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Article

Competitive Forestry Business in a Global Market- Scotland's Experience with a Forestry Cluster and Relevance to Japan

Michael Norton[*1] and Tatsuhito Ueki[*2]

ABSTRACT

The introduction of Japan's New Production Systems for forestry has raised the profile of a systems approach to strengthening forestry supply chain competitiveness. Such an approach has been practiced in Scotland via its Forestry Industries Cluster, bringing together government agencies and forestry businesses along the supply chain. Since the Cluster's formation, increasing timber availability has been matched by private investment in expanded processing capacity and biomass, so that currently Scotland produces ~7mil.m³ of timber annually of which over 80% is processed or used in Scotland. The authors have reviewed the Cluster's activities and carried out a field survey in 2008 involving interviews with participating organisations, supplemented by a questionnaire. We examine factors underlying current performance, and evaluate the hypothesis that the cluster organisational model has helped the industry's growth and competitiveness. The paper concludes by considering similarities and differences between Scottish experience and Japan.

Keywords: forestry management, Scotland, forestry cluster, competitive forestry

BACKGROUND TO THIS STUDY

Japan's domestic timber production of 17.62mil.m³ in 2007 accounted for just 20% of domestic demand (Japan Forestry Agency, 2008), and is only around 25% of the annual volume increment of ~80 mil.m³/yr currently available, as the artificial forests planted during the 1950s and '60s mature (Japan Forestry Agency, 2007a). To encourage growth in the domestic timber market, the Forestry Agency has introduced support for 'New Production Systems'. As the NPS name suggests, these bring a systems approach to the forestry industry supply chain (Japan Forestry Agency, 2007a; Tateiwa, 2007).

Previous authors have drawn comparisons between Japan and overseas forestry practice (e.g. Owari, 2007), but the systems idea behind the recent NPS initiative has not received such comparative attention. Systems approaches to industries are a feature of 'Clusters' – a concept popularised by Porter (1990) and applied in many OECD countries (OECD, 1999; OECD, 2001). Cluster policies seek to encourage competitiveness through strengthening the interconnections between cluster members, and with service providers, related industries, and institutions such as universities and standards institutions. Clusters are held to improve competitiveness through intensifying both competing and cooperative interactions which stimulate productivity improvements and innovation (Porter, 1990).

Following the spread of Porter's ideas, Japan's Ministry of Economy Trade and Industry (METI) introduced an 'Industrial Cluster Project' in 2001 to strengthen Japanese industry and promote the independence of regional economies (METI, 2005). The initial 17 clusters focused on high-tech industries such as IT, biotech, energy, materials, environmental technologies etc., but Porter (1996) has argued that the concept should not be restricted to high-tech sectors and can be applied to traditional industries; indeed many case studies included in the OECD analyses above referred to 'traditional' industries, including forestry. This raises the question whether the cluster approach could be relevant to Japan's New Production Systems.

While cluster thinking has been applied retrospectively to analyse the structures which have evolved in a mature forestry

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industry (e.g. ROUVINEN *et al.*, 1999), we are only aware of one example where Porter's theory has been deliberately implemented to create a new forestry cluster- this is Scotland where a cluster policy was introduced in its forestry sector in 1999 (SFIC, 2000). We thus carried out a preliminary review of the Scottish Forestry Industries Cluster (SFIC) and its potential relevance to Japan (NORTON, 2008). This showed that Japan's current challenge of increasing forest utilisation is similar to that faced by Scotland when it was decided to create the SFIC. Since the Cluster's formation, increasing timber availability has been matched by private investment in expanded processing capacity and new markets such as biomass, so that over 80% of the timber harvested is processed or used in Scotland (NORTON, 2008). Scottish Forestry also produces more timber per hectare of forest than Japan, and is less reliant on Government funding[1]. This suggested that further research into the application of cluster thinking to the forestry sector could be relevant to Japan's own policies, and this was undertaken in 2008 with the support of a grant from the JSPS[2].

METHODS

The hypothesis advanced from the initial review (NORTON, 2008) was that the SFIC, through its existence and mechanisms, contributed to improving the framework conditions and productivity of Scottish forestry. The cluster appeared to have helped the needs of forestry to be integrated into related policy areas including environmental, economic and rural development policies. Network relationships and information flows appeared to have contributed to improved productivity, performance and innovation. To evaluate this hypothesis and uncover factors contributing to the difference in performance between Scotland and Japan, we carried out a survey from 1 to 11 September 2008, interviewing members of the SFIC, its leaders and organisers, the Forestry Commission Scotland (FCS), and the economic development agency Scottish Enterprise (SE). A total of 18 visits[3] were made to various cluster members in the categories listed in Table 1. Interviews were supplemented by a written questionnaire aimed at identifying the value of the cluster from the viewpoint of its industrial members, and elucidating beneficial mechanisms which might be stimulated by the cluster. The questionnaire comprised five sections: 1) information on cluster membership, extent of participation and motives for participation; 2) the nature and extent of networks developed within the Cluster and their value; 3) evaluating the effectiveness of the Cluster in terms of its usefulness and cost-

Table 1 Visits and Questionnaire conducted in September 2008

Category of Organisation	Number of interviews	Questionnaires returned
Cluster Leadership Group	1	*
Forestry Trade Association	1	*
Cluster Support Office	1	*
Cluster Regional Offices	2	3
Government Departments	2	*
Forestry Management (planting, harvesting)	3	5
Sawmills, Board Manufacture, timber products	2	6
Wood Biomass	1	4
Architects	2	3
Research Organisations	2	1
Training and Education	1	3

* Because the questionnaire concerned the effectiveness of the cluster and government support, it was not issued to the cluster organisation or government departments.

[1] Scotland produced 6.6mil.m³ of timber in 2005 from 13,410km² of forest (Scottish Executive, 2006) - compared with Japan's 16.166mil.m³ from 251,000km² of forest. In Scotland, the income of the forestry and primary wood processing industry was £760M in 2005, compared with forestry-related support from Government of ~ £50M (NORTON, 2008). In 2005/6, Japan's forestry production was ¥416.8 billion and income from wood processing ¥200 billion (Japan Forestry Agency, 2008), compared with government expenditures on forestry of ¥859 billion for 2007 (Japan Forestry Agency, 2007b).

[2] This work has been funded by the Japan Society for the Promotion of Science Grant No 20530235.

[3] We acknowledge the generous cooperation of the Cluster Leadership and its support office, and from the two government departments involved (FCS and SE).

effectiveness; 4) collaborative projects and the extent to which the Cluster had contributed to their formation; 5) access to government grants. Respondents were asked to mark which of the factors provided applied to them (see Table 2 for the primary factors provided) and also asked to provide additional qualitative information (e.g. examples of collaboration) where relevant. The questionnaire was given to relevant organisations visited and also circulated on our behalf by the SFIC to other members. The 25 returned included 11 from the organisations visited and 14 returned as a result of the mailed request[4]. A classification of those returned is also in Table 1.

Drawing on the information gathered through interviews, background material provided and the questionnaire, we provide the following overview of the condition of Scottish forestry and identify critical factors which have contributed to its growth since the inception of the SFIC.

SCOTLAND'S FORESTRY POLICY AND THE SCOTTISH FOREST INDUSTRIES CLUSTER

Forest Industry Structure and Policy Background

Scotland's forested area of 13,410km^2 comprises 17% of its land area. Scotland produces the majority of UK timber[5] and forestry is thus relatively more important for the local economy, contributing up to 2% of GDP[6]. National forest comprises 38% of the forested area, and is managed by the Forestry Commission for Scotland (FCS). The remaining private forest owners number between 16-26,000, but only 1,000 of these own over 100ha, and together account for 75% of the privately-owned forest area (Scottish Executive, 2000). The dominant commercial species is Sitka Spruce, with Scots and Lodgepole Pine the next most significant commercially (Fig. 1). Extensive planting of Sitka Spruce during the 1960s, '70s and '80s has led to an age distribution (Fig. 2), providing a rapid increase in maturing timber from 2000.

The availability of raw material and proximity to markets in Scotland and neighbouring England has allowed industries to develop in pulp, paper, sawnwood, panels and most recently, bioenergy. There are 73 sawmills (down from 113 in 1995) with a total capacity of over 3 mil.m^3; in addition Scottish timber is exported to mills in Northern England (see Fig. 3 for the largest 20 Scottish mills and 4 large mills just across the England border). The latest sawmill[7] to come on line was producing 380,000m^3 of sawn wood per year during 2008, based on two six-hour runs. It incorporates kiln-drying, chemical treatment, 100% FSC certification, and in-line strength testing to enable C16 quality certification[8]. Panel and board manufacturers (also 100% FSC certified) at the sites shown in Fig. 3 have a local capacity of 2mil.m^3/yr, and recent substantial investment in large-scale biomass[9] will soon use over 1mil.m^3/yr. Paper mills consume ~300,000m^3/yr. The Scottish industry serves the whole UK market where over 80% of softwood demand is met by imports (SFIC, 2000).

Before 1998, forestry had been a UK Government responsibility, but powers were devolved in 1998 to a new Scottish Government. The latter initiated a review of its new responsibilities (Scottish Executive, 2000), focused on exploiting the increasing volume of maturing timber as a result

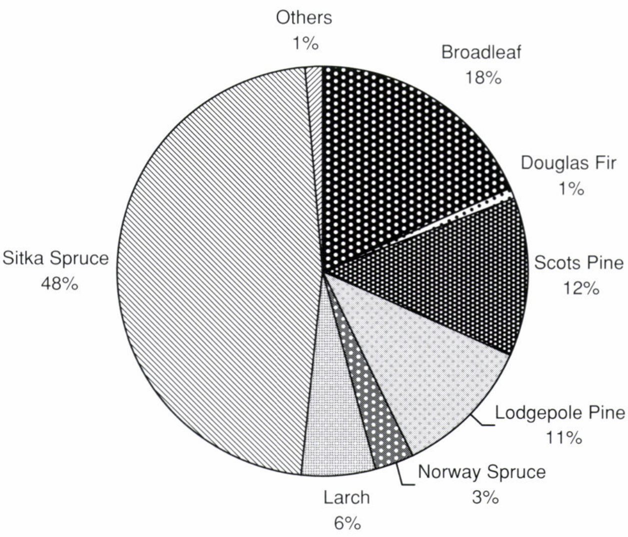

Fig. 1 Scotland's Forest Species (% of total woodland area)
Source: Forestry Statistics (2008).

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[4] Since the SFIC does not have a formal membership system and is open to anyone to participate, it is not possible to calculate an accurate return rate. However, active membership estimated by Cluster staff is around 100 which would make the response rate 25%.

[5] Scotland accounts for 2/3 of the total UK softwood harvest (Forestry Statistics, 2008).

[6] In 1999, forestry and related primary wood processing contributed about £800M (1%) and employed 11,000. However if the contribution that forestry makes to sectors such as tourism, and processing of imported wood is included, output was £1,400M and employment 44,000 (Scottish Executive, 2000).

[7] The Kenmuir mill of Howies Forest Products Ltd.

[8] C16 is the standard for general structural timber in the UK construction market (British Standard BS 4978 (2007)).

[9] The Steven's Croft power station has a capacity of 48 MW and uses 450,000 tonnes per year; Balcas plc wood fuel pellet plant at Invergordon will use 350,000; and a new combined heat and power plant at UPM ltd. 400,000 tonnes per year.

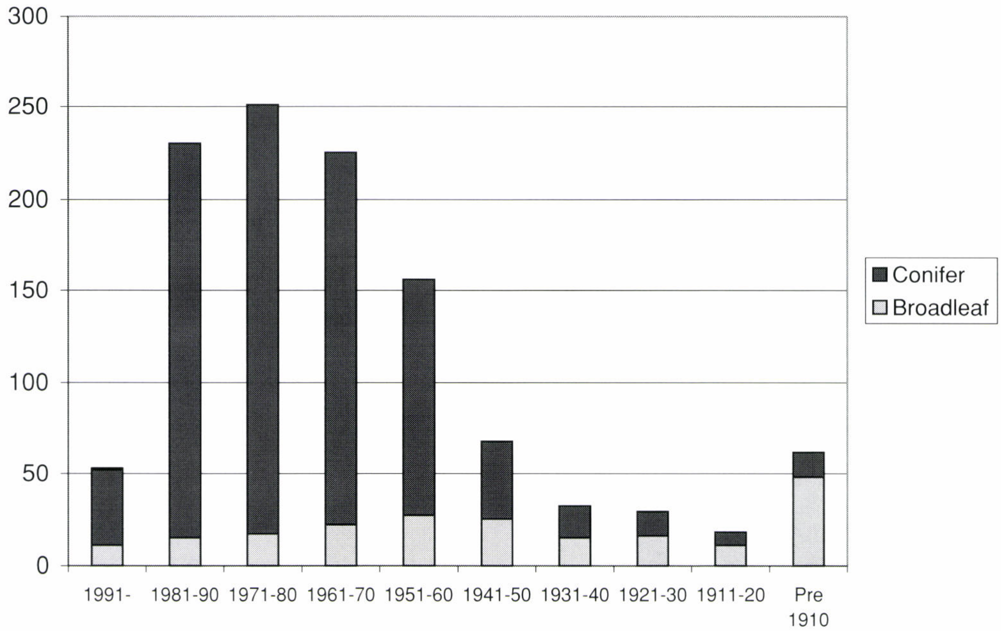

Fig. 2 Age Distribution of Scottish Forests by year of planting (1,000 hectares)
Source: Forestry Statistics (2008).

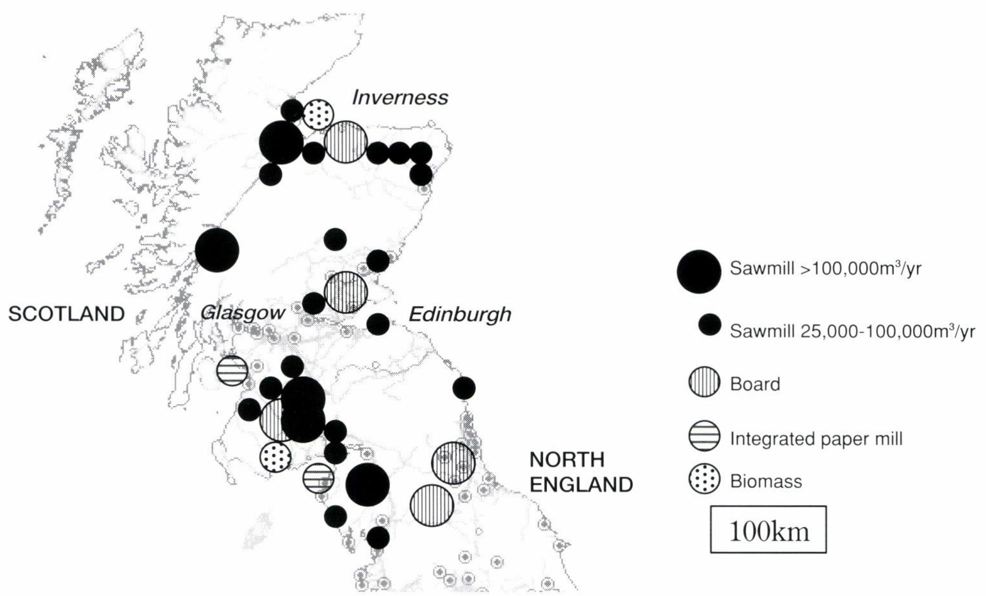

Fig. 3 Location of Main Wood Processing Facilities in Scotland and North England
Source: Scottish Enterprise.

of earlier plantings (Fig. 2). It estimated that harvest volume would increase from 5 to 9mil.m^3/yr by 2020, and created a policy to ensure this resource was effectively used for the benefit of the Scottish economy. The new forestry policy established five *Strategic Directions* of which one was to "*maximise value to the Scottish economy of forest resources over the next 20 years*" and a second to make this contribution sustainable by creating "*a diverse forest resource of high quality that will contribute to the future economic needs of Scotland*"[10].

[10] The remaining 3 strategic directions concerned forests' contribution to the environment, leisure and to communities.

These have been retained in the policy updated in 2006 (Scottish Executive, 2006). The latter also adopted a long-term target of increasing forest cover to 25% in order to support large-scale processing, new value-adding enterprises, local timber processing, biomass for energy, non-timber forest products and more tourism-related businesses (Scottish Executive, 2006). The 2006 strategy also strengthened targets for contributing to tackling climate change, flood management, and more adaptable ecosystems.

Forest Management

The Forestry Commission Scotland (FCS) acts as the Scottish Government's forestry agency; it administers the National forests, and is also responsible for delivering social (e.g. health and leisure) and environmental (including biodiversity and climate change) forestry objectives. The FCS develops long-term cutting plans for the National forest to deliver a predictable and reliable supply of wood for each main species (primarily Sitka Spruce and Scots Pine). The FCS must also approve cutting and replanting plans for private woodlands which, as already pointed out, are dominated by large holdings (both by individual landowners or forest management and investment companies). Because of this concentration of forest into National forest and large private holdings, 80% of Scotland's forest can be managed by engaging fewer than 1,000 owners and the FCS, facilitating reliable forecasts of supply[11]. Such forecasts enable local users of wood- particularly large-volume consumers such as sawmills-to make appropriate investment decisions.

Forestry management aims for a stable supply by balancing harvesting with replanting in accordance with the UK Woodland Assurance Standard (UKWAS) for sustainable forestry management (UKWAS, 2006), which is compliant with Forest Stewardship Council (FSC) accreditation. Operational decisions are subject to consultation with stakeholders (including landowners, local authorities, environment and wildlife groups, leisure and sports interests), whose views are taken into account in the plans for roads, recreation facilities, conservation and harvesting. 50-year Plans cover the years in which coupes are to be cut and associated re-planting strategies, and provide the basis for supply forecasts. FCS executes its forestry management and timber production via an internal business division (Forest Enterprise). Harvesting typically employs mechanised, cut-to-length harvesting (using harvesters and forwarders) with typical cutting costs of £9.6/m^3, and transport costs of ~ £8/m^3 to local users (2008 figures provided in interviews). Forest Enterprise employs its own harvesting equipment and operators, but the majority of wood is harvested by contractors via competitive contracts.

FCS is also responsible for rural development and environmental objectives of National forests. Forest-related tourism can be an important part of the local economy. Walking, bird-watching, and most recently mountain biking, attracted 8.7 million visitors to National forests in 2006 (FCS, 2009). Environmental objectives also influence replanting strategy. As monoculture forests are felled, replanting aims to reduce impact on rivers and streams by leaving a deciduous corridor to reduce erosion, help biodiversity and improve visual amenity for tourism. Low-impact silviculture (e.g. leaving islands of native Scots pine uncut to regenerate native forest) is also being introduced and is now used in 5.2% of the forest area (FCS, 2009).

Integrated management (from planting to harvesting) is not limited to the national forests – there are a number of specialist management companies which develop long-term management plans for private forests, including annual yields of timber, costs of replanting, maintenance, etc. Such services also include obtaining FSC certification, and managing the sale of timber to maximise income[12]. The private forests we interviewed typically have similar costs to FCS costs cited above– felling £9/m^3 and transport £6/m^3 (to local mills)[13], providing a standing price of £35/m^3.

The Supply Chain and the Role of the SFIC

The mass flow for timber from Scottish forests (before the 2008 economic downturn) is shown in Fig. 4. 84% of the timber cut is processed in Scotland, and most of the remaining 16% 'exported' is processed in neighbouring England (equivalent to the next Prefecture in Japanese terms). The current system thus succeeds in capturing most of the economic added value of processing in Scotland. Larger timbers are processed for sawnwood, smaller wood can be used in board manufacture, and residues are finding an increasing market for biomass, fuel pellets, compost, etc. Sawmills are increasingly integrated with other companies in terms of their co-products. Bark is sold to DIY stores and garden centres; other co-products go to paper manufacture, are used as biomass for heat on site (for drying), and also sold to intermediaries supplying biomass markets. Efficient management of co-product residues makes a key contribution to profitability. The diversity of potential end-

11 Current forecasts of harvest volume from both public and private sectors are for growth from 6.893 mil.m^3 over the 2007-11 period to 8.942 mil.m^3 by 2020.

12 For instance, the Scottish Woodlands company manages private forests with a combined annual yield of 850,000m^3, and offers a range of sales methods and markets adjusted to individual client's timber reserves and circumstances.

13 Figures provided for a medium-scale (5000 hectares) private forest.

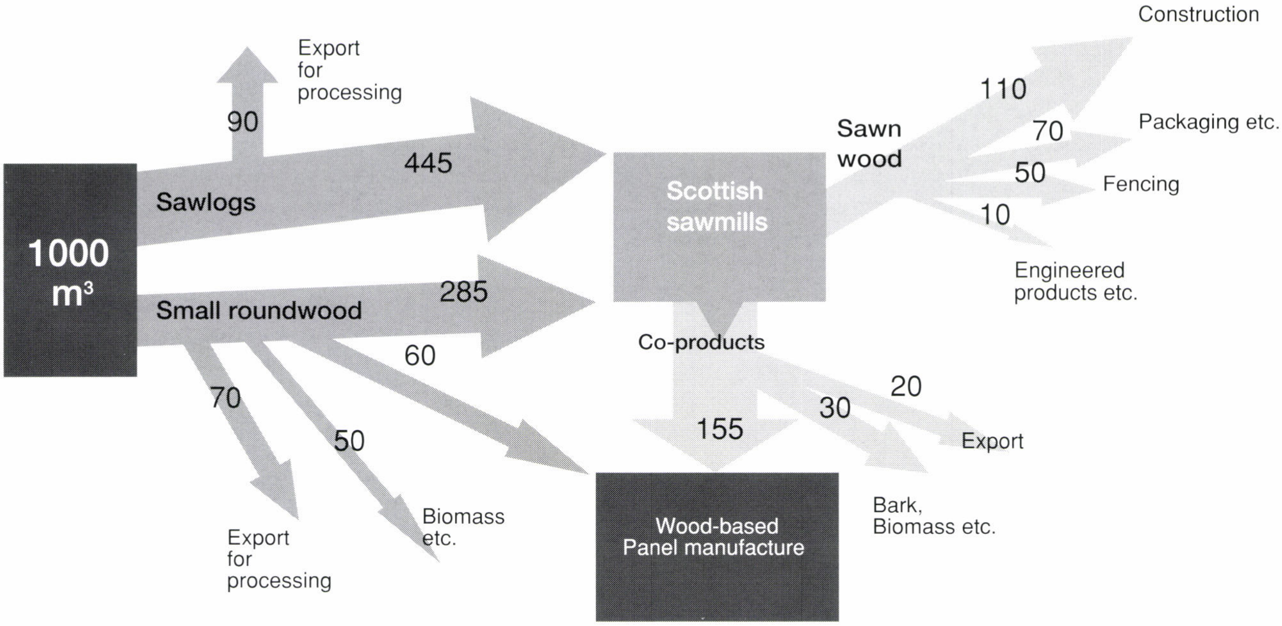

Fig. 4 Mass flow for Scottish timber
Source: updated from SFIC (2004)

uses also offers managers flexibility to adjust supply according to prevailing market conditions- for instance, in 2008 the main markets for construction timber declined but demand for biomass was growing; thus small roundwood which would have been used for board manufacture could be sold for biomass instead.

Let us now consider how the Scottish Forestry Industry Cluster has contributed to the current industry condition. As stated earlier, a primary aim of the 2000 Forestry Policy was to maximise economic benefits from the increasing yield of timber. The SFIC was thus established in 1999[14] with the purpose of mobilising the various industry stakeholders towards common goals and objectives, strengthen competitiveness and links between suppliers and users of wood, stimulate innovation and encourage the investments necessary to exploit the timber available (SFIC, 2000). Leadership was assigned to a 'Leadership Group' of 18 of whom 15 were senior representatives of the forest industry and supply chain, one NPO and one representative each of the two government departments involved (SE and FCS).

The SFIC first conducted a SWOT analysis and decided its priorities (SFIC, 2001) as:

1) Supply chain efficiency improvement (reduce transport costs, introduce e-business and adopt lean manufacturing techniques).
2) Training and Education – a shortage of skilled workers[15] led to a new training centre for forestry, and a Forest Education Initiative for schools.
3) R&D. The industry lacked a R&D base and SFIC promoted the formation of the Centre for Timber Engineering at Napier University.
4) Networks. Information dissemination, working groups and conferences to strengthen communication between members and associated organisations (including government).
5) Markets. Promoting the sustainability benefits of wood as a construction material with architects and the public, and ensuring building standards recognised the role of wood in sustainable construction.

An evaluation in 2005 (Ecotec, 2005) suggested that the cluster strategy had enabled the industry to act in a more coordinated way with a longer-term and more strategic vision, especially in its approach to supply chain relationships and efficiencies, training, research and innovation. Being members of the cluster appeared to have encouraged greater collaboration between companies, as well as a more outward-looking vision and open-ness to new ideas. Industry's confidence had increased, and the Cluster had succeeded in

[14] Cluster policies were under review by Scottish Enterprise in other economic fields, and a decision was taken to combine the new forestry policy with a Cluster organisation.

[15] The average age of workers in a recent survey was 45, with difficulties encountered in recruiting younger people (SFIC, 2007a).

raising the profile of the industry both with customers and government. The results of the field survey and questionnaire (Tables 1, 2) allow us to independently judge whether this positive evaluation in 2005 still applies to the industry in 2008.

Interviewees supported in general terms the positive evaluation of the SFIC's impact above. The responses from the questionnaire are summarised in Table 2, which lists factors which participants consider relevant to their involvement with the Cluster (the bracketed numbers in Table 2 are the number of times that factor was selected in the 25 returned questionnaires). These results indicate that a majority of respondents considered the cluster had allowed them to develop new relationships and collaborative projects. In terms of the benefit obtained compared to the time spent engaging with the Cluster, half considered participation cost-effective or very cost-effective, 45% felt that the benefits of participation balanced the time invested and only 5% considered participation non-productive. The primary purpose of membership reveals the importance assigned to the network function of the cluster (exchange of know-how, personal contacts, finding partners), with the next priority related to competitive factors (cost reduction, quality improvement, benchmarking, client-supplier relationship). This confirms clusters as organisations where both competition and cooperation take place (PORTER, 1990). Overall benefits were assessed (in decreasing order of

Table 2 Questionnaire and Results Summary

Questionnaire Topic	Results
1 Cluster participation a) In what activities do you participate?	General meetings (16) Information exchange (15) Specialist working groups (13) Management/leadership bodies (12) Cooperative activities with other cluster members (7) Technology application and Standards development (3)
b) What are the motives for participation?	Exchange of know-how(19) Personal contacts (19) Access to new markets (9) Strengthening client-supplier relationship (9) Benchmarking (8) Finding partners (8) Improve quality (7) Access to centralised services (5) Cost reduction (4)
2 Networks a) Has the SFIC allowed you to develop new network relationships?	New knowledge, business or collaborative relationships (13); for example with forest owners, Government, transport and processing industry, markets, IT providers and wood fuel suppliers/sawmills.
b) Examples of networking outcomes.	Improved efficiency via e-business; Industry-wide cooperative attitude; New building design; Forest education and regional training programmes; Source of R&D; Better understanding of industry structure and links; Biomass clients; Improved contacts.
3 Effectiveness a) How do you evaluate Cluster effectiveness?	Very cost-effective (3) Cost-effective (7) Neutral cost-benefit (9) Not cost-effective (1)
b) What are your main uses of the SFIC?	Information (e.g. market trends, technology, standards) (17) Exchange of experience with similar companies (13) Facilitation of supply chain links (10) Insights into improving productivity (8) Source of potential partners (4) Public funding opportunities (3)
4 Collaborative projects and whether facilitated by Cluster participation.	Collaborative projects extend over Technology/R&D, Procurement, Production, Logistics, Marketing/sales, training. Of 15 projects, 2 were not possible without the Cluster, the Cluster helped with 10, and the Cluster had no influence on the remaining 3 collaborations.
5 Government grants obtained.	15 Government grants accessed in fields of planting, wood fuel supply, capital support and transport.

Source: 25 responses. Bracketed numbers indicate the number of responses in which that factor was selected. In the case of networking outcomes, collaborative projects and government grants, examples are those offered by the respondents.

importance) as a) information (e.g. market trends, technology, standards), b) exchange of experience with similar companies, c) facilitation of supply chain links, d) insights into improving productivity, e) source of potential partners, and f) public funding opportunities.

In terms of specific achievements, respondents placed particular emphasis on supply chain efficiency improvement. The SWOT analysis carried out at the start of the cluster had shown that Scottish timber was price-competitive with Nordic countries, but that transport typically absorbed 30% and harvesting 40% of sales income, thus reducing the stumpage value (SFIC, 2003). Two of the cluster's early initiatives addressed this problem. The Timber Transport Forum sought efficiency savings through better use of roads and vehicles (as well as enhanced safety and public acceptability), and the E-business project developed and introduced special protocols to substantially reduce transfer costs in the supply chain.

A second key factor highlighted in interviews was the importance of integrating the needs of forestry into other areas of government policy- particularly environmental, economic and rural development policies, and their associated subsidies[16]. Specific support for forestry from Government had included:

- Supply of staff from SE and FCS to act as 'mediators' to help identify potential cluster initiatives and create support within the industry.
- Timber Transport Fund: to improve transport efficiency- through timber containerisation, improved forestry road design and use of larger vehicles (FCS, 2006).
- Scottish Biomass Support Scheme to support costs of wood-fuel boilers, supply chain infrastructure (e.g. chippers, drying sheds) and training (Scottish Government, 2008).
- Timber Development Programme: e.g. to improve knowledge of timber resources, innovate towards high-value end markets[17], develop carbon benefits of timber-based construction (FCS, 2007).
- Scottish Rural Development Programme: support for woodland creation and management and new businesses in forestry products.

In terms of overall indicators, since the Scottish forestry policy was implemented and the SFIC formed, the annual harvested volume has grown by 40% in less than 10 years (from ~5 mil.m^3 in 1999 to 7.2 mil.m^3 in 2007), while the rate of private investment (~£600M from 2004-8)[18] was over triple that before the new forest policy was introduced. This was attributed by interviewees as due in part to better coordination and strategic collaboration across the supply chain facilitated by the Cluster.

In terms of market promotion, the SFIC has sought to stimulate the overall market for wood (especially in the housing sector) and to displace imports in the UK market. Actions in the first category include public campaigns to emphasise the sustainability and environmental credentials of timber construction, and working with standards organisations to ensure that the role of timber is fully recognised in emerging sustainability-oriented building standards (SFIC, 2007b). To promote competitiveness with imports, strategies include in-line strength testing in sawmills to certify that timber meets construction industry standards, and a demonstration house built from Scottish Timber. Professional development courses for architects on the sustainability and environmental benefits of wooden buildings are offered by the Centre for Timber Engineering; architects specialising in buildings constructed from Scottish timber are also active in the Cluster developing guidance on timber use in buildings put out for competitive tender so that contractors can offer solutions involving local wood.

Finally, FSC certification is a factor in the UK market with implications for the competitiveness of Scottish timber. Government has required 'legal and sustainable' certified timber for public procurement since 2000 (CPET, 2009), and environmental NGOs have launched campaigns against illegal and unsustainable timber imports which have led large DIY retailers[19] to commit themselves exclusively to sustainably-sourced timber. Scotland's high rate of FSC compliance[20] could offer a competitive advantage but surveys (Oliver, 2005) show that it is unusual to attract any price premium because there is abundant supply of FSC-compliant timber in imports from other European countries. FSC certification has thus become a condition of participating in the market rather than offering a competitive advantage.

DISCUSSION; ASPECTS OF SCOTTISH EXPERIENCE WITH RELEVANCE TO JAPAN

Scotland and Japan's forestry industries face the same

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[16] Table 2 (Topic 5) indicates that 15 of 25 respondents had benefited from one of more forestry-related grants.

[17] For instance, evaluating Massive Timber, engineered wood and secondary processing.

[18] This comprises modern sawmills (£84M), Bioenergy (£355M), panels (£140M) and investments in harvesters, baling machines and stump harvesters (Source: FCS briefing).

[19] For example, the B&Q chain decided from 1999 that all timber stocked must be FSC-certified.

[20] All National forest is compliant with FSC and the proportion of private forest certified has also been increasing; overall, 6.1 of the 7.2 mil.m^3 harvested in 2007 was FSC- certified (FCS, 2009).

challenge of operating in a competitive global market affected by global price shifts; both also have a high domestic demand for wood and high import penetration, so that import substitution is a major opportunity. With these similarities, what do we conclude from this study are the main factors which have allowed Scotland to make greater use of its forest resources than Japan? We suggest 2 fundamental structural differences contribute:

1. The role of National forests. The proportion of National forests in Japan is lower (31%) than in Scotland (38%) and their role is different. Scotland's National forests include large artificial forests which are managed by FCS with timber production as a primary objective. In Japan, the proportion of National forest zoned for sustainable use of wood resources is 6% with the remainder zoned for social benefits (Japan Forestry Agency, 2008).
2. Ownership structure. The highly concentrated ownership of Scotland's forests described above facilitates integrated management and achieving predictable and reliable yields. Japan's highly fragmented ownership structure[21] necessitates separation of ownership and management and the creation of many intermediate organisations such as Forestry Owner Cooperatives (Fujisawa, 2004).

A third factor may be related to the organisational models used. While the SFIC uses cluster theory as the basis for its model, Japan has recently introduced the 'New Production System' (Japan Forestry Agency, 2007a) to integrate the forestry supply chain (harvesting, transport and processing), reduce costs and meet the needs of major customers (especially house builders). Each NPS is charged with developing improved efficiencies related to its particular forests, geography and circumstances (Tateiwa, 2007), leading to detailed guidance manuals and training on optimum methods and equipment[22].

By emphasising integration along the supply chain, and better links with users, the NPS and the SFIC have similar objectives, but use different means of achieving these objectives. The SFIC's priorities are decided by a Leadership Group of senior representatives of companies in the supply chain (assisted by specialist staff from FCS or SE). The SFIC thus helps synthesises industry's view on how government can improve the structural framework within which private investment decisions are made (e.g. reliability, quantity and quality of supply, system conditions such as research and training, market stimulation measures such as biomass). The consequence is that the limited government support available has been targeted at what the *industry* believes are the most cost-effective support measures. Government support has remained well below the level of private sector investment, and has been designed to be catalytic rather than to substitute for private sector investment. Government has thus sought to influence the initiatives and entrepreneurial power of industry, and how and which priorities are set, rather than seek to take the lead itself.

A fourth difference to emerge from our study is the influence of FSC or equivalent certification. Green government purchasing standards differ, with Japan, by specifying 'legality' only, setting less demanding targets than the UK's 'legal and sustainable' requirements described earlier. Japan's level of certification (FSC and SGEC) of 2.5% in 2007 (Ota, 2007) also contrasts with Scotland's 86% certified harvest in 2007 (FCS 2009). Economic benefits have been reported locally from certification (Ota, 2007) but recent surveys (Owari and Sawanobori, 2007) did not find general price premiums for certified timber[23]. While this finding is similar to UK market conditions described earlier, the basic market framework conditions are very different. The UK market has evolved over the last 10 years to the point that certification has become a *competitive precondition* for Scottish timber. If we envisage a scenario where the Japanese market evolves along a similar path, then a low rate of FSC/SGEC compliance would create a competitive disadvantage for domestic timber relative to certified imports. Scottish experience tells us that certification is an important *competitive* (as well as environmental) factor; thus Japan's approach to certification (including what signals the Government chooses to provide through its green procurement standards) is clearly relevant to the objectives of the Forestry Agency's NPS strategy.

In conclusion, this survey of Scottish forestry management and the role of clusters support the hypothesis that the application of the industrial cluster model has contributed to a more competitive forestry industry in which the private sector has invested to allow the majority of harvested wood to be processed near to its source, thus capturing added value within Scotland's economy. This initial analysis also suggests a direction for future research to determine how far the cluster model could be applied beneficially in Japan -by examining in detail the supply chain relationships and networks which

[21] There were 920,000 owners in the Forestry Agency's 2005 census (Japan Forestry Agency 2008). Even the holders of larger (>50ha) forests number over 10,000.

[22] For instance, covering optimum approaches depending on road density, slope, local rules, road strength, optimum use of machinery, vehicles etc.

[23] Qualitative benefits were however reported- improved 'environmental communication' (public reputation and acceptance from environmentally sensitive customers and environmental groups) and customer relations.

contribute to improved efficiency and innovation in Prefectural forestry and New Production Systems, and to compare with the Scottish cluster's operational mechanisms. By identifying underlying factors which have contributed to the selection of each locality's organisational model, such an analysis could be valuable as the Japanese model of substantial leadership and direction from the government evolves.

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Article

Simulation Study of Size-structure Dynamics with Changing Spatial Pattern of Tree Sizes in a Lattice-planted Japanese Cedar (*Cryptomeria japonica* D. Don) Plantation

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ABSTRACT

In coniferous plantation forests, a detailed understanding of the temporal and spatial dynamics of tree sizes is important for designing silvicultural treatments as well as controlling stand productivity. However, previous investigations have yielded unclear results regarding size dynamics, especially those of coefficient of variation (*CV*) in diameter at breast height (*DBH*) soon after canopy closure. We evaluated how differences in the spatial pattern of tree sizes at canopy closure affected the subsequent size structure dynamics of a monoclonal Japanese cedar (*Cryptomeria japonica*) plantation using an individual competition-based model. In the model, local competition among adjacent trees determined tree growth. The model was parameterized using empirical equations derived from a 12-year-old monoclonal *C. japonica* plantation. We varied the spatial pattern of tree sizes while the size frequency distribution at canopy closure was fixed. Three types of initial spatial patterns were compared, where large and small trees were aggregated (large adjacent to small), random or segregated. The variation in spatial pattern of tree sizes at canopy closure resulted in differences in the dynamics of *CV* of *DBH* among stands. Our results suggested that, even in plantation forests with the same size structure and lattice planting design, different spatial patterns of tree sizes might lead to different *CV* dynamics in *DBH*. The variable size dynamics observed in previous studies may have been caused by variation in spatial pattern or short observation period. Interactions between spatial pattern of tree sizes and other factors affecting *CV* dynamics must be verified through long-term studies in actual plantation forests.

Keywords: canopy closure, coefficient of variation, competition model, plantation forests, spatial pattern of tree sizes

INTRODUCTION

Size structure dynamics in even-aged plant monocultures frequently shows nonmonotonic changes (Mohler *et al.*, 1978; Knox *et al.*, 1989). Analyses of interannual data sets from young plantations of Japanese cedar (*Cryptomeria japonica* D. Don) indicate that the coefficient of variation (*CV*) of diameter at breast height (*DBH*) may increase (Yoshida, 1929; Yoshida and Aikawa, 1940; Negishi *et al.*, 1988), decrease (Tanaka, 1992; Kunisaki, 1998), or remain unchanged (Yoshida, 1991) after the onset of canopy closure. This suggests that there is no clear age-related trend in the *CV* dynamics of plantations (Kunisaki, 2001). For example, Negishi *et al.* (1988) reported that the *CV* of *DBH* increased with stand development in three young *C. japonica* stands from age 14 to age 20 irrespective of

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stand density. On the other hand, TANAKA (1992) predicted that the *CV* in young stands before canopy closure would decrease with stand development. KUNISAKI (1998) indicates that, in many cases, *CV* decreased in young stands of five species including *C. japonica*. It is unclear why such variation in *CV* dynamics occurs among plantation forests. A detailed understanding of the size dynamics of plantation forests would allow us to realize, through appropriate silvicultural treatments, the stand structure and productivity that we wish to accomplish.

The causal mechanisms behind size structure dynamics of plant populations have been explored using size-dependent growth models (e.g. WESTOBY, 1982; KOHYAMA, 1991, 1992, 1993, 1994; HARA, 1984, 1986, 1992) and individual based models (e.g. FORD and SORRENSEN, 1992; PACALA *et al.*, 1993; HARA and WYSZOMIRSKI, 1994; WEINER *et al.*, 2001). In size-dependent growth models, size structure dynamics are determined by diffusion equations, which may not adequately describe the complicated dynamics observed at the population level (e.g. PUKKALA, 1989; FORD and SORRENSEN, 1992; COURBAUD *et al.*, 2001; GOREAUD *et al.*, 2002; REYNOLDS and FORD, 2005). On the other hand, in individual based models, population-level dynamics are the result of local competition among neighboring individuals, which may be a better representation of variable size structure dynamics observed in actual plant populations.

In many individual based models, model dynamics emphasize competitive effects among neighborhoods (e.g. AGUILERA and LAUENROTH, 1993) and local competition is determined by the distance and size difference between adjacent individuals (BIGING and DOBBERTIN, 1992; SHI and ZHANG, 2003; REYNOLDS and FORD, 2005; INOUE *et al.*, 2008). For example, competitive effects lead to greater size inequality among individuals in random than regular spacing in even-aged stands (WEINER *et al.*, 2001). In plantation forests, where trees are often planted with regular spacing, variations in the spatial pattern of tree sizes (i.e., how large and small trees are distributed relative to each other) is expected to determine the size structure dynamics. For example, if the size difference between two adjacent trees is large, the dominant-suppressed relationship between them will be determined at the onset of competition. Conversely, if the size difference is small, dominance will be determined by the outcome of competition. In addition, various spatial patterns of tree sizes have been observed in plantation forests at the onset of canopy closure, where large and small trees may be dispersed (e.g. COOPER, 1961) or clumped (CANNELL *et al.*, 1984; GHENT and FRANSON, 1986; SEIWA and KIKUZAWA, 1987). This suggests that variation among stands in the spatial pattern of tree sizes at canopy closure may explain the variation in size structure dynamics of plantation forests.

In this paper, we used an empirical individual based model to evaluate how the spatial pattern of tree sizes at canopy closure affect the subsequent size structure dynamics in an even-aged, lattice-planted plantation. We present results from simulations using parameters derived from a 12-year-old monoclonal plantation of *C. japonica* (INOUE *et al.*, 2008). Based on the results of the model simulation, we discuss the relationships between the spatial pattern at canopy closure and the dynamics of *CV* of *DBH* soon after canopy closure, which had been unclear in previous empirical studies.

MATERIAL AND METHODS

Study Site and Data Preparation

Our study site was an even-aged monoclonal plantation of Japanese cedar located in the Forest Research and Instruction Station of Kumamoto Prefecture in southern Japan (32°50' N, 130°45' E, and 110m alt.). The plantation was established in 1986 using cuttings of *C. japonica* cv. Shakain. The stand density was 15,635 stems ha^{-1} with a spacing of 0.8×0.8m in a lattice design. We established a 20×20 tree study plot in the stand. The stand area was 0.256ha. For details of the study site see OHASHI *et al.* (1999) and INOUE *et al.* (2008).

The stand reached canopy closure at age 6 and no individuals died due to suppression during the first 12-years. When the stand age was 8 years, we selected 81 trees in the plot and measured the tree height (*H*) and diameter at breast height (*DBH*; 1.2 m above ground) of each tree (Table 1). These trees were not neighboring dead trees, did not include edge trees and their size frequency distribution of *DBH* was

Table 1 Stand structure of the monoclonal stand of *Cryptomeria japonica* in Kumamoto Prefecture, Japan. Values are mean ± s.d. The data for age 8 were used as starting values for the simulation model.

Stand age (yr.)	Tree height (cm) (n=81)	*DBH* (cm) (n=81)	Stem volume (cm^3) (n=20)
8	433.69 (±17.13)	3.77 (±0.32)	2973.90 (±444.76)
9	507.00 (±13.98)	4.09 (±0.33)	3907.34 (±537.33)
10	576.54 (±17.54)	4.32 (±0.35)	4874.93 (±647.85)
11	620.22 (±18.41)	4.52 (±0.36)	5815.29 (±762.59)
12	679.48 (±18.10)	4.71 (±0.38)	6805.83 (±902.00)

normal. The size attributes of the 81 trees were used as starting data in our simulation.

In February 1998, when the stand age was 12 years, INOUE *et al.* (2008) determined the growth history of *H* (cm), *DBH* (cm), basal area (*BA*, 1.2m above ground; cm^2), and stem volume (*V*; cm^3) of 20 sample trees using stem analysis (Table 1). The 20 sample trees were growing adjacent to each other in a rectangle of 4 × 5 trees and did not include edge trees. These data were used to construct an empirical model of *V* growth.

Competition-based Model of Stem Volume Growth

In the previous study, we showed the dominant factor affecting stem volume growth in this stand after canopy closure (from age 8 to 12) was neighborhood competition (INOUE *et al.*, 2008). Using a competition-based model of tree growth, we simulated size structure dynamics after canopy closure in our study stand. Our model included empirical equations for calculating annual stem volume growth (*dV*) based on individual competition and *DBH* from *V* and *H*. To quantify competition, we used a competition index (*CI*) based on distance-weighted size difference between adjacent trees (TOMÉ and BURKHART, 1989):

$$CI_i=\sum_{j=1}^{8}\{(BA_i-BA_j)/d_{ij}^{\ 2}\} \qquad (1)$$

where BA_i and BA_j are the *BA* (cm^2) of the focal tree *i* and adjacent tree *j*, respectively and d_{ij} is the distance (cm) between tree *i* and tree *j*. Eight trees surrounding each focal tree in the lattice planting design were used to calculate *CI* (INOUE *et al.*, 2008). Theoretically, the sum of *CI*s of all trees in an infinite stand is 0 because size difference among trees will cancel out. Hence, mean *CI* of an infinite stand is expected to be 0.

INOUE *et al.* (2008) derived a linear regression model describing the variation among trees in *dV* after canopy closure (15 individuals at age 8-11) using *CI* as the explanatory variable.

$$dV=922.16+49720\cdot CI \qquad (2)$$

(n=60, R^2 = 0.697, F = 116.7, Mean squared error (*MSE*) = 5420, p<0.001)

This relationship was used to calculate stem volume growth for year *t* (dV_t) of each tree in our model. During the simulation period, tree height growth (*dH*) was assumed to be constant. This assumption contradicts the "co-operative phenomenon", in which individual growth is negatively related to size (e.g., NAGASHIMA 1999), but the co-operative phenomenon has not been clearly shown to occur in trees. The assumption also contradicts size dependent growth, in which growth is positively related to size (e.g., SOUTH and MANSON 1991). INOUE *et al.* (2008) found that there were unclear trends in the *H-dH* relationship in the study stand, and *dH* was

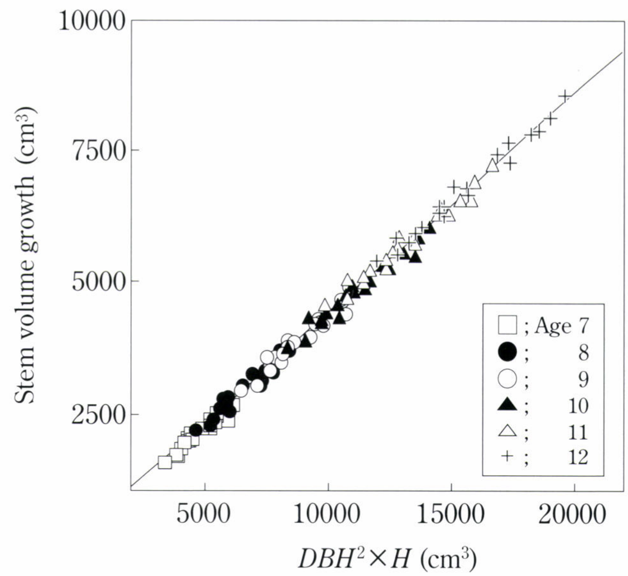

Fig. 1 Stem volume growth in relation to *DBH* and *H* from age 7 to 12 in a monoclonal *Cryptomeria japonica* plantation. The solid line represents the linear regression equation used in our simulation model.

constant from age 6 to 12 with little variation among individuals such that *dH* averaged 0.625 ± 0.097 m (mean ± s.d.). This is because our study stand was established using genetically uniform clonal cuttings and spatial distribution of soil water and nutirients was uniform (INOUE *et al.*, 2008). Based on these observations, *dH* of all individuals was fixed at 0.6 m per year in our model. *V* after canopy closure could be derived from *DBH* and *H* by the following empirical relationship (Fig. 1):

$$V = -45.36 + 0.4036\cdot DBH^2\cdot H \qquad (3)$$

(n=120, R^2=0.997, F = 19186.2, *MSE* = 17604, p<0.001)

This relationship was used to calculate *DBH* for year *t+1* (DBH_{t+1}) from V_t and H_t in our model. In our model, we calculated tree size for each year of stand growth after canopy closure using equations (1), (2), (3) and the fixed value of *dH* (0.6m).

Simulation Procedure

We simulated the growth dynamics of our study stand using the model of *V* growth described above. To evaluate the effects of spatial pattern of tree sizes on size structure dynamics, we varied the spatial pattern of tree sizes at canopy closure, the initial year of our simulation.

Our goal was to evaluate the effects of spatial pattern on size structure dynamics in a lattice design. First, we generated 300 eight-year-old stands consisting of 81 trees planted in a 9 × 9 lattice design. For each stand, the size attributes (DBH_8,

H_8 and V_8) of the 81 trees was set to the observed values of the 81 sample trees in the study stand at age 8. The size attributes of the 81 sample trees were spatially randomly assigned to each tree in the generated stand to vary the spatial pattern of tree sizes. Thus, the frequency distribution of tree sizes at age 8 was the same for all 300 stands and only the spatial pattern of tree sizes varied among 300 stands so that we could examine the unconfounded effects of spatial pattern on size structure.

To evaluate the difference in the spatial pattern of tree sizes among the 300 stands, we used the aggregation index (*AI*, m) proposed by CLARK and EVANS (1954) to assess the degree of aggregation among large and small trees. For example, the bivariate K-function (K_{12}, e.g. DIGGLE, 1983; ROWLINGSON and DIGGLE, 1993) can also be used to evaluate the spatial pattern of association between large and small trees. We chose *AI* over other statistics because we wanted a single, easily calculated statistic to compare the spatial pattern among our simulated stands.

To calculate *AI*, we categorized the 81 trees into three *DBH* size classes of equal number (large, medium and small), each comprising 27 trees. We then calculated the distances from the 27 large trees to its nearest small tree. Therefore, *AI* was defined as:

$$AI = \frac{\left(\sum_{i=1}^{n_i} \min_{j=1}^{n_j}\{dist_{ij}\}\right) \Big/ n_i}{\mathrm{sqrt}\left(A \Big/ (n_i+n_j)\right)} \qquad (4)$$

where n_i and n_j are the numbers of large and small trees, respectively and $dist_{ij}$ is the distance between large tree i and its nearest small tree *j*. *A* is the plot area. When *AI* is small, then the distances between large and small trees are small (i.e., aggregated pattern). Because 300 realizations might be insufficient for calculating the 95% confidence intervals for testing spatial randomness using *AI*, we generated 10,000 additional stands using the same procedures as for the 300 stands and calculated *AI* for each stand. The 95% confidence intervals for testing spatial randomness obtained from the frequency distribution of *AI* for the 10,000 stands was $1.031 < AI < 1.187$.

Based on the *AI* value, we grouped the 300 stands into aggregated (AG: $AI > 1.031$), random (RD: $1.031 < AI < 1.187$), and segregated (SE: $1.187 > AI$) spatial patterns of association between large and small trees, of which there were 7, 286 and 7 stands, respectively. In the AG stands, there were many clumps in which large trees were adjacent to small trees (Fig. 2). In the SE stands, there were many clumps consisting of either large or small trees. We randomly chose 7 of the 286 RD stands and together with the AG and SE stands used them as the initial stands in our simulation model. In our simulation model, the spatial pattern changed with each year of stand development as a result of tree growth through neighborhood competition.

We then calculated the *CI*s of each of the 81 trees in the 21 stands (7 stands each of AG, RD and SE) using equation (1). To exclude edge effects, the edges of simulated stand were assumed to be torus design. For each year of stand development, the dV_t of each tree was calculated from *CI* using equation (2). The standard error (e = 74.88) of the regression equation (2) was added to dV_t as random error, and dV_t was added to V_t to obtain V_{t+1}. H_{t+1} was calculated as H_t + 0.6m and DBH_{t+1} was calculated from V_t and H_t using equation (3). This procedure was repeated from age 8 to age 14 for each of the 21 stands.

Evaluation of the Simulation Results

To evaluate if tree size reflected competitive status, we calculated Spearman's rank-order correlation coefficient between BA_t and CI_t (r_{CI}). Increasing values of r_{CI} suggests increasing discrimination between dominant and suppressed trees and decreasing effects of competition. We compared the

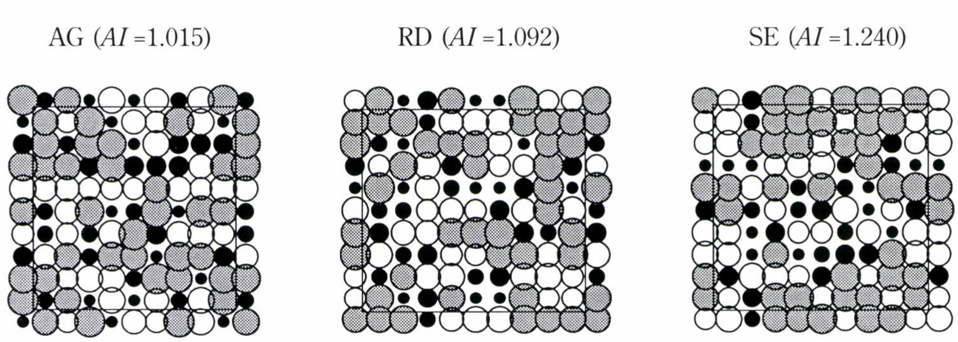

Fig. 2 Examples of the spatial pattern of tree sizes observed in our 300 generated stands of monoclonal *Cryptomeria japonica*: aggregated (AG), random (RD) and segregated (SE). The boundary line indicates edge trees. The 81 trees inside the boundary were used to simulate stand development. Circle diameter represents *DBH*. Shaded, open and filled circles indicate large, medium and small trees, respectively.

effects of the initial spatial pattern of tree sizes on size dynamics using mean, standard deviation (s.d.) and *CV* of *DBH* during stand development. We compared the simulation results with the mean, s.d. and *CV* of *DBH* for the study stand. All analyses and model simulations were carried out using STATISTICA 2000 (StatSoft Inc, Japan) and R (R Development Core Team, 2006).

RESULTS

The *AI* decreased with increasing stand age for all three initial spatial patterns indicating increasing aggregation (Fig. 3). The *AI* for the AG stands reached the lower confidence limit (1.031) four years after canopy closure. The *AI* for the RD and SE stands took longer to reach the lower confidence limit (half of the stands reached the lower confidence limit after age 13 and 14, respectively). S.d. of *CI* at age 8 was larger for the AG stands than for the RD and SE stands. At age 14, the differences among spatial patterns were more marked. The r_{CI} for the AG stands was higher than for the RD or SE stands at age 8. The r_{CI} gradually increased with increasing stand age for all three spatial patterns. At the end of the simulation, the r_{CI} for the AG stands was higher than for the SE stands.

Mean *DBH* was similar among the three spatial patterns throughout the simulation (Fig. 4). However, at the end of the simulation, the s.d. of *DBH* was higher for the AG stands than for the RD and SE stands. *CV* is obtained by dividing the s.d. by the mean, therefore, change of *CV* corresponds to dynamics in the mean and s.d. of *DBH*. *CV* of *DBH* for the AG stands decreased slightly to age 10, and then increased toward the end of the simulation. On the other hand, the *CV* of *DBH* for the SE stands decreased more markedly to age 10, and then gradually increased. At the end of the simulation, CV of DBH for the AG stands was greater than the starting value, whereas it was less for the SE stands.

For the AG stands the s.d. of *DBH* increased with stand development while, *AI* remained relatively constant (Fig. 5). For the SE stands, s.d. of *DBH* did not show notable increase until *AI* values were less than 1.05. Similar trends were observed for the RD stands.

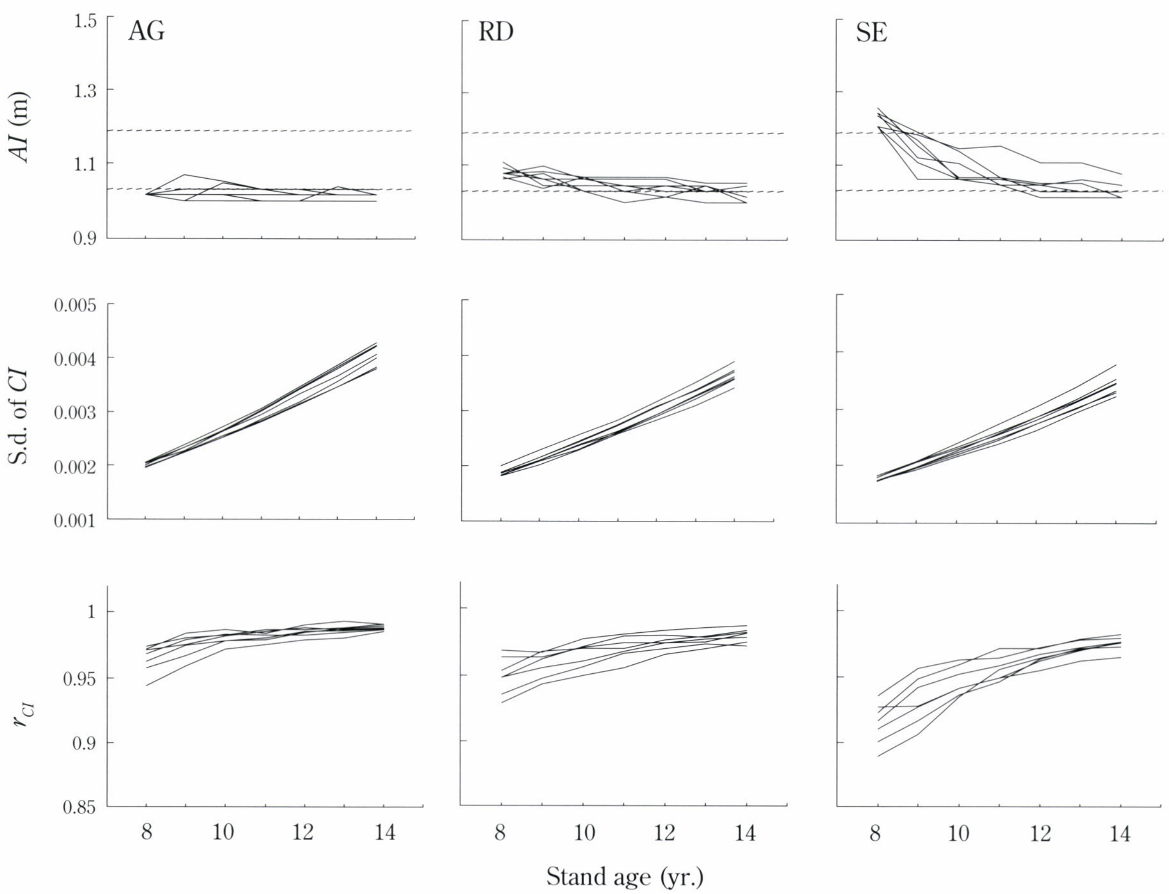

Fig. 3 Changes in the aggregation index (*AI*), standard deviation (s.d.) of competition index (*CI*), and Spearman's rank-order correlation coefficient between basal area (*BA*) and *CI* (r_{CI}) during simulated stand development of a monoclonal *Cryptomeria japonica* stand. Horizontal dotted lines represent 95% confidence intervals for *AI*.

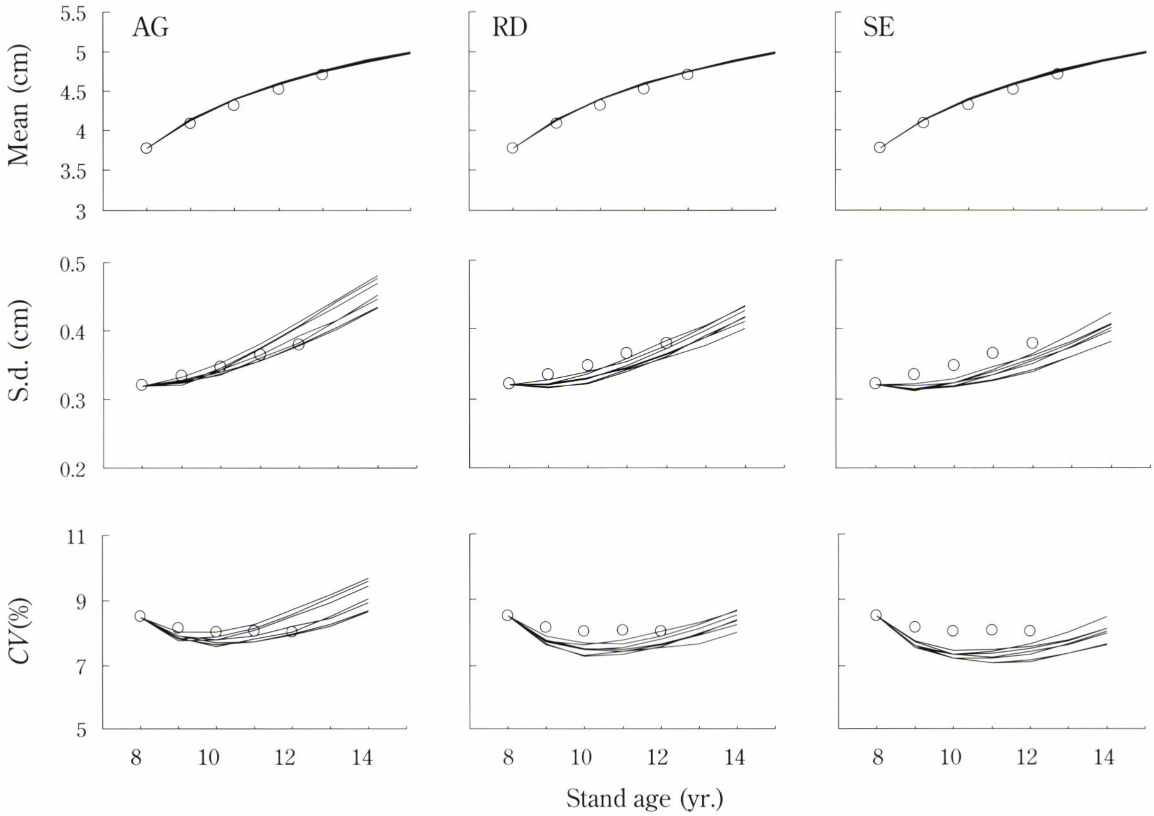

Fig. 4 Changes in mean diameter at breast height (*DBH*), standard deviation (s.d.) of *DBH*, and coefficient of variation (*CV*) of *DBH* during simulated stand development of a monoclonal *Cryptomeria japonica* stand. Open symbols represent observed data of the study stand.

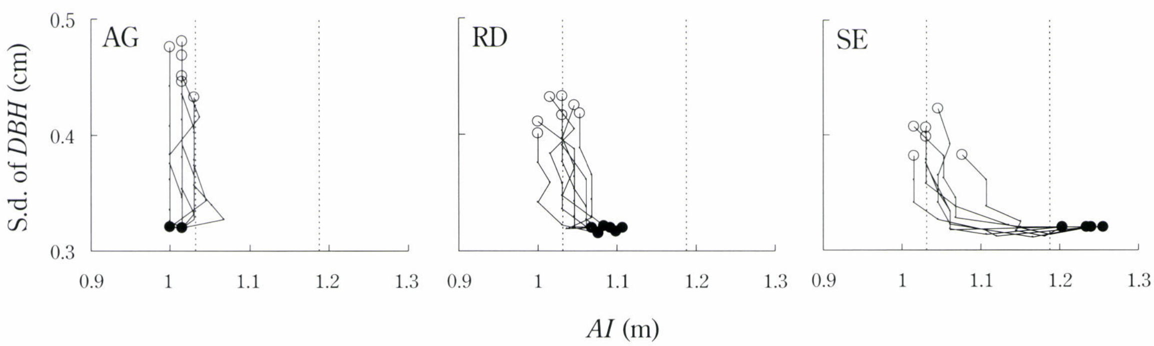

Fig. 5 Trajectories of the relationship between the aggregation index (*AI*) and standard deviation (s.d.) of *DBH* during simulated stand development of a monoclonal *Cryptomeria japonica* stand. Vertical dotted lines represent 95% confidence intervals for *AI*. Filled and open circles indicate starting and ending values of the simulation for each stand, respectively.

DISCUSSION

Although our model was parameterized for the study stand (Inoue *et al.*, 2008), the simulation results offer some general insights regarding the changing patterns of spatial structure of tree sizes in plantation forests. In mature plantation forests, large trees are often found adjacent to small trees (e.g. Cannell *et al.*, 1984; Seiwa and Kikuzawa, 1987; Ford and Sorrensen, 1992; Suzuki *et al.*, 2008). In our simulations, the aggregated spatial pattern, in which large trees were adjacent to small trees, was maintained from canopy closure to maturity in the AG stands (Fig. 3). In the RD and SE stands, the spatial pattern shifted toward aggregation with increasing stand age. Thus, the spatial dynamics observed in our simulation seemed to correspond to the actual spatial dynamics of forest plantations, giving support to the validity of our model structure.

In our model simulations, *CI* determined stem volume growth, which was used to calculate *DBH*. Because mean *CI* is 0 in all the simulated stands, the difference in spatial pattern among stands is obviously not reflected in the difference in mean *DBH*. However, the difference in the spatial pattern among stands clearly led to differences in the magnitude of variation in *DBH* (Fig. 4). This was an expected result based on the model structure, which can be explained as follows. In the AG stands, local dominant-suppressed relationships were already determined at canopy closure as indicated by high initial r_{CI} values. If the r_{CI} value is high, *CI* becomes synonymous with the target individual size. Therefore, even in an individual based competition model such as ours, individual growth appears as if it is determined by individual size (i.e., strong size dependent growth caused by high r_{CI} value; Fig. 3). Because size dependent growth results in increasing the size differences among individuals (KUNISAKI, 2001), the high degree of size dependency of growth at early simulation stages had caused high s.d. of *DBH* in the AG stands. On the other hand, in the SE stands, the local dominant-suppressed relationships were not clearly determined at canopy closure and subtle differences in tree-size between neighboring trees gradually increased through competition. In addition, the s.d. of *DBH* in the AG stands was larger than that of the RD or SE stands at the end of the simulation. Thus, our results suggested that the initial spatial pattern of tree sizes, i.e., the degree of "nested aggregation" in which large and small trees are adjacent to each other, increased the rate of change in the s.d. of *DBH*.

Our results also suggested that for stands whose initial spatial pattern of tree sizes is not "nested aggregation", the spatial pattern shifts toward "nested aggregation" with stand development. The age-related pattern of change in the relationship between s.d. of *DBH* and *AI* (Fig. 5) indicated that, for the RD and SE stands, the size difference among trees drastically increased after the spatial pattern reached a threshold level of aggregation. This indicated that the temporal dynamics of spatial pattern were linked to the increasing dynamics of s.d. of *DBH* on our model simulation.

An unexpected result of our study is that the variation in spatial pattern of tree sizes at canopy closure resulted in differences in *CV* dynamics among stands. For example during the first four years, *CV* in the AG stands remained almost constant, whereas *CV* in the RD stands and SE stands decreased (Fig. 4). In addition, comparing the initial *CV* value with that of the end of simulation within the same spatial pattern, *CV* in AG stands was larger, *CV* in RD stands was constant, and *CV* in SE stands was smaller (Fig. 4). Our results also showed that, *CV* in AG stands remained almost constant during the first four years and increased near the end of the simulation. These simulation results provide two insights that may explain the variation in *CV* dynamics just after canopy closure; the effects of spatial structure and observation period. The complicated dynamics of *CV* observed in previous studies of plantation forests might be the result of variation in spatial pattern of tree sizes among stands or ephemeral dynamics due to short observation periods (KUNISAKI 2001).

Data accumulated from previous studies suggest that size dynamics in plantation forests after canopy closure are affected by: 1) mean growth increment of the population (the intercept in Eq. 2); 2) the intensity of competition affecting variation in individual growth (the slope in Eq. 2); 3) the size structure of the population. In our simulation, variables other than the spatial pattern of tree sizes were fixed. Nevertheless, the model produced variable dynamics of *CV* in *DBH*, which has not been shown before. Our simulations suggested that the spatial pattern of tree sizes may be linked to the dynamics of *CV* of *DBH* in plantation forests, indicating that individual based models could be used to partition effects of the various factors associated with the unstable and complicated dynamics of size structure in plantation forests. To elucidate the factors that affect *CV* dynamics, we must develop models that evaluate the effects of variables associated with the above four factors, which influence size dynamics in plantation forests.

Few studies have made an attempt to explain the unclear dynamics of *CV* of *DBH* at the onset of canopy closure. We indicated the possibility that differences among stands in the spatial pattern of tree sizes affect *CV* dynamics, although such differences are one of many factors affecting size dynamics. Moreover, our simulation was based on parameters obtained from a high-density stand (15,635 stems/ha). To understand the dynamics of *CV* of *DBH* in more detail, the interactions among the various factors influencing size dynamics must be verified through observation in actual plantations of various densities. A detailed understanding of the temporal and spatial dynamics of tree sizes, would be useful for designing spatially explicit silvicultural treatments to achieve the desirable stand structure.

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Article

Development and Application of an Algorithm to Calculate Cross-cutting Patterns to Maximize Stumpage Price based on Timber Market and Stand Conditions: A Case Study of Sugi Plantations in Gunma Prefecture, Japan

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ABSTRACT

We developed a cross-cutting pattern algorithm to maximize the stumpage price of each diameter class of timber, depending on market prices, and applied it to Sugi (*Cryptomeria japonica*) plantations in Gunma Prefecture, Japan. We used a relative-taper curve and a relative height-diameter curve to estimate taper by diameter at breast height class. Using this algorithm, we estimated the optimum cross-cutting pattern method based on Sugi log prices at different points in time. The optimum cross-cutting pattern allows the stumpage price to rise more dramatically than by the fluctuation of log prices alone. During 6 months, which is a relatively short period of time when considering market conditions, an obvious difference in optimum cross-cutting pattern was confirmed; in some cases, a focus on 3.65-m logs was beneficial, whereas in other cases, 4-m logs produced greater benefits. The difference accords with the prospective cross-cutting pattern considered profitable by the Gunma Forest Association. This result indicates that the algorithm can estimate optimum cross-cutting patterns according to changes in the timber market without contradicting empirical rules.

Keywords: cross-cutting pattern, stumpage price, timber market

INTRODUCTION

With declining prices of timber produced from plantation forests in Japan, the importance of unmanaged forests is increasing. More than half of the area of plantation forests in Japan has not been thinned for 10 years (Hiroshima and Nakajima, 2006; Matsumoto *et al*, 2007; Nakajima *et al.*, 2006a,b), and an increase in mature Sugi and Hinoki stands is evident. Approximately half of all Japanese plantation forests are more than 40 years old and could be thinned to harvest timber (Forestry Agency, 2005).

For this reason, it is important to expand the harvested area not only by clear cutting, but also by commercial thinning, to develop plantation stands and implement effective use of forest resources. To expand the area of commercial thinning, it is necessary to decrease harvesting costs and increase harvesting income. Kanomata (2007) introduced a methodology for estimating harvesting efficiency by aggregating a harvest cost and income simulation model with the Local Yield Table Construction System (LYCS: Shiraishi, 1986; Matsumoto, 1997; Matsumoto and Nakajima, 2007; Nakajima and Shiraishi, 2007) and a Geographic Information System. This methodology requires accurate estimates of economic values of forest resources depending on the timber market, conversion of timber, and stand conditions. Nagumo *et al.* (1981) analyzed stumpage price in relation to stem cross-cutting in even-aged stands of Sugi (*Cryptomeria japonica*). Yoshida compared the harvesting income from the use of an optimum cross-cutting pattern to the harvesting income from the use of a standard cross-cutting pattern (1989). Iehara (1992) estimated the stumpage price with conversion of large timber in actual clear-cut areas. However, few studies have analyzed optimum cross-cutting pattern and harvesting income over time, during which log prices fluctuate continually.

We developed a method to calculate a cross-cutting pattern that maximizes harvest income depending on log prices and stand data, and applied this method to the actual timber market in Gunma Prefecture, Japan. Single-stand parameters such as average tree height, diameter at breast

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height (DBH), and stand age were used. In this study, we calculated stumpage price as the sum of the log prices that exclude the harvesting cost.

METHODS

We constructed an algorithm to calculate the optimal cross-cutting pattern, which depends on the timber market and stand conditions, to maximize the stumpage price. We then applied the algorithm to the Sugi timber market in Japan.

Construction of the Algorithm

The framework of the algorithm is shown in Fig. 1. To

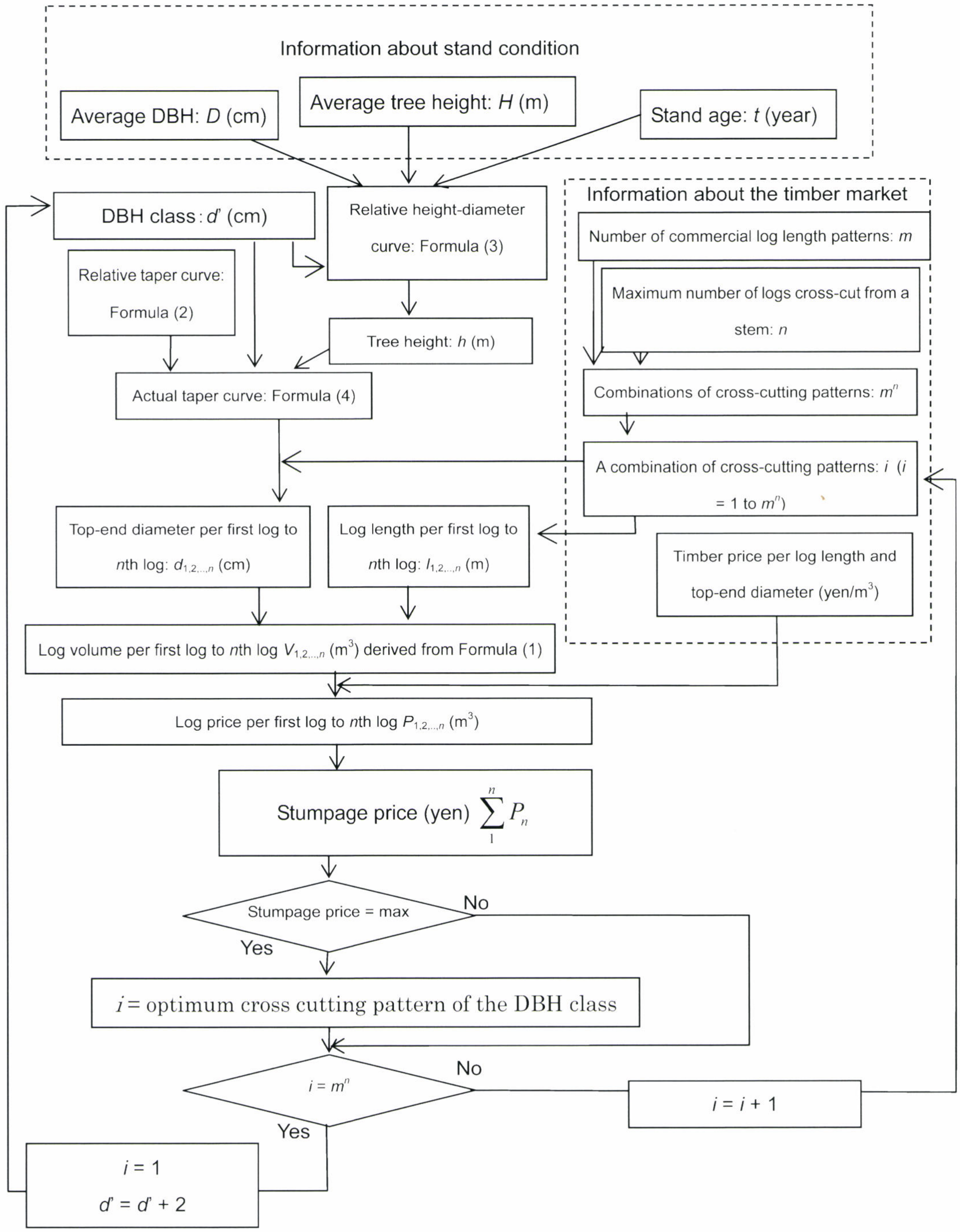

Fig. 1 Framework of the algorithm to estimate stumpage prices from stand conditions and timber market conditions.

include information about stand conditions, we considered the diameter distribution, average stand height, and stand age in the algorithm. For information about the timber market, we considered log prices (yen/m³), which depend on log length and top-end diameter, in the algorithm. Based on the stand condition data and curves for relative taper and relative height by diameter, this algorithm is able to estimate top-end diameter, which depends on log length. We estimated log volume with formula (1) and converted log volume to stumpage price using log prices.

$$V = d^2 l \tag{1}$$

where V is log volume (m³),
d is top-end diameter (cm),
and l is log length (m).

In this study, we calculated the timber volume according to the Japan Agricultural Standards. For the timber of which the top-end diameter was less than 14cm, we dropped the fractional part. For example, if the diameter was 11.9cm, it was converted into 11cm. When, on the other hand, the top-end diameter was more than 14cm, we rounded the number down to the nearest multiples of 2cm. For instance, if the diameter was 17.5cm, we regarded it as 16cm.

A top-end diameter was estimated based on a relative taper-curve, DBH class, and tree height. We applied a relative taper-curve obtained from the University Forest in Chiba by NAGUMO and TANAKA (1981):

$$y = \alpha\chi + \beta\chi^2 + \gamma\chi^3 \tag{2}$$

where y is the relative stem radius (0-0.5),
χ is the relative distance from the top of the tree (0-1.0), and
α, β, and γ are fitted parameters.

The tree height of each DBH class could be estimated by the relative height-diameter curve obtained by SHIRAISHI (1981).

$$h = H\left(\frac{d'}{D}\right)^{0.5594-0.00178t} \tag{3}$$

where h is tree height (m),
H is average tree height of the stand (m),
d' is DBH class (cm),
D is average DBH of the stand (cm), and
t is stand age (year).

The parameters in formulas (2) and (3) were not developed in Gunma Prefecture, but were relativized for application to other areas. We assumed that these parameters could be used to estimate the tree height distribution and taper of *Cryptomeria japonica* plantation forests in Gunma Prefecture.

We can calculate the top-end diameter at an arbitrary height with formula (4), which is the actual taper-curve based on the relative taper-curve in formula (2):

$$Y = \frac{d'\left(\frac{\alpha X}{h} + \frac{\beta X^2}{h^2} + \frac{\gamma X^3}{h^3}\right)}{\alpha\left(1-\frac{1.2}{h}\right) + \beta\left(1-\frac{1.2}{h}\right)^2 + \gamma\left(1-\frac{1.2}{h}\right)^3} \tag{4}$$

where Y is the stem radius (cm),
X is distance from the top of the tree (m),
d' is the DBH class (cm),
and 1.2 is breast height (m).

This procedure is applied to all log length combinations from the first log to the last log for each DBH class.

All length combinations were calculated as follows:

$$i = m^n \tag{5}$$

where i is all length combinations
m is the number of commercial log length patterns,
and n is the number of logs cross-cut from a stem.

Using formula (1), we can calculate the log volume per first log to nth log based on length combinations and the top-end diameter derived from formula (4). The log price can be calculated by multiplying the log volume to timber price per log length and top-end diameter. The stumpage price is the sum of these log prices. If the stumpage price is at a maximum, we identified the length combination as the optimum cross-cutting pattern for this DBH class. Finally, the algorithm performs this procedure for all length combinations.

Application of the Algorithm to Plantations

To analyze the optimum cross-cutting pattern and stumpage price at different points in time, we applied the algorithm to a Sugi plantation forest in Gunma Prefecture. We incorporated the log prices (yen/m³) on 13 April 2007 (first time point) and 23 October 2006 (second time point) as reported by the Gunma Forest Association (Table 1) into the algorithm to include information about the timber market. In Gunma Prefecture, the major log lengths are 3, 3.65, and 4 m; normally, a stem is cross-cut into four logs at most. We assumed that no more than four logs per stem were harvested.

We entered the stand condition data into the algorithm as follows. The cutting age was 55 years. The average tree height and DBH were 22.7m and 31.2cm, respectively. These data were introduced from a standard yield table of a middle site class in the North Kanto Abukuma area (FORESTRY AGENCY, 1955), which includes Gunma Prefecture. We assumed that the diameter distribution of harvested timber ranged from 26 to 50cm. Finally, we compared the stumpage price and optimum cross-cutting pattern for each DBH class at the two time points. To estimate the effect of maximizing the stumpage price by using the optimum cross-cutting pattern, we calculated the stumpage prices of stems cross-cut to 3 or 3.65m log lengths. The stumpage prices calculated using these simple cross-cutting patterns were compared to those

Table 1 Log prices of the timber market in Gunma Prefecture.

Log prices at the first price point (on 13 April 2007)

Log length(m)	Top-end diameter class(cm)	Price (yen/m³)
3.00	16 ~ 18	11,200
	20 ~ 24	11,500
3.65	20 ~ 30	11,500
	30 ~	11,300
4.00	10 ~ 13	9,700
	14 ~ 18	12,000
	20 ~ 28	12,100
	30 ~	12,000

Log prices at the second price point (on 23 October 2006)

Log length(m)	Top-end diameter class(cm)	Price (yen/m³)
3.00	16 ~ 18	14,800
	20 ~ 24	15,100
3.65	20 ~ 30	14,900
	30 ~	14,000
4.00	10 ~ 13	11,000
	14 ~ 18	14,200
	20 ~ 28	14,100
	30 ~	13,300

calculated using the optimum cross-cutting pattern.

RESULTS AND DISCUSSION

The optimum cross-cutting patterns of almost DBH classes at the first price point were constructed using a 4-m log length (Table 2). In contrast, at the second price point, 3-m or 3.65-m logs had higher values than that of the 4-m logs (Table 3). Therefore, the optimum cross-cutting pattern was constructed mainly on 3-m or 3.65-m logs at the second price point. In some DBH classes, 4-m logs were included for the optimum cross-cutting pattern. One of the reasons for this inclusion is that 4-m logs with a top-end diameter >10 cm are marketable (Table 1). In contrast, 3-m logs and 3.65-m logs require a top-end diameter >16cm and >20cm, respectively, to be marketable. Furthermore, because the volume of a 4-m log is greater than that of a 3- or 3.65-m log, a 4-m log can have a higher timber volume or stumpage price, even when log prices (yen/m³) are lower than those of 3- or 3.65-m logs. For this reason, part of the diameter distribution in the optimum cross-cutting pattern includes 4-m logs, even though the log price of a 3- or 3.65-m log is higher than that of a 4-m log.

As mentioned above, the algorithm allows the estimation of the optimum cross-cutting pattern, which depends on the timber market. The Gunma Forest Association, through the timber market, offers some beneficial cross-cutting patterns. According to these methods, it is recommended that 3-m logs be mainly converted at the second point, whereas 4-m logs dominate at the first point. This recommendation is consistent with our findings of the optimum cross-cutting pattern (Tables 2 and 3). The algorithm developed here can estimate the optimum cross-cutting pattern based on the timber market without contradicting existing forestry rules.

Fig. 2 shows the stumpage price of each diameter class based on log prices at the first and second points. In general, larger diameter classes have higher stumpage prices because large trees can be cut into logs with a large top-end diameter, resulting in a higher price and a larger volume. At the second

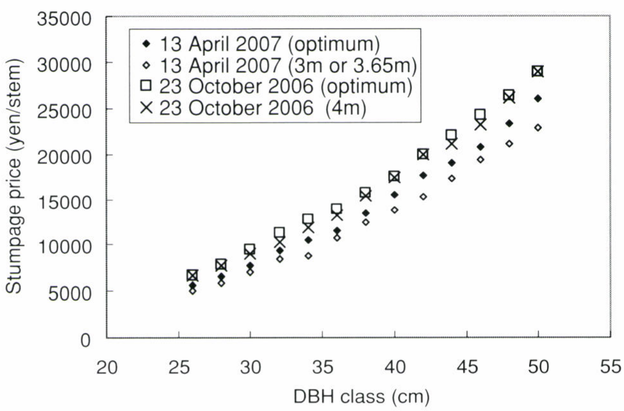

Fig. 2 Stumpage price based on two timber price points by diameter at breast height (DBH) class.

point, the difference between the optimum stumpage price and stumpage price with 4-m log length of each diameter class ranged from 0 to 9%. The average difference between the optimum stumpage price and the stumpage price with a 4 m log length in each diameter class was 3% on average. In this case, the optimum cross-cutting pattern can increase the stumpage price per tree (Fig. 2). However, at the first point, the difference between the optimum stumpage price and a stumpage price with 3- or 3.65-m logs for each diameter class ranged from 7 to 21%. The average difference between the optimum stumpage price and the stumpage price with a 3- or 3.65-m log length for each diameter class was 12% on average. In this case, the optimum cross-cutting pattern increased the stumpage price per tree by approximately 12% (Fig. 2). The change in cross-cutting pattern compared to, for example, the construction of forest roads, can be implemented with less labor and effort. By alternating conversion methods, improving the stumpage price by optimizing the cross-cutting pattern can be an effective way to increase timber profits without great risk.

Fig. 2 shows that the stumpage price at the second point

Table 2 Optimum cross-cutting pattern depending on the timber market at the first price point.

DBH class (cm)		Cross-cutting patterns			
	Length (m)	4.00	4.00	4.00	4.00
26	Diameter (cm)	22	0.13	0.1	11
	Volume (m³)	0.19	18	16	0.05
	Length (m)	4.00	4.00	4.00	4.00
28	Diameter (cm)	24	20	16	12
	Volume (m³)	0.23	0.16	0.10	0.06
	Length (m)	3.65	4.00	4.00	4.00
30	Diameter (cm)	26	22	18	14
	Volume (m³)	0.25	0.19	0.13	0.08
	Length (m)	3.65	4.00	4.00	4.00
32	Diameter (cm)	28	24	20	16
	Volume (m³)	0.29	0.23	0.16	0.10
	Length (m)	3.65	4.00	4.00	4.00
34	Diameter (cm)	30	24	22	18
	Volume (m³)	0.33	0.23	0.19	0.13
	Length (m)	4.00	4.00	4.00	4.00
36	Diameter (cm)	30	26	22	18
	Volume (m³)	0.36	0.27	0.19	0.13
	Length (m)	4.00	4.00	4.00	4.00
38	Diameter (cm)	32	28	24	20
	Volume (m³)	0.41	0.31	0.23	0.16
	Length (m)	4.00	4.00	4.00	4.00
40	Diameter (cm)	34	30	26	22
	Volume (m³)	0.46	0.36	0.27	0.19
	Length (m)	4.00	4.00	4.00	4.00
42	Diameter (cm)	36	32	28	24
	Volume (m³)	0.52	0.41	0.31	0.23
	Length (m)	3.65	4.00	4.00	4.00
44	Diameter (cm)	38	34	30	26
	Volume (m³)	0.53	0.46	0.36	0.27
	Length (m)	4.00	4.00	4.00	4.00
46	Diameter (cm)	40	34	30	26
	Volume (m³)	0.64	0.46	0.36	0.27
	Length (m)	4.00	4.00	4.00	4.00
48	Diameter (cm)	42	36	32	28
	Volume (m³)	0.71	0.52	0.41	0.31
	Length (m)	4.00	4.00	4.00	4.00
50	Diameter (cm)	44	38	34	30
	Volume (m³)	0.77	0.58	0.46	0.36

Table 3 Optimum cross-cutting pattern depending on the timber market at the second price point.

DBH class (cm)		Cross-cutting patterns			
	Length (m)	3.00	3.00	3.00	3.00
26	Diameter (cm)	22	18	18	16
	Volume (m³)	0.15	0.1	0.1	0.08
	Length (m)	3.00	4.00	4.00	4.00
28	Diameter (cm)	24	20	18	14
	Volume (m³)	0.17	0.16	0.13	0.08
	Length (m)	3.65	4.00	4.00	4.00
30	Diameter (cm)	26	22	18	14
	Volume (m³)	0.25	0.19	0.13	0.08
	Length (m)	3.65	4.00	4.00	4.00
32	Diameter (cm)	28	0.23	20	16
	Volume (m³)	0.29	24	0.16	0.10
	Length (m)	3.65	4.00	4.00	4.00
34	Diameter (cm)	30	24	22	18
	Volume (m³)	0.33	0.23	0.19	0.13
	Length (m)	3.65	3.65	3.65	3.65
36	Diameter (cm)	30	26	24	20
	Volume (m³)	0.33	0.25	0.21	0.15
	Length (m)	3.65	3.65	3.65	3.65
38	Diameter (cm)	32	28	24	20
	Volume (m³)	0.37	0.29	0.21	0.15
	Length (m)	3.65	3.65	3.65	3.65
40	Diameter (cm)	34	0.33	26	22
	Volume (m³)	0.42	30	0.25	0.18
	Length (m)	4.00	4.00	4.00	4.00
42	Diameter (cm)	36	32	28	24
	Volume (m³)	0.52	0.41	0.31	0.23
	Length (m)	4.00	3.65	3.65	3.65
44	Diameter (cm)	38	34	30	26
	Volume (m³)	0.58	0.42	0.33	0.25
	Length (m)	3.65	3.65	3.65	3.65
46	Diameter (cm)	40	34	32	26
	Volume (m³)	0.58	0.42	0.37	0.25
	Length (m)	3.65	3.65	3.65	3.65
48	Diameter (cm)	42	36	32	28
	Volume (m³)	0.64	0.47	0.37	0.29
	Length (m)	4.00	4.00	4.00	4.00
50	Diameter (cm)	44	38	34	30
	Volume (m³)	0.77	0.58	0.46	0.36

increased more than the stumpage price at the first point. The reason for this is that log prices were greater at the second point. Different cross-cutting patterns and stumpage prices, which vary depending on timber market conditions, were estimated using the algorithm. In Fig. 2, the ratio of the stumpage price with optimum cross-cutting pattern at the first point to that at the second point was 16% on average. Clearly, the fluctuation in log prices had a greater impact on the stumpage price than did the selection of optimum cross-cutting pattern. In contrast, the ratio of stumpage price to the optimum cross-cutting pattern of log prices at the first point to that at the second point was 11 to 22%. In other words, there were some cases in which the flucuation of log prices had less impact on the stumpage price than the difference in the cross-cutting pattern, depending on the diameter distributions. For instance, in Fig. 2, the ratio of the stumpage price of 42 cm diameter logs under the optimum cross-cutting pattern between the first and second points was 13%. In contrast, the ratio of the stumpage price of 34 cm diameter logs, for which the optimum cross-cutting pattern was used for the first log prices to that of 3- and 3.65-m logs, was 16%. As described, depending on the diameter distribution, the stumpage price changed according to the log price. Although the stumpage price is determined by log prices, an optimized cross-cutting pattern may allow the stumpage price to rise more dramatically than the ratio by the fluctuation of log prices. Additionally, the algorithm developed here works by inputting the essential data of the objective stands, including the average tree height, diameter distribution, and stand age. It may be possible to estimate the stumpage price of timber harvested from actual stands by including ground survey data in the algorithm.

In this research, as mentioned above, we input data on average stand conditions from a yield table. However, it is possible to input stand conditions such as average tree height or tree age. It is also possible to estimate the stumpage price determined by various stand conditions, timber markets, and cross-cutting patterns. Hence, these options are important in accurately estimating the stumpage price of harvested timber.

Stand conditions such as average tree height and diameter distribution could be predicted by LYCS. The incorporation of the algorithm into LYCS also makes it possible to estimate future harvests, as well as the current harvest. The relative stem curve estimated from the Tokyo University Forest in Chiba should not be used in regions far from the Kanto area or for tree species other than Sugi; however, INOUE (2001) developed a method to estimate relative stem curves from tree height, DBH, and volume. Applying Inoue's methodology to tree height, DBH, and volume estimated by LYCS, the algorithm could be applied to other districts or tree species for which the relative taper-curve estimated for University Forest in Chiba is unsuitable.

KANOMATA (2007) proposed the introduction of a simulation system to predict harvesting income using LYCS. This algorithm helps LYCS to estimate harvest profits with greater accuracy. The next challenge is to estimate the stumpage price, which depends on the various stand density control plans, by introducing the algorithm into LYCS. We named this algorithm "Wood Max."

CONCLUSION

We developed a cross-cutting pattern algorithm that maximizes the stumpage price for each diameter class, depending on log length and top-end diameter, and applied it to the Sugi timber market in Gunma Prefecture. During a 6-month period, which is a relatively short period of time when considering market conditions, an obvious difference in optimum cross-cutting pattern was confirmed. In some cases, a cross-cutting pattern centered on 3.65-m logs was beneficial. In other cases, 4-m logs produced greater benefits. This was in accordance with the prospective cross-cutting pattern regime considered profitable by the Gunma Forest Association. Therefore, we demonstrated that the algorithm developed here can estimate the optimal cross-cutting pattern according to changes in timber market conditions, without contradicting empirical forest rules.

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Article

Predicting the Vertical Distribution of the Stem Cross-sectional Area Increment for an Even-aged Stand of Hinoki Cypress

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ABSTRACT

As a useful tool for planning stand density management, a model to predict the vertical distribution of the stem cross-sectional area increment for even-aged stands of Hinoki cypress was developed. The model consists of two sub-models: one for predicting the distribution from total height and three sunny crown dimensions, and one for estimating these sunny crown dimensions using stand density and total height increment. The model requires three independent variables (stand density, total height and its increment) and seven parameters. To demonstrate the validity, the model was applied to five long-term permanent sample stands of Hinoki cypress. The model gave good predictions in most stands and growth stages. The model improves upon some shortcomings of existing models, and produces more realistic distributions at a practical level of precision. The model has wide applicability because it can predict distributions using common parameter values among stands or growth stages. Furthermore, the model has two constructional advantages. First, it is rationally designed through a growth process. Second, the model provides a simple and robust framework. Therefore, it is possible to modify the model for a particular aim, and to use it as a basis for other growth models. In conclusion, the model is a useful tool for planning stand density management for even-aged stands of Hinoki cypress.

Keywords: stem cross-sectional area increment, vertical distribution, Hinoki cypress, prediction model, stand density management

INTRODUCTION

The geometrical distribution of annual rings in a stem (*i.e.*, width, uniformity, angle to the longitudinal axis, and consequent stem form at any time) is of prime importance for timber quality, including characteristics such as dimension, fineness of grain, stiffness, strength, dimensional stability, and wood density. Because the distribution can be artificially regulated by thinning, which modifies the growing space available to trees (Fujimori, 2001; Fujiwara, 2008), predicting distribution as a result of thinning provides useful information for stand density management. The position of the annual ring at a given height depends on the stem cross-sectional area (SA) in the last year and the stem cross-sectional area increment (ΔSA) in the current year. Therefore, the ability to predict the vertical distribution of the ΔSA along the stem allows the prediction of the geometrical distribution of the annual rings.

Several models designed to predict the geometrical distribution of annual rings explicitly focus on the vertical distribution of ΔSA. For example, Mitchell (1975) developed a yield prediction system for the distribution for second-growth Douglas fir (*Pseudotsuga menziesii* Franco). Deleuze and Houllier (1995; 2002) and Houllier *et al.* (1995) designed growth models to predict the inner ring structure of Norway spruce (*Picea abies* Karst.). In Japan, to our knowledge, growth models with these capabilities have been developed for only two coniferous species: Todo fir (*Abies sachalinensis* Mast.) (Inose, 1985) and Japanese cedar (*Cryptomeria japonica* D. Don) (Kajihara and Ugai, 1995).

Hinoki cypress (*Chamaecyparis obtusa* Endl.) is one of the most economically important conifers grown in plantations in Japan because of the high quality of its wood, which is used mainly as structural timber and flitches for overlaid laminated wood. Nevertheless, no models to predict the vertical distribution of ΔSA for Hinoki cypress have been developed. Waguchi and Ueda (2006a) proposed a model to estimate the vertical distribution of ΔSA for Hinoki cypress using four tree

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attributes: total height (H), sunny crown length (CL), stem volume increment (ΔSV), and ΔSA at the base of the sunny crown. Furthermore, WAGUCHI and UEDA (2008; 2009) found that ΔSV per unit sunny crown volume (CV) was stable among even-aged stands of Hinoki cypress, and that the ΔSA at the base of the sunny crown was proportional to the sunny crown volume increment (ΔCV), defined as the volume of the external shell of the sunny crown, including the current-year foliage. These results suggested that the vertical distribution of ΔSA in a Hinoki cypress tree could be estimated using three sunny crown dimensions: CL, CV, and ΔCV, when H is known.

Because these sunny crown dimensions are directly affected by competition with neighbor trees, information about competition among trees, including inter-tree distance, status in H, and crown occupation, is required to estimate the vertical distribution of ΔSA in an individual tree. However, such information is lacking for most stands (a situation that is unlikely to change in the near future) because collection is time-consuming and labor-intensive. Therefore, even if a model to predict the distribution using these dimensions were constructed for an individual tree, the model could not be immediately utilized.

At present it is uncommon in stand density management to regulate the geometrical distribution of annual rings of an individual tree in a given stand. Thus, it is clear that a model to predict the vertical distribution of ΔSA in an individual tree is much too detailed. In other words, the prediction of the distribution at stand level is enough for most forest managers. Within the stand, the distribution of trees of average size and form is helpful in assessing the stand level. Although the tree is hypothetical, periodic changes in size and form of the tree probably represent those of the actual trees in the stand. Therefore, the stand-level distribution, just like that of the actual tree in the stand, will be also affected by growing conditions in the stand. WAGUCHI (2009) presented stand-level distributions in five even-aged stands of Hinoki cypress. As expected, variation in form among the distributions was associated with intraspecific competition in the stands. This result clearly demonstrated that stand-level distribution is a useful indicator for evaluating the effect of growth conditions, and consequently, for stand density management.

Therefore, the aims of this study were to develop the first model that can predict the vertical distribution of ΔSA at the stand level for even-aged stands of Hinoki cypress, and to demonstrate its validity.

FRAMEWORK OF THE MODEL

The model consists of two sub-models: one for predicting the vertical distribution of ΔSA from H and three sunny crown dimensions, and one for estimating these sunny crown dimensions using total height increment (ΔH) and stand density. Thus, H, ΔH, and stand density are known variables in this model.

Predicting the Vertical Distribution of the Stem Cross-sectional Area Increment

When H of a Hinoki cypress tree is known, the vertical distribution of ΔSA can be described as the combination of two linear equations derived from three tree attributes (CL, ΔSV, and ΔSA at the base of the sunny crown), as follows:

$$\Delta SA(t, z) = \theta_1 z I_1 + (\theta_2 + \theta_3 z) I_2, \tag{1}$$

where $\Delta SA(t, z)$ is the ΔSA (m^2) between ages t-1 and t (year) at the distance z (m) from the apex, and θ_1, θ_2, and θ_3 are parameters defined as follows (respectively):

$$\theta_1 = \frac{\Delta SA(t, CL(t))}{CL(t)}, \tag{2}$$

$$\theta_2 = (\theta_1 - \theta_3) CL(t), \tag{3}$$

$$\theta_3 = \frac{2\Delta SV(t) - (2H(t) - CL(t))\,\Delta SA(t, CL(t))}{(H(t) - CL(t))^2}, \tag{4}$$

where $CL(t)$ and $H(t)$ are the CL (m) and H (m) at age t, $\Delta SV(t)$ is the ΔSV (m^3/year) between ages t-1 and t, and I_1 and I_2 are dummy variables defined as follows:

$$I_1 = \begin{cases} 1 & \text{if } 0 \le z \le CL(t) \\ 0 & \text{otherwise} \end{cases},$$

$$I_2 = \begin{cases} 1 & \text{if } CL(t) \le z \le H(t) \\ 0 & \text{otherwise} \end{cases}$$

(WAGUCHI and UEDA, 2006a). On the other hand, WAGUCHI and UEDA (2008) found that ΔSV per unit CV was stable among even-aged stands of Hinoki cypress. Thus, assuming that $\Delta SV(t)$ is proportional to CV gives:

$$\Delta SV(t) = \theta_4 CV(t), \tag{5}$$

where $CV(t)$ is the CV (m^3) at age t, and θ_4 is a parameter. Moreover, WAGUCHI and UEDA (2009) have shown that $\Delta SA(t, CL(t))$ is proportional to ΔCV for Hinoki cypress. This result leads to the following equation:

$$\Delta SA(t, CL(t)) = \theta_5 \Delta CV(t), \tag{6}$$

where $\Delta CV(t)$ is the ΔCV (m^3/year) between ages t-1 and t, and θ_5 is a parameter. Substituting eqs. (5) and (6) into eqs. (2) and (4) gives:

$$\theta_1 = \frac{\theta_5 \Delta CV(t)}{CL(t)} \tag{7}$$

and

$$\theta_3 = \frac{2\theta_4 CV(t) - \theta_5 (2H(t) - CL(t))\,\Delta CV(t)}{(H(t) - CL(t))^2}. \tag{8}$$

At this stage, the model requires H, CL, CV, and ΔCV as variables, and θ_4 and θ_5 as parameters to predict the vertical distribution of ΔSA.

Predicting Sunny Crown Dimensions

The sunny crown profile of a Hinoki cypress tree can be represented as a function of ΔH, as follows:

$$CR(t, z) = \theta_6 \Delta H(t)^{\theta_7} z^{\theta_8}, \tag{9}$$

where CR(t, z) is the sunny crown radius (m) at age t at distance z; $\Delta H(t)$ is the ΔH (m/year) between ages t-1 and t; and θ_6, θ_7, and θ_8 are parameters (WAGUCHI and UEDA, 2005b). Sunny crown extension is obviously limited by stand density as a consequence of inter-tree crown contacts. WAGUCHI and UEDA (2006b) represented the relationship between the sunny crown basal area and stand density of seven even-aged closed stands of Hinoki cypress as follows:

$$\frac{1}{\sum_{i=1}^{N} CA_i} = \frac{\theta_9}{N} + \theta_{10}, \tag{10}$$

where CA_i is the sunny crown basal area (m^2) of the i-th tree in a stand, N is the stand density (trees/ha), and θ_9 and θ_{10} are parameters. Thus the CR(t, CL(t)) of the hypothetical tree in a closed stand at age t can be formulated as follows:

$$CR(t, CL(t)) = [\pi(\theta_9 + \theta_{10} N(t))]^{-\frac{1}{2}} \tag{11}$$

where N(t) is the N at age t. From eqs. (9) and (11), CL(t) in the closed stand is consequently:

$$CL(t) = \left[\theta_6 \Delta H(t)^{\theta_7} \sqrt{\pi(\theta_9 + \theta_{10} N(t))}\right]^{-\frac{1}{\theta_8}}. \tag{12}$$

If N(t) decreases by self or artificial thinning, eq. (12) no longer applies. The thinning creates a situation where CL(t) is shorter than it should be, given a new N(t). To overcome this inconsistency, we assumed that the height to the base of the sunny crown remains constant until the stand canopy closes again, meaning that CL(t) increases with $\Delta H(t)$ as long as the stand remains open. Therefore, we improved eq. (12) as follows:

$$CL(t) = \min\begin{pmatrix} CL(t-1) + \Delta H(t), \\ \left[\theta_6 \Delta H(t)^{\theta_7} \sqrt{\pi(\theta_9 + \theta_{10} N(t))}\right]^{-\frac{1}{\theta_8}} \end{pmatrix}. \tag{13}$$

The CV(t) and ΔCV(t) are expressed as:

$$CV(t) = \pi \int_0^{CL(t)} CR(t, z)^2 dz \tag{14}$$

and

$$\begin{aligned} \Delta CV(t) &= CV(t) - CV(t-1) \\ &= \pi \int_0^{CL(t)} CR(t, z)^2 dz \\ &\quad - \pi \int_0^{CL(t) - \Delta H(t)} CR(t-1, z)^2 dz \end{aligned}, \tag{15}$$

respectively, indicating that each of the terms CL(t), CV(t), and ΔCV(t) can be predicted from ΔH(t) and N(t). Therefore, the model finally requires three independent variables (*i.e.*, H, ΔH, and N), and seven parameters (*i.e.*, θ_j: j = 4, …, 10) to predict the vertical distribution of ΔSA.

DATA FOR MODEL EVALUATION

To evaluate the model, data from five long-term permanent sample plots in even-aged pure stands of Hinoki cypress on the Kii Peninsula in central Japan were used: Takatoriyama-I (HOSODA *et al.*, 2001), Takatoriyama-II (HOSODA *et al.*, 2001), Koyasan-I (HOSODA, 1996), Koyasan-II (IEHARA and HASEGAWA, 1986; UENO and HASEGAWA, 1976), and Myogabuchi-yama (TANAKA *et al.*, 2003). In these plots, H and the diameter at breast height (DBH) of every living tree have been measured continuously in 5- to 10-year intervals for more than 40 years. Each plot has been thinned several times, and associated changes have been recorded.

Because stem form was not directly measured in these plots, the vertical distribution of ΔSA was estimated as follows. In even-aged Hinoki cypress stands, relative stem form is similar among trees, regardless of stem size (KAJIHARA, 1985). Thus, the average relative stem curve (KAJIHARA, 1973b) at each measurement was determined, assuming that every tree in the stand had the same relative stem form. WAGUCHI (2005) presented relative stem curves, which change with increasing H, for even-aged Hinoki cypress stands in Nara Prefecture on the Kii Peninsula. Here we applied these curves to the average relative stem curves in the five sample plots. The stem form at each measurement was estimated by substituting the published average H and DBH as sizes that represent the stand into the average relative stem curve. Stem forms just before and after thinning were estimated. The periodic vertical distribution of ΔSA was obtained as the difference between stem forms at the beginning and end of the successive measurements. The periodic distribution was converted to the periodic annual distribution by dividing the former by the number of years in the period.

MODEL APPLICATION

To demonstrate the validity of the model, the model was applied to the five sample plots. The vertical distribution of ΔSA was predicted for every year in each period for successive measurements, and then the periodic distribution was obtained by summing all of the annual distributions for the period. The periodic distribution was converted to the periodic annual distribution. The prediction procedure is explained below.

First, the sunny crown profile was estimated by substituting ΔH into eq. (9). The ΔH was estimated by using published average Hs at the beginning and end of the period, assuming that ΔH was constant throughout the period. Parameters θ_6, θ_7, and θ_8 were set to 0.445, -0.222, and 0.641 obtained from 112 sample trees in 6 stands of even-aged Hinoki cypress in Nara Prefecture (WAGUCHI, 2004; WAGUCHI and UEDA, 2005b). Second, CL was estimated by substituting ΔH, N, and the last CL into eq. (13). The N at the beginning of each period was used for the entire period, as its decrease was always sufficiently small. Parameters θ_9 and θ_{10} were set to 0.0407687 and 0.0000873 obtained from seven Hinoki cypress stands (WAGUCHI and UEDA, 2006b). At the beginning of a period with thinning, the CL just after thinning was used as the last CL, and estimated as follows. The CL just before thinning was estimated by using eq. (12) because the stand canopy was probably closed. The height of the base of the sunny crown just before thinning was computed as the difference between the published average H and the CL estimation. In even-aged closed stands, there are no correlations between H and height to the base of the crown (FUJIMORI, 1970; FUJIMORI *et al.*, 1984; TAKEUCHI, 2005). Thus, assuming that the height of the base of the sunny crown was constant among trees within a stand, indicating that the height of the base of the sunny crown remains stationary by thinning, the CL just after thinning was computed as the difference between the published average H just after thinning and the estimation of the height of the base of the sunny crown just before thinning. Third, CV and ΔCV were estimated by substituting the sunny crown profile, CL, and ΔH into eqs. (14) and (15). Finally, the vertical distribution of ΔSA was estimated by substituting H, CL, ΔSV, and ΔSA at the base of the sunny crown into eqs. (1) through (4). At the beginning of the period, the published average H was used, and the rest of the time, H estimated from ΔH was used. The ΔSV and ΔSA at the base of the sunny crown were estimated by substituting the CV and ΔCV into eqs. (5) and (6). Parameters θ_4 and θ_5 were set to 0.000699 and 0.000288 as obtained from the 112 sample trees (WAGUCHI and UEDA, 2008; 2009).

RESULTS AND DISCUSSION

Predicted vertical distributions of ΔSA approximately agreed with those obtained using average relative stem curves (Fig. 1). In general, the vertical distribution of ΔSA in a tree can be schematically represented by two straight lines, divided into three types as shown in Fig. 2. The observed distributions in the five sample stands were of all three types. Although several models that assume the distributions to be as diagrammed in Fig. 2 have been presented (*e.g.*, DELEUZE and HOULLIER, 1995; KAJIHARA and UGAI, 1995; MITCHELL, 1975), most of those models have adopted only type 2, leading to under- or overestimation of the lower portion of the ΔSA for type 1 or type 3, respectively. This systematic bias obviously hampers the prediction of the geometrical distribution of annual rings. Our model can predict all distribution types using eq. (1). In most periods, predictions matched well with vertical distributions obtained using average relative stem curves. Therefore, our model is superior to existing models.

To our knowledge, the only other model that can predict all types of distribution is that developed by INOSE (1983;

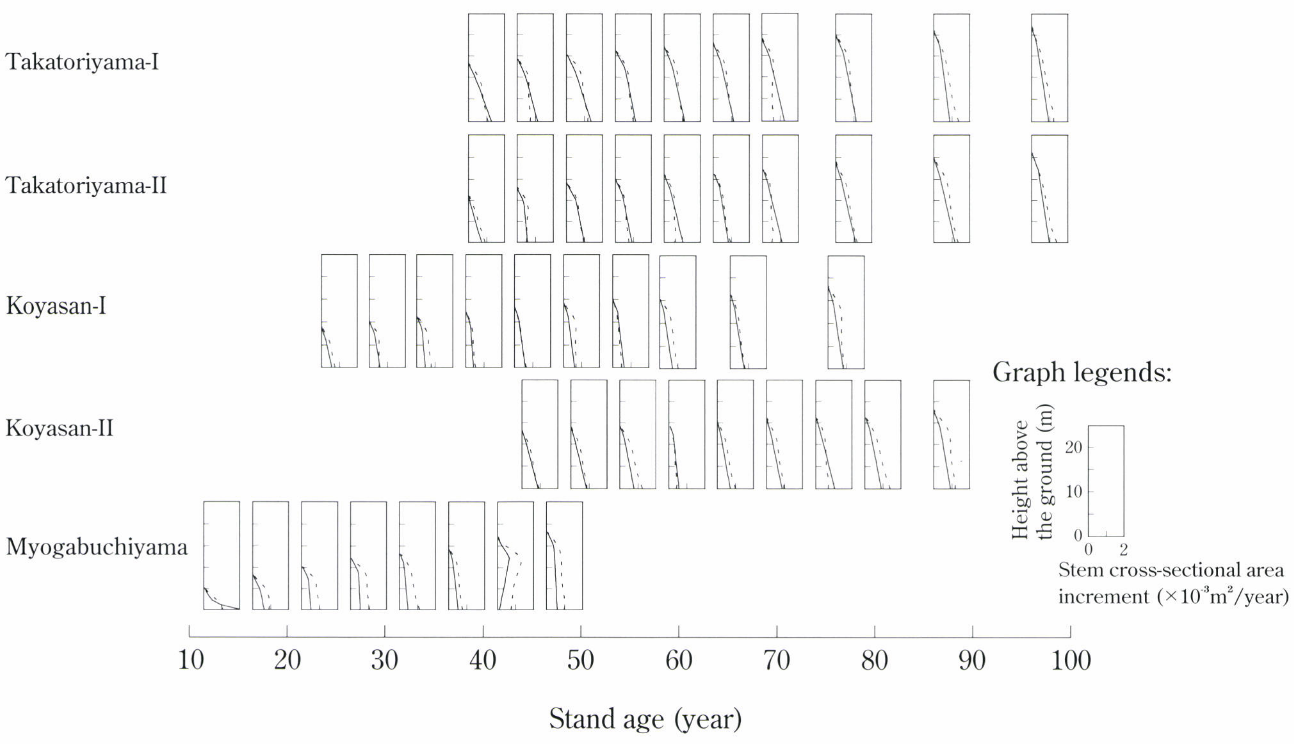

Fig. 1 Vertical distributions of stem cross-sectional area increment in five permanent sample plots
Solid and dashed lines represent vertical distributions predicted and obtained using average relative stem curve, respectively.

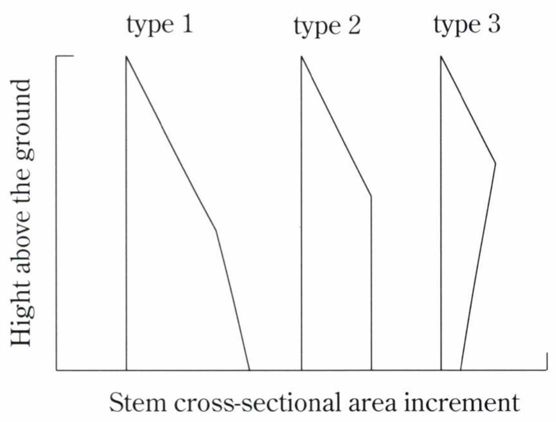

Fig. 2 Schematic diagram of vertical distribution of stem cross-sectional area increment

1985). When H is known, the diagrams shown in Fig. 2 can be determined using three attributes: ΔSV, the height at which two straight lines intersect, and ΔSA at any height. In INOSE's model, ΔSA at ground height was used as that at any height. However, the ΔSA often increases dramatically in the vicinity of the butt (ASSMANN, 1970; ONAKA, 1950; WAGUCHI and UEDA, 2006a). Thus, it is not reasonable to predict the vertical distribution of ΔSA using ΔSA at ground height as a variable in models that represent the distribution using two straight lines because the models clearly do not take into consideration the dramatic increase in the vicinity of the butt. To overcome this, the ΔSA at the sunny crown base was used as that at any height in our model.

Because the intersectional height of two straight lines is determined by CL, the good predictions in the present study indicate that the CL, and consequently the sunny crown profile that largely determines CL, were predicted appropriately. This finding further supports the suitability of the estimates of the CV and ΔCV, which are based on the CL and profile estimates. Although models that represent crown profiles as mathematical equations are useful, some can be problematic in two ways. One is the representation of the crown profile. Many of the models assume the crown profile to be a simple geometric solid such as a cone or a paraboloid (*e.g.*, HOULLIER *et al.*, 1995; KIYONO, 1990; SAIGUSA *et al.*, 1996; TAKESHITA, 1985; VALENTINE *et al.*, 1994; VALENTINE and MÄKELÄ, 2005; YOSHIDA, 1990; 1991). The sunny crown profile of Hinoki cypress, however, lies somewhere between a cone and a paraboloid (KAJIHARA, 1981; MIZUNAGA, 1998; WAGUCHI, 2004). Because the volume of the crown was assumed to be a paraboloid, it is 1.5 times that assumed to be a cone; even if these crowns have the same crown length and basal area (KAJIHARA, 1973a), the profile should be represented as realistically as possible. Our model can present a more realistic sunny crown profile because of the representation using the power equation in eq. (9). The other limitation of previous model is the estimation of the crown basal area in closed stands. Many models focus on the relationship between the crown basal area and stand density, and assume no space between crowns (INOSE, 1981; KIYONO, 1990; MATSUE, 2000; MIZUNAGA, 1998). However, the crowns of even-aged older stands are often separated by space, while those in younger stands are not (CHIBA, 2008; FUJIMORI, 2001). On the other hand, we reported that the sum of the sunny crown basal area per unit stand area increased with increasing stand density in even-aged closed stands of Japanese cedar and Hinoki cypress (WAGUCHI and UEDA, 2005a; 2006b). These studies showed that the crown occupation in a closed stand changes across growth stages or stand densities. Thus the assumption clearly leads to an overestimate of crown basal area in older or thinner stands. In our model, the regression equation obtained for seven Hinoki cypress stands (eq. (10)), which shows an actual relationship between the sum of the sunny crown basal area and stand density (WAGUCHI and UEDA, 2006b), is used to estimate the sunny crown basal area. Therefore, our model avoids overestimating the crown basal area in older and/or thinner stands.

In this study, common parameter values were used for every sample stand and prediction period. Moreover, these values were obtained from only six or seven stands that were independent of the sample stands. Nevertheless, our model returned good estimations. This result indicates the wide applicability of our model, which makes predictions using common parameter values among stands or growth stages. This is a valuable advantage for popularizing this model in the future. The development of growth models for old plantations is needed because of the extension of the rotation period. The good estimations reported herein for periods of 70 years or more, despite using parameter values obtained from 10- to 72-year-old stands (θ_4, θ_5, θ_6, θ_7, θ_8; WAGUCHI, 2004; WAGUCHI and UEDA, 2005b; 2008; 2009) imply that our model would be useful for managing old Hinoki cypress stands.

To evaluate the usefulness of the model, the prediction error in ΔSV and the stem basal area increment for each period was computed and plotted (Fig. 3). The predictions of both increments were underestimated, especially at younger and older growth stages. For overall prediction periods, the means $\pm$ standard deviation in error were -0.00158 $\pm$ 0.00227m^3 for ΔSV and -0.00007 $\pm$ 0.00027m^2 for the stem basal area increment. However, the root mean square error in the stem basal area increment was only 0.00027m^2. This underestimation of the area of a circle results in slight underestimations of annual ring width: 0.85mm for a circle of 10cm diameter, 0.43mm for a circle of 20cm diameter, and 0.29mm for a circle of 30cm diameter. Given only three variables and common parameter values among stands and prediction periods, this level of error would be acceptable. True parameter values in each prediction period are unknown because of lack of information about sunny crown dimensions in the five sample plots. Therefore, it is impossible to discuss causes of underestimations at younger and older growth

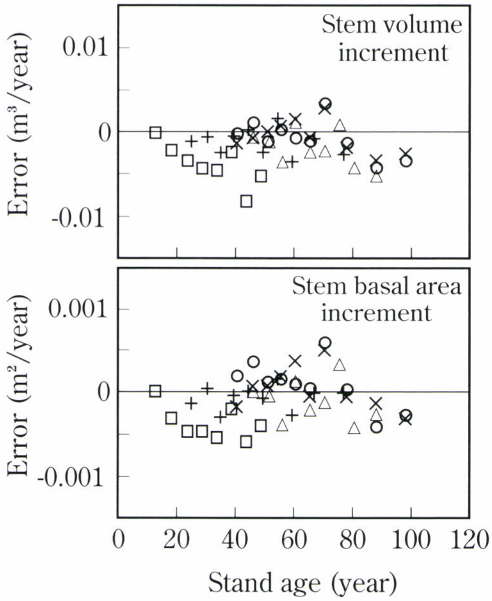

Fig. 3 Prediction errors in stem volume increment (upper) and stem basal area increment (lower)
Circles, crosses, pluses, triangles, and squares represent errors in Takatoriyama-I, Takatoriyama-II, Koyasan-I, Koyasan-II, and Myogabuchiyama, respectively.

stages in this study. Exploration into the detailed characteristics of the parameters will be valuable for more accurate predictions.

CONCLUSIONS

In this study, a model to predict the vertical distribution of the stem cross-sectional area increment for even-aged stands of Hinoki cypress was developed and applied to five long-term permanent sample plots. The model improves upon some shortcomings of existing models, and produces more realistic distributions at a practical level of precision. In addition, the model has wide applicability because it can predict distributions using common parameter values among stands or growth stages.

This model requires only three independent variables: stand density, total height, and its increment. Stand density is generally a known variable in managed stands. Total height at the beginning of a prediction period is easily measured with hypsometers, and its increment during the period can be predicted using site index curves (NISHIZAWA, 1959) or existing total height growth models with stand age and total height. This model is therefore accessible because of the availability of these variables. In other words, the model could predict the present distribution of stands, despite uncertain silvicultural management factors such as fewer but more intensive thinning operations or extended rotation periods, as long as these variables are available. This inference will be supported by good estimations obtained using common parameter values among stands and prediction periods.

The model has two constructional advantages. First, it is rationally designed through a growth process. The vertical distribution of the stem cross-sectional area increment is affected by stand conditions such as site quality, stand density, and growth stage (WAGUCHI, 2009). Those conditions directly affect crown dimensions first, and then the affected dimensions determine stem volume increment and its vertical distribution. In the model, the impacts of these conditions on the distribution are significantly mediated through the shape and size of the sunny crown. Second, the model provides a simple and robust framework. The relationships among variables are constructed using simple equations. Thus the prediction process is easy to understand. In addition, the validity of each equation has already been experimentally demonstrated (WAGUCHI, 2004; WAGUCHI and UEDA, 2005b; 2006a; 2006b; 2008; 2009). Therefore, it is possible to modify the model for a particular aim, and to use it as a basis for other growth models.

As mentioned above, the model has wide applicability and constructional advantages. We therefore conclude that this model is a useful tool for planning stand density management for even-aged stands of Hinoki cypress.

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Article

Homegarden Agroforestry in Bangladesh: Assessment of Its Role for Farmers' Income Source in Thakurgaon District

Sourovi Zaman*[1] and Masato Katoh*[2]

ABSTRACT

This study was conducted in Thakurgaon district of Bangladesh and focused on the species composition of homegardens, species richness, economic importance of homegardens, underlying constraints that limit homegarden productivity and the future prospects of homegarden production. In Bangladesh homegarden agroforestry is the traditional land use system that provides about 65-70% of saw logs and about 90% of fuelwood and bamboo consumed in Bangladesh. The homegarden production system was found poor in terns of level of management in cultural practices. More space might be made for growing more trees through proper management of trees. Organic fertilizers were not available in sufficient quantities as agricultural residues were used as fuel and cattle feed. Modern technology and extension support for improvement of traditional production system were almost not available. In spite of land constraint problem in Bangladesh, there were some vacant niches in the homegardens that can be taken under new plantation.

Keywords: agorforestry, forestry, Thakurgaon, Bangladesh.

INTRODUCTION

Bangladesh is one of the most densely populated countries of the world (1,146 people/sq. km in 2007). The present population of country stood at 153 million (GOVERNMENT OF BANGLADESH, 2007). The country covers an area of 14.7 million hectares, of which land covers 13.76 million ha and river 0.94 million ha. There are 9.57 million ha of cultivable land and about 2.5 million ha of forests in Bangladesh (FOOD AND AGRICULTURE ORGANIZATION, 2005). About 80% of population lives in the rural areas in 17.1 million households spread over 68,000 villages (GOVERNMENT OF BANGLADESH, 2007).

Rural poverty and deforestation in Bangladesh are critical and interrelated problems. The problems are accelerated by over-population, land scarcity and natural disasters. Due to a number of causes including high rate of population growth, global environmental degradation, recovery of land from the forest for human habitation and agricultural practices, as well as high demand for wood and fuelwood, the natural vegetation along with the area of forest land has been decreased to an alarming stage demanding immediate steps for adequate aforestation in Bangladesh (LAI, 1988). In this country the village forests are in imminent danger of rapid depletion due to population pressure, and last but not least there is a lack of direction of forestry research (BHUIYAN, 1994). Homegarden agroforestry system is both productive and environmentally sound and it has the potential not only to increase the production of food, fuel, and income for farmers, but also to help stop destruction of the world's forest land (FERNANDES and NAIR, 1990).

Homegarden agroforestry is also an age old practice in Indian sub-continent where it plays a fundamental role in

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agricultural economy (Jacalne, 1984). Of the total fuel energy consumed in Bangladesh, 83% supply comes from biomass (Haque, 1992). Fuelwood together with twigs, leaves and branch of trees constitutes 15% of biomass energy, while cowdung and crop residues constitute 24% and 61% respectively. Private lands, homesteads and village groves supply 75% of timber used in the country (Haque, 1992). Homegarden agroforestry is the traditional land use system in Bangladesh and sustained the population in this area by providing food for families and cash income (to purchase land, buying agricultural inputs, repaying loan, meeting educational and marriage expenses for family members) (Khaleque, 1987). Since time immemorial, farmers have been growing various trees on their homegardens and crop lands depending on their needs and experiences, leading to diversification of species (Khaleque, 1987).

In Bangladesh, flood is very common, raising trees on homegardens are more reliable and are less vulnerable to flood hazards (Haque, 1996). From the socio-economic point of view homegardens is more stable, as farmers never sell their homegardens before their crop lands. A typical homegarden contains several types of multi purpose tree species, a selection of herbs and vegetables with some animals (Bene *et al.*, 1977). Trees on homegardens also provide protection to the houses against storm, shade and other tangible and intangible benefits. Homegardens were the center of all post harvest processing activities. Home gardens are generally dominated by trees which can protect the deforestation and improve the forest resources. In spite of these things homegardens are coming under pressure in Bangladesh; principal cause is growth of population and land hunger.

Homegardens are the most productive component of the forestry sector in Bangladesh which received little attention. Moreover, there has been no program specifically to improve the overall productivity of homegarden agroforestry, or to introduce yield increasing technology (FMP, 2000).

The study objective was to focus the present situation of homegardens (homegarden size, land holding, distribution of land and species composition) which are supplying most of the fuelwood, timber as well as livestock's use and economic importance in Thakurgaon. The study was also conducted to assume the socio-economic constraints that limit homegarden productivity. It is expected that this study will be able to come up with some valuable information that can be used as a tool for different Government and Non Government Organizations working in same field, in designing appropriate research and development activities in Thakurgaon district.

STUDY AREA

The study area Thakurgaon district is situated at the northern part of Bangladesh. The over all forest condition in Bangladesh (Fig. 1) is very poor and in northern part is even

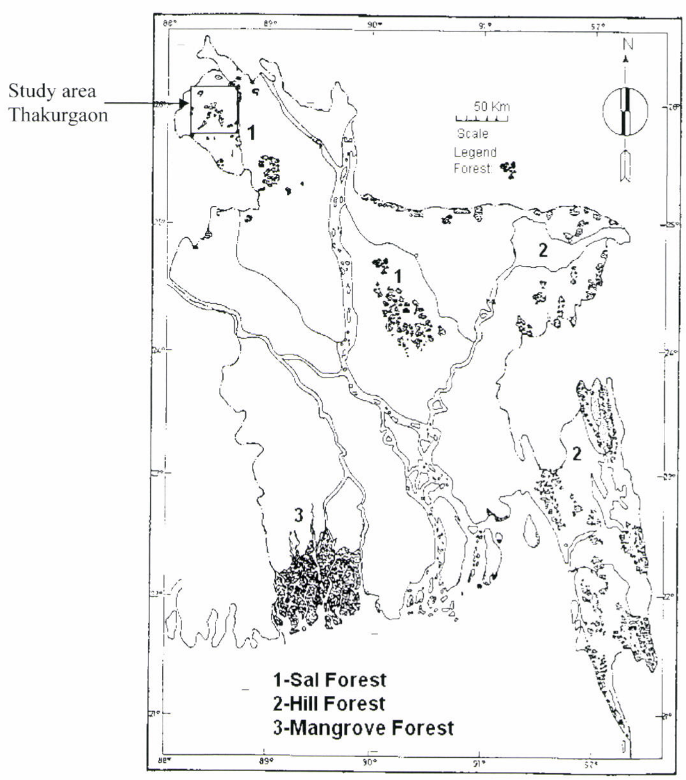

Fig. 1 Map of Bangladesh showing distribution of forests (Source-Dinajpur Forest Division)

worse with compare to total area, population and environment. For total land area of 2,497.92km², forestland is estimated to be only 0.57% (BBS, 2002). The over all tree crown covered area (including homestead trees) was estimated only 2% (Dinajpur Forest Division, 2005). Thakurgaon district is located in a long distance from the divisional towns as well as central part of Bangladesh. The district did not get any attention to the government or any other development organizations as the place has neither economic nor ecological importance. The district has 5 thanas names- Thakurgaon Sadar, Baliadangi, Horipur, Ranishonkoil and Pirgonj and the total population of these 5 thanas was about 1.6 million (GOVERNMENT of BANGLADESH, 2007).

METHODOLOGY

Data Collection

The study was conducted during February to March 2003 in Thakurgaon district; two thanas namely Baliadangi and Thakurgaon sadar were selected and 10 households were randomly selected from each category of each thana. All households were grouped into five farm categories according to size of land holdings. Using a structured questionnaire, formal and informal interviews and field observations were collected for the information. Some information was also gathered by group discussions with the farmers.

Categories of households were as follows:

1. Large: owned land >2.00ha
2. Medium: owned land 1.01- 2.00ha
3. Small: owned land 0.51- 1.00ha
4. Marginal: owned land 0.21- 0.5ha
5. Landless: owned <0.2ha

The farmers who own land upto 0.2ha were identified and eliminated from the list. They do not practice agroforestry in their homegardens because most of their lands are occupied by their houses. A sample of 80 households was selected, 40 from 2 thanas with equal number of household from each farm category by stratified random sampling. The major limitation of the study was heavy reliance of the farmer's memory. Farmers do not keep any record of their farm input used and out put obtained. The collected information was verified through survey the villages and also confirmed with the information of Thana Agriculture Extension Office. Information was collected from both primary and secondary sources. These were gathered by survey as well as non survey methods. The survey sources include interviews through a pre-tested interview schedule, and farmers' group discussions while non-surveys include the information through field survey, direct observations and secondary sources.

Collection of Primary Data

Household survey

Data were collected from the head of household through interviews. Collected information was verified through visits and discussions with other individuals and groups of farmers.

Species composition of homegardens

The species composition of homegarden was noted with the help of the farmers and the assistants. In each garden each specimen of all perennial species with their name, age and individual number was recorded by asking the owner of household and counting by authors.

Household income

Income of each household was categorized into 2 groups; income from crop field, income from homegarden.

Secondary data was collected from relevant literature, from DAE[(1)], BARC[(2)], BARI[(3)], SRDI[(4)], previous research, village extension workers, school teachers and local community leaders.

Data Analysis

At the end of the survey, the relevant information was fed into the computer for analysis by the MINITAB 11.2 statistical packages.

1. Qualitative Data Analysis- analyzed by using descriptive statistics and presented as means, percentages, frequency distributions, and cross tables.
2. Quantitative Data Analysis- was summarized into categories to facilitate statistical analysis. The same statistical package was used and data were analyzed.

Chi- square tests

Chi-square tests were employed to asses the homogeneity of household responses among the different farm categories.

RESULTS AND DISCUSSIONS

Constraints of Present Production System

Some constraints were noted during the period of field work.

1. Lack of cash to buy good quality seeds or seedlings in the smaller farm categories.
2. Due to financial stringencies the smaller farm categories can not retain trees for a longer period in their homegardens and they harvest trees at the prime growing stage.
3. Unavailability of space and conflict with neighbors were found as major constraint in the small and marginal farm

(1) DAE- Department of Agricultural Extension
(2) BARC- Bangladesh Agricultural Research Council
(3) BARI- Bangladesh Agricultural Research Institute
(4) SRDI- Soil Resource Development Institute

categories.

4. Lack of knowledge about new technology of homegarden management.
5. Difficulties to establish the tree seedlings because of damage by cattle.

Lack of high-quality seeds and seedlings to meet local demand is also one of the major problems in Thakurgaon district due to bad communication and long distance from the divisional cities (ABEDIN and QUDDUS, 1988). Though the major portion of this district is either flood-free drought area or only affected by shallow flooding, high rainfall limits seedlings during rainy season through occasional submergence and saturation of the soils. Low organic matter content of the soil, sandy substratum at a shallow depth and winter drought may also be the other constraints in Thakurgaon district. Interaction between forestry and agriculture sector is also has some lacking in this zone.

Home Garden Size and Total Land Holdings

The average size of homegarden was found different within the farm categories. There was strong correlation between the total land holdings and the homegarden size. The average size of land holding for the large category was 4.798ha while the land holding for medium, small and marginal farm category was 1.6, 0.758 and 0.327ha respectively (Table 1). It was observed that larger the farm size, larger the homegardens, more scope for agriculture production and forest as well as increase farmer's income. About 45% of marginal farms had a homegarden below 0.05ha while only 5% of large farms had this small size of homegardens. Out of this, about 65% of large farms had a homegarden in a range of 0.11-0.5ha while only 20% of marginal farms had this size of homegardens (Table 2). Though the large farms had a large homestead area, they required an open space for different household works like threshing of crops, drying of crop products and cloths, and for various social activities. In relation to use of total land as homegarden, the percentage of total land used as homegarden was different within the farm categories. Large farm owner keep a large portion for the homegarden. The area of homestead varies from 0.1 to 1.0ha depending on the locality or on the financial position of the house owner and due to high rate of population growth; the area of homestead is decreasing day by day (HAQUE, 1996).

Species Composition in the Homegarden

Homegardens in Bangladesh feature a unique combination of trees, shrubs, vegetables, livestock, animals, ducks, poultry and pigeon from ancient time (HOSSAIN and BARI, 1996). Integration of trees into the farming systems is common all over the country. A total of 77 perennial species was noted from the total households surveyed. The most common species found in the homegardens were mango, jack fruit, betelnut, banana, and neem. Mango and banana were common species for all households surveyed. There was no spatial pattern of species distribution found in the homegardens of the study area. Lots of non commercial tree species such as flower tree species and some other tree species that used for fencing of garden were also found. These species did not use as income source of households. Though it was found 77 species but actually 55 species of trees were earning source of

Table 1 Size of total land holdings &homegardens in different farm categories (20 households in each category).

Farm category (N)	Average size in ha (%)				
	Total land holding	Home garden	Farm	House	Others
Large (20)	4.798	0.330 (6.88)	2.370 (49.40)	0.250 (5.21)	1.848 (38.52)
Medium (20)	1.600	0.180 (11.25)	0.720 (45.00)	0.160 (10.00)	0.540 (33.75)
Small (20)	0.758	0.087 (11.48)	0.369 (48.68)	0. 078 (10.29)	0.224 (29.55)
Marginal (20)	0.327	0.066 (20.18)	0.121 (37.00)	0.049 (14.98)	0.091 (27.83)

Note: Figures in the parenthesis indicate percentage of total land uses as homegarden

Table 2 Percentage of households by size of homegardens in different farm categories (20 households in each category).

Farm category	Homegarden size ha			
	<0.05	0.05-0.1	0.11-0.5	>0.5
Large	5	15	65	15
Medium	5	35	50	10
Small	15	65	20	0
Marginal	45	35	20	0

χ^2 = 32.32, DF = 9, P- value = 0

framers (Table 3). There are some shade loving crops which grow well under and near by the canopies of trees. These were *Zingiber officinale*, *Annona squamasa*, *Curcuma longa*, *Ipomoea batatas*, *Capsicum frutescens*, *Colocasia spp.*, *Xanthosoma spp.*, *Alocasia sp.*, *Amorphophallus spp.*, *Piper betle* and many vegetables and spices. It was a source of extra income for those farms. After discussion with the farmers and local agricultural officers it noted that there was a tendency to plant new trees among the households. The present campaign of Government on tree plantation might be supplemental to enrich the homegarden with new trees and plants in all farm categories. Besides this some NGOs have also been working on tree plantation programs especially for poor farmers. In association with trees different categories of crops, in respect of light requirement, plant height, canopy structure, and erectness of stem and leaf size, can be grown in the farm yard and home yard under multi-layered production system of agroforestry. The age of the trees in homegarden is an indicator of the development of consciousness for planting trees. Most of the trees were found in the age group 1-5 and 5-10 years in all farm categories. Least number of trees was found in the group above 20 years of age. Better off households apply a lower discount rate to their cutting decisions than poorer households, therefore cutting trees at a higher age. The larger farm categories had more old trees (>20 years) than the smaller farm categories.

Economic Importance of Homegarden

The income from homegarden was significantly different within the farm categories (P= 0). The smaller farm categories were getting relatively more income from their homegardens than the larger farm categories. 55% of large farms had less than 10% income from their homegardens whereas no household from the marginal farm category got less than 10% of their income from homegardens. 40% of marginal farms got 20-30% of their income from homegardens whereas no farmer from large farm category got more than 20% of their income from homegardens. The smaller farm category depended more on their homegardens and intensively cultivated by them (Table 4). It might be the reason why they got higher percentage of income from their homegardens. While most of the large category homegarden owner used their produce for their own household's consumption. Occasionally farmers sold homegarden produce for cash income. However, the farmers of the study area did not practice homegarden primarily for cash income. The farmers of Thakurgaon district had practiced homegarden as a part of traditional farming wisdom. Though now a day farmers manage their livelihood from homegarden and its produce.

Livestock and Its Use

The farmers, who own large properties, keep more animals than the farmers who own small properties (Table 5). It was noted that some households from small and marginal farm categories do not keep animals. Shortage of cash money to buy the animal was the major reason not to keep livestock. Lack of manpower for attending the animals, shortage of grazing land also reported as reasons by the farmers those who do not keep livestock. Livestock and poultry in rural farm families serve as bank savings that can be easily cashed when

Table 3 Number of trees (/ha) in homegardens according to age of the trees and farm categories. (20 households in each category)

Farm category	Total species	Age of the trees in years					
		1-5	5-10	10-15	15-20	>20	Total
Large	19	188	110	25	26	20	368
Medium	13	160	113	35	15	22	345
Small	12	263	180	26	11	8	487
Marginal	11	359	185	29	4	6	582

*Plant species- other than non commercial tree species

Table 4 Income share from homegardens according to farm categories (20 households in each category)

Farm category	Income percentage (from total* net income).			
	< 10	10-20	20-30	>30
Large	55	45	0	0
Medium	20	60	15	5
Small	5	65	30	0
Marginal	0	40	40	20

χ^2 = 37.366, DF = 9, P- value = 0
* Total income = Income from crop field + Income from homegarden

Table 5 Average number of livestock in different farm categories (20 households in each category)

Farm category	Average number			
	Cattle	Goat	Buffalo	Poultry
Large	6.10	2.75	0.30	25.55
Medium	3.50	1.80	0.00	19.25
Small	2.45	1.70	0.10	10.65
Marginal	1.75	1.40	0.00	11.60

Table 6 Practice of feeding livestock by different farm categories (20 households in each category).

Farm category	Nature of feeding (kg)			
	Natural grass	Crop residues	Leaf fodder	*others
Large	10.60	79.15	2.00	8.25
Medium	9.26	83.42	1.62	5.70
Small	15.17	76.94	2.22	5.67
Marginal	18.46	66.15	11.69	3.69

*Others - concentrates, molasses, rice, etc
Note: Figures in percentage

needed (Razzak, 1987). Also farmer can earn money by selling the milk from dairy and egg from poultry. In Thakurgaon district maximum farmers were using their animals for agriculture work such as land plaughing and post harvesting labor. All categories of farmers were found using crop residues (66-83%) as livestock feed. The larger categories were found to use more concentrate as cattle feed than smaller farm categories. The smaller farm categories used more natural grass as cattle feed than the larger farm categories. Marginal farmers used more leaf fodder (11.69%) than the others (Table 6). As smaller farm categories own the smaller piece of crop land, they also had very small quantity of crop residues to feed their livestock and also less income from crop fields. It might be one of the reasons why they feed more natural grass and leaf fodder and also use the small amount of concentrates. Free grazing of animal is common practice, but restricted when the fields are covered with crops. Almost everywhere cattle and goats were being to graze, often leading to over-grazing of an area due to scarcity of forage. Use of rice straw as fuel was one of the causes for feed shortages in many farm families, particularly in poorer farm categories.

CONCLUSIONS

In Bangladesh the population is increasing day by day and creates tremendous pressure on the land. People would surely migrate from over populated area to other arable and forest lands for housing and settlement. As population increases there is a need to intensify the land use in order to support the larger population. Over use and destruction of forest resources already have negative impacts on welfare of people in northern part of Bangladesh and threatening their food security and sustainability of production system. There is an urgent need to replenish the forest and tree resources for the well-being of the people as well as country. Within the diminishing trend of forest reserves and land scarcity, only agroforestry especially homegarden agroforestry remains as one of the important options to meet the diverse necessities of rural people and forestry both.

Small farm owner has a shortage of land, so they have to use the land mostly by practicing agriculture and forestry together. They may wait to get the return from the trees for years and can invest more to get much more from their farms but the needy ones desire quick return from their small investment. It might be the major reason to have less number of old trees in the smaller farm category. It also indicated that the resource poor farmers cut down their almost all old trees to meet-up their need for cash and they only think about the return so they are usually not interested about species diversity as they are uneducated too; though small farmers have more no of tree but there are mainly the combination of same about 10 tree species. Other hand the large farm owner use to plant different types of tree species for manages the biodiversity including wild atypical trees.

After the survey analysis and discussion with the agriculture officer it was found that the traditional homegarden production system in Thakurgaon district was poor in terms of level of poor management in cultural practices. The homegardens were under-utilized and there were some vacant niches that can be taken under new plantation program, especially in the larger farms. The modern technologies and extension supports to develop the traditional production systems were almost not available. To improve socio-economic conditions of households, designing of new program to develop the homegarden agroforestry production system in accordance with farmer's needs, resource base, goals and preferences and bio-physical setting is an urgent issue. Bangladesh Government has been patronizing the private sector to set up dairy farms, but no step has been taken to ensure adequate supply of fodder. It was revealed that acute shortage of fodder causing malnutrition to livestocks and reduced livestocks produces. If proper steps are taken in this regards, number of livestocks can be increased and also more dairy farms can be set up and more employment opportunities can be created. Farmers were maintaining their soil fertility by using various types of crop residues, tree litter, animal litter, etc. Thakurgaon district faced lots of problem of over population and supply of their demand and overall the environmental disasters due to limitations of land and it use. In order to solve these problems, improvement and development of homestead forest are necessary. Increased tree plantation in non-forest area especially in the homegardens should be the strategy for enhancing tree cover of the country in order to meet demand for food, fuelwood and timber for households and fodder for livestock, as well as to maintain the sustainability of production system.

RECOMMENDATIONS

1. Development of appropriate small-scale nursery techniques, particularly homestead-based, utilizing low-cost inputs available to the household.
2. It is very important to give high research priority to improve the indigenous fruit and timber tree species for homegarden agroforestry and to identify the fast-growing trees and MPTS suitable for homegarden plantation for the poor one.
3. Management of crop residues to optimize production of both crops and livestock is important.
4. Farmers training are needed in agroforestry technology to increase per unit area of production and some basic knowledge about agroforestry with its benefits. Mainly the training need on the basis of farm ownership. Large and medium farmer need to know how to use their land properly, marginal and small farmer needs to know more about biodiversity, help to keep environment conservation.
5. It can be recommended that farmers especially the marginal and small farmers should be provided with a suitable credit facility so that trees could be offered as collateral and the loan paid back after harvest of trees at desired maturity which will give benefit to both the financial institutions and the farmers. Providing technical support in terms of quality planting materials, technical know-how for planting and upkeep is also very important.

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Article

Predicting Site Indices of Japanese Cedar Plantation in Niigata Prefecture using Environmental Factors

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ABSTRACT

The objectives of this study were (a) to evaluate the correlation of environmental factors with the site index of Japanese cedar, and (b) to develop the best-fit equation model for the site index. Multiple regression models for a site index of sugi plantation in Niigata Prefecture were constructed using environmental factors as independent variables. The environmental factors used were climate data (snow depth), soil type data and topographical data (aspect, slope, elevation, hillshade, distance from ridge, wetness and curvature). Through a backward stepwise procedure, the elevation, hillshade and soil type were selected for a best-fit regression model. In this model the multiple correlation coefficient was 0.523, and standard error estimate 2.84m.

Keywords: GIS, site index of sugi plantation, environmental factors, multiple regression model

INTRODUCTION

Japanese cedar (*Cryptomeria japonica*), 'sugi' in Japanese, is the most economically important timber species in Japan. It has been cultivated over extensive areas for timber and as ornamental trees in temples and shrines. The total area of forest in Japan is 25.212 million ha, and man-maid forests occupy about 10.327 million. The percentage of sugi plantation forests is approximately 43.8% (4.536 million ha) of the whole man-made forests. Niigata Prefecture has about 142 thousand ha of sugi plantation (MSCIE, 1995).

Recently in Japan, many researchers use the topographical factor to predict the site index such as sugi plantation (Chen and Abe, 1999), sugi and hinoki (Teraoka *et al.*, 1991), and Japanese larch plantation (Nishizawa *et al.* 1965 and Mitsuda *et al.* 2001). Outside of Japan, also many researchers estimate the site index using environmental factors; for example, Iverson *et al.* (1997) used GIS-derived data to develop the integrate moisture index to predict forest composition and productivity of Ohio Forest; Chen *et al.* (1998) predicted the site index of trembling aspen by developing multiple regression using climatic, topographic, soil physic and chemical properties; Wang (1998) developed a model for site index conversion among species (lodge pole pine and white spruce).

It is efficient to analyze environmental factors using the Geographic Information System (GIS). GIS is a powerful set of tools for collecting, storing, retrieving, manipulating, analyzing, transforming and displaying both spatial and non-spatial data obtained from the real world, which acts as a decision- support system involving the integration of spatially referenced data in a problem solving environment (Burrough and McDonnell, 1998). Thus, GIS provides a comprehensive tool to predict the site index from environmental factors.

The objectives of this research are (a) to evaluate the correlation of environmental factors with the site index of Japanese cedar, and (b) to develop the best-fit equation model for the site index.

MATERIALS AND METHODS

Study Area

The study area is located in Niigata Prefecture, Japan. The area of Niigata Prefecture is 12,582.29km² which extends from northeast to southwest through about 2 degrees of latitude 36°40'-38°40'N and longitude 137°42'-140°00' E (Niigata Yearbook, 2002).

The feature of the climate in Niigata Prefecture is typical of districts with the Japan Sea type climate; comparatively low

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precipitation in the summer and high in the winter. The maximum annual precipitation is about 1,708mm in Niigata city and 3,300mm in the mountainous area. Niigata Prefecture is known as a snow country, with a snow depth of less than 50 cm in the city and more than 500cm in the mountainous area. In 2002, mean temperature was about 26.4°C in summer and 1.5°C in winter. The relative humidity of the study area was 70-98% (Niigata Yearbook, 2002). The study area has topography between plate and mountainous areas. Elevation is between 55 and 1322m above mean sea level (msl) and slope is between 5 and 38 degree.

The vegetation in the study area consists of coniferous and broadleaf species. Coniferous species form most of the plantation forest. Almost all coniferous species are sugi (*Cryptomeria japonica*) and others are akamatsu (*Pinus densifloria*) and kuromatsu (*Pinus Tunbergii*). Broadleaf species are mostly a secondary forest. Some of the broadleaf species are buna (*Fagus crenata*), mizunara (*Quercus mongolica*), hounoki (*Magnolia obovata*) and tochinoki (*Aesculus turbinate*) (MSCIE, 1995).

Data

The data used in this research were obtained from a ground survey, yield book, forest inventory, manuscript map and digital mesh point data. Environmental data are summarized in Table 1. The manuscript map data set was obtained from the soil type map (Niigata Prefecture, 1973; 1976; 1978a; 1978b; 1979a; 1979b), scale of 1:50,000, and digital map data sets were formed from the digital map with a 50m-grid elevation (mesh-point data) and administrative boundary of Niigata Prefecture. Table 2 summarizes the data of the field survey.

The plot were established based on the Niigata Prefecture Forestry Division method (plot size; 40m×40m, tree size; diameter of breast height, total height, tree condition; healthy, unhealthy, straight and oblique tree for each tree in the plot). Reasonable plots were set up for the uniform distribution of sugi plantation (92 plots, size; 40m×40m), mature stand, and variation of topographic factors. Ground survey was conducted in June-November 2003 at each location shown in Fig. 1.

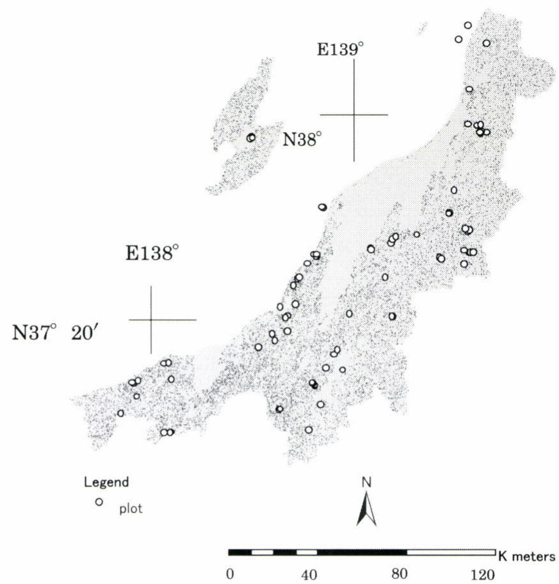

Fig. 1 Location of each plot

Table 1 Summary of the environmental data

No	Items	Minimum	Maximum	Mean	SD
1.	Snow depth (cm)	0	428	130.24	75.33
2.	Slope (°)	5	38	17.56	8.05
3	Aspect (°)	3	358	204.01	104.53
4.	Elevation (m)	55	1322	374.19	262.44
5.	Curvature	−1.79	1.49	0.01	0.75
6.	Hillshade	150	254	225.53	26.17
7.	Distance from ridge (m)	0	108	40.31	29.03
8.	Wetness	−4.66	6.54	−2.20	1.78

Table 2 Summary of the field survey data

No	Items	Minimum	Maximum	Mean	SD
1.	Average DBH (cm)	21.60	50.70	34.89	5.45
2.	Average H (m)	11.86	28.92	21.44	3.69
3.	Average HDT (m)	19.22	34.40	26.74	3.44
4.	Volume/ha (m^3/ha)	151.22	1372.36	713.29	241.68
5.	Basal Area (m^3/ha)	16.56	111.74	67.01	17.41
6.	Number of trees (trees/ha)	194	1244	674.61	194.19
7.	Age (yr)	36	81	67.18	7.16

Using the spline interpolation command in the ARC-GIS 3D Analyst, we used 'Digital Map 50-m grid' published by Japan Geographic Survey Institute to construct the DEM data in this research. Spline is a general-purpose interpolation method that fits a minimum-curvature surface due to the input points. This method is best for gradually varying surfaces such as elevations, water-table depths and pollution concentrations (Booth, 2000). After the DEM data was built, the environmental factors were calculated.

Site Index

Site index is defined as the average height of dominant trees in a forest stand at a reference age. In this study, the average height of dominant trees in each plot was calculated as average tree height of the highest 20% trees, and the stand age was obtained from Forest Database (Niigata Prefecture,1999). As reported by Nishizawa *et al.* (1965), the site index of each plot refers to the guide curve that was developed based on field survey data (92 values) and data from Yield Table (167 values) (Niigata Prefecture, 1980) with the reference age at 60 years. The guide curve is calculated by the Mitscherlich equation using SPSS (11.5.1J) program (Equation (1)).

1) Decision of guide curve

$$Yt = 41.5452 \times (1 - e^{(-0.01446t)}) \quad (1)$$

Where, Yt: average height of dominant tree

t: stand age

The guide curve shown in Fig. 2.

2) Standard deviation of tree height at each stand age

We calculated standard deviation of tree height in each age class (5 years interval) from the following formula.

$$\sigma_t = \sqrt{\frac{\sum_{i \in DT} (yt_i - yyt_i)^2}{nT}} \quad (2)$$

yt; Average dominant tree height of age t of each plot
yyt; Average dominant tree height of age t from guide curve
DT; Set of data of age class T
T; age class
nT; Number of data at T
Relationship between σ_t and t is obtained as follows.

$$\sigma_t = 0.02037 \times t + 1.5606 \quad (3)$$

The value of σ_t for each age class is calculated by this equation.

Assuming that the difference between site index value (Y) and the tree height at age 60 obtained from the guide curve (Y_{60}) is proportional to σt_{60}, and that between yt and ytt is proportional to σ_t

$$yt - ytt / \sigma_t = Y - Y_{60} / \sigma_{60} = RY \quad (4)$$

Thus, tree height at each age class (yts) with site index Y is calculated by

$$yts = yyt + RY\sigma_t$$

For instance, the average height of dominant tree at age 30 is obtained as follows.
From formula (1) ytt at age 30 is 14.62m, and $\sigma_{30} = 2.17$ ytt at age 60 and σ_{60} is 24.1 and 2.78, respectively. Applying these values to formula (4),

$$Y - Y_{60} / \sigma_{60} = 20 - 24.1 / 2.78 = -1.4748$$
$$yts = 14.62 - 1.4748 \times 2.17 = 11.42\text{m}$$

Repeating such calculation for the stands at various ages, we can obtain site index curves.
To estimate SI of each plot,we calculated from the following formula.

$$SI = Y_{60} + (yt - yyt)\frac{\sigma_{60}}{\sigma_t} \quad (5)$$

SI; Site index of plot
yt; Average dominant tree heit of t

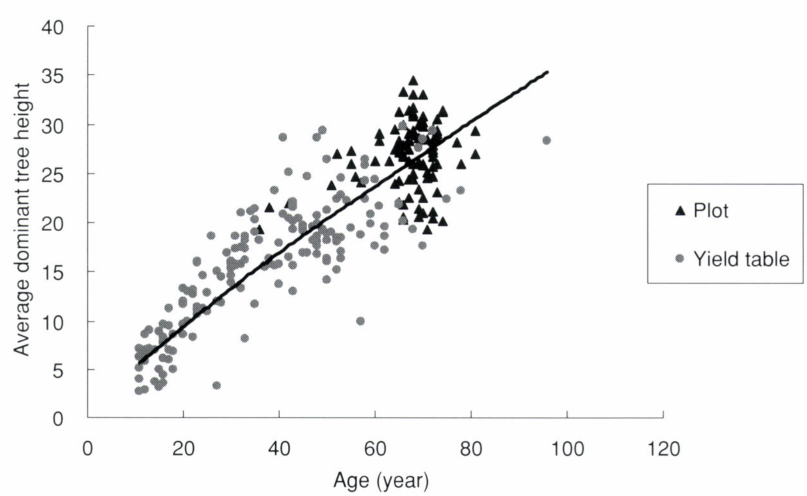

Fig. 2 Site index curve of sugi

yyt; Average dominant tree height of age t from guide curve
Y_{60}; Average dominant tree height from 60 years (standard age) from guide curve
σ_{60} and σ_t; Standard deviation of tree height in 60 years (standard age) and age *t*

Environmental Factors

The environmental factors that were used to predict the sugi site index were climate data (snow depth), soil type data, topographical data (aspect, slope, elevation, hillshade, distance from ridge, wetness and curvature). These environmental factors were selected for this research based on the assumption that these factors were highly correlated with the site index according to some previous studies (NISHIZAWA *et al.*, 1965; TERAOKA *et al.*, 1991). Table 2 summarizes the data of these factors. 92 plots are used for calculating the relationship between environmental factors and site index.

1) Elevation

Elevation affects various factors such as snow depth, microclimate and soil. However, in this study elevation should be analyzed from the viewpoint of the correlation with the site index. NISHIZAWA *et al.* (1965) considered elevation and the soil factor as factors affecting the site index. We can not estimate the coefficient of the correlation between elevation and soil type. On the other hand, the correlation of coefficient between elevation and snow depth is shown 0.57 indicating a little high correlation.

2) Snow depth

Niigata Prefecture is a snowy area with heavy snow cover in many areas especially in mountainous areas such as Myoko, Tsugawa and Joetsu. The effect of heavy snow accumulation on trees usually leads to deformation of the trees such as branch bending, tearing and breakage. Accumulation of snow by drifting can have different effects on trees, generally it delays snowmelt and reduces the growing period accordingly (BÉGIN and BOIVIN, 2001). At the end of each winter we can see sugi trees damaged by snow. Therefore, the snow depth influencing sugi growth was represented by the site index.

3) Soil type

The private sugi forests in Niigata Prefecture have 21 soil types; the five major kinds were BD, BD(d), BE, BlD and γBD (Niigata Prefecture, 1973-1979). Plot samples in this study were obtained from only the two representative soil types of BD, BD(d) which were detected on the soil map attached to the report of right tree for right site (Niigata Prefecture, 1973-1979). To represent soil type in the following regression analysis, we used a dummy variable coded 1 for BD and 0 for BD(d) (SALL, 1981).

4) Aspect

Aspect is the compass direction toward which a slope faces, and was measured in degrees from north in clockwise direction (ESRI, 1994). Aspects were divided into four classes according to the degrees: (1) north, 0-45° and 315-360°; (2) east, 45-135°; (3) south, 135-225° and (4) west, 225-315°.

5) Slope

Slope is a measure of change in surface area, expressed in degrees or as a percentage (ESRI, 1994). Slop was used to calculate the relationship between site index and environmental factors. The slope range of field survey data was between 5-38 degrees.

6) Hillshade

The environmental factors, hillshade, curvature, flow accumulation, distance from ridge and wetness were derived from the digital elevation map (DEM).

$$\text{Hillshade} = 255.0 \times ((\cos(\text{Zenith}) + \cos(\text{Slope}) + (\sin(\text{Zenith}) + \sin(\text{Slope}) \times \cos(\text{Azimuth-Asp})) \quad (6)$$

Hillshade describes intensities of solar radiation varying with the slope angle, aspect, position and accounts for shading from adjacent hills (IVERSON *et al.* 1997). According to SASE *et al.* (1998), the Japanese cedar is more sensitive to shortage of water than other conifers during the summer season in Japan. Therefore, hillshade was calculated in 2003 summer season at the longest day, which was June 23th with daylight of 14 hours 38 minutes, sun direction (azimuth) of 300 degrees and solar elevation (altitude) of 77 degrees. This method was similar to that of MITSUDA *et al.* (2001), who predicted the Japanese larch site index in Hokkaido. Hillshade is calculated using 'Hillshade' command in Spatial Analyst or 3D Analyst of ARC-GIS Software (ESRI, 1994). By default, shadow and light are shades of gray associated with integer from 0 to 255. A low value represents low solar radiation or area shaded by the adjacent hill and high value represents high solar radiation or area free from shading.

Range of the hillshade data was between 150 and 254 with an average of 225.53 and standard deviation of 26.17.

7) Distance from ridge

Distance from ridge (DR) is calculated as the distance from the ridge obtained as a line vector data through 'Distance' commands in Raster Calculator in Spatial Analyst of ARC-GIS software (ESRI, 1994). Flow accumulation data is used as an input data in calculating distance from ridge. Flow accumulation (FA) is calculated as the accumulated water flowing down a slope (IVERSON *et al.* 1997) and the algorithm for FA was given in JENSON and DOMINGUE (1988). In ARC-GIS software, it is calculated using the 'Flow accumulation' command in Workstation. At the ridge tops, flow accumulation may be minimum and the valley bottoms it may be maximum. Therefore, the ridge top will have a minimum value and the valley bottoms will have a maximum value.

Range of distance from ridge data was between 0 and 108m, with an average of 40.31m and standard deviation was 29.03m.

8) Wetness

Wetness index (BEVEN and KIRKBY 1979) is an index of moisture retention. Wetness index is shown in Equation 6, which is calculated using Raster Calculator command in

Spatial Analyst of ARC-GIS software. The higher value represents the moisture area and the smaller value represents the non-moisture area.

$$\text{Wetness} = \text{Ln (flow accumulation/tan (slope))} \quad (7)$$

Range of wetness was between −4.66 and 6.54, with an average of −2.20 and standard deviation is 1.78.

9) Curvature

Curvature measures the shape of the landscape: whether it is flat, convex or concave (IVERSON *et al*., 1997; BURROUGH and MCDONNELL, 1998) and the algorithm for curvature as a landform characterization is given in BLASZCZYNNSKY (1997). The positive curvature represents the concave area and the negative curvature represents the convex area. Curvature is calculated using 'Curvature' command in Workstation of ARC-GIS Software.

Range of curvature data was between −1.79 and 1.49 with the average of 0.01 and standard deviation of 0.75.

Data analysis

Parameters effective for estimating site index were selected by multiple regression analysis adopting stepwise procedure. Variables were selected by the stepwise procedure at significant level of 0.05.

RESULTS

All of the environmental factors (9 factors) were used for estimating the site index model of sugi plantation. Variables selected by stepwise procedure for best-fit regression model were elevation, hillshade and soil type, and Table 3 shows the regression equation for determining the side index using these three variables. The elevation and hillshade are shown by numerical values, but soil type are shown by letters as BD and BD(d). Therefore, to form the multiregression equation shown in Table 3, we expressed BD and BD(d) as 0,1. Multiple correlation coefficient was 0.523 (Determination coefficient; 0.274), and the correlation was not so high. However, standard error of estimate was 2.84m and analysis of variance shown in Table 4 was significant at 1% level, showing the validity of this equation. Among the three variables in this equation, soil type showed the highest standardized partial correlation coefficient followed by hillshade and elevation in this order (Table 5). Although the soil type used in the site index table in the study on the right tree for the right site in Niigata prefecture were B, BD(d), BD, BE, BF and BD, the soil type included in the present study was only BD(d) and BD but it correlated with the site index.

DISCUSSION

In the backward stepwise procedure, effective variables are selected stepwise, and the selection of variables is not arbitrary. From 1966, the countrywide survey of sugi stand land productivity in national and private forests started, and the number of quantified sample data all over the country exceeds 20,000. SAKAGUCHI *et al.* (1983) examined the factors that affected site index in each region. According to these studies soil type had the greatest effect on the site index in most of the regions. In the stands of trees other than sugi, the soil type has been reported to have the greatest effect on site index (NISHIZAWA *et al.* 1965, CORONA *et al.* 1998, YAMANE 1990). Results of the studies on the right tree for the right site also indicated the soil type as an important factor in estimating site index. In the study on the right tree for the right site in Chuetsu forest planning area, the coefficient of partial correlation of site index with the soil type was 0.59 (calculated by Quantification Method I). These results suggest that the soil type is an indispensable factor for estimating site index. According to SAKAGUCHI *et al.* (1983), the effect of elevation, though variable, is large in Niigata, Akita, Nara, Kumamoto

Table 3 Regression model for predicting site index from environmental factors

Model	Multiple correlation coefficient	SEE
SI = 31.233—0.005 (elevation)— − 0.026 (hillshade) + 1.758 (soil type)	0.523	2.842

Elevation and hillshade are observed values. Soil type of BD, BD (d) mean as 0, 1.
SEE; standard error of estimate

Table 4 Analysis of variance

Source	df	SS	F
Regression	3	63.304	7.837
Error	88	8.078	
Total	91		

Table 5 Standardized partial correlation coefficient of variables

Variable	Standardized partial correlation coefficient	
Elevation	−0.368	**
Hillshade	−0.282	**
Soil type	0.330	**

**significant (at 1% level)

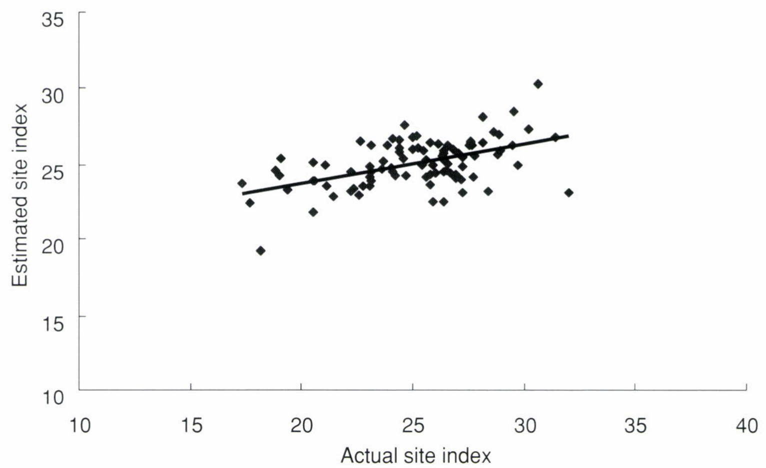

Fig. 3 Relationship between actual site index and estimated site index

and other prefectures. In the score table of Niigata prefecture, elevation showed a high coefficient of partial correlation with site index next to soil type. Thus, the soil type and elevation selected in this study support the previous reports. NISHIZAWA *et al.* (1965) reported that the coefficient of correlation between soil type and elevation was 0.244 (calculated by Quantification Method Ⅰ). At a higher elevation, humus does not decompose, and it shows a correlation with the soil type. In the present data, soil type is given by dummy variables.

On the other hand, there are some reports on the method of site index estimation without using information on soil type. MITSUDA *et al.* (2001) estimated side index of larch using topographical factors obtained from GIS. The factors selected by stepwise procedure were average slope gradient, degree of exposure and shading. TERAOKA *et al.* (1991) determined the effective water storage capacity, degree of exposure and effective relief as the moisture environment of forest, and obtained site index using these factors as independent variable. The multiple correlation coefficient of the estimation was 0.832. IVERSON *et al.* (1997) estimated moisture retention of forest from the amount of hillshade. The amount of hillshade is a measure of the intensity of solar radiation, and is used to estimate the dryness of slope. Thus, the cases of analyses using the factor obtainable from GIS are increasing. However, the areas investigated by IVERSON *et al.* (1998), MITSUDA *et al.* (2001) and TERAOKA *et al.* (1991) were 475, 3,735 and 150ha, respectively, and were small watersheds.

Topographic factors might be more effective than soil type for small watershed. It is important to consider the area of the target site when estimating the site index. In the present study, we modeled the site index using data collected all over the prefecture. The objective of the present study was to estimate the soil index of the area where the studies on the right tree for the right site had been conducted based on the young stand, using mature stand data. Thus, various kinds of data were collected from all over the prefecture. The multiple regression coefficients were not high in spite of the use of as many as 9 factors. Thus, forming a prediction formula for the whole prefecture is difficult. In this study, soil type was selected as an effective factor and the previous studies on the right tree for the right soil also showed the soil type as an effective factor. In all prefectures of Japan, soil type has already been mapped based on the results of the studies on the right tree for the right site. Digitization of these soil maps for the use of GIS may make it easy to use the soil type as a factor for estimating site index, and increase the accuracy of the estimate.

In this study, we examined snow depth as a meteorological factor that influences the growth of Japanese ceder plantation. Precipitation, solar radiation, temperature, etc. also affect the growth of the ceder plantation. However, we examined as many as 92 plots, and we could not form regression equations including multiple meteorological factors. The correlation of site index with meteorological factors other than snow depth will be examined in separate studies.

We showed actual site index of a plot and site index presumed using multi regression on Fig. 3. The tendency for presumed accuracy to decline was showed for the plot with lower site index

CONCLUSION

Among the data obtained from all over Niigata Prefecture, only altitude, soil type and hillshade affected the value of site index, which differed from the results obtained in a small watershed. Soil type is an important factor for predicting site index in the whole prefecture. In Niigata prefecture, site index has been estimated using 9 items (elevation, Aspect, Slope, Soil type, Deposition type, Local topography, Surface horizon geology, Snow depth, Region) by Quantification theory Ⅰ. But the data of the investigation on mature stand suggested the necessity of reappraisal of the items.

ACKNOWLEDGEMENT

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Article

Differing Perceptions of Japanese Black Bears in Urban and Rural Japan

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ABSTRACT

The resolution of conflict between humans and the Japanese black bear (*Ursus thibetanus japonicus*, hereafter "black bear") has become an issue on the Japanese islands from Honshu south. On the other hand, several local populations have been listed as endangered, and efforts are being made to maintain a stable population. In 1999, Japan's Wildlife Protection and Hunting Law was partially amended to reflect the environmental concerns of city dwellers (who account for the vast majority of Japanese), and in response to changes in wild populations of birds and animals including bears. The Specified Wildlife Conservation and Management Plan wildlife management system was implemented with these legal amendments. However, the majority of damage caused by bears affects rural areas. Here, bears are exterminated by residents who have experienced damage caused by bears out of fear of further crop depredation or physical harm to humans. Thus, human-black bear conflict resolution measures are themselves conflicted between policies and practice in the field. Policies that often place the entire onus of damage control measures on rural residents tend to abet or encourage extermination because it is the simplest and most effective method of bear control. In the hopes of alleviating some of the conflict between policy and practice and developing new damage control measures, this paper presents the results of a questionnaire distributed to urban and rural residents of Morioka, a city in Iwate prefecture. This survey revealed the existence of an urban-rural gap in experience with and attitudes about bears. Country dwellers were more likely to have experience with bears and to support their capture and slaughter to prevent crop depredation. These differences of experience and opinion suggest that a new policy must be created to support rural crop depredation control measures. Additionally, a policy should be implemented to encourage understanding of these measures and increase mutual understanding between urban and rural populations.

Keywords: Japanese black bear, human-black bear conflicts, urban and rural, wildlife management, questionnaire

INTRODUCTION

In recent years, the resolution of conflict between humans and bears has become an issue in Japan. In fiscal 2004, crop depredation damages are estimated at 20.6 billion yen. Of this, 54% (11.1 billion yen) was caused by monkeys, deer, and wild boars. While damage caused by bears was a comparatively small 400 million yen, bears are given attention as the only domestic animal with the potential to inflict harm on humans (Ministry of Agriculture, Forestry and Fisheries of Japan, 2006).

Maita (1998) lists Japan's black bear population at about 13,000. The bear populations of the Shimokita Peninsula, the Kii Peninsula, the Kyushu Region, the mountains of Shikoku, the western Chugoku Region, and the eastern Chugoku Region have all been designated locally threatened populations (Japan Integrated Biodiversity Information System, 2006). Despite this, from 2002 to 2004 a total of 1300 black bears were killed annually (Ministry of the Environment, 2006). In this light, it is difficult to be optimistic about Japan's black bear population.

Japan is an urban society: nearly 70% of all Japanese are city dwellers (Japan Association of City Mayors, 2006). In this context, wildlife conservation efforts are focusing on the preservation of biological diversity, and the promotion of human interaction with nature (Wildlife Conservation Research Association, 2001). The Wildlife Protection and Hunting Law were amended and the Specified Wildlife Conservation and Management Plan system implemented in

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1999 in response to these societal needs. These policies promote scientific, well-planned wildlife management and long-term conservation and breeding of local populations. Japan's prefectural governors judge the status of wildlife populations and plan conservation measures for which the Ministry of the Environment provides subsidies. This is evidence that wildlife management promotion is being carried out at the policy level.

However, human-bear conflicts occur primarily in rural, agricultural areas affronting or overlapping bear habitat. Unlike their urban counterparts, residents of these areas are forced to shoulder most of the financial and practical burden of carrying out damage prevention and control measures. Aversive conditioning is a promising non-lethal wildlife management method that does not require bear trapping, but is not popular with local residents because of misgivings about allowing bears known to have caused damage (however minor) to roam free in and around human settlements. Thus, the capture and extermination of bears continues in the field. This suggests that there is a gap between national policies and local responses. Japan's majority urbanites are increasingly expressing environmental concerns, including a desire for a stable bear population. This national mood is sure to place some of the burden on residents of rural areas where bears live.

Additionally, the role of municipalities in Japan's Wildlife Protection Project Plan (in which the Specified Wildlife Conservation and Management Plan is subsumed) is not clearly defined. However, Iwate prefecture's black bear management plan assigns each municipality the role of taking measures appropriate to its individual situation, and working to increase public awareness of the plan itself and of bears (Iwate Prefecture, 2003). The plan also states that it is desirable that damage prevention and control measures be carried out primarily at the municipal level (NAGASAKA and YAMAMOTO, 2005). However, to effectively implement this plan, discourse is necessary between such diverse players as municipal administrations, hunting clubs, and agricultural cooperatives. The results of these discussions must be reflected in actions in the field. Municipalities need to improve their response policies based on these outcomes. Human-black bear conflicts must be resolved through appropriate management that grows out of this dialogue between decision-making bodies and parties in the field.

Municipal policies must reflect the will of their constituencies. Recent municipal mergers have increasingly led to municipalities with mixed urban-rural populations; clarifying the differences of opinion and attitude between these two groups will positively affect policy decisions. It is also relevant to the creation of new community damage prevention and control measures. Until now the implementation of such measures has been the responsibility of those people living in rural areas bordering bear habitat. However, insufficient human and financial resources, and the weakening of community bonds has made it difficult to cooperate in preventing bear damage. It is unclear to what extent city residents understand this situation.

FUJIWARA (2000) reported on the difference in residents' opinions between hamlets in the city of Tono, Iwate that suffered from bear damage and those that do not. KAMEDA and MARUYAMA (2003) investigated the differences between areas of Hokkaido's Oshima Peninsula which experienced frequent brown bear (*Ursus arctos*) encounters and those that did not. However, this paper is the first study to examine the urban-rural attitude gap. It is based on the results of a survey of urban and rural residents of Morioka, Iwate.

STUDY AREA

The study area was the city of Morioka, in Iwate prefecture, Japan (Fig. 1). The city of Morioka merged with its northern neighbor, Tamayama, in January, 2006, but this study was performed prior to the merger and does not include the Tamayama area. Morioka is the prefectural capital. It covers 489km^2 in the center of Iwate, It lies between the Kitakami Highlands on the east and the Ou Mountain Range on the west. The Kitakami, Shizukuishi, and Nakatsu rivers converge near the center of urban Morioka. This urban zone is surrounded by agricultural land, but particularly in the southern plains of Morioka that farmland is being increasingly developed into residential areas.

Of the 144,830 working residents of Morioka aged 15 or more, 4,908 (3%) are engaged in the primary industries of agriculture, forestry, and fisheries.

Fig. 2 shows the number of bear sightings and incidents of damage in Morioka since 1994. However, because this is the

Fig. 1 Location of Morioka, Iwate

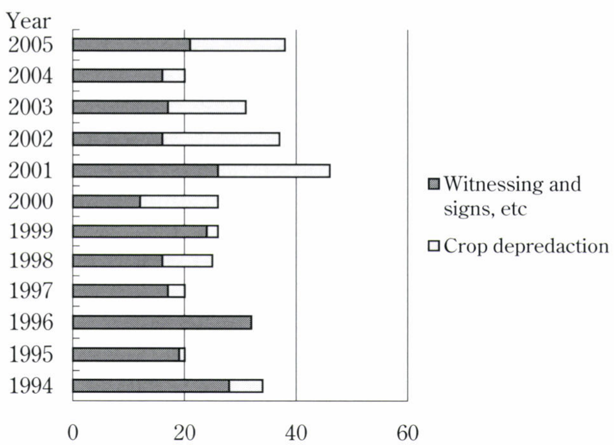

Fig. 2 Bear sighting and damage in Morioka (based on materials obtained from Morioka city employee)

Table 1 Characteristics of study areas

	Characteristics			
areas	Adjacent to bear habitats	Damage[a]	Go out[b]	Agriculture[c]
D	×	×	×	×
C	○	×	○	×
B	○	○	○	○
A	○	○	○	○

a. It is shown whether damage by the bear is or doesn't exist.
b. It is shown whether the bear infests.
c. Whether the farmer is a lot or few is shown.

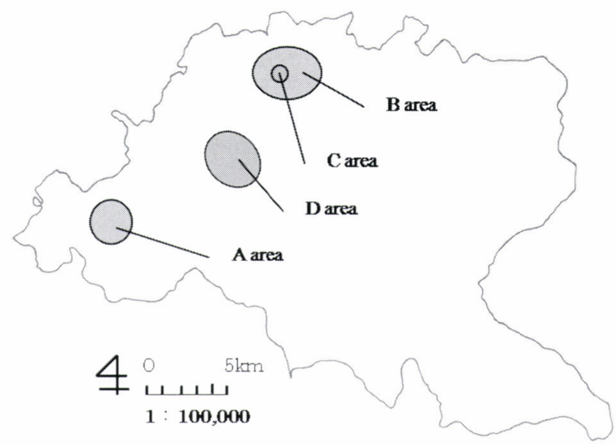

Fig. 3 Location of study areas

first year for which data were available, this figure is not sufficient to determine when sightings and damage began to increase. However, testimony from hunting club members, municipal employees involved in bear issues, and others working in the field, and the fact that Morioka's first bear attack was recorded in the area B in 2000 suggest that bear sightings and damage may have begun increasing in the mid-1990s. Additionally, the number of reported sightings and incidents of damage is changing each year. Apples, field corn, and sweet corn have become the primary targets of bear damage.

The questionnaire was handed out to residents of four areas within Morioka. These four areas are area A, area B, area C, and area D in the city. Consideration to urban resident and rural resident's bears for the sake of comparison, residents of area A and B were made rural resident's representative, and residents of area C and D were selected as urban resident's representative. Their characteristics are listed in Table 1 and their locations in Fig. 3.

The area A overlaps the Ou Mountains in the southwest of Morioka. Rice paddies are plentiful, and there are apple orchards on the hills. Though no attacks on humans have been reported in A, the orchards experience damage in the form of apples consumed and branches broken. Several orchard owners have formed a cooperative and installed electric fencing to ward off the bears. The area has 209 households totaling 675 residents.

The area B overlaps the Kitakami Highlands in the northeast of Morioka. The area produces feed crops, which are significantly depredated by bears. B. is also the location of Morioka's only reported bear attack, which occurred in 2000. The area has 540 households totaling 1,480 residents.

The area C also overlaps the Kitakami Highlands in the northeast of Morioka. This is a new development inside the area B. It was built two decades ago, and most residents commute to jobs in the city center. Bear sightings are comparatively frequent, as this development was constructed in existing bear habitat. The area has 1,026 households totaling 3,147 residents. Both the area C and B are surrounded by forest land. Bear bells have been installed by school commuting routes in both the area C and B by local organizations and PTAs. Children are encouraged to wear their own bear bells. These efforts are independent and unique to these areas.

The area D is located in the center of urban Morioka and has no history of bear sightings. The area has 2,801 households totaling 4,966 residents.

METHODS

With the cooperation of local governance organizations, one questionnaire was distributed to each household in each of the four areas in October 2005. Sentences of the outline explanation were affixed, I asked chairmen of the autonomy organization, and it distributed it to each house. The number of households exceeds that of questionnaires because the local organizations were not always aware of every household counted in city demographic data. The survey included an explanation of its purpose (to assess the general attitude of residents toward bears), and a return envelope. Questionnaires were returned by mail in the middle of November 2005.

Table 2 Questionnaire distribution

District	A	B	C	D	All
The number of distribution	165	593	942	750	2450
The number of collection	75	226	344	231	876
Collection rate (%)	45.5%	38.1%	36.5%	30.8%	35.8%

Distribution and response rates are shown in Table 2. Note that only one local organization was approached in the area D.

The survey was composed of nine question areas.

1) Experience with hunting, capturing and killing, encountering, or being the victim of bears
2) Whether individual enters mountain areas and if so, why and with what, if any, protection
3) Protective measures taken in agricultural areas
4) Protective measures taken in residential areas
5) Estimated incidence of bear-caused damage and captures/killings
6) Thoughts about bear populations and sightings
7) Desired response to bear sightings by sighting type
8) Overall desired response to bears
9) Subjects' gender, age, and occupation

Most questions were multiple choice; several allowed subjects to comment freely. The survey questions and answers were based on those of Kameda and Maruyama (2003). The following section discusses the results of questions in categories (1), (7), and (9).

RESULTS

Survey Results

Subjects' gender, age, and occupation

All respondents were 56.7% male, 40.7% female. 2.6% of subjects did not respond to this question. The age of respondents was as follows: 0.34% under 20, 4.8% 20-29, 6.0% 30-39, 21.4% 40-49, 31.0% 50-59, 18.9% 60-69, 12.6% 70-79, and 3.0% over 80. 1.9% of subjects did not list their ages. More than 70% of respondents were aged 40-69. Both age and gender ratios seem explicable by the fact that one questionnaire was distributed per household, and it is likely that in many cases the head of each household responded.

4.7% of respondents listed primary industries as their occupation. 29.2% of area A respondents, 8.4% of B. respondents, 0% of C respondents, and 0.4% of area D respondents made their living in primary industries.

It is assumed that C and D are urban areas, while A and B are rural from character of four areas and the result of the questionnaire.

Table 3 The number of the answers of each question item in the experience of the bear

question[a]	urban	rural
(1)	113	124
(2)	100	124
(3)	50	36
(4)	54	50
(5)	11	25

a. The question item of (1)～(5) is as follows.
(1) seen evidence of bear(s)
(2) seen bear(s) at a distance
(3) encountered bear(s) at close range
(4) seen captured or slaughtered bear(s)
(5) other experience with bear(s)

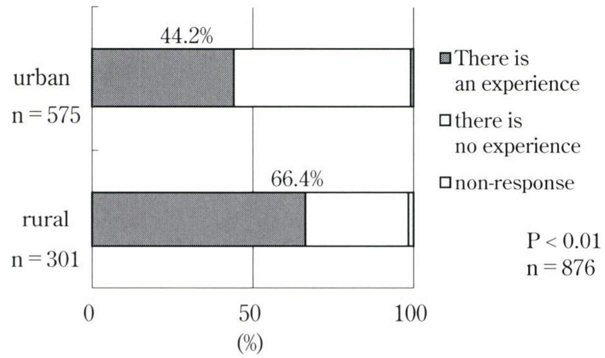

Fig. 4 Experience with wild bears

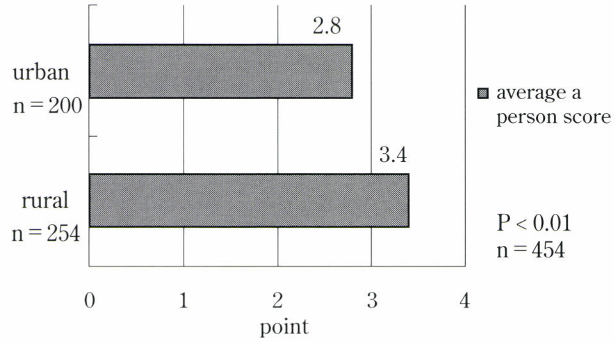

Fig. 5 Average individual experience with wild bears

Experiences with wild bears

Subjects were asked to mark all applicable responses from the following choices: (1) seen evidence of bear(s), (2) seen bear(s) at a distance, (3) encountered bear(s) at close range, (4) seen captured or slaughtered bear(s), (5) other experience with bear(s), and (6) no experience. All responses other than (6) were classified as constituting experience with bears. Subjects marking one or more of these responses were considered to have bear experience. The percentage of respondents from each area falling into this category is summarized in Fig. 4. In rural residents number was 66.4% and in urban residents number was 44.2%. And, the answer of the urban residents and rural residents was done χ^2-test, therefore a significant difference was admitted between those ($P < 0.01$). This clearly indicates that residents of rural areas have more experience with wild bears.

Next, these responses were analyzed to determine the extent of these experiences. Each response was assigned a numerical value based on the immediacy of the experience, as follows. (1) seen evidence = 1pt., (2) seen at a distance = 2pt., (3) encountered at close range = 3pt., (4) seen captured or slaughtered = 4pt., (5) other = 1 pt. With these numbers, the average individual experience score of each resident was calculated. The results are shown in Table 3 and Fig. 5. In rural residents number was 3.4 and in urban residents number was 2.8. And the answer of the urban residents and rural residents was done t-test, therefore a significant difference was admitted between those ($P<0.01$). This confirms that rural residents have had, on average, comparatively more immediate experiences with wild bears.

Experience with bear-caused damage

Respondents were asked about their experience with bear-caused damage. Multiple responses were accepted. The choices were, (1) have been attacked, (2) have sustained property damage, (3) family member(s) or relative(s) have been attacked, (4) family member(s) or relative(s) have sustained property damage, (5) friend(s) or acquaintance(s) have been attacked, (6) friend(s) or acquaintance(s) have sustained property damage, and (7) no experience. All responses other than (7) were classified as constituting experience with bears. Subjects marking one or more of these responses were considered as having experienced bear-caused damage. The percentage of respondents from each area falling into this category is summarized in Fig. 6. In rural residents number was 31.6% and in urban residents number was 9.6%. And the answer of the urban residents and rural residents was done χ^2-test, therefore a significant difference was admitted between those ($P <0.01$). this clearly indicates that residents of rural areas have more experience with wild bear-caused damage.

Next, these responses were analyzed to determine the extent of these experiences of damage. Each response was assigned a number value based on the immediacy of the experience, as follows. For the purposes of this study, physical harm to humans and property damage were assigned the same values: (1) and (2) = 3pt., (3) and (4), = 2pt., (5) and (6) = 1pt. The results are shown in Table 4 and Fig. 7. In rural residents number was 2.1 and in urban residents was 1.3. And the answer of the urban residents and rural residents was done t-test, therefore a significant difference was admitted between those ($P<0.01$). This clearly indicates that residents of rural areas have more immediate experience with wild bear-caused damage.

Table 4 The number of the answers of each inquiry category in damage experience of a bear

question[a]	urban	rural
(1)	1	0
(2)	22	1
(3)	14	5
(4)	21	9
(5)	39	30
(6)	21	14

a. The question item of (1)～(6) is as follows.
(1) have been attacked
(2) have sustained property damage
(3) family member(s) or relative(s) have been attacked
(4) family member(s) or relative(s) have sustained property damage
(5) friend(s) or acquaintance(s) have been attacked
(6) friend(s) or acquaintance(s) have sustained property damage

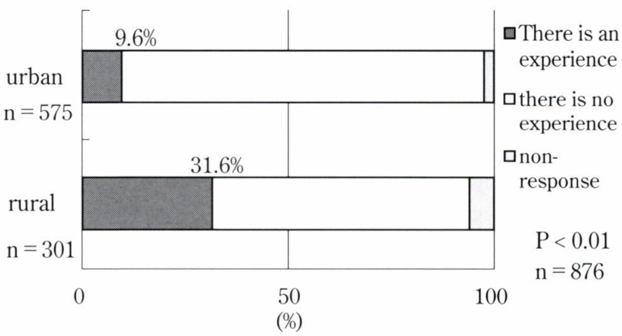

Fig. 6 Experience of bear - caused damage

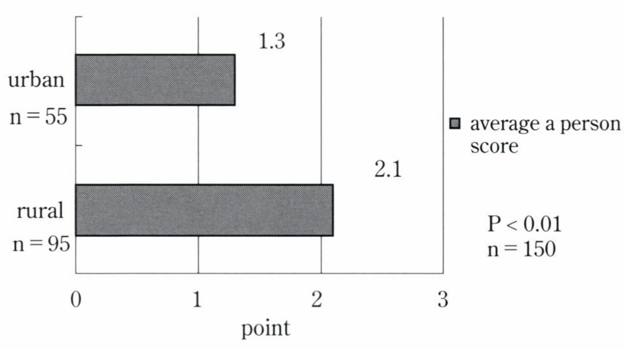

Fig. 7 Average individual experience of bear - caused damage

Desired Response to Bear Depredation of Crops or Livestock

This section discusses responses to some of the questions regarding subjects' desired response to bear sightings by sighting type. Respondents were asked to choose the responses they would like to see in the cases of sightings, crop depredation, and physical harm to humans. These responses were further broken down by the area in which these events might occur: mountains, farmland, and around human habitation. Of particular interest are the desired responses should bears appear in agricultural areas and damage crops or livestock. Respondents selected one of four answers: (1) capture and exterminate, (2) capture and release into uninhabited mountains into which no humans venture, (3) frighten away, and (4) nothing.

Responses (2), (3), and (4) were categorized as non-lethal responses. The results are shown in Fig. 8. In rural residents number was 40.3% and in urban residents number was 24.2%. And the answer of the urban residents and rural residents was done χ^2-test, therefore a significant difference was admitted between those ($P<0.01$). This clearly illustrates a preference in rural areas for lethal response to bear-caused damage.

It was hypothesized that occupation might play a role in respondents' desired responses. Specifically, it was conjectured that residents involved in primary industries might prefer different responses in the case of a bear found depredating crops or livestock in a farming area. As previously mentioned, the percentages of residents in primary industries are 29.2, 8.4, 0, and 0.4 for the A, B, C, and D areas respectively; very few urbanites are involved in agriculture, forestry, or fisheries.

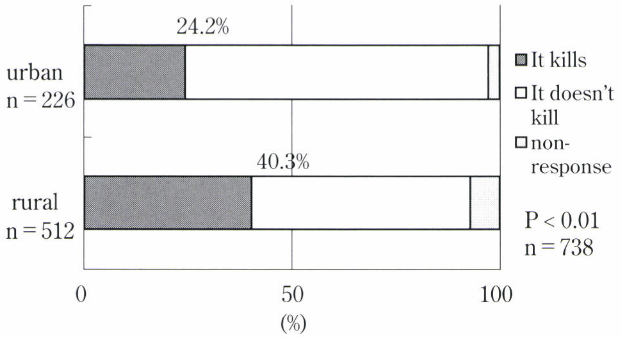

Fig. 8 Desired response to bear depredation of crop or livestock
A note) 138 invalidity answers do not include it

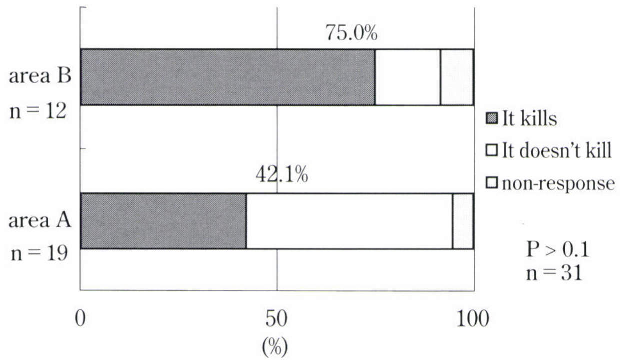

Fig. 9 Capture and kill preference of primary industry workers for bear damage in farming areas

For this reason, the number of rural residents (area A and B) in primary industries who chose capture and extermination as the preferred response to bears causing damage in agricultural areas was examined. The results are shown in Fig. 9. 42.1% of primary industry workers in the area A and 75.0% in the area B chose capture and extermination as their desired response. And the answer of the primary industry workers of area A and area B was done χ^2-test, therefore a significant difference wasn't admitted between those ($P>0.1$). It is thought that it is because the sample was few.

However, the gap between the two rural areas, A and B was seen from Fig. 9. This likely reflects the impact of the 2000 bear attack in B, Morioka's first and only such recorded incident. Mr. N.'s face was mauled by a bear when he encountered a bear on the way to work in his fields. This is presumed to have greatly affected the thinking of primary industry workers in B. Fujiwara notes a similar disparity between the attitudes of rural hamlets which have experienced bear attacks and those which have not (FUJIWARA, 2000).

DISCUSSION

The questionnaire results revealed a significant gap between the experience and attitudes of urban and rural residents.

The experience of rural residents with wild bears was shown to be greater in quantity and degree than that of urban residents. This held true for damage inflicted by bears as well. This suggests that rural residents' experiences with both wild bears and the damage they cause are more immediate and personal than that of city dwellers.

A great divide was also observed in desired responses to bear sightings and crop or livestock depredation in farming areas. Rural residents were comparatively more likely to prefer lethal responses than were their urban counterparts. More than an urban-rural divide, this reflects the importance accorded to incidents of crop depredation. It appears that city residents tend not to see crop damage as a sufficient reason to employ lethal force.

Based on the hypothesis that this difference was influenced by occupation (whether subjects were involved in primary industries), the number of agriculture, forestry, and fisheries workers who indicated a preference for lethal methods of bear control was examined. With no primary industry workers in the C and D areas, only responses from A and B were examined. The majority of primary industry workers in these two areas were found to have selected lethal methods as the desired response. This suggests that the comparative weight they place on crop depredation is because of its immediate impact on their lives and livelihoods.

However, there exists a large disparity even between these two rural areas: 75.0% of these area B respondents favored lethal methods as opposed to only 42.1% in A. This is most likely due to the serious facial mauling of a man heading to work the fields in the area B. Fujiwara examines the influence of bear attacks on rural hamlets (Fujiwara, 2000). The mauling of a fellow worker on the job would certainly have strengthened the feelings of these primary industry employees about the need for lethal methods.

All of this indicates that city dwellers must be better informed of the realities of bear-caused damage, including crop depredation. This would lead not only to bear conservation, but also to a better understanding by urbanites and consequent reflection in policy of the need to support rural residents. Specifically, this support would include such things as indemnifying crop depredation, technical support, and the dispatch of experts into the field. This should make it possible to alleviate the gap between national policy and ground-level practice in wildlife management.

Additionally, mutual understanding between urban and rural residents of the same municipality must be fostered in municipal decision making. The city of Morioka exemplifies a municipality with both rural and city areas, and the need to match bear response to the characteristics of both zones and groups of residents. The same can be said of different rural communities within the same municipality: consensus building and appropriate management based on the experience with bears and unique character of each area is necessary to formulate and implement new community-level damage prevention and control measures.

CONCLUSIONS

A significant gap exists between the experience and attitudes of urban and rural residents. Rural residents have more experience with bears, and tend to favor lethal measures of bear-caused damage prevention more than city dwellers.

To overcome these differences and eliminate the gap between policy and practice, new policies to support rural crop depredation control measures must be implemented, and mutual understanding built between urban and rural residents.

Municipalities must provide opportunities for urbanites to understand the situation rural residents face. This first step to mutual understanding should be followed up with a forum to further promote it. The forum would be a chance for rural and urban residents to recognize their differences and create new bear-caused damage prevention measures through discourse and dialogue.

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