Journal of Geographical Sciences 15, 3 (2005) 346–352 ISSN: 1009–637X www.geog.cn

Dynamic analysis and evaluation of Xinjiang forest resources: based on RS and GIS

LI Hu[1,2], *WANG Xiaofeng*[2], *CHEN Shujiang*[2], *HOU Ping*[3]
(1. Department of Geography, Fujian Normal University, Fuzhou 350007, China;
2. Department of Geography, Xinjiang Normal University, Urumqi 830054, China;
3. Department of Environmental Science, Xinjiang Agricultural University, Urumqi 830052, China)

Abstract: The forest resources in Xinjiang were surveyed and analyzed based on RS and GIS. Satellite data interpretation was adopted to obtain the general situation of Xinjiang forest resources in assistance with the sampling method and on-the-spot investigations. Based on GIS, related data obtained from satellite remote sensing in 1996 and 2001 were studied through contrastive analysis. Moreover, the dynamic variation of Xinjiang forest resources was studied in an all-around way. In the past five years, the areas of the forestland, woodland, sparse woodland, nursery garden and the land usable for forestry in Xinjiang kept growing, moreover, the forest cover rate and the total standing stock volume increased correspondingly, showing that the wooded area and the amount of growing stock in Xinjiang were increasing. The forestland area in Xinjiang went up to 17,837 km^2 from 17,331 km^2, with an annual average increase of 101 km^2. Accordingly, the forest vegetation came to 1.08% from 1.05%, up 0.03 percentage point; the total standing stock volume went up to 289,985,200 m^3 from 262,416,000 m^3, a total increase of 27,569,200 m^3, an annual average increase of 5,514,000 m^3 and an annual average net growth rate of 2.00%. The analysis results showed that the forest resources in Xinjiang were increasing on the whole, however, there remained some problems, such as the sparse natural forests, low forest cover rate, imbalanced wood age structure, and mono tree species composition, etc.
Key words: Xinjiang; forest resources; development variety; RS and GIS
doi: 10.1360/gs050308

Xinjiang makes up about 1/6 of the total land area of China, and plays an important role in the national economy. Among the local plant community types, Xinjiang's forests, standing in the arid desert zone, possess the largest biomass and the most complicated structure of plant community, which exert great influence on the ambient environment. Xinjiang only has a forest vegetation of about 1.8%, however, never could we neglect its great ecological function and significance for environment.

1 Method of survey and analysis

1.1 Survey area and data

The survey area amounted to 1.647 million km^2, covering the whole territory of Xinjiang. The Landsat TM image data obtained from remote sensing in whole Xinjiang during the periods 1995-1996 and 2000-2001 were adopted. The time phase interval of the data was June 1 to September 20. The scale of RS interpretation and image data was 1:250,000 at prefectural level, 1:100,000 or 1:50,000 at county (forestry center) level. The precision of survey and statistics was 90%-95%. Related professional and thematic information included the forest resources survey data of the past years, the digital relief map of Xinjiang with a scale of 1:250,000, and various kinds of forestry thematic maps with the scale of 1:50,000 or 1:100,000.

Received: 2005-02-17 **Accepted:** 2005-04-21
Foundation: National Natural Science Foundation of China, No.00013989; No.90302012
Author: Li Hu (1962-), Professor, specialized in investigation and monitoring of resources and environment.
E-mail: lihu2881@yahoo.com.cn

1.2 Method of survey and analysis

1.2.1 RS survey The survey was made on the basis of satellite images interpretation and on-the-spot investigation on plots. The sampling survey method was adopted to obtain the forest resources data of Xinjiang, involving the type, area, distribution and the growing stock of forest, etc. (Ministry of Forestry, 1998).

PCI software was used for image enhancement, image classification, image interpretation, geographic feature superimposing, automatic classification and digital change detection, etc. Meanwhile, the interpretation keys of forest type, land type, distribution and some other factors were established based on preview and spot verification. According to the interpretation keys, the forest survey factors were interpreted by means of man-machine conversation. After being verified and modified through on-the-spot investigations, the findings of survey were input into computer in the form of VFP database table, and the attributive database was set up accordingly.

1.2.2 Data processing Arc/Info software was used to complete the data entry, data edition, and quadrature with topological method. Then, through integrating with the attributive database, the geographic information data, accompanied with attributive data, came into being, which was further converted into proper file formatted data. The forest resources were surveyed and calculated at the county level, which jointly formed the general information data of whole Xinjiang forest resources. The dynamic data of Xinjiang forest resources was deduced through the dynamic analysis and contrast analysis of the RS forest resources data obtained in 1996 and 2001 (Yang *et al*., 2001; Singh A, 1989).

2 Dynamic variation of Xinjiang forest resources

In the past five years, the areas of the forestland, woodland and non-forested land in Xinjiang kept growing, moreover, the forest cover rate and the total standing stock volume increased correspondingly, all of which showed that the wooded area and the growing stock in Xinjiang were increasing.

2.1 The change of forestland area

The area of forestland in Xinjiang went up to 47,691 km^2 in 2001 from 40,941 km^2 in 1996, having a total increase of 6750 km^2, an annual average increase of 1350 km^2 and a net growth rate of 3.05% (Table 1).

2.2 The change of forest resources

The total standing stock volume in Xinjiang went up to 2.90×10^8 m^3 in 2001 from 2.62×10^8 m^3 in 1996, having a total increase of 0.28×10^8 m^3, an annual average increase of 5.51×10^4 m^3 and a net growth rate of 2.00% (Table 2).

In these five years, the area of natural forest in Xinjiang went up to 14,718 km^2 from 14,351 km^2, having an annual average increase of 73 km^2 and a net growth rate of 0.51%. The growing stock of natural forest went up to 2.18×10^8 m^3 from 2.14×10^8 m^3, having an annual average increase of 87.22×10^4 m^3 and a net growth rate of 0.40%. The increased natural forests were

Table 1 The change of forestland area in Xinjiang from 1996 to 2001 (unit: km^2)

Land type	Area change in the primary/late stage of the survey		Difference between the primary/late stage	Annual average difference	Net annual growth rate
	1996	2001			%
Woodland	17331	17837	506	101	0.57
Sparse woodland	4882	5463	581	116	2.24
Shrub forest	8925	8841	-84	17	-0.19
Non-woodland	9285	15126	5841	1168	9.57
Young woodland	504	397	107	21.4	4.75
Nursery land	14	27	13	2.6	12.7
Total	40941	47691	6750	1350	3.046

Table 2 The change of forest resources in Xinjiang from 1996 to 2001

Item	Year 1996	Year 2001	Difference	Annual mean difference	Annual average rate of change (%)
Area of natural forest /km^2	14306	14684	378	75	0.51
Growing stock of natural forest /m^3	213757700	218118800	4361100	872200	0.40
Area of natural economic forest /km^2	45	34	-11	-2	-5.06
Area of natural sparse woodland /km^2	4637	5114	477	95	1.95
Growing stock of natural sparse woodland /m^3	15650500	17916400	2265900	453200	2.70
Area of artificial forest /km^2	2441	2514	73	15	0.61
Growing stock of artificial forest /m^3	22706400	35900700	13194300	2638900	9.01
Area of artificial economic forest /km^2	539	605	66	13	2.27
Total growing stock of artificial forest /m^3	22706400	35900700	13194300	2638900	9.01
Area of artificial sparse woodland /km^2	245	349	104	21	7.07
Growing stock of artificial sparse woodland /m^3	589400	1693700	1104300	220900	19.35
Young woodland /km^2	504	397	-107	-21	-4.66

mainly distributed on the northern slope of the Tianshan Mountains and the mountainous areas of Altay in North Xinjiang (the mountainous areas in North Xinjiang' hereinafter). All these forests came from natural growth and stock.

The area of artificial forest went up to 3865 km^2 from 3729 km^2, having an annual average increase of 27 km^2 and a net growth rate of 0.71%. The increased artificial forests were mainly distributed over the deserts and oases on the plain areas of South and North Xinjiang ('the plain areas' hereinafter). Correspondingly, the growing stock of artificial forest went up to 0.38×10^8 m^3 from 0.23×10^8 m^3, having an annual average increase of 285.97×10^4 m^3 and a net growth rate of 9.39%.

3 Dynamic change analysis of forest resources

Every forest is actually a complicated ecological system, all the internal changes of which are correlated mutually. Further cause analysis of the dynamic changes of Xinjiang forest resources in the past five years is made in the following.

3.1 The cause analysis of area change of main land types

The area of forestland in Xinjiang has increased in the past five years. As for its internal structural changes, the area of forestland, woodland, sparse woodland, nursery garden and the land usable for forestry increased, meanwhile the area of shrubbery land and young woodland decreased (Table 3).

Totally 1538 km^2 of land changed to the woodland from other land types in Xinjiang in the past five years; meanwhile, the area of former woodland had a reduction of 1032 km^2. The net growth of the woodland amounted to 506 km^2, up 0.81%. As for the reduction of the former woodland area, one reason was that some woodland changed to sparse woodland due to disasters and unlawful felling of trees, the other was that some changed to young woodland due to irrational wasteland reclamation and deforestation. In the plain areas, 455 km^2 of woodland changed to non-forested land mainly because of irrational deforestation and wasteland reclamation, most of which was distributed over the peripheries of oases or along the banks of the Tarim River.

The net growth rate of the sparse woodland was 1.92%, mainly resulting from some woodland changing to sparse woodland due to deforestation and fire disasters, most of which was distributed in the mountainous areas of North Xinjiang. Some sparse woodland changed to other land types. As we know, some changed to the woodland in virtue of reforestation and closing of hillsides to facilitate afforestation; some changed to the young woodland, non-forested land owing to wasteland reclamation, disasters and unlawful felling of trees.

Table 3 The internal structural change of forestland in Xinjiang from 1996 to 2001 (unit: km^2)

Area change	Woodland			Sparse woodland			Shrubbery land			Non-forested land		
Land type	Inc-from	Dec-to	V	Inc-from	Dec-to	V	Inc-from	Dec-to	V	Inc-from	Dec-to	V
Woodland				310	22	288		13		201	128	73
Sparse woodland										76	52	24
	22	310	-288									
Shrubbery land	13		13									
Young woodland	269	63	206	13	13							
Undeveloped land usable for afforestation	89	128	-39	39	50	-11	11	82		91	65	26
Clear cut area	39	76	-37	13	26	-13						
Non-forestland	1106	455	651	356	39	317				5936	221	5715
Total	1538	1032	506	731	150	581	11	95	-84	6307	466	5841

Note: Inc- = Increased; Dec- = Decreased; V = variance

The area of the shrubbery land had a reduction of 84 km^2, annual average variation accounting for -0.19%. It was mainly caused by the fact that some shrubbery land changed to the woodland, and some changed to the non-forested land due to irrational wasteland reclamation and deforestation, most of which was distributed over the peripheries of oases in the plain area or along the banks of the Tarim River.

The net growth rate of the non-forested land was 9.57%. Most of the non-forested land came from the land used for the state ecological construction, meanwhile, some young woodland, sparse woodland and woodland also changed to the non-forested land owing to drought, water deficit and failing of reforestation after felling of trees.

3.2 Dynamic change analysis of forest resources

3.2.1 Dynamic change analysis of general resources The total standing stock volume in Xinjiang went up to 2.90×10^8 m^3 in 2001 from 2.62×10^8 m^3 in 1996, having a total increase of 0.28×10^8 m^3, an annual average increase of 551.40×10^4 m^3 and an annual average net growth rate of 2.00%. The amount of growing stock had an increase of 0.18×10^8 m^3, having an annual average increase of 351.09×10^8 m^3 and a net growth rate of 1.43%. Per ha growing stock increased to 147.703 m^3 from 141.198 m^3, having an increase of 6.505 m^3. The increase of growing stock in unit area mainly relied on the increase of density and age of stocking, and also the increase of artificial forest growing stock in unit area.

The annual average growth increment of forest amounted to 868.63×10^4 m^3, having an increase of 317.47×10^4 m^3 and a net growth rate of 44.91%.

The annual average consumption of forest was 332.46×10^4 m^3, having an reduction of 44.17×10^4 m^3. Among the forest consumptions, 242.48×10^4 m^3 were due to felling of trees, having an reduction of 39.69×10^4 m^3; 27.06×10^4 m^3 were from the mortality of forest, having an reduction of 48.47×10^4 m^3; and 62.92×10^4 m^3 were caused by disasters and other factors, having an increase of 43.99×10^4 m^3.

The total growth increment of stand amounted to 665.80×10^4 m^3 and the total consumption was 253.22×10^4 m^3. Because the total growth increment was much higher than the total consumption, the overall growing stock of forest in Xinjiang increased significantly thereby.

3.2.2 Dynamic analysis of natural forest The growing stock of natural forest had an increase of 436.11×10^4 m^3, making up 24.8% of the growing stock increment of forest. The natural forest in the mountainous areas of North Xinjiang had an increase of 446.30×10^4 m^3, while the growing stock of forest in the plain areas had a reduction of 10.19×10^4 m^3.

The increase of natural forest area was 366 km^2, making up 83.8% of the area increment of standing forest. Its annual average net growth rate was about 0.51%. In virtue of the constructions of 'the shelterbelt program for natural forest' and 'the three-north afforestation

Table 4 The change of natural forest area in Xinjiang from 1996 to 2001 (unit: km^2)

Area change	Total	Of which			
		Artificial woodland	Sparse woodland	Young woodland	Non-forested land
Natural forest area increased from	453		419	23	11
Natural forest area decreased to	87	41	11	11	24
Interval net growth	366	-41	408	12	-13
Annual average net growth	73	-8	82	2	-3
Annual average net growth rate %	0.51				

Table 5 The change of artificial forest area in Xinjiang from 1996 to 2001 (unit: km^2)

Area change	Total	Of which					
		Natural woodland	Sparse woodland	Shrub forest	Young woodland	Non-forested land	Non-forestland
Artificial forest area increased from	681	41		14	280	122	224
Artificial forest area decreased to	541	27	135		54	95	230
Interval net growth	140	14	-135	14	226	27	-6
Annual average net growth	28	3	-27	3	45	5.4	1.2
Annual average net growth rate %	0.92						

project', as well as the implementation of classified forest management, many forests in deserts and river valleys obtained well protection and rehabilitation, resulting in the increase of natural forest area. Moreover, much of natural sparse woodland changed to natural woodland owing to the density increase (Table 4).

3.2.3 Dynamic analysis of artificial forest The growing stock of artificial forest had an increase of 0.13×10^8 m^3, making up 75.2% of the growing stock increment of forest. The artificial forest in the mountain areas of North Xinjiang had an increase of 15.05×10^4 m^3, while the increase was 0.13×10^8 m^3 in the plain areas. About 98.86% of the growing stock increment of artificial forest came out of the plain areas; one reason was that the amount of artificial forest in the mountainous areas was much less than that in the plain areas, the other reason was that the fast-growing broad-leaved species were more often used for afforestation in the plain areas, on the contrary, the slow-growing coniferous species were usually used for afforestation in the mountainous areas.

The net increase of artificial forest area was 140 km^2. Newly increased artificial forest in the mountainous areas of North Xinjiang amounted to 41 km^2, and in the plain areas 640 km^2. However, affected by the improper technology and management applied in afforestation, totally 541 km^2 of artificial forest and woodland degraded to the non-forested land due to the low surviving rate (Table 5).

4 Evaluation of forest resources

4.1 Forest type in Xinjiang

4.1.1 Timber forest The timber forest in Xinjiang mainly included the frigid-temperate coniferous forest, such as '*Larix sibirica Ledb*', '*Picea obvata Ledb*' and '*Abies sibirica Ledb*'; the cool-temperate coniferous forest, such as '*Picea schrenkiana Fisch. et Mey. tianschanica* (*Rapi*) *Cheng et Fu*' and '*Juniperus centrasiatica Kom* [*Sabina centrasiatica Kom*]'; the mountain broad-leaved forest, such as '*Betula tianschanica Rupr.*'; the desert riparian forest, such as '*Populus diversifolia Schrenk* (*P. Euphratica Oliv.*)' and '*Populus pruinosa Schrenk*'.

4.1.2 Shrub forest The shrub forest in Xinjiang mainly included the mountain shrub forest, such as *Juniperus pseudosabina*, *Juniperus sabina* and *Caragana*; the valley scrub forest, such as *Hoppophae rhamnoides*; the halophilous shrub forest, such as '*Halyxylon ammodendron*' and

'*Halimodendron halodendron*'; the psammophilous shrub forest, such as '*Halyxylon persicum*' and '*Calligonum spp*.'.

4.2 Ecological and geographic position of the forest in Xinjiang

The arid and dry environment of Xinjiang came into being under the common influence of three factors, including its geographic position far away from oceans, the mountain-surrounded land configuration and the Qinghai-Tibet Plateau uplift (Editorial Committee of Forest in Xinjiang, 1989; Li, 1996). The special geographic position of Xinjiang resulted in the appearance of 'arid and dry' and 'ecologically vulnerable environment', which were just like a pair of 'twin brothers' that took the fundamental influence on the sustainable economic and social development of Xinjiang. The mountain ecosystems, desert ecosystems and the plain & oasis ecosystems, also including the natural forests, artificial forests and the desert timber & shrub forests, jointly played a non-negligible role in the economic and social progress of Xinjiang.

The natural forests of the mountain ecosystem in Xinjiang were mainly distributed over the middle zones of the mountains, which were just located in the steep slope areas, thus, its function of 'soil and water conservation' could be significant. As for the desert ecosystems, the *Populus euphradica* forests and dwarf elm forests growing in riversides and peripheral regions of alluvial fans formed the natural oases in the deserts. Both of these two kinds of forest could grow into special forests and create local climates in the desert-surrounded regions with annual precipitation less than 50 mm, and breed up diversified bio-species. Standing in the front line of combating the severe wind and sand aggression, the shrub vegetation growing in the deserts played an important role in fixing drift sand, preventing desertification and consolidating the development of oases for hundreds of years. The artificial shelterbelts and other forests in the oasis ecosystems had always been working as the important protector of oases, positively taking indisputable effects on alleviating wind and sand aggression, creating favorable local climate in oases, and inhibiting desertification as well.

Through geospatial integration, the mountain ecosystems, desert ecosystems and the plain & artificial oasis ecosystems in Xinjiang organically composed a 'life support system' based on green plants. For a province located in the typical inland arid area, water means everything for the green plants in Xinjiang. All of the surface water resources (including both of the influx and efflux) were generated in the mountain regions. Therefore, the mountain ecosystems were actually the sources of the whole 'life support system' in Xinjiang, and the desert ecosystems and the plain & oasis ecosystems should be considered as the extension of the mountain ecosystems in spatial-time range. For such a 'life support system' depending on the green plants, forests became the main factor to ensure the overall ecological security. The mountain natural forests, the timber & shrub forests in deserts and the artificial forests in the plain areas jointly made up the protection system for the mountain ecosystems, desert ecosystems and the plain & oasis ecosystems. On account of this, the construction of the security protection system for the whole 'life support system' in Xinjiang should mainly depend on developing a green ecological protection system based on the perfect forestry ecological system (including the mountain natural forest, the timber & shrub forests in deserts and the artificial forests in the plain areas).

4.3 Features of Xinjiang forest resources

4.3.1 Limited forestland area Being a forestry and husbandry crisscross area, the forestland and the woodland in Xinjiang only accounted for 26.3% and 20% of the gross operating area respectively, just holding a small proportion of the forest regions. Woodlands and large-area uneven grounds always lay in staggered arrangement in the forest regions, and open spaces existed widely. Fertile pasturelands became the bases for developing livestock husbandry. Owing to the contradiction between forestry and husbandry, the reforestation and resources management in the forest regions of Xinjiang were still facing with some difficulties.

4.3.2 Irrational wood age structure, and ageing of forest In the forest areas, the structure of forest resources was in disproportion. It was shown that the proportion of mature and overmature forest was large, but the proportion of young and middle growth was small; moreover, the

resources reserve was insufficient. All these factors would seriously inhibit the sustainable development of Xinjiang forest resources. As in detail, the area of mature and overmature forest accounted for 61.4% of the gross stand area, young and middle growth 17%, nearly-mature forest 21.6%; and the growing stock volume of mature and overmature forest made up of 71.3% of the total, young and middle growth 8.9% and nearly-mature forest 19.8%.

4.3.3 Forest regions with high-gradient land and mono tree species composition The forest regions in Xinjiang always had the land with high gradient, and 60% of the commercial forests was distributed over the lands with gradient of 25°-35°, resulting in limited yield from felling. The forest regions generally had mono tree species only, for instance, 97% of the stand area and 99% of the growing stock came from *Picea schrenkina*, a dominating tree species there.

4.3.4 Low forest crown density The average crown density of the overall forest area was 0.52. As in detail, the average crown density of the shelter forest area was 0.50, commercial forest area 0.57, and special-use forest area 0.52.

5 Conclusions

The survey and monitoring of forest resources are one of the basic tasks of natural resources management. Xinjiang is an important province for implementing the national strategy of Great Western Development. It is of utmost importance to set up the monitoring system of resources and environment in the future economic and ecological construction. Presently, the application of RS, GIS and GPS (global positioning system) techniques still remains in the initial stage and could not completely satisfy the actual demand in an all-around way. However, this monitoring has been well performed through adopting RS and GIS techniques in assistance with conventional sampling method.

The analysis results showed that the forest resources in Xinjiang was increasing on the whole, however, there still some problems remained, such as the sparse natural forests, low forest cover rate, imbalanced wood age structure, and mono tree species composition, etc. From now on, the natural forest protection projects, the diversified forest management and the regional desertification harnessing should be the important tasks of Xinjiang forestry work.

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