Chapter 1

Satellite Remote Sensing Monitoring Technology of Forest Damages Caused by Pine Caterpillars

On July 23, 1972, Landsat-1, originally named ERTS-1, was launched from Vandenburg Air Force Base in California. The launch of Landsat-1 was the beginning of a new era in monitoring the Earth's natural resources. Today, acquisition of resource data from Earth-orbiting satellites is commonplace. This chapter discusses the progress and feasibility of satellite imagery for monitoring and assessment of forest conditions, the characteristics of two satellites used for detecting forest health presently in orbit, and applications in forest health protection in China.

1. Spectral properties of vegetation and principle of monitoring forest damage with remote sensing

There is a typical reflectance curve for healthy vegetation. The absorption features centered at approximately 0.48 and 0.68 μm represent strong chlorophyll absorption. The reflectance at 0.52-0.60 μm indicates the green portion of visible light, which is not absorbed. The strong reflectance feature extending from approximately 0.75 to 1.3 μm, referred to as the near-infrared (NIR) plateau, characterizes healthy leaf tissue. The sharp rise in the curve between 0.68 μm and the NIR plateau is referred to as the red edge. The slope and position of this red edge have been directly correlated with leaf chlorophyll concentrations.

Chlorophyll and carotenoid concentrations may vary, and additional pigments may build up within leaves in response to stress. Such variations can appear as subtle spectral changes in the visible and red-edge portions of reflectance curves from vegetation in decline. The position and slope of the red edge also change as healthy leaves progress from active photosynthesis through senescence. Such phenological and health information is an important aspect of the remote detection and recognition of stress response (damage) in vegetation.

High reflectance values in the NIR plateau characterize healthy leaf tissue. Reflectance in this region is due to multiple refractions occurring along cell wall-water-air interfaces as a result of differing refraction indices for these leaf components. The studies suggest that changes in cellular health within leaves are associated with reduced reflectance along the NIR plateau. Such spectral properties, which can be remotely detected, may provide information regarding cellular health in vegetation over large areas.

The reflectance values in the 1.65 μm and 2.20 μm region can provide an accurate indication of leaf water content. Study results suggest that spectral data from the reflective short-wave infrared (SWIR) may be very useful in detecting various levels of water-related stress in vegetation.

Therefore the near-infrared (NIR) and short-wave infrared (SWIR) are the important spectral regions for forest resources change. If we want to detect the forest conditions effectively, we had better choose satellite sensors that have NIR and SWIR channels.

2. Strengths and weaknesses of remote sensing techniques in monitoring forest damage

Earth-orbiting satellites have the capacity to view and capture large areas of land in a single image, making them an excellent tool for monitoring and assessment of land cover and land use. Another strength of satellites is that they return to the same point over the Earth's surface at regular intervals (e.g., Landsat satellite's return time or temporal resolution was 16 days). Provided that cloud-free or near-cloud-free weather conditions exist, satellites can obtain data at predictable intervals for monitoring change. The satellite data is received in digital form, ready for computer-assisted analysis, and many Earth-orbiting satellites have spectral sensitivities in the visible, near-IR, and thermal-IR regions of the electromagnetic spectrum(EMS). And the regions of EMS can make it easier for us to identify different kinds of vegetation and vegetation condition.

The major weakness of the Earth-orbiting satellites in operation today, especially with regard to forest health protection, is their relatively low spatial resolution and low temporal resolution. While present day spatial resolutions such as Landsat TM satellite are adequate for many natural resources applications£-such as analysis of land form, land use, crop forecasting, and land cover mapping, they are still unable to resolve the fine to moderate levels of forest damage of vital interest to forest health specialists. Generally the biowindows of forest diseases and insects damage is less than 15 days. Consequently, use of data from Earth-orbiting satellites in forest health protection has, to date, been limited to test and demonstration projects. Fortunately some high spatial resolution satellite will be launched in succession in the coming years. And they can obtain data in the shorter intervals. Therefore we can be full of hope for satellite application in forest protection.

3. Landsat and its data properties

The Landsat satellites have been acquiring Earth resource data since 1972 and all have been in a polar orbit. Landsats 1, 2, and 3 returned over the same point on the Earth's surface every 18 days, and Landsats 4, 5, and 7 returned over the same point on the Earth's surface every 16 days. (Landsat 6 was lost in space.)

The early Landsat satellites (Landsate 1-3) were equipped with a four-band multispectral scanner. Spectral resolution consisted of two visible bands and two near-IR bands (Tables 1.1). Spatial resolution was 80 m, temporal resolution was 16 or 18 days, and image swath width was 185 kilometers.

Table 1.1. Spectral resolution of Landsat MSS

Band	Spectral Resolution (µm)	Spectral Location
4	0.5 - 0.6	Green
5	0.6 - 0.7	Red
6	0.7 - 0.8	Near - IR
7	0.8 - 1.1	Near - IR
8*	10.4 - 12.6	Thermal - IR

*Band 8 was first made available on Landsat 3

MSS data have been used for land cover classification, change detection, geological investigations, geomorphological mapping, hydrological studies, forest inventory, soil studies, oceanography, and crop yield estimations. In forest health protection, MSS imagery has been used for mapping areas of extensive forest defoliation and tree mortality.

The Landsat Thematic Mapper (TM), first carried aboard Landsats 4, 5, and 7 in addition to the MSS, is a more sophisticated instrument with increased spectral and spatial resolution. The TM has a spatial resolution of seven bands selected specifically for forest vegetation analysis (Table 1.2). Spatial resolution for all bands except band 6 is 30 meters, while band 6 has a 120-meter resolution. Area covered by a single TM scene is 31,450 square kilometers (185 kilometers by 172 kilometers).

Table 1.2. Spectral resolution of Landsat TM

Band	Spectral Resolution (μm)	Spectral Location
1	0.45 - 0.52	Blue
2	0.52 - 0.60	Green
3	0.63 - 0.69	Red
4	0.76 - 0.90	Near - IR
5	1.55 - 1.75	Mid - IR
6	10.4 - 12.5	Thermal - IR
7	2.08 - 2.35	Mid - IR

TM data have been widely used in many disciplines including agriculture, cartography, civil engineering, forestry, geology, geography and land and water resources analysis. Applications in forest health protection include mapping of heavy, widespread damage and change detection.

Landsat 7, which was launched April 1999, has on board an enhanced TM capable of producing panchromatic data with a spatial resolution of 15 meters and a multi spectral resolution of 30 meters. Ground receive stations are around the world. And more pleasantly we can obtain the data with low cost in time.

Now Landsat 5 and 7 are in the orbit. Therefore we can obtain the data in shorter intervals.

4. IKONOS and its data properties

IKONOS is a high resolution commercial Earth imaging satellite launched September 1999. The satellite is owned and operated by SpaceImaging headquartered near Denver, Colorado, and is considered to be the world's highest-resolution commercial satellite. IKONOS is in a sun-synchronous polar orbit at an altitude of 681 kilometers (423 miles). A single image captures an area of 11 by 11 kilometers. Spatial resolution is 1 meter in panchromatic mode and 4 meters in multi spectral mode. Spectral resolution of the multi spectral band is 4 meters, with band sensitivities in the blue, green, red, and near-IR regions of the EMS (Table 1.3). Temporal resolution is given at three days at 1-meter resolution and 1.5 days at 4-meter resolution.

Table 1.3. Spectral resolution of IKONOS

Sensor Mode/Band	Spectral Resolution (μm)	Spectral Location
Multispectral		
1	0.45 - 0.52	Blue
2	0.52 - 0.60	Green
3	0.63 - 0.69	Red
4	0.76 - 0.90	Near - IR
Panchromatic 1	0.45 - 0.90	Blue-near - IR

It is anticipated that IKONOS imagery will find applications in precision farming and agriculture, mapping, natural resources management, urban planning and zoning, oil and gas exploration, travel and tourism etc. Although it is difficult to obtain the data now, we are confident to its application in forest health protection.

More high resolution commercial Earth imaging satellites will be in orbit in the coming years. They can promote the application of satellite imagery in forest healthy protection.

5. Applications (pine caterpillar defoliation mapping) in China

In the past ten years, forest damage caused by diseases and insects has become more and more serious and resulted in tremendous loss in APEC members. One of the main reasons is that people can not make timely and precisely monitoring and make long-term forecasting about forest diseases and insects so that we can not control it at the beginning. Although people can not precisely predict the occurrence and development of the diseases and insects on current science and technology level, we can detect the early calamity location and do our best to minimize the loss. The following introduces a method to detect the early damage areas with TM data and make a rudimental understanding about the process of occurrence and development of forest diseases and insects through comparing and analyzing the recent year's data. It is admitted that satellite imagery data can make effective monitoring for pest origin. This opinion provides the possibility of making macroscopic monitoring about the important forest diseases and insects with the satellite remote sensing technology and provides a new technology for prevention of damage. At the same time, through analyzing the dynamic change of forest pest damage and the biologic property of forest diseases and insects, people can make long-term forecast of forest diseases and insects to realize the sustainable development of forestry.

In China, forest diseases and insects occurred vast area in recent years, 80,000 square kilometer per year, have resulted in 5 billion yuan direct economic loss. Frequent forest diseases and insects have maintained high level and has strong tendency to rise. Among the top ten types of forest diseases and insects, pine caterpillar disaster ranks first. So effective monitoring and controlling of forest diseases and insects has special value in reducing the loss of forest pest damage of our country.

In the past half century, the science of forest protection has made rapid progress. But it is a passive procedure. Forest biological disaster control at the turn of the century is confronted with great crisis.

For the artificial forest, there are four problems to be resolved in China.

•Some serious biological disasters in history have not been controlled, for example, the continuous harm of pine-moth *Dendrolimous pinidiatrea*, the continuous menace to£¢Three North Shelter Forest£¢system caused by poplar borer *Saperda calcarata*, *Valsa sordida* and *Dothiorella gregaria*.

• Some secondary forest biological disasters are turning to main menace. For instance, Pine Diprionidae's occurrence in large scale is menacing the shelter forest of Three Gorges in Chongqing Municipality, and paper pulp industry in south China is being threatened by the extension of *pseudomnas solanacearum*.

•Quarantining pests are becoming menace. Pine's withering caused by *Bursaphelenchus xylophilus* through the medium of *Monochamus alternatus* still continues to spread and ruin pine woods.

•With the deterioration of whole ecological environment, ecological diseases break out into disasters, as an example, recently, plenty of city green trees have died of *Valsa* in northeast and north China.

For the natural forest, there are two problems to be resolved in China.

•Natural forest not exploitation and no direct disturbing and distroyed by human being. Stable forest ecosystem has occured disaster because of the change of the global climate. Such as the *Lophodermium* **sp.** causes the *Abies* death in large belt area in Xizang Autonomous Region.

•Natural forest disturbed and destroyed by human being. The biological disasters are very serious because of the over-exploitation in this kind of forest.

5.1 Introduction

Masson pine (*Pinus massoniana* Lamb) is one of the principal timber species in south China and has a wide distribution. Its amount of volume is more than half of the whole timber amount in south China. However, its distribution area is often invaded by masson pine caterpillar, one of the most serious forest insects in China. Pine tree growth is influenced and the harvest of turpentine is reduced in the low damaged forest, and trees are killed in the heavy damaged forest. The masson pine caterpillar also has impact on human being and ecological environment. The governments and administrative departments of these areas have utilized a great number of labor forces, materials and financial resources to measure, protect and harness the damage caused by pine caterpillar, this has restrained the damage from rapid infestation. As the pine caterpillar is characterized by its quick development, it is very difficult to effectively control and predict the damage by traditional ways.

Although the damage symptoms caused by different agents may vary, analysis of the damage caused by pine caterpillar can provide insight into other types of damage that result in needle loss. The pine caterpillar feeds on the buds and needles of old shoots of massion pine. In severe outbreaks, it may feed on previous year’s needles. Most feedings occur in late spring, early summer or early autumn. The partially consumed needles and other feeding debris become caught in a web-like feeding tunnel produced by the pine caterpillar and adhere to the tree for a short time. The feeding debris is eventually knocked off by wind and rain, and bare branches become exposed.

Remote sensing systems provide a means of discriminating, mapping and monitoring vegetation efficiently. The overall objective of this study was to correlate various levels of forest defoliation in South China with remote sensing data, some specific goals are as follows: (1) to determine the feasibility of using satellite-borne sensors such as Landsat Thematic Mapper(TM) data to map, measure and monitor coniferous forest defoliation caused by the pine caterpillar through time, (2) to describe the relationships between spectral data and defoliation (percentage of needle loss), and (3) to determine what levels of coniferous forest defoliation can be detected.

Assessments of defoliation caused by the pine caterpillar permit monitoring of an outbreak and estimation of the distribution and quantity of damage. Such assessments can also be used in some forest jurisdictions as a measure of stand condition. This, in turn, is used to determine where to implement pine caterpillar control programs, to assist harvest scheduling and to plan other silvicultural measures. Leckie D.G. et al (1987) had predicted that approximately 20% differences in defoliation can be discriminated with the best spectral bands and that there were significant differences between four classes of defoliation for most spectral bands.

In all, satellite-borne remote sensing could acquire forest condition information over large areas periodically and provide technical possibilities for timely monitoring of forest diseases and insects.

We have made further research in many regions of China, such as Qianshan county in Anhui Province, Jiangshan city in Zhejiang Province, Chaoyang region in Liaoning Province, and so on. The biological property of pine caterpillar hazard can be remarkably distinguished in these test area. These study areas are typical regions with frequent pine caterpillar hazard.

5.2 Universal management of remote sensing data

5.2.l Data collection

Landsat's TM5 and TM7 data can be obtained from Remote Sensing Satellite Ground Station of Chinese Academy of Sciences. In order to reduce the difference caused by phenology, data with close phonological period is often of first choice.

5.2.2 Data pre-process

At first, we make precise geographic calibration and registration to the yearly data. To keep the precision in one pixel, ground control points from the newest 1:10,000 topographic map were chosen. Meanwhile, DGPS can also be used to achieve ideal result.

5.2.3 Data normalization

To facilitate the comparison and analysis, normalization has been done to the yearly TM data.

5.2.4 Disaster information extraction

According to previous experience, during the slow growing season of plant, because of the withering of herbs and defoliation of forest, the green biomass will reduce, and this make the detection of forest disaster more convenient. The stress index is an ideal parameter to identify the green biomass difference.

5.3. Data analysis and results in Anhui Province

5.3.1 Data analysis

TM image data of November 15, 1993, December 7,1995 and October 22, 1996 are selected respectively.

To understand the methodology of extracting forest damage information from TM data, we selected the data set of 700 hectare sample areas in disaster forest, in terms of sight analysis for three years image. Figure 1.1 shows the DN values of the three years TM data, which have a decreasing tendency (except TM6). In figure 1.2, standard deviation increases yearly. So these data comprise abundant information. Figure 1.3 shows that the maximal difference of four ratios between 1996 and 1995 or 1993 sample data is situated on the ratio TM5/4. And the maximal standard deviation of those ratios between 1996 and 1995 or 1993 sample data is also situated on the ratio TM5/4. From the analysis of several kinds of ratio, we can find that TM5/4 is the best vegetation index to extract forest change information in the winter, which coincides with previous research result very well.

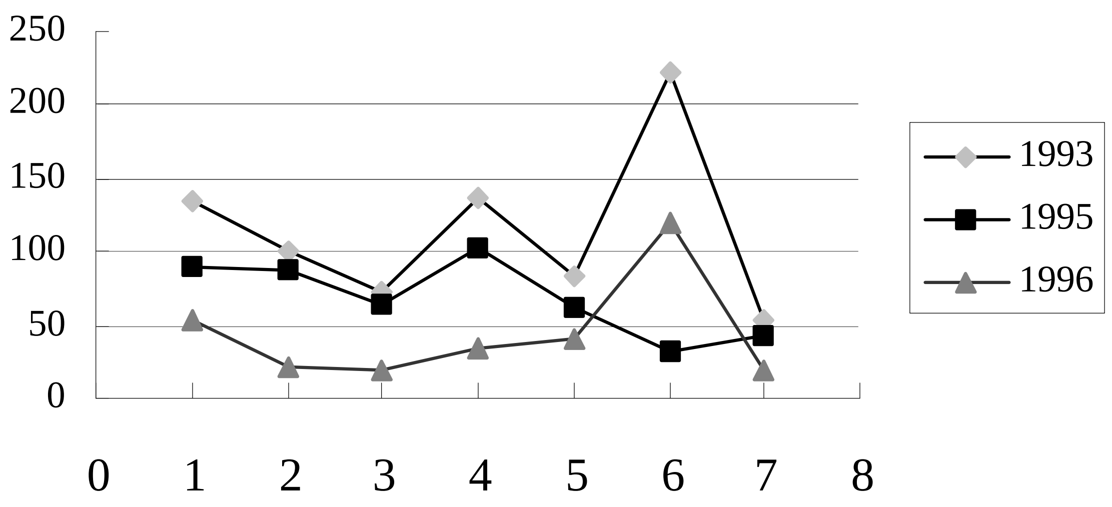


Fig.1.1 DN values of seven TM bands

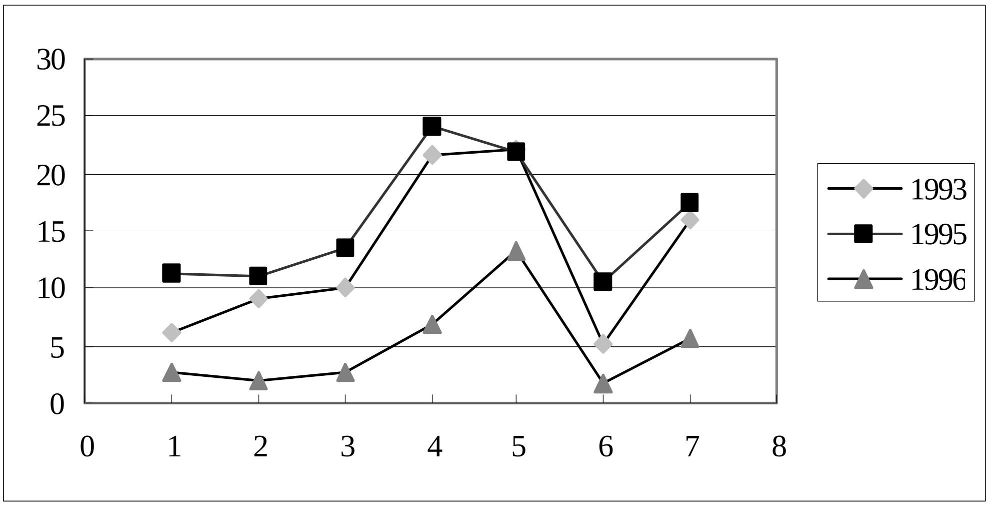


Fig.1.2 Standard deviation of seven TM bands

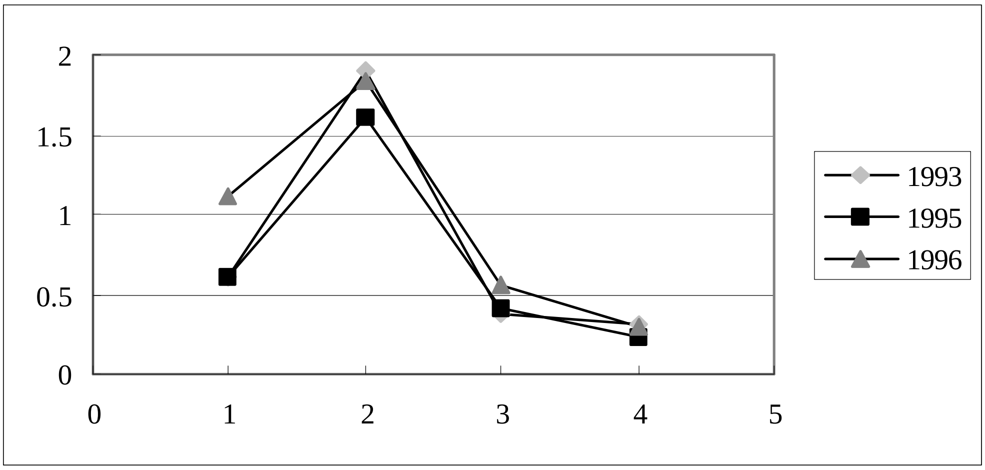


Fig.1.3 Comparison of four ratios vegetation index.(1-TM5/4, 2-TM4/3, 3-TM7/4, 4-TM(4-3)/(4+3))

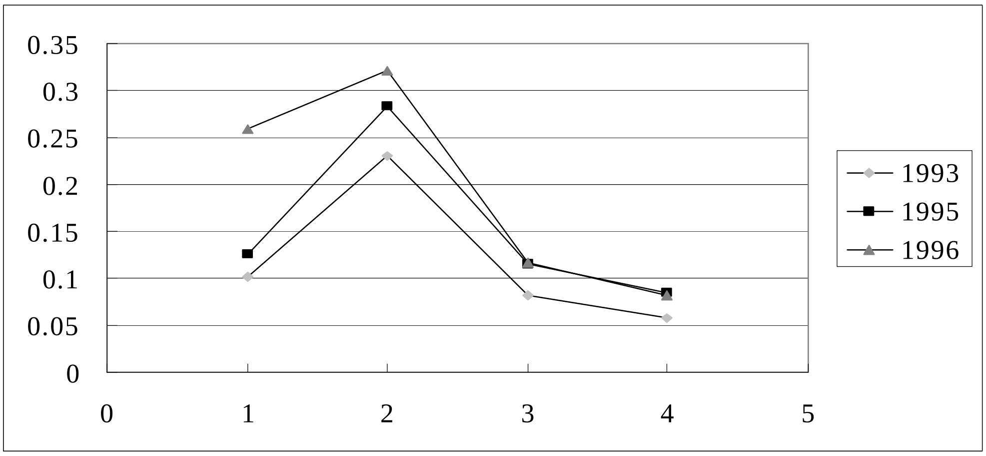


Fig.1.4 Standard deviation of four ratios vegetation index

5.3.2 Early damaged area

To make a clear illustration of the feasibility and validity of satellite remote sensing techniques in monitoring forest insects and diseases, we have chosen TM images of three regions and made automatic classification to them, this has formed an actual description of the spectrum change of the hazard regions during four years. (see Fig. 1.5, Fig. 1.6, Fig. 1.7)

From forenamed three groups of images, we can find that the occurrence and development of forest diseases and insects is a process from point to surface. Satellite remote sensing data can actually record this gradual change process. The areas of three hazard regions in the 1995 image are very small. But after three generations of the pine caterpillar, the hazard rapidly diffused in vast region in 1996. Therefore, if the start points of pests can be detected timely and precisely, the disaster in vast areas will not occur and the damage loss will be reduced.

5.3.3 Post-classification process

To improve classification precision and get rid of the non-forest change information, we took the filtering process to the analysis results based on the pixel and removed the non-forest change information with GIS data, finally, we got the change image map of forest health change of the whole county. (see Fig. 1.7 and Fig. 1.8)

5.3.4 Results

Through a comprehensive view of last decades' research results and experience of the world, we select American Landsat TM data as the main information source to study the quick extraction of forest damage caused by pine caterpillar with remote sensing. After precise geometric calibration of three years' data, all data were normalized with the 1993 data as the base data, and this can be used for getting rid of the changes of non-forest region. After filtration and vectorization, the forest health change vector image map for the two years were obtained. There are three levels: The better growing - excellent (the leaves are well or the needle loss is under 40%), the worse growing - medium (the defoliation are between 40% and 70%), and the worst growing - serious (the defoliation are beyond 70% or the forest is deforested or fired). The change ratio of each level is shown in table 1.4.

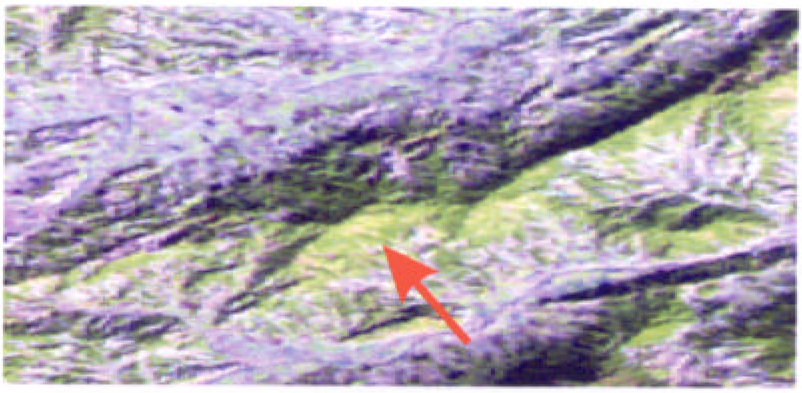
Table 1.4 Degree of forest healthy change

	Good	Medium	Severe	Sum of polygons
1995	2218	456	21	2695
1996	1921	1174	470	3565

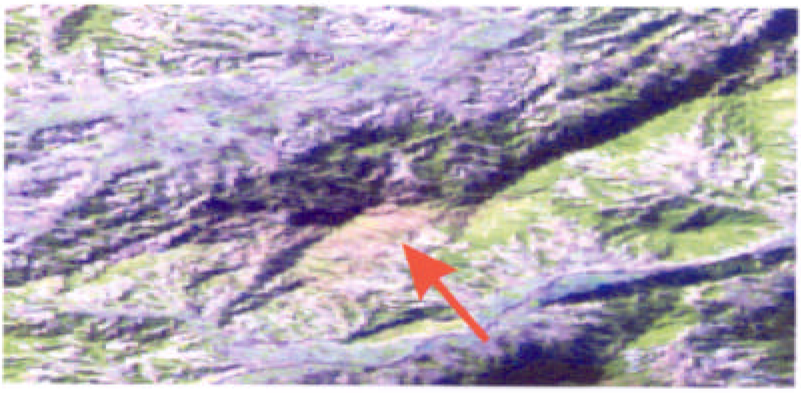
We can output the inner points of all disaster areas of different levels and transform them into the coordinate value under WGS-84 coordinate system. Then we go to the field to begin our validation and investigation. Considering many factors, we just make the ground validation with medium or serious changes. These changes were caused by forest diseases and insects, deforestation, fire and so on. Table 1.5 shows the validation results, and it satisfies the need of practical production. Of course, this is just the beginning, we will continue improving our monitoring model in order to make integrated detection and assessment for current year's forest healthy change through annual periodic detection. According to the biologic property, the distribution range of pest can be reconstructed to guide the investigation of forest diseases and insects of the following year, including determining the temporal investigation routine, and temporal standard areas. Through these works, we hope the origin of pests can be found as early as possible so as to take prevention and protection measure, control its diffusion, and minimize the loss. For provincial level management department, they will not only analyze the data provided by local region, but also supervise and manage the disaster information to obtain real time information, to guide macroscopic adjustment and controlling of the disaster.

Table 5 Polygon validation of field investigation

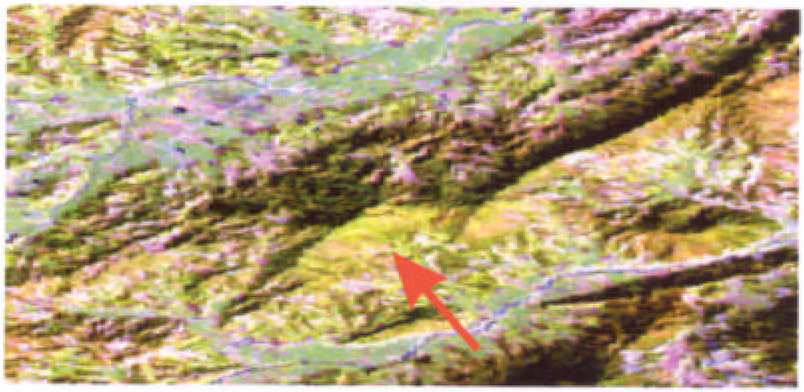
		Medium	Heavy
1995	Sum	138	20
	Polygons caused by forest diseases and insects	97	7
	Polygons caused by deforestation and fire		13
1996	Sum	179	119
	Polygons caused by forest diseases and insects	171	109
	Polygons caused by deforestation and fire		10



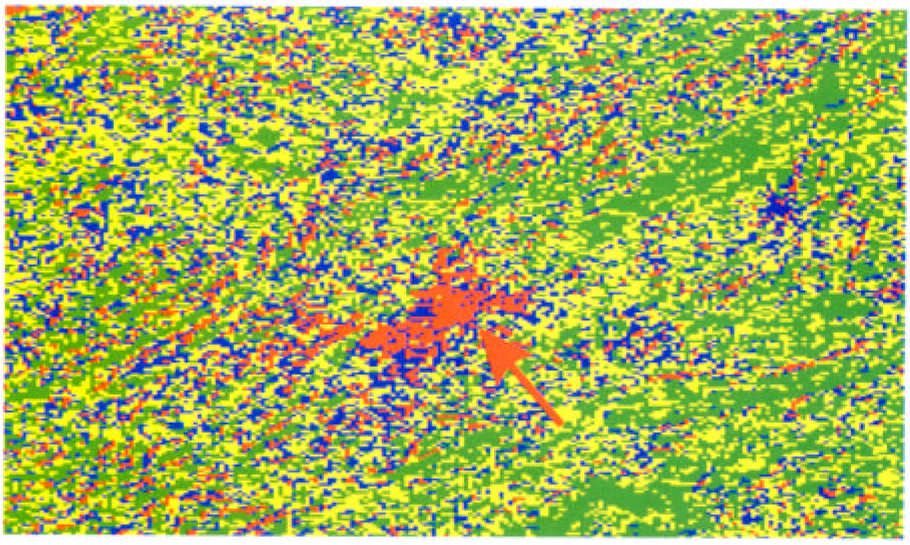
a) TM composite image in 1993



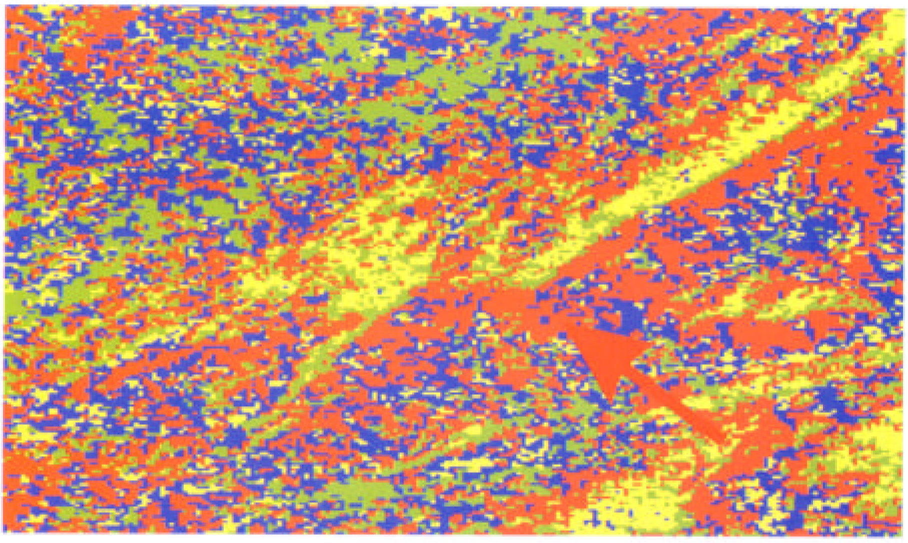
b) TM composite image in 1995



c) TM composite image in 1996



d) Green biomass change map based on single pixel(1995)



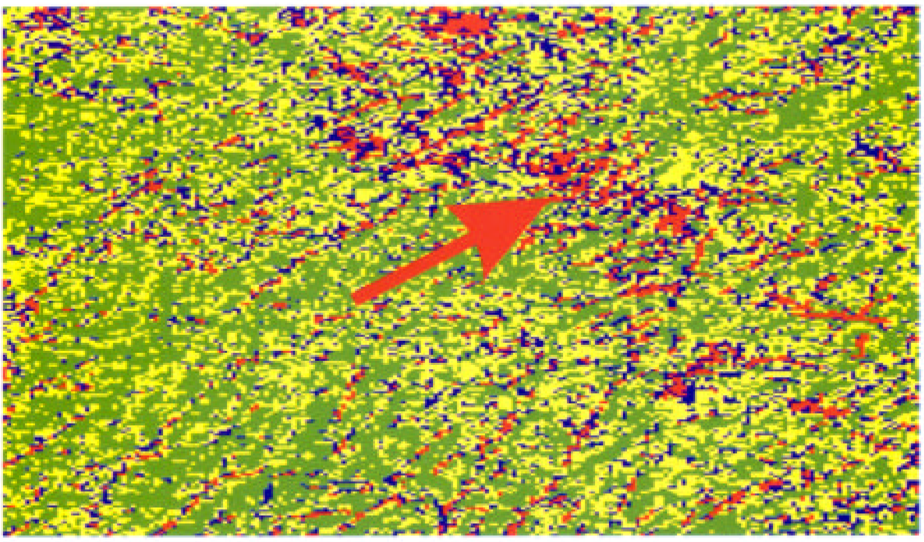
e)Green biomass change map based on single pixel(1996)

Fig.1.5 Evolving process of yearly green biomass change based on TM images in site A

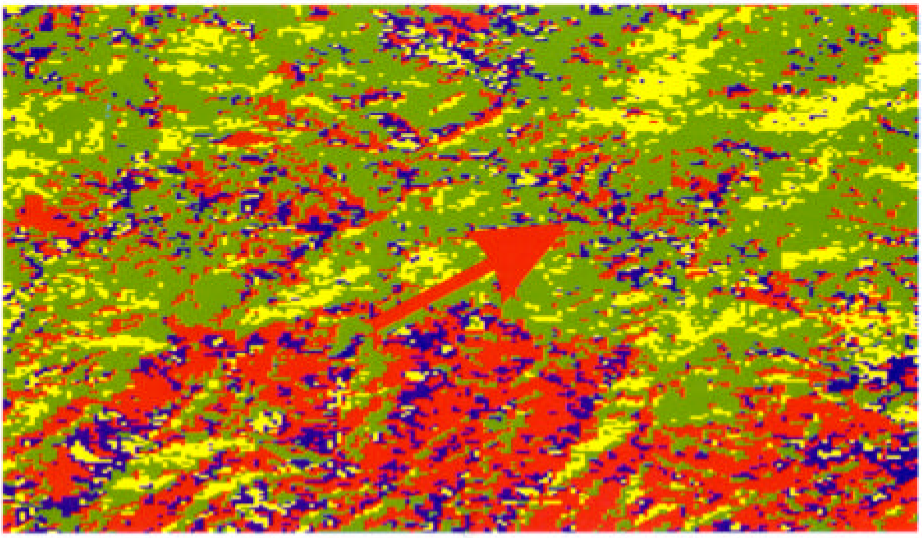
a) TM composite image in 1993

b) TM composite image in 1995

c) TM composite image in 1996

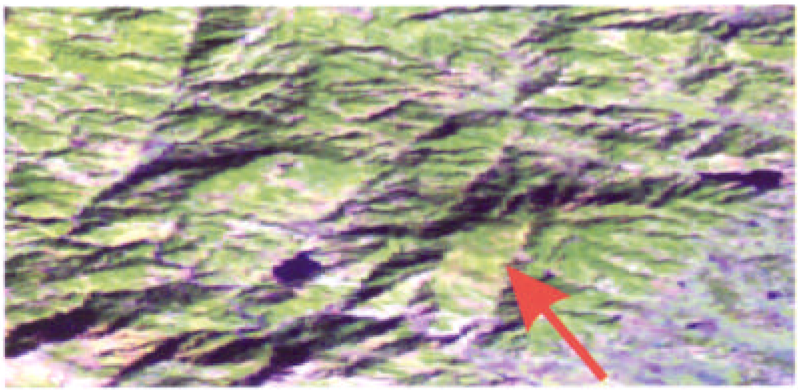


d) Green biomass change map based on single pixel(1995)

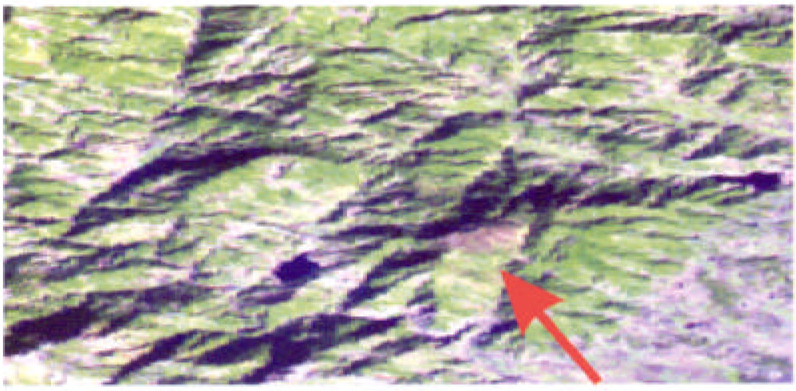


e) Green biomass change map based on single pixel(1996)

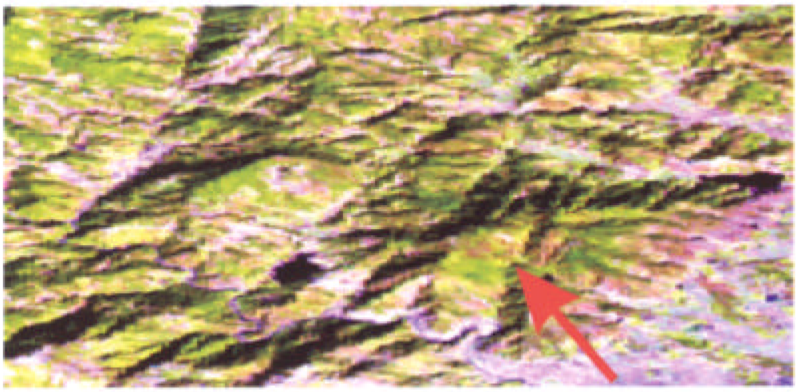
Fig.1.6 Evolving process of yearly green biomass change based on TM images in site B



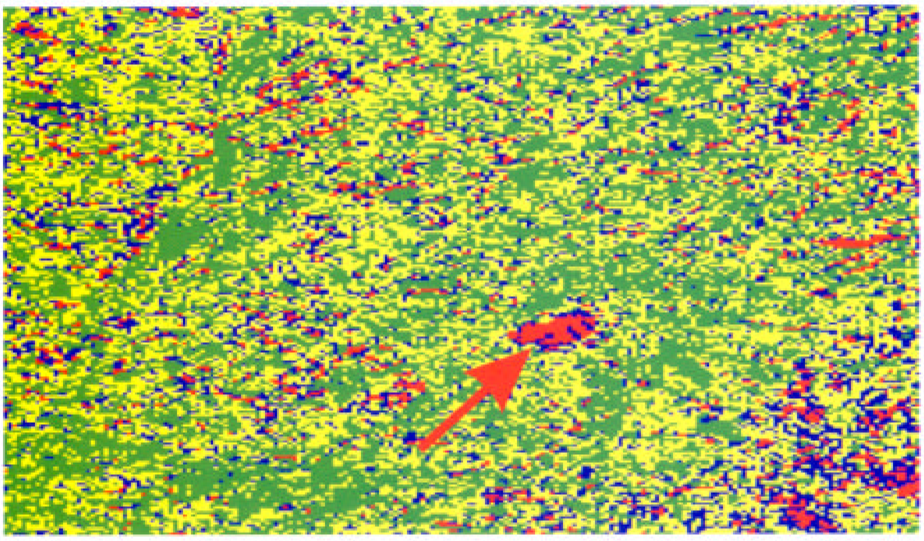
a) TM composite image in 1993



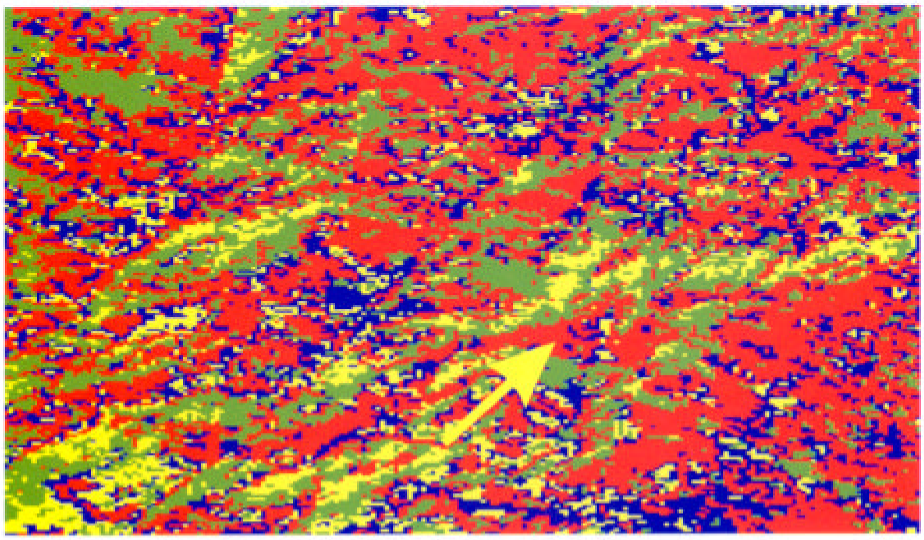
b) TM composite image in 1995



c) TM composite image in 1996



d) Green biomass change map based on single pixel(1995)



e) Green biomass change map based on single pixel(1996)

Fig.1.7 Evolving process of yearly green biomass change based on TM images in site C

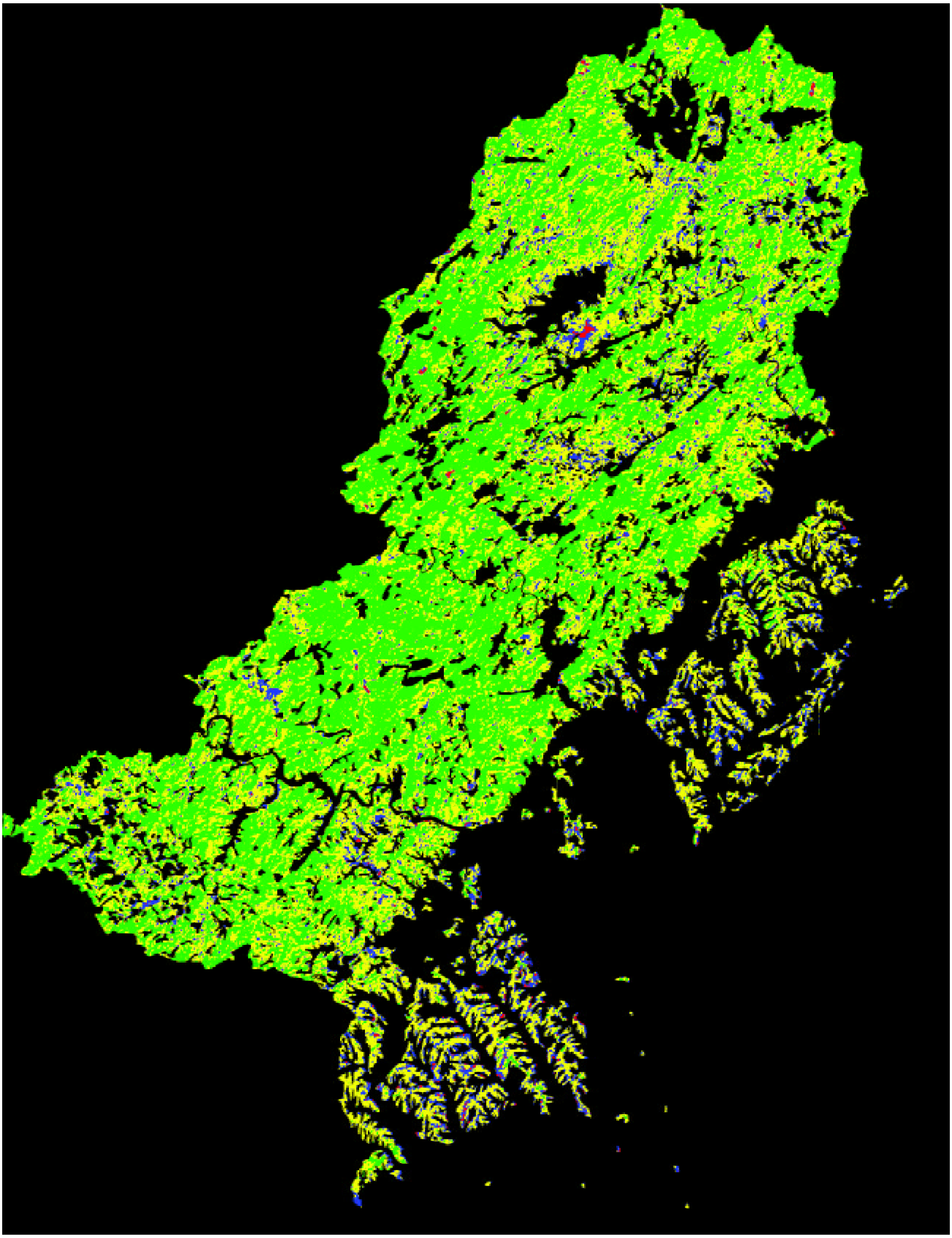


Fig.1.8 Forest health change map of Qianshan County of Anhui Province in 1995£¨Green¡ªealthy forest, Yellow¡ªaround 30 of needle loss percentage, Blue¡ªaround 50 of needle loss percentage, Red¡ªLarger than 70 of needle loss percentage)

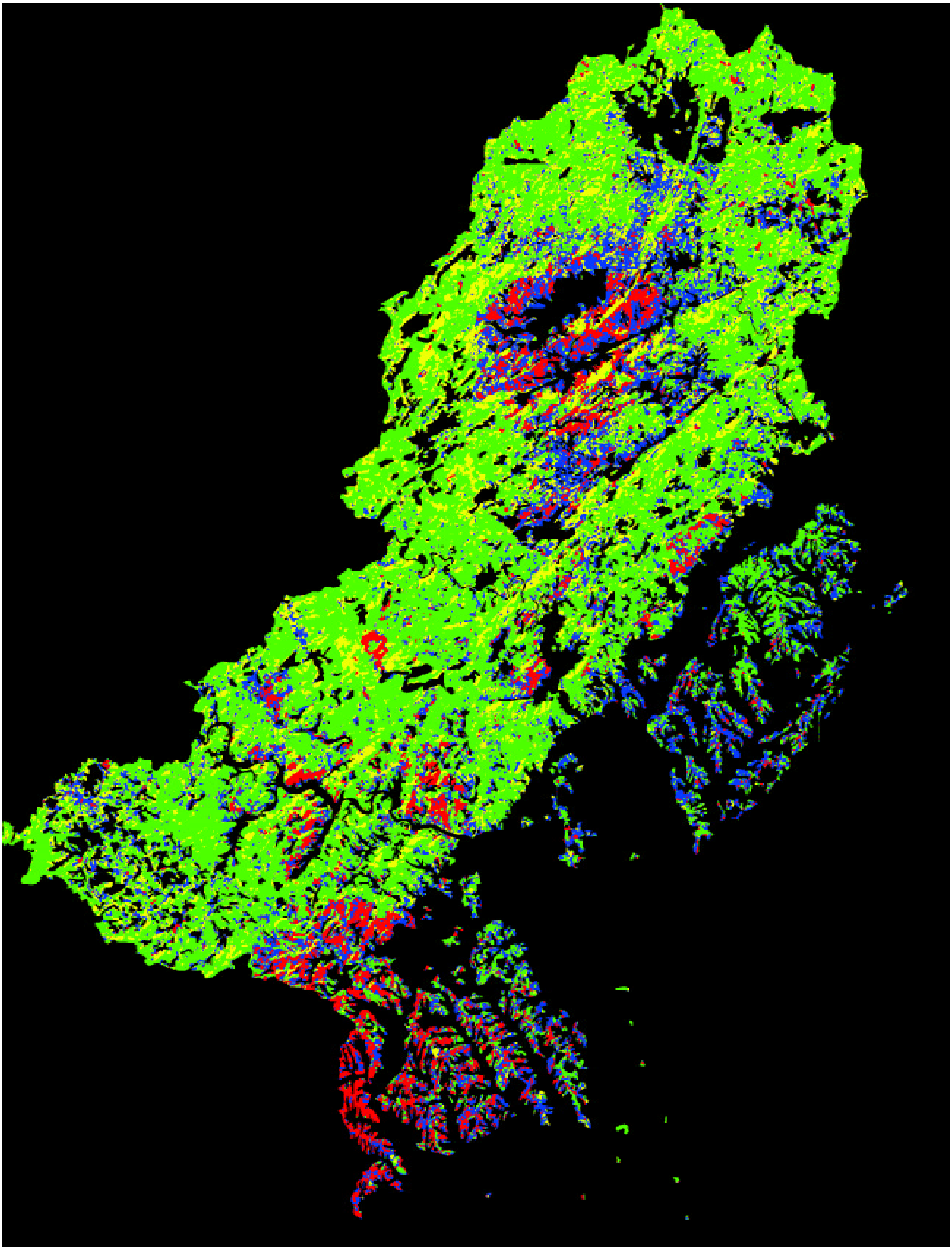


Fig.1.9 Forest health change map of Qianshan county of Anhui Province in 1996(Green¡ªhealthy forest,Yellw¡ªaround 30 of needle loss percentage, Blue¡ªaround 50 of needle loss percentage, Red¡ªLarger than 70 of needle loss percentage)

5.4 Data analysis and results in Zhejiang study areas in southeast China

The research was conducted at the pine forest located in Jiangshan City, Zhejiang Province in southeast China. Half of the city is covered by masson pine distributed in hillsides.

The city is mainly covered by immature stands of different densities and suffered varying levels of defoliation by pine caterpillar from August to September in 1992.

5.4.1 Remote sensing data acquisition

Four Landsat-5 TM half scenes covering the region described above were obtained and they were acquired on November 29, 1989, November 21, 1992, October 20, 1992, and October 26, 1994 respectively. The 1994 and 1989 data sets represent conditions that the forest was not damaged by the insects, whereas the 1992 data sets were acquired during major defoliation caused by pine caterpillar. Although the 1992 data were acquired one to two months after what is considered to be the peak of the infestation, it is not long enough for vegetation to recover yet and the defoliation were still quite evident.

The above data sets can also be divided into two groups of which the October data sets stand for conditions in growing season and the November data sets stand for conditions in non-growing season. For every group of data sets, solar azimuth and elevation were similar. And it is assumed that vegetation was at phenologically comparable states for both groups of data sets. Ancillary data, such as 1:10,000 topographic map (partly) and 1:25000 forest maps made in 1989 were used to exclude the disturbances.

5.4.2 Ground survey

A total of 702 field plots were sampled in March 1993. The plots were stratified by high versus low elevation£¬ high versus low canopy closures and high versus low damage levels. Selected plots were required to support individual pine stands with minimum stand size of one hectare. It was later determined that 321 plots did not meet the design criteria of overstory homogeneity and were thus withheld from further analysis.

The stand ages of the above plots typically ranged from 5 to 22 years, the tree heights from 2 to 8 meter, the diameter at breast height from 5 to 12 centimeters, and the crown class from 1 to 4. There were about 5 to 10 whorls in each plot. Ground cover under canopy varied greatly with herbs or shrubs being predominant.

Table 1.6 Stand types of constant damage region in study area

Stand types	Canopy closure	Understory coverage(%)
1	£¾0.45	¡Ý50
2	£¾0.45	£¼50
3	£¼0.45	¡Ý50
4	£¼0.45	£¼50

A total of four types of pine stands located in the regions with constant damage were selected(see Table 1.6) and they were chosen to represent a gradient from low to high levels of forest damage. A ground survey was conducted from March to April, 1993. Three hundred and eighty one quadrates(100m¡Á100m) were selected in building the monitoring model, and they are the training areas for carrying out inventory of pine forest stand and damage. The quadrates locations were marked on a configuration map (1:10,000 scale topographic maps). Since losing needles is one of the major symptoms of the forest infested by the pine caterpillar, the percentage of needle loss was estimated by visual interpretation with an accuracy of about 10% in each quadrate. Meanwhile the plot’s other information such as crown closure, diameter at breast height, average tree height, crown class and understory compositions are all investigated and recorded. All the plots were positioned in field by measurement with the positioning error less than 20 meters.

5.4.3 Image pre-processing

Four subsets of images representing the study area were extracted from TM scenes acquired. In order to alleviate the confusion of multi-temporal spectral radiance differences, the 1992 data sets were normalized against the October 1994 and the November 1989 data sets respectively using a series of bright or dark ground targets. To normalize data, the digital number(DN) values of all bands were extracted from all targets for four data sets. The 1992 values were regressed against the 1994 and the 1989 values and a linear relationship were obtained. The regression equation was used to convert the 1992 DNs into values comparable to 1994 and 1989 values. All ground targets for normalization were presumed to have undergone minimal amounts of reflectance change between the acquisition of the two group of data sets. The TM data were rectified to Transverse Mercartor grid using a nearest neighbor resampling method. A 3¡Á3 kernel of pixels surrounding the center of each plot was extracted from the TM data sets. Digital numbers for these nine pixels were used to derive an average for each plot.

5.4.4 Data analysis

There are in TM sensor seven bands of which band 2, band 3 and band 4 are respectively green reflectance region, red strongly absorbed region and near-infrared strongly reflectance region of healthy vegetation. In particular, band 3 and band 4 form a sharp contrast between absorption and reflection and both of them are important bands for detecting chlorophyll concentration, estimating leaf area index and biomass. Moreover, Band 5 and band 7 in the mid-infrared spectrum can sensitively discriminate differences of temperature and water content in vegetation. When pine forest is invaded by pine caterpillar, the needles will be reduced and there will be exposed barks, branches and twigs. Under these circumstances, the digital numbers of band 2 and band 4 will decrease and the values of band 1, band 3, band 5 and band 7 will increase correspondingly. All of the above facts constitute the theoretical basis for detecting forest damage with TM data sets.

According to statistical analysis of the November data sets, spectral signatures of field plots damaged correspond to the previous research results. Table 1.7 shows the difference between 1989 and 1992 November data sets. It indicates that the defoliation or reduction of green biomass caused by pine caterpillar has evident reflection in the TM imagery in 1992. How to enhance and extract these damage information is one of our major study objective.

Table 1.7 Comparison between 1989 and 1992 data sets in November

Items	Years	TM1	TM2	TM3	TM4	TM5	TM7
Mean	1989	50.74	19.43	18.66	34.68	42.33	15.30
Mean	1992	58.20	26.22	26.04	34.43	51.33	21.79
Standard variance	1989	2.267	1.733	2.802	6.573	10.424	4.680
Standard variance	1992	2.993	2.347	3.989	6.158	11.697	5.216
Minimum	1989	45.00	15.22	11.44	14.00	9.78	3.00
Minimum	1992	51.88	20.47	17.76	13.14	14.21	7.87
Maximum	1989	59.00	26.67	30.22	50.56	69.67	30.67
Maximum	1992	67.19	31.31	35.73	48.91	79.49	34.28

5.4.5 EXTRACTION OF DAMAGE INFORMATION

William *et al*.(1985) used ratio vegetation indices of Landsat MSS band 5 over band 7 to discriminate heavy forest defoliation from a category of moderate defoliation and healthy forest with accuracies of 75 to 80 percent. Williams and Nelson(1986) developed techniques to delineate and assess forest damage due to defoliating insects with a reported

90 percent classification accuracy for delineating insect-damaged and healthy forest. Vogelmann and Rock(1988) evaluated Landsat TM data for its ability to detect and measure damage to spruce-fir stands and their study indicated that TM band 5/4 and 7/4 ratios correlated well with ground observation of forest damage defined as percentage of foliage loss.

Change detection using multi-temporal data had previously been employed primarily for the evaluation of land cover changes associated with urbanization(Christenson and Lachowski, 1976; Wickware and Howarth, 1981; Estas *et al*., 1982), desertification(Coiner, 1980; Robinove *et al*., 1981) and coastal zone monitoring(Weismiller *et al*., 1977; Hong and Iisaka, 1982). Specific applications of change detection to monitor defoliation include Nelson(1983), who evaluated image differencing, rationing, and vegetative index differencing of Landsat MSS data for detecting defoliation due to gypsy moth. That study concluded that the vegetative index differencing and an MSS 5 ratio gave the best indication of forest canopy change, with accuracies of about 78 percent. Vogelmann and Rock(1989) used multi-temporal Landsat TM band 4 image differencing with single-date band 3 and 5 data to distinguish between high and low levels of defoliation of hardwood forests caused by the Pear Thrips.

5.4.5.1 Extraction of defoliation in non-rowing season with single-date TM data

In south China, deciduous forest usually drop foliage in early to middle November and herbage vegetation has also faded at this moment. Because the understory vegetation is mainly deciduous broadleaf trees and herbage, the effects of understory vegetation on spectral contribution can be neglected. Analysis of the plots data showed that when canopy closure of the stand(dense pine forest) is greater than 0.45, TM ratios 5/4, 7/4 and (4-5)/(4+5) were found to be strongly correlated with defoliation at the 0.05 level of confidence. Especially, ratio TM 5/4 is the best vegetation index to distinguish four damage levels: healthy pine stand, light damaged stand, moderate damaged stand and heavily damaged stand(0%-30%-50%-70%-100%). As for sparse canopy(canopy closure<0.45), it is difficult to distinguish defoliation differences with single-date TM data sets.

5.4.5.2 Extraction of defoliation in growing season with single-date TM data

In order to probe into effects on spectral reflectance of understory vegetation, we used TM data sets in October during whcich all vegetation are green to find the way for differentiating defoliation. Firstly, we divided dense pine forest into two categories in terms of the presence or absence of understory vegetation, here £¢presence£¢ was defined as greater than 50 percent shrub vegetated cover. While ratio TM 5/4 is still an effective vegetation index to detect damage changes for the latter, only ratio TM 4/3 can be used to measure differences of defoliation for the former case. As for sparse canopy, it is still a difficult problem with single-date TM data.

5.4.5.3 Extraction of damage with multi-temporal TM data

Image differencing or delta detecting (ID) is a technique whereby changes in brightness values between two or more data sets are determined by cell-by-cell subtraction of co-registered image data sets. The subtraction (differencing) produces an image data set where positive and negative values represent areas of change.

(1) Monitoring damage during vegetation’s non-growing period Because the understory vegetation such as the broadleaf trees and the herbs have dropped leaves or become yellow and faded in late November in the study area£¬it can be considered that spectral contribution of understory vegetation is very little and can be neglected. By analyzing various transformations £¨K-T, K-L, IHS£©and their combinations, it can be concluded that ratio TM5/4 is an effective parameter to reflect the level of forest damage when the closure of understory vegetation is small. Analysis of the difference of TM5/4 between the two years showed that ¦¤TM5/4 (difference of TM5/4 between the two years) can be used to assess four levels of needle loss damage. Result of variance analysis showed that the difference is obvious.

(2) Monitoring damage during vegetation’s growth period As the understory vegetation is still vigorous in October, spectral contributions from understorey vegetation will gradually increase with the decrease of crown leaves

of the top layer and the ability to monitor damage caused by forest disease and insects using remote sensing method will decrease. As some plots were covered with cloud on Oct. 26, 1994, only 367 of plots are used for analysis. It can be shown that only three levels of needle loss can be assessed by ¦¤TM4/3(the difference of TM4/3 between the two years). Result of variance analysis showed that the difference is obvious.

It is still an urgent important problem how to get rid of or lessen the disturbance of the understory vegetation and to build effective models for monitoring damages.

5.4.5.4 Building remote sensing monitoring model of pine caterpillars

Because visual method were used in the surveying of the damage, there will be errors. So it is reasonable to consider that the value of TM5/4(x) of a plot whose damage percentage is y% is the powered average of TM5/4 values of the known plots whose damage values and TM5/4 values are y_i% and X_i respectively. Non-parametric regression method can be applied to study the relation between y and x.

(1) Non-parametric regression method to build the relation between y and x. Suppose that the regression relation in which we are interested is f(y)=E(x|y),¬ where y¡ÊR[1] and f(y) is usually estimated by non-parametric kernel regression method whose form can be described as following:

where K(x) is called the kernel function and is usually a probability density function; hn>0 is called the width

$$f(y) = \frac{\sum_{i=1}^{n} X_i K\left(\frac{Y_i - y}{h_n}\right)}{\sum_{i=1}^{n} K\left(\frac{Y_i - y}{h_n}\right)} \qquad (1)$$

function and a good selection is hn=2.345¡Ád¡Án-1/5, where d is the stand error. Formula (1) is called the non- parametric regression estimation of f(y). K(x) can have many forms and in this paper it takes the following form:

$$K(x) = \frac{3}{4\sqrt{5}}\left(1 - \frac{1}{5}x^2\right) I\{|x| \le \sqrt{5}\} \qquad (2)$$

(2) Emulating the above non-parametric regression curve using parameter model. Usually twenty one values of needle loss (y%) are taken respectively as 0%, 5%,¬... 100%. And the corresponding values of f(y) can be obtained through formula (1) as $f_n(0)$, $f_n(5)$, ...$f_n(100)$. The Logist curve :

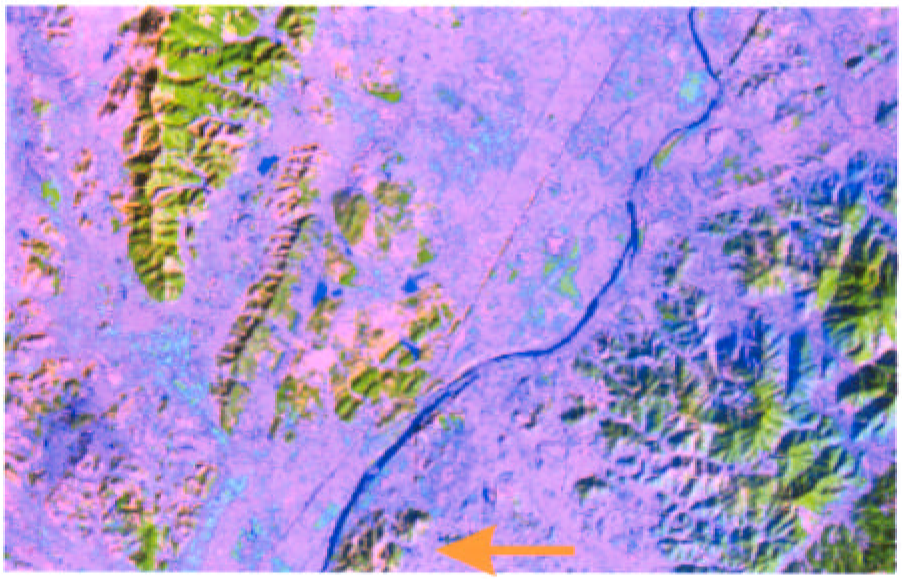
$$x = x_0 + \frac{M}{1 + m \times \exp(-R \times y)} \qquad (3)$$

can be used to emulate the above twenty one points.

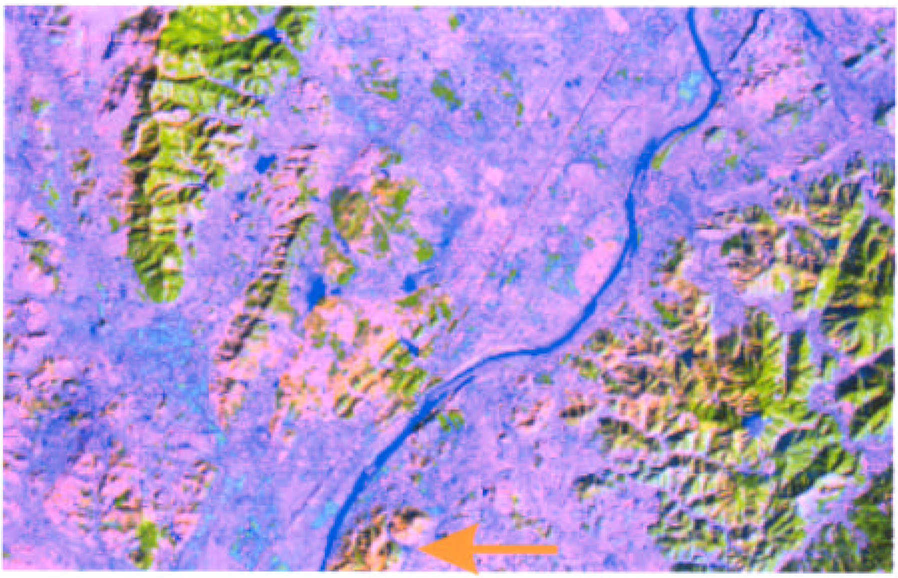
Relation between needle loss (y) and TM5/4 (x) can be obtained from (3) as following:

$$y = -\frac{1}{R} \mathrm{Log}\left[\frac{M}{m \times (x - x_0)} - \frac{1}{m}\right] \qquad (4)$$

and this formula can be used to calculate the damage.



a) TM composite image in 1989



b) TM composite image in 1992

Fig. 1.10 Evolving process of yearly green biomass change based on TM images in Zhejiang Province study area

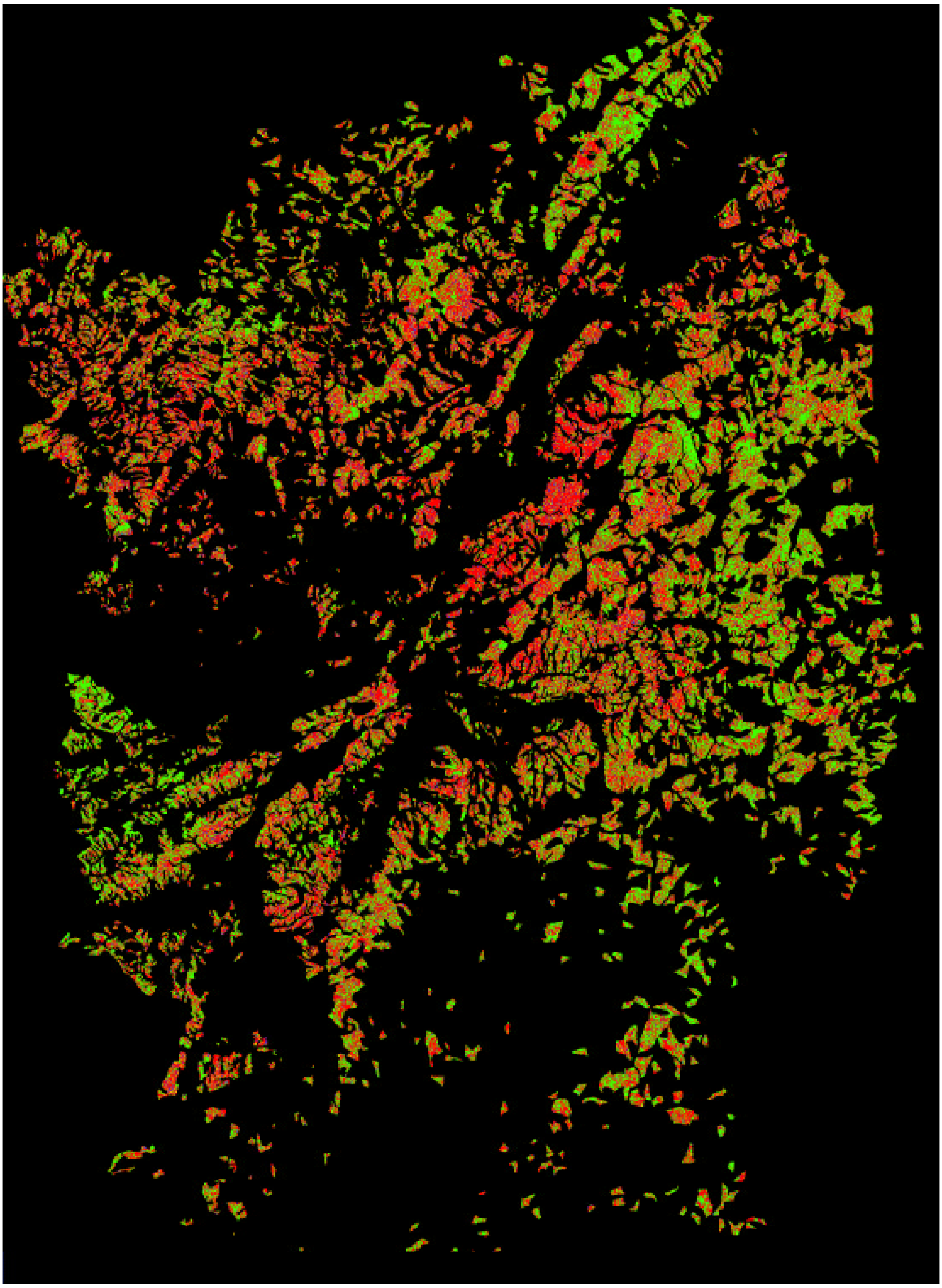


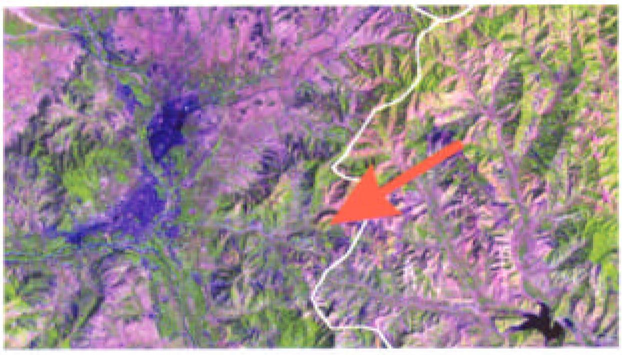
Fig.1.11 Forest health change map of Jiangshan County of Zhejiang Province in 1992(Green¡ªhealthy forest, Yellow¡ªaround 30 of needle loss percentage, Blue¡ªaround 50 of needle loss percentage, Red¡ªLarger than 70 of needle loss percentage)

We can obtain the change map of forest health situation by post-classification progressing.(See Fig.1.11 and Fig.1.12)

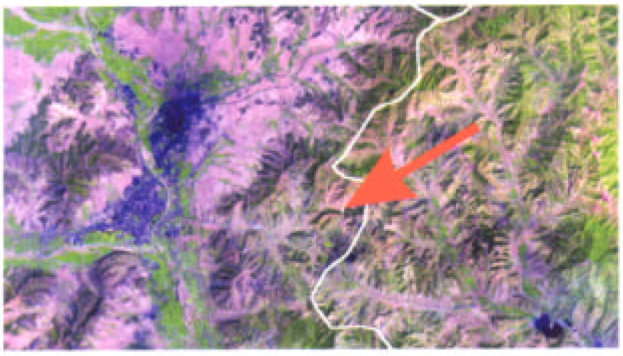
5.6 Detection of forest healthy situation of Liaoning Province in Northeast China

In June, 1987, forest damage caused by pine caterpillar occurred in vast areas of Chaoyang region. In 2000, continual droughts also heavily influenced the growing of forest. From the comparison and analysis of two images, we can clearly see the change of forest quality.

We obtained two scene TM data on 24, June 1987 and on 27, June 2000. After processing and classification, vegetation change information can also be extracted.(see Fig. 1.12 and Fig. 1.13)



a) TM composite image in 1987



b) TM composite image in 2000

Fig. 12 TM imagery in site A of Liaoning Province

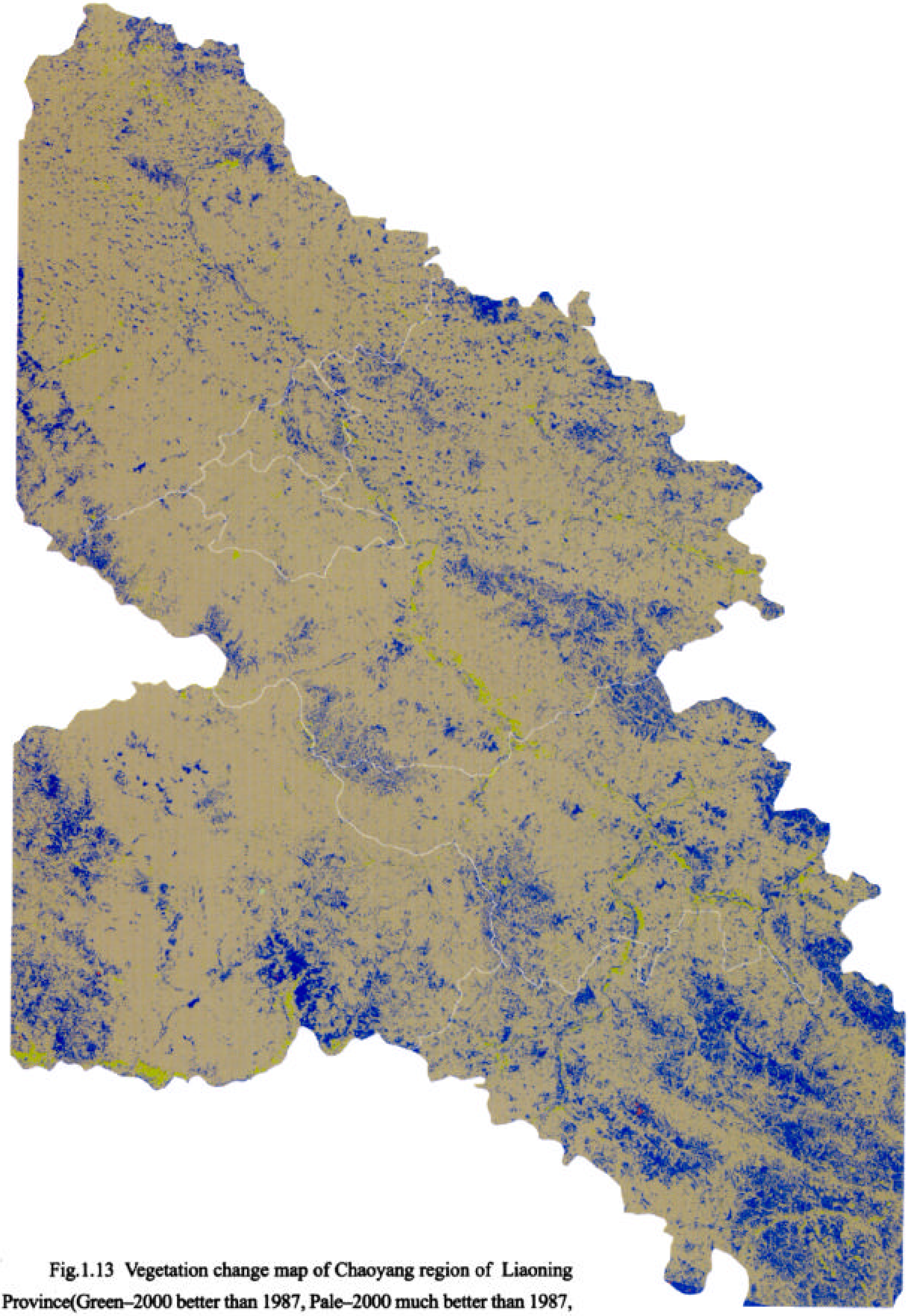


Fig.1.13 Vegetation change map of Chaoyang region of Liaoning Province(Green–2000 better than 1987, Pale–2000 much better than 1987, Blue–1987 better than 2000, Red–1987 much better than 2000)

5.7 Technical methodology

In order to have large scale monitoring, the Landsat TM data is chosen as main data resource. Through nearly ten years of study and probation in Heilongjiang, Zhejiang, Anhui and Liaoning provinces in China, a series of methodology has been obtained to rapidly analyze and process the remote sensing data, preliminary models assessing forest damage have been established. The main flow of the technology is demonstrated by figure 1.14.

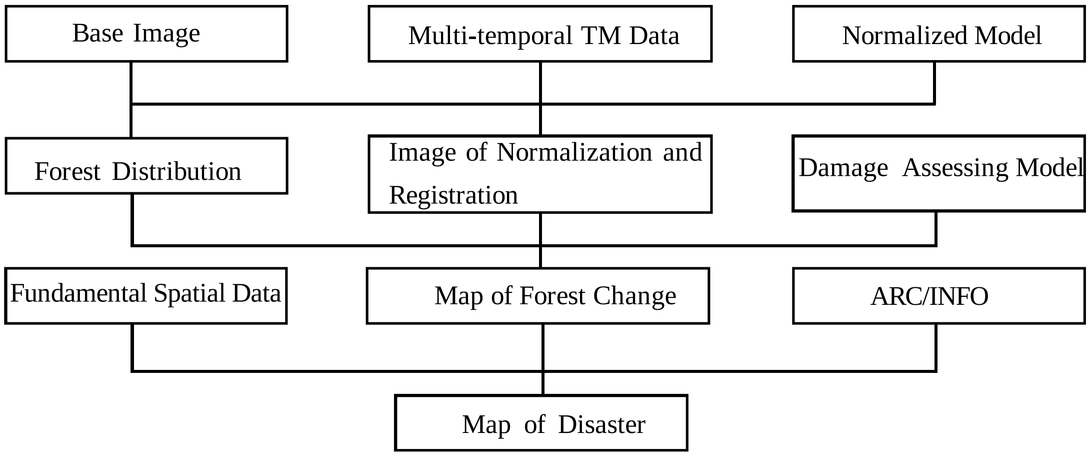


Fig.1.14 Flow chart of the technology

5.8 IKONOS image and its potential

Fig.1.15 shows a Spaceimaging's 1- meter panchromatic image. It can distinctly differentiate the single tree. But the color changes of tree foliage and crown cannot be reflected. Fig.1.16 shows a Spaceimaging's 4- meter multispectral image. We can also discriminate between different tree crowns but the characteristics of single tree cannot be distinguished, and we can use its NIR information to detect the early and subtle changes of foliage. Fig.1.17 is a Spaceimaging's 1-meter orthorectified products obtained in October 1999. It provides map-accurate metric data and combines the spatial content of the 1-meter black-and-white data, with the color content of the 4-meter multispectral data. We can distinctly identify the single tree crown. It is possible to detect the single tree changes quantificationally and positionally. It is out of question that high resolution satellite data can be used to detect the forest pest damage while there are not any reports. It is successfully used to monitor the agricultural damage. Therefore its application will be very extensive in forest health protection.

Fig.1.15 1-meter panchromatic image of IKONOS

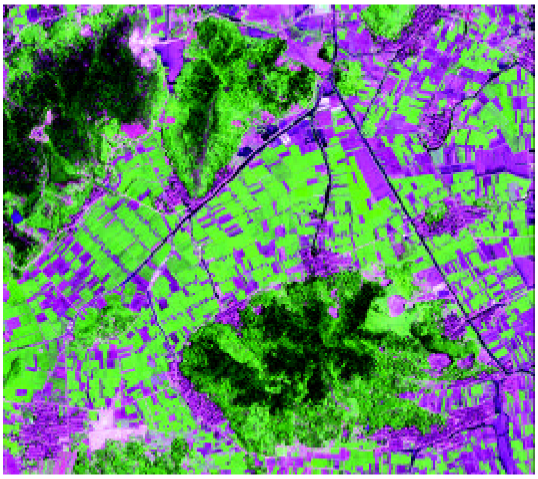


Fig.1.16 4-meter color image of IKONOS

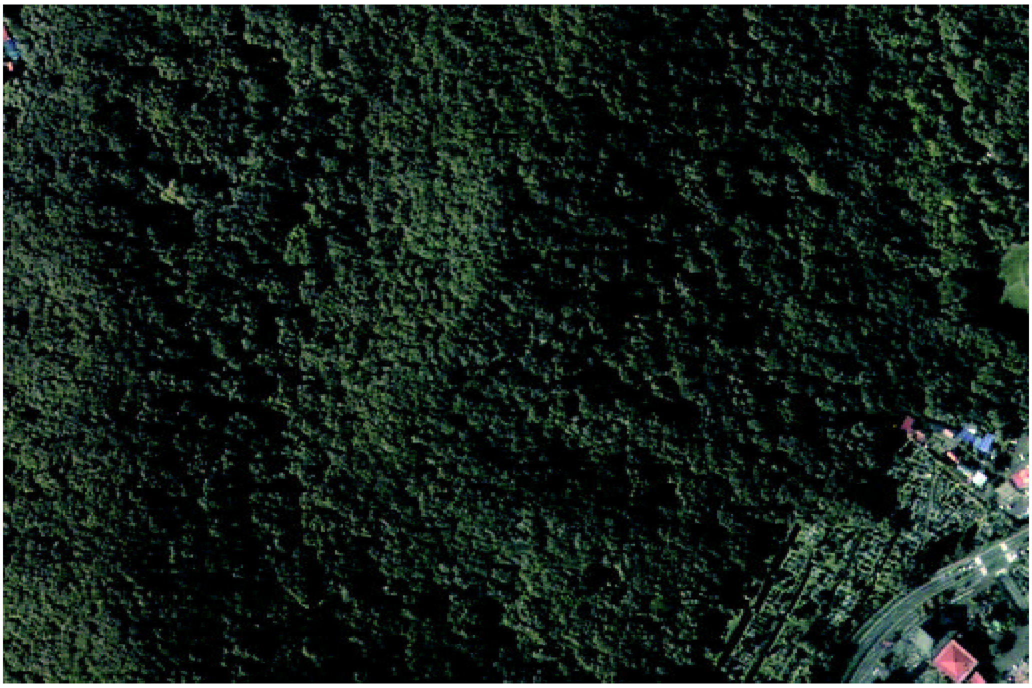


Fig.1.17 1-meter color image of IKONOS

6. Conclusions

Advancement in space and computer technology has greatly facilitated the wide applications of remote sensing, geographic information system and global positioning system. They have become important tools in the production and management of forest resources in developed countries. However, in developing countries like China, the economy and technology are not so advanced and the management works are mainly done by backward investigation method. We hope that these techniques can be improved through our research works, so that they can be widely used in forest resource management and contribute to the social economic sustainable development.

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