forestry activities must be taken into account in regional scale with which most public functions fulfill themselves. Forest policies of regional governments are designed to improve functions of whole regions. However, previous research has not focused on the influences of upper-scale management on forest functions that are brought with the lower-scale and individual forest activities.

The DSA developed in this study shows the changes of forest functions in the long-term view by simulating individual forestry activities affected by forest zoning as a regional-level forest management method. BN model with the observed behavior of forestry activities was used to construct the simulation model. Simulating individual decision-making as lower-scale management make this approach realistic by directly connecting alternatives for forest policy with future allocations of forest resources. This kind of approach is suitable for a hierarchical forest planning system very well. Adding to that, due to the BN model with which the DSA was constructed, the approach itself can be improved with iterative learning. Establishment of plans in long-term view is difficult since only scarce data about forestry harvesting are available currently in Japan. On the other hand, this simulation model improves its accuracy by collecting data in the loop structure of planning.

In order to assess sustainability, indicators for crucial forest functions were developed with the scientific analysis in the DSA. These indicators are expected to complement sets of indicators developed by municipal governments to improve the comprehensiveness. Some forest functions such as soil soundness, water quality, or biodiversity that are vital for forest sustainability are usually ignored due to difficulties in the evaluation. The researchers should tell their importance and provide relatively easy methods to evaluate them scientifically. Advanced and appropriate evaluating methods can be incorporated into the DSA for better decision-making on regional forest planning.

Further researches are expected to improve this DSA. Firstly, more detailed analysis for the influence of zoning on forestry activities are required. More efficient policies can be established by understanding key factors for decision-makings by forest owners. Secondly, attempts to apply the approach to the actual field should be made. The approach was designed to make communications smooth, however, this research have not gathered opinions of decision-makers against the approach. It should be modified to be acceptable widely. Adding to that, the accuracy of simulation results should be evaluated with the real data. Creating data sets with enormous information is essential to solve these issues. Due to the lacks of evaluation systems, data collecting systems for forestry has been poor in Japan; benefits for collecting data have not been recognized for long time. Data formats managed by individual governments are too inconsistent to be organized well. NFI data, that have consumed huge time and labor to be collected, have scarcely analyzed and utilized for forest management. A system that enables to collect and handle mass data easily would promote data utilization. Cloud system as a new technology has been introduced to forestry in recent for better communications with detailed data [57], however, it usually focuses only on timber distribution. We need to design a system for managing forest and forestry data for more comprehensive purposes concerned with forest ecosystem services.

In spite of the need for improving, the DSA developed in this research can be a potent tool for constructing the triple loop structure of forest planning. A hierarchical planning method and indicators based on scientific analysis offers the objective basis for decision-making. Moreover, these are improved with data gathered from lower-scale management continuously. The triple loop structure can be expected to eliminate distortion among hierarchies of forest management. This paradigm would definitely improve the sustainability of regional forest management and planning.

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COLOPHON

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DECLARATION

The author declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Yusuke Yamada