

## CHAPTER 6

### DISCUSSION – FOR OPERATIONAL IMPLIMENTATION OF REMOTE SENSING FOR THE SUSTAINABLE FOREST MANAGEMENT

In the previous three Chapters, the author analyzed the winter satellite images of boreal forests and the forest structures taken within the images, and proposed some prototype models, which were supposed to be implemented for the operational forest inventory and monitoring of the boreal forests, using remote sensing. In this Chapter, firstly the results will be generalized and discussed according to the five conditions proposed in Chapter 1. Then, the role of remote sensing in the era of the new forest management concepts will be discussed.

#### 6.1 The Methodologies Describing the Current Forest Condition by Stand Parameters Familiar for Foresters

In Chapter 3, it was found that the occurrence of cut and the stand age after cut could be clearly estimated by a time series of winter satellite images in the Russian Far East. It was also shown that on a single image the regeneration stage for a couple of decades after cut was well explained by the Tasseled Cap's Wetness index on a summer image. In Chapter 5, it was found that the above-ground biomass, the basal area, and the mean diameter of the larch stands in Central Yakutia were relatively well estimated by a winter satellite image. They were the stand parameters that the foresters were familiar with in their activities on the ground.

The stand parameters familiar for the foresters are often the present values of stands that can be measured directly on the ground, however, it has been rather difficult for remote sensing to estimate them at the densely foliated forest vegetation. The researchers have taken effort for decades to measure such parameters, however, the results were degraded by noises such as canopy forest floors (GEMMELL, 1995), stand structures (AWAYA, 1998), the inappropriate pixel sizes (ANDERSON *et al.*, 1993; GEMMELL, 1995; TROTTER *et al.*, 1997), *etc.*

To correct such effects, geometric-optical canopy reflectance models are a

possible option to apply, which deal with the tree's shape and size and the stand density that can be correlated to the stand parameters. Many of such models, either empirical or functional, or mixed, have been proposed for decades (*e.g.* LI and STRAHLER, 1985; ROSEMA *et al.*, 1992; JUPP and WALKER, 1997; HUEMMERICH, 2001), however, implementation to the existing vegetations have been rarely done. Winter boreal forest, where the limited components of the simple species structure with high contrasts of reflectance, is a suitable field for both the empirical examination of the models and the stand parameter estimation for the operational uses.

## **6.2 The Methodologies Depending on the Characteristics of Local Ecosystems and Climate**

Virtually all the case studies of remote sensing have been carried out for specific vegetations in specific regions, and they often describe empirical relationships between the vegetation and the remotely sensed data (COHEN *et al.*, 1995; AWAYA, 1997; JAKUBAUSKAS, 1996; AWAYA, 1998; COHEN *et al.*, 1998). Also empirical were the results in Chapters 3 and 5, which mainly depended on the contrast between the snow and the forest canopies of different densities. They successfully utilized the characteristic local climate of snow in the boreal forests by correlating the ground truths as independent variables to the reflectances on images as dependent variables. The age after cut interpreted from the time series of winter images was the independent variable in Chapter 3, while the field-measured stand parameters in Chapter 4 were the independent variables in Chapter 5.

Chapter 4 revealed the unique trajectories of the larch stands of the study area. It apparently showed that the canopy becomes sparse as the trees grow in terms of the relative spacing index, which suggested more forest floor was observed from above in the older stands. Not only this result itself was unique in terms of the tree growth, but also this certain relationship between the individuals and the stands were indispensable for empirical estimation of the larch stand parameters using satellite image.

Even at a same area of interest, the sun geometries are different on different

images depending on the data and time of acquisition. For generalizing the relationships between these independent variables and the images for more reliable results, considerations on the geometry of the sun, the terrain, and the trees (and the view angle in case the sensor does not always point nadir) are required. For Chapter 3, because of the mountainous terrain, the geometric illumination compensation (SENOO *et al.*, 1990; FRANKLIN *et al.*, 1994; MURAKAMI, 2002) would have yielded a better result, though appropriate terrain models were not available. For Chapter 5, the dependency of the stand reflectance on the sun allocation could be explained by the proportion of the components of snow, crowns and shadow calculated by a geometric-optical model, for which the individual tree shape models are necessary for estimating the cast shadow in addition to the stand structure models derived from Chapter 4.

### **6.3 The Methodologies Utilizing Images Taken in the Season When the Sky Is Clearest and the Phenology Is Stable**

The author assumes that the availability of images is the bottleneck for the operational application of remote sensing for the forest management. Few researchers have paid attention to the stable image availability when they develop a methodology using optical satellite images. However, as TAKAO (2000) revealed in the Russian Far East, for certain regions usable images are not constantly available in the foliated season, when the majority of developed methods are applicable. The methodologies that utilize the images of phenologically unstable season like WOLTER *et al.* (1995) are no use for the operational applications. A very long recurrent period of 46 days of ALOS (Advanced Land Observing Satellite), a soon-to-be-launched Japanese satellite, is nothing more than disappointing because it would not have sufficient chance of image acquisition even in the clearest season (though it will have the pointing function, it is for the post-event observation, but not for the pre-event observation in regular basis).

For the Russian Far East in Chapter 3, winter was the only season when the cloud-free images were acquired frequently enough and the vegetation and the snow-cover were stable enough. That is the first reason why a series of the winter

images were used in the Chapter. Though Central Yakutia is drier than the Russian Far East, still the precipitation occurs mainly in summer (ISAEV, 2001), which justifies the use of winter images in the region in Chapter 5, too.

When one attempts to develop a remote sensing method robust enough for the operational and regular use, the stable image availability in the region of interest is among the first things to be considered. The availability of the cloud-free images is the most important for the optical images. Even for non-optical data like radar that do not suffer from clouds, the stability of the surface, *e.g.* phenology, snow-cover, or seasonal flood, should be taken into account. Only after the considerations above, the methods to derive information from the remotely sensed data are to be considered.

#### **6.4 The Methodologies Using Images of the Conventional Optical/Infrared Sensors So That the Forest Can Be Retrospectively Monitored**

Change detection during one period just describes whether and where changes have occurred in the period. A time series of the change detections, however, describes a history of the change occurrences through the time. At the present moment, then, the history turns out to be a present value of the age after change. The age after change, *e.g.* cut, plantation, any kind of disturbances, is an important stand parameter for estimating the regeneration stages, the biomass or the biodiversity, and a key factor in the modern sustainable forest management (SEYMOUR and HUNTER, 1999). In Chapter 3, it was presented that a time series of the old satellite images estimated the ages after change far better than any single present image of either winter or summer. The retrospective monitoring with a time series of the archived remotely sensed data can provide a very important stand parameter, the age, which can not be afforded by a single or a pair of present data.

The Landsat images have already been archived for more than three decades since the first Landsat-1 had been launched in 1972. The archive of the continuous observation for a long time is a treasure of the remote sensing. With this, it is possible to virtually time-travel to review landscapes a (human) generation old (FRANKLIN, 2001). Even if the new sensors would be developed in the future, the archive of a longer

history would not be replaced with the new ones. The observations by such conventional sensors must be continued in the future.

## **6.5 The Methodologies Utilizing the Winter Satellite Images with Snow in the Boreal Forests**

One of the advantages of utilizing the winter satellite images is the high and stable image availability in the boreal forests, as already mentioned in Section 6.3. Another advantage is the existence of snow on the forest floor. The snow hides the forest floor vegetation, which is often exposed through the sparse canopy of boreal forest during summer. Because of its high reflectance in the visible wavelengths (DOZIER, 1989), good separabilities were performed in Chapter 3 between forests and open lands and among the stands with different ages after cut. In Chapter 5, the very different spectral reflectance of snow, canopy and its shadow allowed the quantitative modeling of stand parameter estimations.

Another advantage is that only the canopy trees can be observed on the winter images by hiding the complex floor vegetation with a homogeneous media of snow. In Chapter 3, the winter images made the indices long-lasting differences between the disturbed and undisturbed stands. In Chapter 5, the structures of stands are extracted from the winter images regardless of the floor condition.

As the disadvantages, the very severe terrain effects and the long shadow of trees induced by the low incident angle of the sun were recognized in Chapter 5. In addition, the canopy-suspended snow (NAKAI *et al.*, 1999) might affect the reflectance in the heavy snow area, though in such region the winter images would not be suitable in terms of image availability.

The winter images with snow are available, of course, only at the cold region on the earth. In addition, not all the cold region has the stable availability of such images. For example, the west coast of the northern Japan has snow every winter, however, the weather tends to be cloudy and stormy, and the optical image availability is quite low during winter. Thus, it is clear that the methods utilizing the winter images with snow are not for the universal use around the world, but rather they are

only applicable to a limited region. However, for the areas like the Russian Far East or Central Yakutia, the snow-covered images are the best or even the only available images for the operational and regular use. The important point of the present study is that, as discussed in Section 6.3, it utilized the satellite images of such given conditions for the local forest management.

## **6.6 Aspects for the Operational Applications of Remote Sensing in the New Era of Forest Management**

There has been a distance between the academic ideas and the real implementation of the modern sustainable forest management. 'Ecosystem management', 'ecological forestry', or the forest management from Viewpoint 4 in Section 1.1, are just conceptual now and yet to develop the methodologies for implementation; the forest ecosystems are too complex to be totally understood. The concept of natural disturbance patterns is important (SEYMOUR and HUNTER, 1999) to be mimicked by the management, but still the real disturbances would occur after the mimicked disturbances. The criteria and indices for the sustainable forest management are about to be developed, but they have focused on measuring the present state, rather than projecting future levels or developing rules for judging sustainability (DAVIS, 2001). Adaptive management is recommended to deal with the uncertainties, but successful cases of active adaptive management are hard to find (DAVIS, 2001). The process-based models would predict a number of forestry-relevant outputs that would be used in management planning, and LAI estimated from the remote sensing is one of the inputs (FRANKLIN, 2001), but currently LAI gets few attention from the forest managers (HOLMGREN and THURESSON, 1998).

For implementing a management plan, a limited number of indicators with their target values should be presented for the all stands. The author assumes that the process-based models are indispensable for understanding the dynamics of the ecosystem but rarely applicable to the all forests of a region, because parameters the models demand are too complex for the operational use. Instead, simplified empirical relationships between observations and the forest conditions are more likely applicable

to the operational use. A central experimental forest of a region, such as university's forests, should take on evaluating such detailed process-based models then interpret the results to empirical models with a few easy-to-measure parameters, which should be evaluated by a number of local experimental plots so that the local forest managers can rely on the empirical models.

This idea had already been systematically implemented in the era of classic forest management (Viewpoint 1 in Section 1.1) for the sustainable yield prediction and planning. Such an experimental network should be allocated again to bridge between the detailed studies and the measurable parameters of the existing stands for developing the practices of the modern sustainable forest management. The national forest inventory will serve in Japan as another observation network.

Remote sensing, both space-borne and air-borne, plays important roles in the inventory in a wide area and the monitoring of ever-changing land surface through time. Information can be retrieved by combining them with other data on GIS (AMANO and LEE, 1981). Frequent and regular observation is one of the most important properties for operational use as seen in Section 6.3. To improve the frequency, a desirable system is a fleet of single-purpose satellites with a same sensor on board and a short recurrent period. Space agencies should provide the information not only on the image availability but also on the cloud covers of any given location in a user-friendly manner (location-oriented searching instead of scene- or sensor-oriented).

There is no doubt that the new technologies of remote sensing, *e.g.* lidar, hyperspectral scanner or SAR, would play more important roles in the near future in the field of applications like forestry (MONDELLO *et al.*, 2004). Many of such sensors are air-borne and operated by private firms rather than the government-run space agencies as it has been for the satellites, which means the acquired data are dispersed among the firms. Although the new technologies have had not a long history to be looked back yet, the history is for sure being created. To avoid double-investments of data acquisitions in a same area, and to allow the retrospective monitoring by such data in the future as seen in Section 6.4, the derived data should be archived and catalogued with metadata in an appropriate manner. In addition, the catalogue should

be opened to the public no matter whether the data themselves demand costs or the accesses to the data are restricted for any reason. The national government or the industry organization is expected to take initiative for the coordinating role.

Case studies are always the start for developing a remote sensing methodology for a certain vegetation in a region. When implementation of the methodology to the operational use is in the scope, however, the case studies must take into account from the beginning the data availability and the characteristics of the vegetation and land-use (Figure 6.1). If there is no good method applicable to the constantly available data, it means the remote sensing data can not be utilized for the forest management of the region. In addition, a method can be implemented only after a feasibility evaluation, which was not addressed in the present study.

The feasibility evaluation should take a long time because trees grow slowly and disturbances rarely occur. Here is another possibility of the retrospective monitoring, which can evaluate a new method with a series of old data, including not only satellite images and/or aerial photos but also other geographic and ancillary data available.

In summary, easy-to-measure and robust methodologies are required for forest monitoring in the operational forest management that deals with a broad area of complex forest. Such methodologies tend to be more empirical than functional (or process-based) that simplify the relationships between the measures and the target values, even if their uses are limited to the local and they cannot be extrapolated to the unknown conditions. Such empirical methods depend on multiple stages of reliable and abundant statistic data, one of which is remote sensing. Remote sensing can interpolate the ground measurements not only spatially but also temporally in a retrospective manner. And, only those who have insights in both the local vegetation and environment and the remotely sensed data will be able to find out the specific relationships between them. In turn, such relationships may imply insights of the processes between them. To make remotely sensed data usable in the operation, the data acquisition should last for a long period in a regular manner in appropriate seasons. Those archived data will be a public property and an infrastructure that



would secure the human society and the environment in the future.

The present study successfully demonstrated the local and empirical models that bridge the unique boreal forests and the satellite images in winter, the season with the maximum chance of data acquisition.

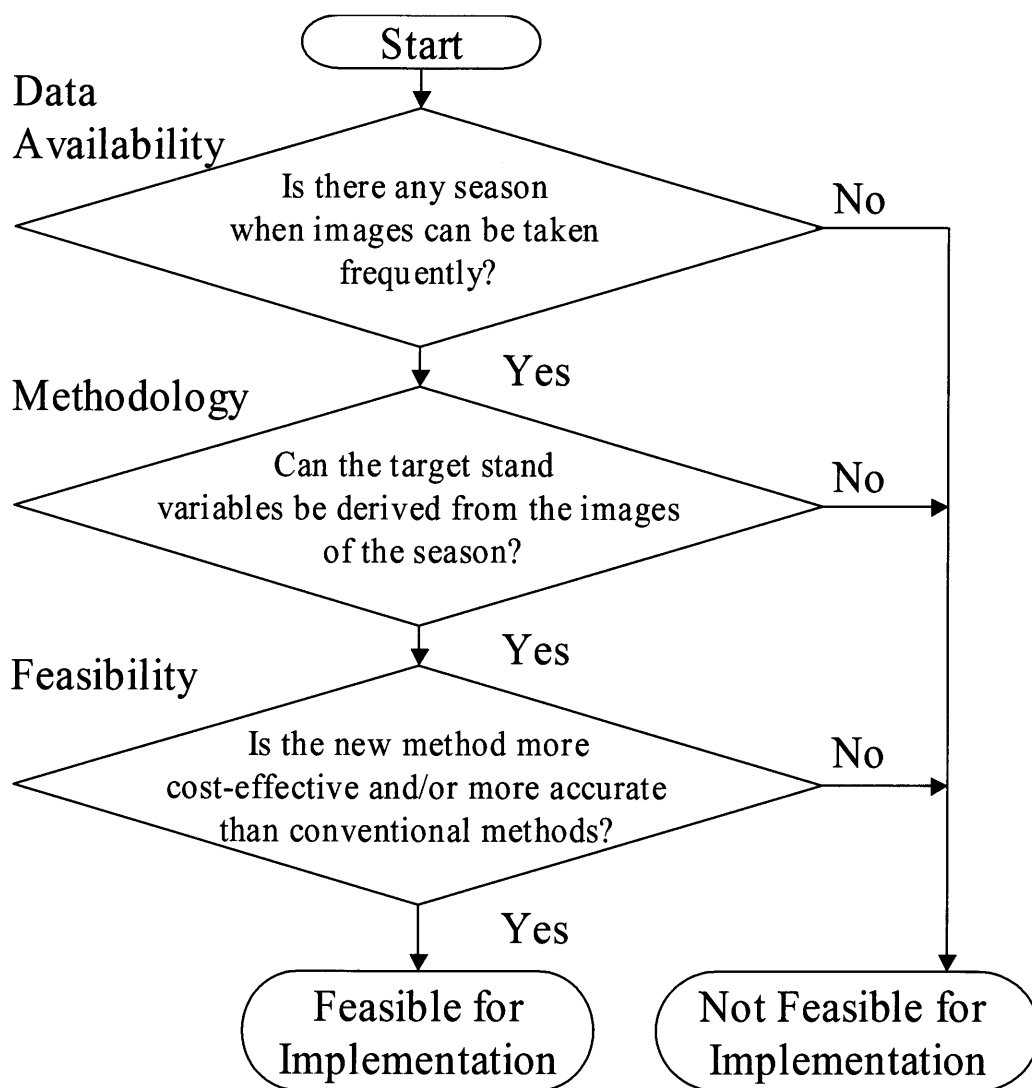


Figure 6.1 Flow of the remote sensing methodology development for operational use

## CONCLUSION

The present study addressed the practical utilization of remote sensing for the forest management and planning operation, and the study area was exclusively focused on the boreal forest.

The study aimed to derive the forest information in the conventional terms forest managers use, to provide the information regularly by using the satellite images taken in the season with high chances of image acquisition, to utilize the local and empirical relationships between the vegetation and the satellite images, and to provide the history of stands by the archived satellite images. By using the snow-covered winter satellite images, the disturbance history and the present above ground biomass and DBH were successfully derived.

It is apparent that the methodologies developed in this study are applicable to only a limited area in the boreal zone on Earth because of the local models in nature. However, what is important is the procedure of developing the methodologies in which the appropriate season in terms of the satellite image availability was assessed at first and then the methodologies were developed on the images of such season. This procedure can be applicable to any other places by those who have insights of the local vegetation.

Forest management is like driving a car. The concept and theory of forest management is the engine, which researchers take effort to tune up as mechanics. They must know the engine and the car in detail, but they do not have to know how to drive. Forest managers drive the car. They do not have to know the car in detail but how to drive it with a wheel, pedals, and a couple of instruments in front of them that indicate the conditions in real time. Therefore, the minimum required variables from the engine and the other parts should be always indicated during the driving. Remote sensing should take on indicating some of the necessary variables from any part of the car to the driver during the driving. Thus, the researchers of remote sensing, as mechanics, should consider carefully what variables are necessary for driving and how they can be indicated effectively in front of the driver. They must remember that the

drivers can not open the bonnet while they are driving.

Finally, the author wishes, and feels responsibility for, the remote sensing being more reliable and straightforward tools to provide the peace and welfare on the earth as well as for the locals.

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