IEA Bioenergy Workshop, Tasks 29, 31, and 39
Biofuels and Bioenergy: Challenges and Opportunities

A GIS-based analysis on the relationship between the annual available amount and the procurement cost of forest biomass in Japan

Takuyuki Yoshioka[1], Rin Sakurai[2], Kazuhiro Aruga[3], Hideo Sakai[2], Hiroshi Kobayashi[2], and Koki Inoue[1]

[1]Nihon University, Japan

[2]The University of Tokyo, Japan

[3]Utsunomiya University, Japan

August 29th, 2006
Vancouver, BC, Canada

Introduction (1)

The Japanese forest industries have been depressed for a long time.

There are so many regions where forestry is not mechanized and the logging cost cannot be reduced.

On the other hand, forest biomass attracts a great deal of attention in such regions.

Introduction (2)

The energy utilization of forest biomass is expected to contribute to:

→revitalizing the forest industries.

→maintaining the relevant ecological, economic, and social functions of man-made forests, but many of which are behind in tending.

Introduction (3)

In order to utilize forest biomass as energy in a region where forestry is the major source of income, it is crucial to know the relationship between the annual available amount (mass) and the harvesting and transporting cost (procurement cost) of biomass in the region.

Introduction (4)

Feasibility of the energy utilization of forest biomass in a mountainous region in Japan is discussed by analyzing the relationship between the mass and the procurement cost of biomass in the region with the aid of a geographic information system (GIS).

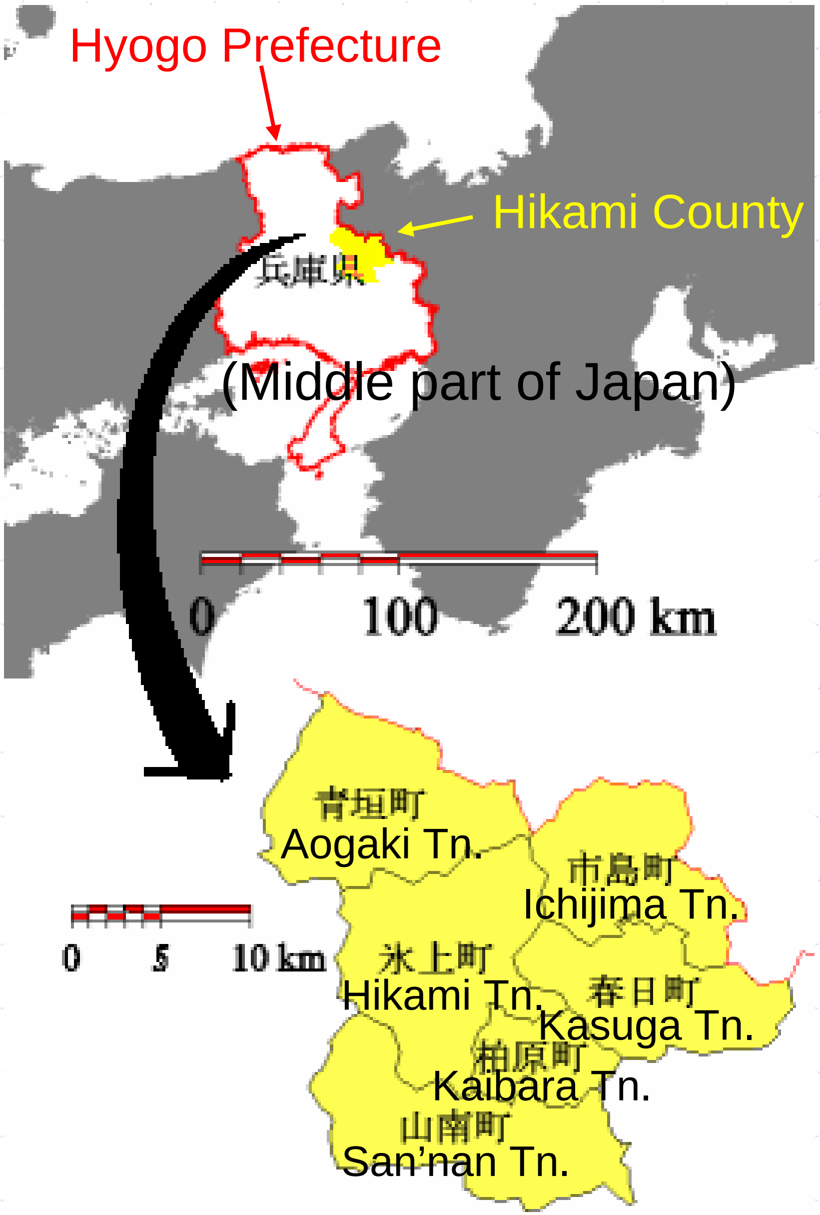
Study Site

Hikami County

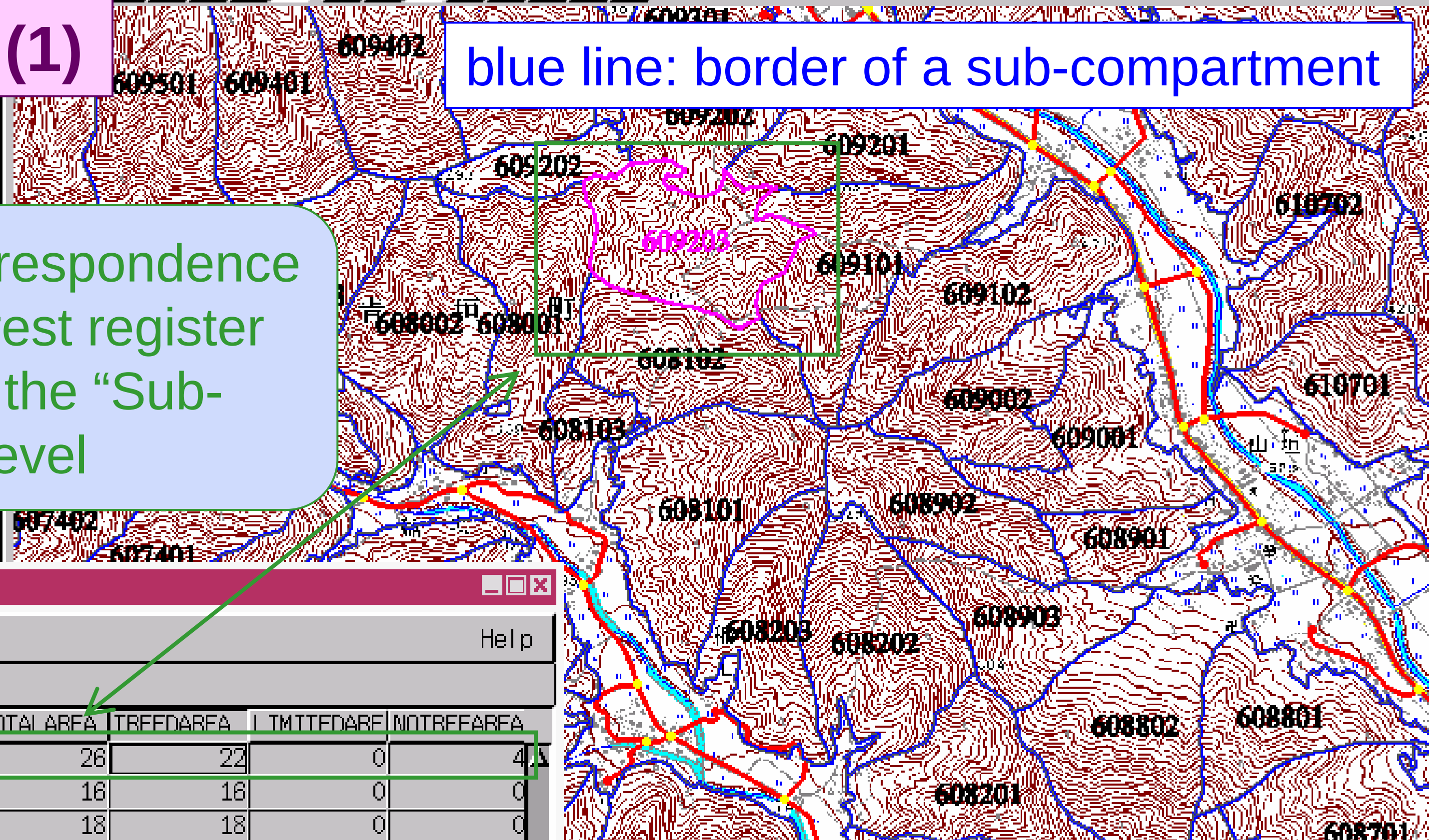
- Gross area: 493.28 km^2
- Population: 72,862
- No. of households: 21,769
- Forest area: 37,202 ha
  (75% of the gross area)
- Man-made forests: 58% of the forest area
- No. of sawmills: 43
- Annual consumption of logs for timber: 78,992 m^3/y

↓

The annual cut volume of logs has dropped almost by 50% in the past five years, and the forest stands behind in tending are increasing.



Materials (1)



One-to-one correspondence between the forest register and the map at the “Sub-compartment” level

aogaki / PolyData / aogaki

RINHAN	SHOUHAN	CODE	TOTALAREA	TREEDAREA	LIMITEDARE	NOTREEAREA
92	c	609203	26	22	0	4
93	a	609301	16	16	0	0
93	b	609302	18	18	0	0
93	c	609303	42	42	0	0
94	a	609401	28	28	0	0
94	b	609402	30	30	0	0
95	a	609501	36	36	0	0
96	a	609601	31	1	30	0
96	b	609602	35	0	35	0
97	a	609701	29	0	29	0
97	b					
98	a					
98	b					

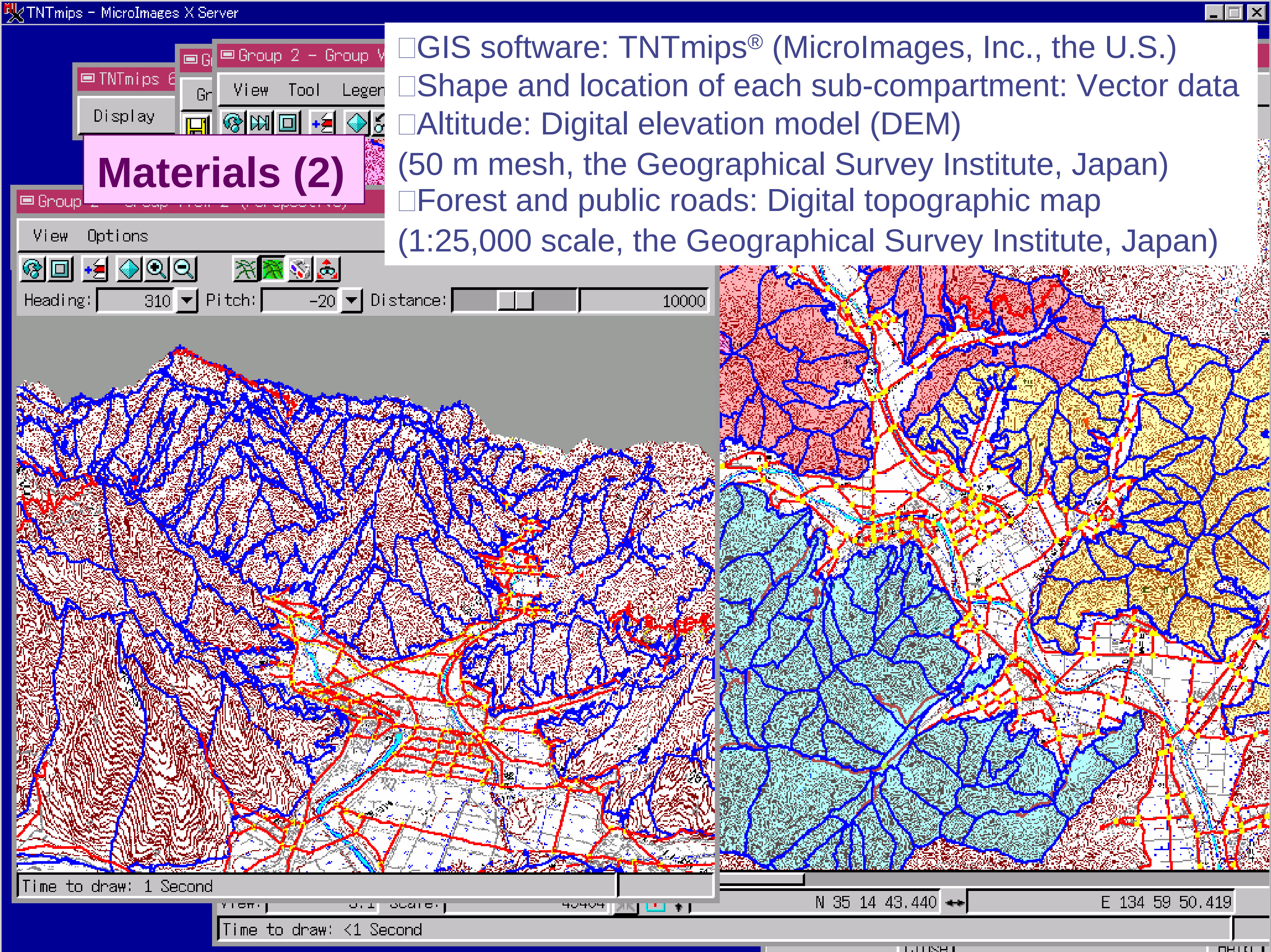
427 of 427 records shown - 1 related to selected elements

Forest register of the region

Compartment, Sub-compartment, ID number, Protection forest or not, Man-made or naturally regenerated, Tree species, Age, Area, Volume

Materials (2)

- GIS software: TNTmips® (MicroImages, Inc., the U.S.)
- Shape and location of each sub-compartment: Vector data
- Altitude: Digital elevation model (DEM)
(50 m mesh, the Geographical Survey Institute, Japan)
- Forest and public roads: Digital topographic map
(1:25,000 scale, the Geographical Survey Institute, Japan)



Methods

Calculation of annual available amount of forest biomass

The annual available amount of forest biomass from each sub-compartment is calculated. Logging residues, thinned trees, and broad-leaved forests are defined as forest biomass.

Preparation for topographic information

The data on the topography of each sub-compartment is prepared.

Classification of harvesting and transporting systems for forest biomass

The systems are classified according to the parts of a tree for energy and the topographical conditions, and the equations for calculating the costs whose variables are slope, skidding/yarding distance, and transporting distance are formed. Mechanization in forestry is supposed to be available.

Calculation of Annual Available Amount of Forest Biomass (1)

The number of sub-compartments in the region is 2,186, and the total growing stock was 7,841,851 m^3 (211 m^3/ha).
→There are 1,113 man-made coniferous forest stands and 398 naturally regenerated broad-leaved forest stands.

↓

These stands are targeted for harvesting logs and energy sources (but the protection forest stands are excluded).

Man-made coniferous forest stands
→Thinning and clearcutting are supposed to be carried out.

Naturally regenerated broad-leaved forest stands
→Selection felling is supposed to be carried out.

Calculation of Annual Available Amount of Forest Biomass (2)

Forest	Age (y)	Operation pattern	Use	Equation (s.v.: Stem volume (m3/ha))	Note
Man-made and coniferous	Over 61	Clearcutting is carried out to all the stands. Trees are limbed and bucked.	Logs are harvested.	Amount (m3/ha) = s.v.× 85/92	□85/92: Ratio of log's volume to stem volume
			Tops and branches are used as energy sources. **= Logging residues**	Amount (tDM/ha) = s.v.× 15/92× 0.40	□15/92: Ratio of tops and branches' volume to stem volume □0.40: Density of a coniferous tree
	31-60	Thinning is carried out in the stands with more than 200 m3/ha growing stocks per hectare with a 20% of thinning rate.	The whole trees are used as energy sources. **= Thinned trees**	Amount (tDM/ha) = s.v.× 20/100× 100/92× 0.40	□20/100: Thinning rate □100/92: Ratio of the whole trees' volume to stem volume □0.40: Density of a coniferous tree
Naturally regenerated and broad-leaved	Over 31	Selection felling is carried out at a 30-year interval cycle.	The whole trees are used as energy sources. **= Broad-leaved forests**	Amount (tDM/ha) = s.v.× 100/80× 0.56	□100/80: Ratio of the whole trees' volume to stem volume □0.56: Density of a broad-leaved tree

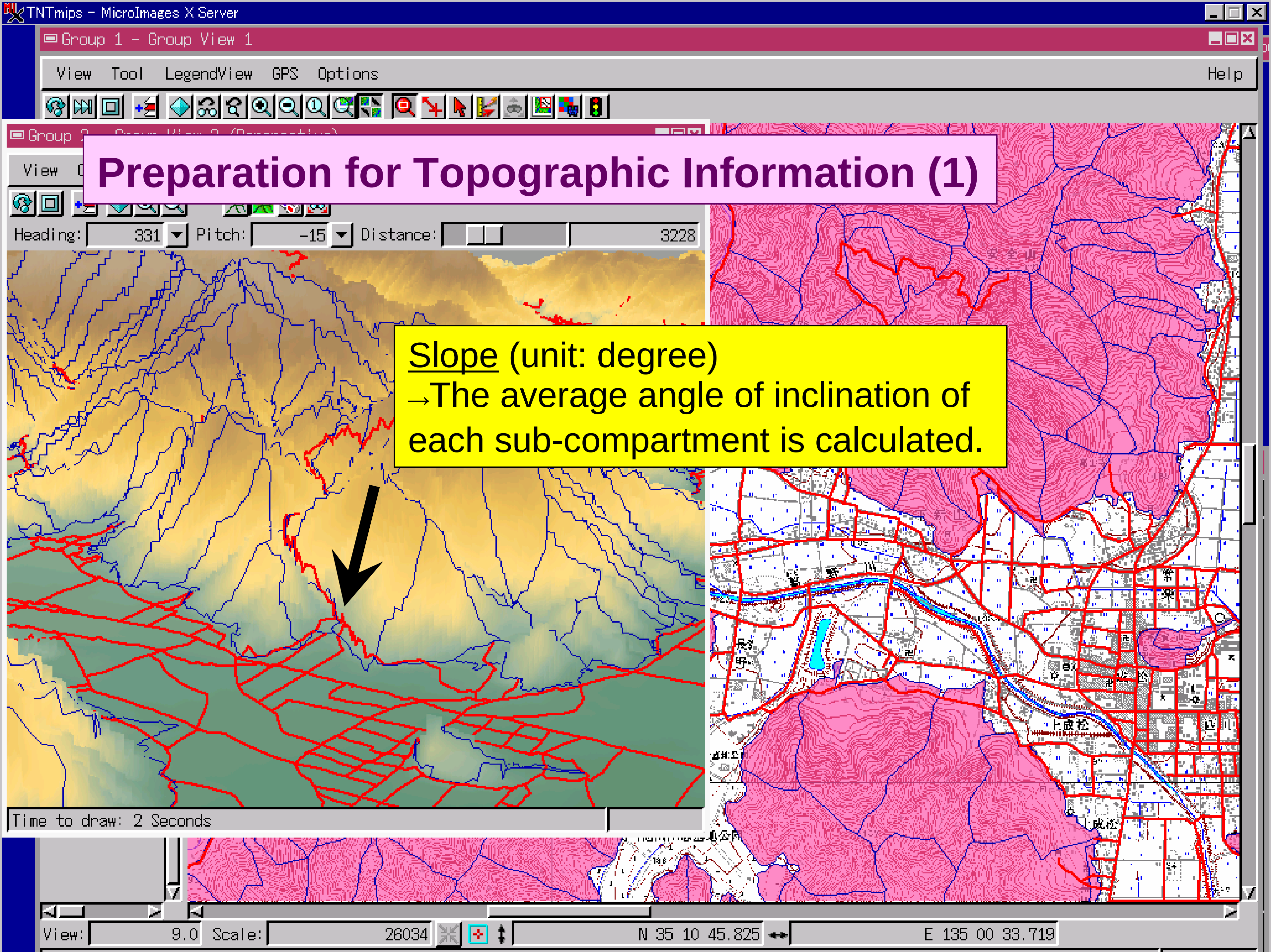
Forest biomass

The annual cut volume of the forest was supposed to be the same as the annual increment, so the cutting cycle was calculated as 9.2016 years.

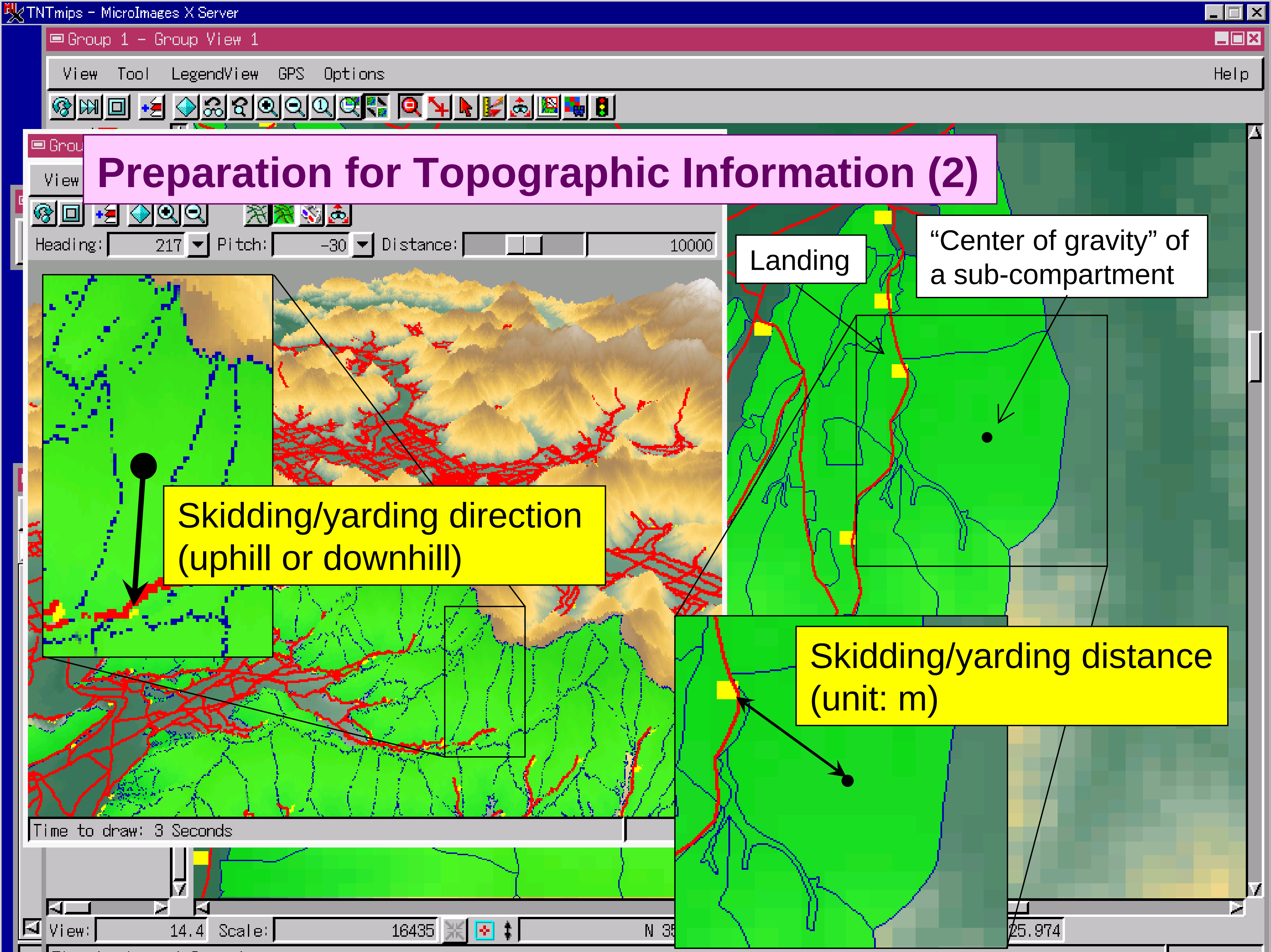
By applying the table to the forest register and considering the cutting cycles of coniferous and broad-leaved forests, the annual available amount of forest biomass from each sub-compartment is calculated,

Preparation for Topographic Information (1)

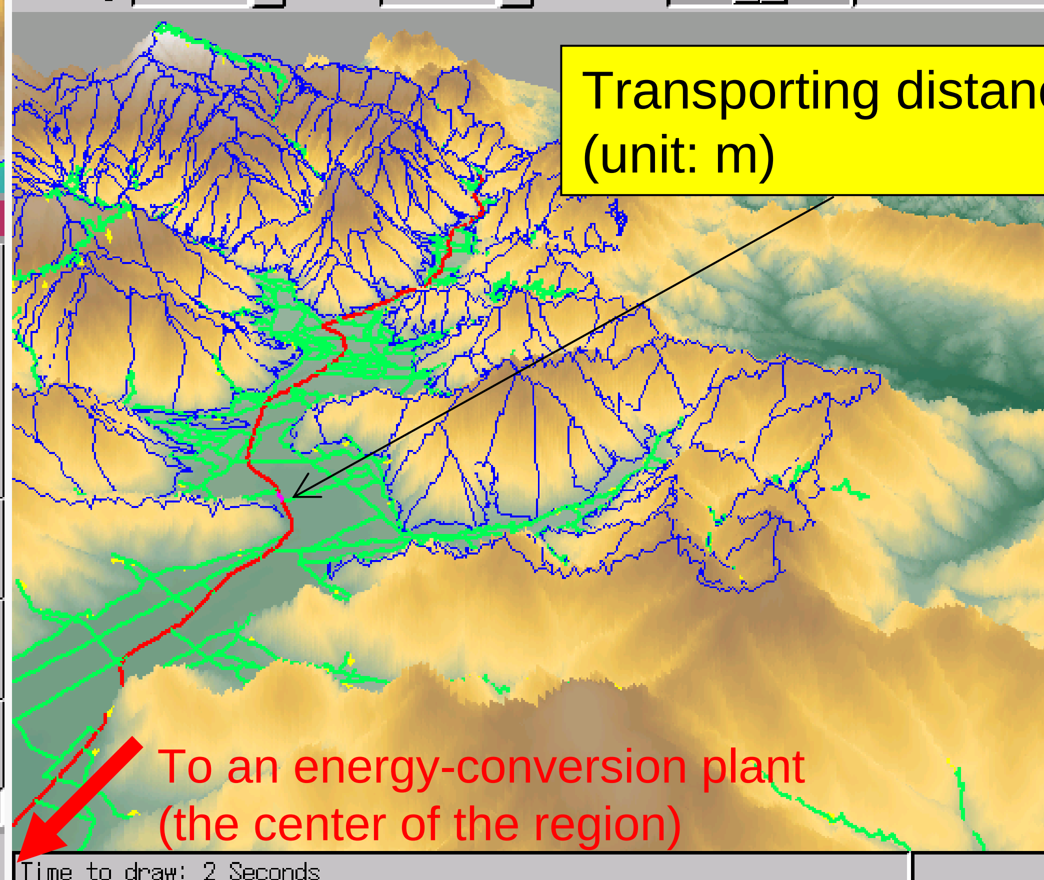
Slope (unit: degree)
→The average angle of inclination of each sub-compartment is calculated.



Preparation for Topographic Information (2)



Preparation for Topographic Information (3)

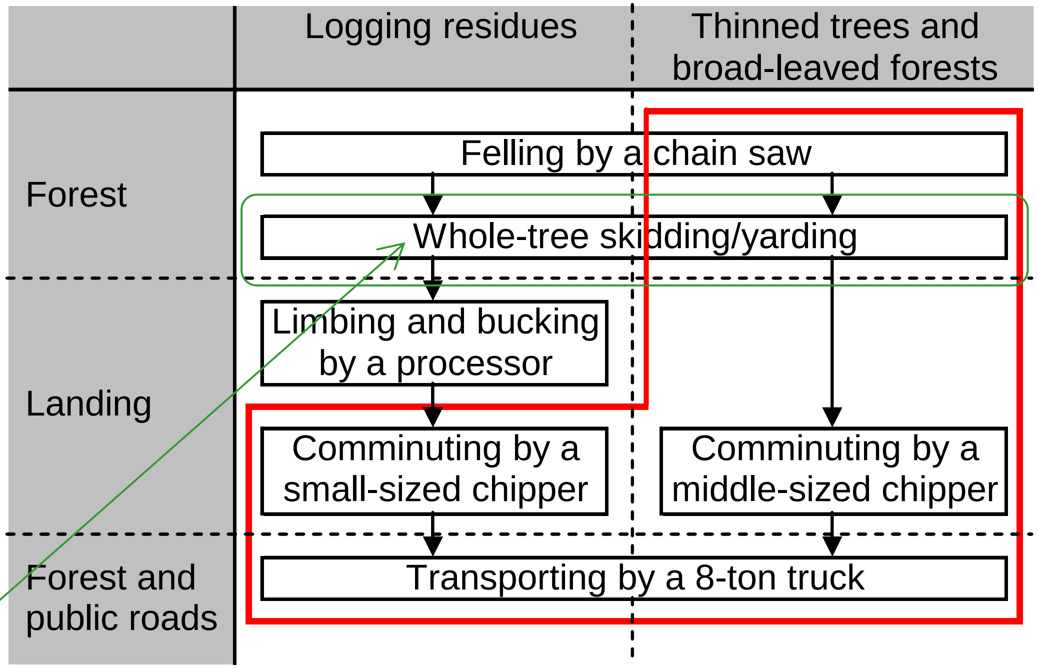


The following data on the topography of all the sub-compartments are prepared.

- Slope
- Skidding/yarding distance
- Skidding/yarding direction
- Transporting distance

Classification of Harvesting and Transporting Systems for Forest Biomass (1)

According to the parts of a tree for energy (logging residues or the whole tree), harvesting and transporting systems for forest biomass are classified into two types.



Processes inside the red line are considered when harvesting and transporting costs are calculated in this study.

The machine for skidding/yarding is usually decided according to the topographical conditions.

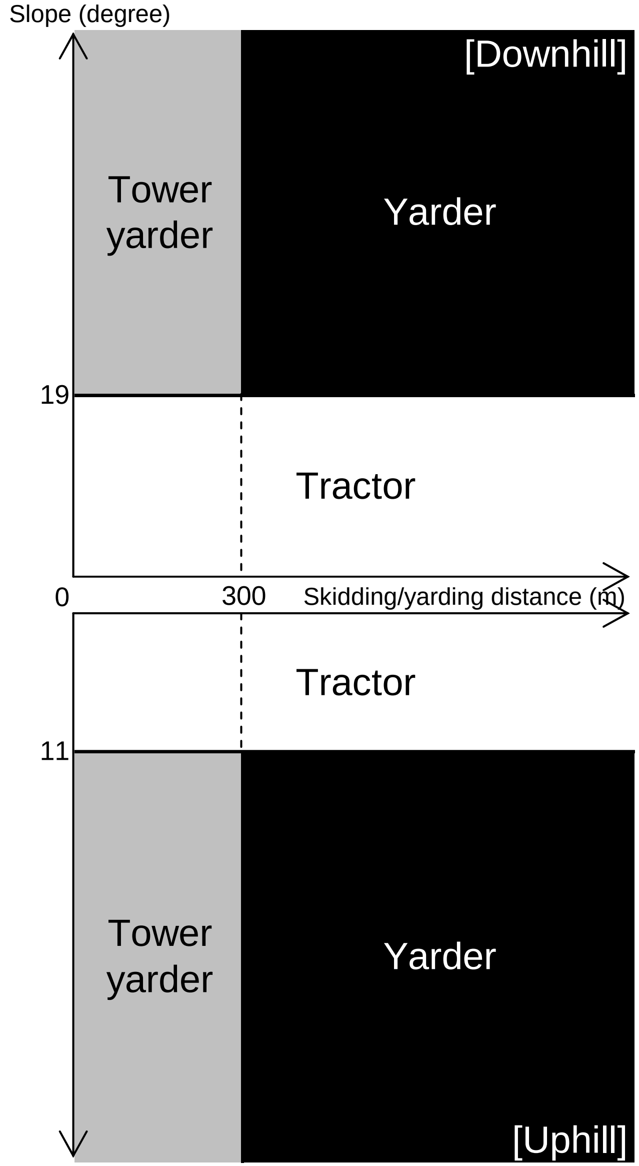
Classification of Harvesting and Transporting Systems for Forest Biomass (2)

Skidding/yarding machines are classified according to the topographical conditions.

↑

Tractors (skidders), tower yarders (mobile yarders), and yarders are to be used for the skidding/yarding process.

- Slope (degree)
- Skidding/yarding distance (m)
- Skidding/yarding direction (uphill or downhill)



Classification of Harvesting and Transporting Systems for Forest Biomass (3)

According to three types of biomass resources (logging residues, thinned trees, and broad-leaved forests) and three types of skidding/yarding machines (tractor, tower yarder, and yarder), nine equations for calculating the costs whose variables are slope, skidding/yarding distance, and transporting distance are formed.

$$\text{Cost [US\$/tDM]} = f_{ij}(d, L_{\mathrm{SY}}, L_{\mathrm{T}})$$

i: biomass resources
(logging residues, thinned trees, broad-leaved forests)
j: skidding/yarding machines
(tractor, tower-yarder, yarder)
d: slope (degree)
L_{SY}: skidding/yarding distance (m)
L_{T}: transporting distance (m)

By applying the topographical data on each sub-compartment to the equations, the procurement costs of forest biomass from all sub-compartments in the region are calculated.

Results: Annual Available Amount of Forest Biomass

Biomass resources	Number of Sub-compartments	Amount (tDM/y)	Cut volume of logs (m3/y)
Logging residues	120	4035	57162
Thinned trees	637	27854	□
Broad-leaved forests	266	20317	□
Total	1023	52206	57162

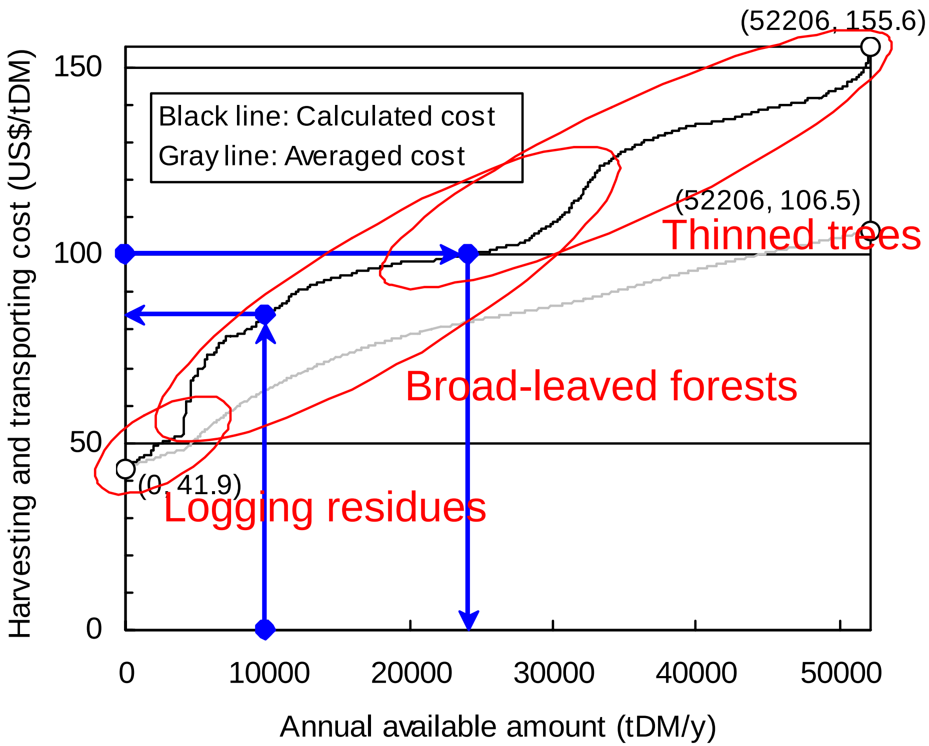
- About half of the sub-compartments in the region are targeted for harvesting logs and energy sources.
- At least 143 tDM of biomass (= 52206 [tDM/y] / 365 [d/y]) can be supplied to an energy-conversion plant every day.
- 57,162 m^3/y of the cut volume of logs corresponds to 72% of the annual consumption of logs for timber in the region.
- The total amounts of logs and energy sources to be harvested are enough to introduce large efficient forestry machines.

Results: Relationship between the Mass and the Procurement Cost of Forest Biomass (1)

Logging residues are the cheapest, followed by broad-leaved forests; thinned trees are the most costly.

In this study, logging residues are regarded as by-products in logging operations. Therefore, the procurement costs of the residues are calculated by considering only the chipping and transporting processes, and are the cheapest.

Although the procurement cost of thinned trees is roughly the same as that of broad-leaved forests per cubic meter, broad-leaved forests are cheaper than thinned trees in the figure because of the higher bulk density of a broad-leaved tree than that of a coniferous tree.



Results: Relationship between the Mass and the Procurement Cost of Forest Biomass (2)

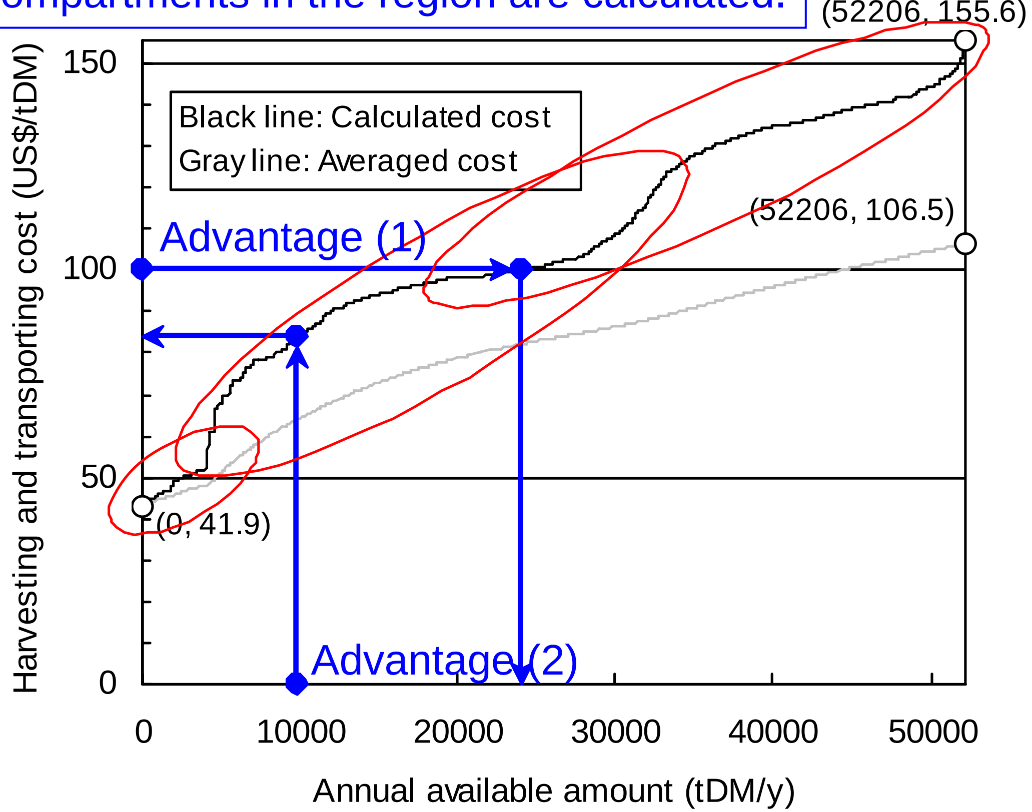
Advantages

(1) When an energy-conversion plant puts the upper limit of a purchase price of biomass, the annual available amount at the plant can be determined.

(2) When the annual amount of biomass necessary is set up, the plant can determine the ceiling on a purchase price.

(3) In both (1) and (2) above, the relationship can contribute to drawing up an operational planning.

Advantage (3)
→The procurement costs from all sub-compartments in the region are calculated.



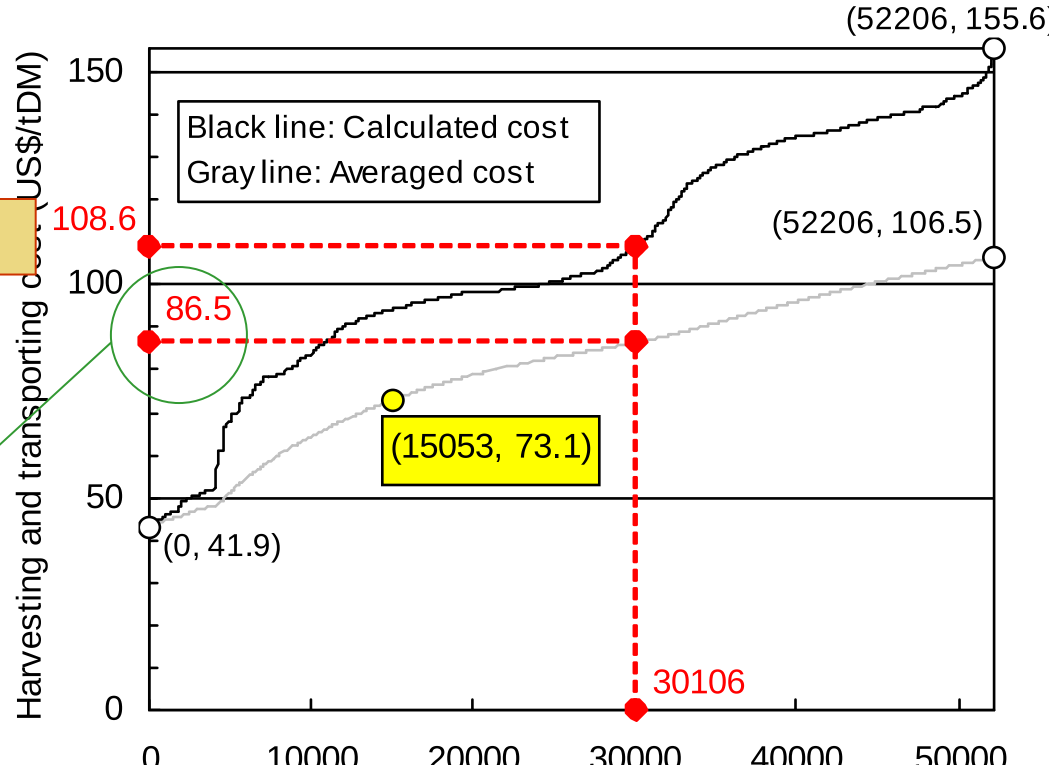
Results: Relationship between the Mass and the Procurement Cost of Forest Biomass (3)

The plan to harvest and transport biomass from the sub-compartments whose costs are cheaper than 108.6 US$/tDM can be laid out.

equivalent to 141 US$/MWh$_e$

↓

From the viewpoint of cost, it seems to be difficult to utilize forest biomass as an energy resource in the region because the unit price of electricity per MWh$_e$ in Japan is 148 US$/MWh$_e$.



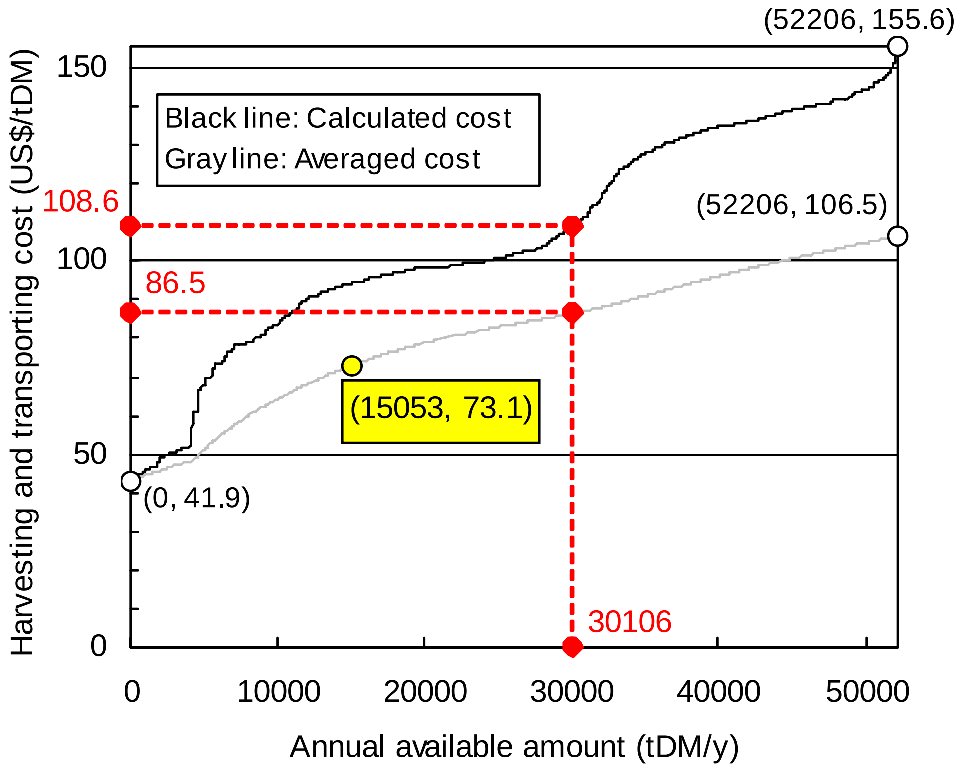
Power-generation plant
(Net power output: 3 MW, thermal efficiency: 12%, operating rate: 70%)
→The plant will cover 5,400 households, i.e., 24.8% of the households in the region.

Results: Relationship between the Mass and the Procurement Cost of Forest Biomass (4)

In addition to the forest biomass discussed in this study, it would be realistic to utilize mill residues, wood-based waste material, and trimmings of park trees, roadside trees, and garden trees together.

If half of the amount of biomass necessary for the supposed plant (15,053 tDM/y) is covered by mill residues, wood-based waste material, and trimmings generated in the region, the averaged cost of forest biomass will be reduced to 73.1 US$/tDM.

Many of the mill residues, the wood-based waste material, and the trimmings can be obtained free of charge, so the reduction in the procurement cost of biomass will be greater on the whole.



Conclusions

Logging residues (the annual available amount was 4,035 tDM/y) were the cheapest, followed by broad-leaved forests (20,317 tDM/y); thinned trees (27,854 tDM/y) were the most costly.

The relationship between the mass and the procurement cost of forest biomass in the region could contribute to drawing up an operational planning.

In addition to forest biomass, it would be realistic to utilize mill residues, wood-based waste material, and trimmings generated in the region together.

Thank you very much for your attention!