## NELDA TEST SITE REPORT

# Site 7 – Tomsk region. Middle Taiga. "Vasjuganie"

1) Site location
a) Country, State, Province, center coordinates
b) General characteristics of terrain
c) Climate
d) Land use
e) Major types of vegetation disturbance and land cover change
2) Satellite Imagery
3) Ground Data
4) Land Cover Map
a) Map Legend
b) Imagery pre-processing
c) Clouds/Shadows/Haze mask
d) Unsupervised classification
e) Classes assessments
f) Classes distribution
5) Land Cover Change
6) Publications using site data
7) List of Contributors to Site Data and Report
8) Acknowledgements
Appendices:
Appendix A. Tasseled Cap image
Appendix B. Classified image and map legend.
Appendix C. Table. The compliance matrix

#### 1) Site location

a) Country, State, Province — Russian Federation, south part of Tomsk Region (Tomskaya oblast').
Center coordinates - 57° 19' 8.19" N, 82° 6' 5.35" E (Landsat ETM+, Path 150, Row 20)



Figure 1. Test site Vasuganie. Image location.

#### b) General characteristics of terrain.

The test site "Vasjuganie" is located at the south-west part of the West-Siberian Plain in the South Taiga zone with elevations from 110 to 130 m a.s.l. The studied area is drained by Chaya River and its feeders: Iksa, Bakchar, Teterenka, Andarma and Parbig rivers. Watersheds are occupied by bogs. Left-side river terraces are usually paludificated. Bog massifs formation started 4.5 - 5 thousand years ago and since that time the peat deposits cover the initial relief roughness. Watershed bogs have peat depth about 3-4 m.

Underlying soils are mostly carbonate loams and clays with lake-alluvial genesis. Soils are sodpodzol and sod-gley type with relict humus horizons, remained from intense humus accumulation epoch in the Holocene climatic optimum. The natural vegetation is very various. The large part of the area is occupied by wet of paludificated broad leaved forests (Betula pendula Roth. and Polulus tremula L.). Darkconiferous forests with herbaceous-moss layer typical for the South Taiga zone covers very small areas. Mires occupy about 50% of the West Siberia area. Mire types at the test site are presented by open sphagnum and sedge fen, ridge-hollow and ridge-lake complex, pine-shrub-sphagnum community (or "ryam"). Ryams with different tree height (Pinus sylvestris L.) and tree layer density are located at bogs periphery and in the central parts of bog massifs.

### c) Climate

The climate is continental with cool wet summers and long cold winters. The long-term average annual temperature is  $0.53 \pm 0.56$  °C. The annual temperature varied from -0.35°C in 2006 to +1.74 °C in 2007. The average total annual precipitation was  $488 \pm 117$  mm. According to the 20 years average snow cover lasts from 2 November till 22 April. The length of snow free period was  $192 \pm 10$  days. The average May - September air temperature was  $13.6 \pm 0.7$  °C. About 58% of total precipitation (or 285  $\pm 91$  mm) occurred during these months.

#### d) Land use

The area is weakly populated due to high wetland contents. Settlements and agricultural lands (plowed fields, grasslands and hayfields) are located on well drained areas along rivers. The largest village (Bakchar – district center) with adjoined agricultural lands is located in the place of four rivers junction. Reduction of areas of use of plowed fields and hayfields in 1990s results in formation of secondary meadows and partial overgrowing by young birch.

A part of the area is occupied by dark coniferous forests, but clearcuts are relatively small (up to 50 ha per year) due to fact that forests was considerably disturbed by fires in the beginning of XX century. Clearcut are located in the north part of the test site. Clearcuts near the settlements are quite rare. Some forest areas were disturbed at roads and power lines construction.

## e) Major types of vegetation disturbance and land cover change

During the XX century the vegetation cover was exposed to natural and anthropogenic changes. Fires at the beginning of the century during intense area exploration have significant influence on formation of the present forests. Fired areas and clearcuts are occupied by tall grasses preventing coniferous trees restoration. It brings to wide distribution of spare small-leaved forests. Dark coniferous forests with spruce, fir and Siberian pine are pushed to more damp habitats. Fires with periodicity from 12 till 20 years happen both in forests and bogs periphery during the dry years when burns out the top layers of peat.

The natural process changing shape of vegetation is active paludification as at the periphery of bogs and the surface depressions. The specific indicator of the paludification process is presence of pine forest with sedge-sphagnum layer on peat.

Drainage of the part of the Bakcharskoe bog located in a southern part of the test site by the open channels method was done in 1965-1970. Drained area is 22 000 ha. Drainage was done without peat excavation and the subsequent channels swallowing occurred. Now areas along the channels are covered by deciduous species (birch, willow), and adjoining ryams increase in growth of a pine.

## 2) Satellite Imagery

Landsat imagery is the primary source; the stack includes 3 images from 1976 to 1999;

a) Landsat 7 ETM+, 16 Sep 1999, bands 1-5, 7, resolution 28.5 m, GeoTiff, (Haze in the top right and top left corners)

b) Landsat 5 TM, 30 Aug 1990, bands 1-7, resolution 28.5 m, GeoTiff.

c) Landsat 5 TM, 20 July 2007, bands 1-7, resolution 28.5 m, GeoTiff.



Figure 2. Image overview. Landsat 7 ETM+, 16 Sep 1999.

## 3) Ground Data

We use ground data to find classes of unsupervised classification corresponding to known classes. For each item from the map legend we pick out a number of points at the satellite image. The ground points with the known vegetation type were selected using data of field works (stationary and track observations, botanical descriptions, landscape-typological maps), Google Earth images, and expert knowledges on the landscape types. The total number of grund data is 1522. The number of ground point for each class is given in Table 4.



Figure 3. Ground data locations. Map fragment.

# 4) Land Cover Map

a)	Table	1.	Map	Legend
/			r	

Class	Code	Definition
Water	W	Perennial natural water bodies where water is present over 11 months per year.
Bare Land	В	Primarily non-vegetated areas containing less than 15% vegetation cover during at least 10 months per year.
Herbaceous	Н	Main layer consists of herbaceous vegetation with less than 15% tree crown cover. Usually cultivated lands with grasslands or fields. at a different stage of agriculture processing (mowed grass, fallen grass)
Herbaceous.Wetland	HW	Herbaceous and moss vegetation with less than 15% trees on land with water table near/at/above soil surface for enough time to promote wetland or aquatic processes (bogs).
Shrub	S	Vegetation height 0.5-3m with main layer of shrub species with less than 15% tree crown cover.

Shrub.Wetland	SW	Vegetation height 0.5-3m with main layer of shrub species with
		less than 15% trees on land with water table near/at/above soil
		surface for enough time to promote wetland or aquatic
		processes (bogs).
Tree.Broadleaved.Deciduous.	TBDC	Vegetation height greater than 3m with the main layer
Closed		consisting of broadleaved deciduous woodland with a crown
		cover greater than 65%.
Tree.Mixed.Closed	ТМС	Vegetation height greater than 3m with no dominant woodland
		type and crown cover greater than 65%.
Tree.Mixed.Closed.Wetland	TMCW	Vegetation height greater than 3m with no dominant woodland
		type and crown cover greater than 65% on land with water table
		near/at/above soil surface for enough time to promote wetland
		or aquatic processes (bogs).
Tree.Mixed.Open.Wetland	TMOW	Vegetation height greater than 3m with with no dominant
		woodland type and crown cover 15-65% on land with water
		table near/at/above soil surface for enough time to promote
		wetland or aquatic processes (bogs).
Tree.Needleleaved.Evergreen	TNEC	Vegetation height greater than 3m with the main layer
.Closed		consisting of needleleaved evergreen woodland with a crown
		cover greater than 65%.
Tree.Needleleaved.Evergreen	TNECW	Vegetation height greater than 3m with the main layer
.Closed.Wetland		consisting of needleleaved evergreen woodland with a crown
		cover greater than 65% on land with water table near/at/above
		soil surface for enough time to promote wetland or aquatic
		processes (bogs).
Tree.Needleleaved.Evergreen	TNEOW	Vegetation height greater than 3m with the main layer
.Open.Wetland		consisting of needleleaved evergreen woodland with a crown
		cover 15-65% on land with water table near/at/above soil
		surface for enough time to promote wetland or aquatic
		processes (bogs).

The bare lands usually are represented by sands on river banks, plugged fields of after fire places on wetlands. Bare build up was not detected on the image, because settlements on the studied area are small and have more grass cover than buildings.

## b) Imagery pre-processing

The 16-Sept-1999 Landsat ETM+ scene (Path 150, Row 20) used for land cover mapping was acquired at level 1G processing with a 28.5-m spatial resolution and UTM projection (zone 44N, WGS84).

The image-based COST method for atmospheric correction (Chavez Jr. 1996) combined with radiometric calibration (Skirvin 2000) was applied for image processing. Finally, the six ETM+ reflectance bands were transformed into Tasseled Cap indices of brightness, greenness, and wetness (Crist 1985).

Chavez, P. S., jr. 1996. Image-based atmospheric corrections - Revisited and Improved. Photogrammetric Engineering and Remote Sensing 62 (9): 1025-1036.

Skirvin S. M. 2000. Notes on COST\_ETM7 Atmospheric and Radiometric Correction Script, http://arsc.arid.arizona.edu/resources/image\_processing/landsat/

Crist, E.P. 1985. A TM tasseled cap equivalent transformation for reflectance factor data. Remote Sensing of Environment 17: 301-306

#### c) Clouds/Shadows/Haze mask

Mask was constructed basing on unsupervised classification of the image. The image was constructed from 6 bands, including thermal infrared band. Thermal infrared band (#6.1 10.4-12.5  $\mu$ m TIR) allows recognize partially clouded areas and atmospheric haze. A standard procedure of automatic cloud cover assessment [Irish 2000] does can't solve this problem. The composite image was classified into 30 classes. Three classes was reffered to cloudly/haze areas where natural mosaic spatial structures replaced by uniform areas with a single class. These areas were combined to the clouds mask.

R.R. Irish, "Landsat 7 Automatic Cloud Cover Assessment," Algorithms for Multispectral, Hyperspectral and Ultraspectral Imagery VI, SPIE, Orlando, FL., USA, 24-26 April 2000, pp.348-355.



Figure 4. Clouds mask.

#### d) Unsupervised classification

The 1999 Tasseled Cap image was classified into 62 land cover classes using multiple iterations of ISODATA unsupervised classification after applying clouds mask. The classified image was filtered to minimum mapping unit ~0.7 ha (3x3 pixels) with the use of "clump" and "eliminate" procedures. 1 pixel =  $(28.5m*28.5m) = 812.25 m2 \cdot 9 pixels = 7310.25 m2$ .

#### e) Classes assessments

For each class from 30 to 180 points were selected as training data basing on the ground data. The compliance matrix (see Appendix C.) was created to find classes of unsupervised classification corresponding to known classes at ground data. Some unsupervised classes clearly correspond to a single class from map legend (Bare, Water). Spectral characteristics of some classes are very close. For example, we can not exactly separate grassland (herbaceous vegetation) from sedge-sphagnum fens (wetland herbaceous vegetation). Wetlands contain specific objects (water flow lines, forested islands) and can be easily recognized by eye. After classes assessments we manually process the image to correct the classification results. Wrongly determined upland classes (H, S, TNC) located on wetlands were marked as the consequent wetland classes (HW, SW, TNCW). Wrongly determined wetland classes (HW, SW) located in well drained areas were marked as the consequent upland classes (H, S). The second accuracy assessment was carried after manual correction of the classification results (see Table 2). A subset from 398 ground data points was used during the second assessment.

Classified Data	B	M	т	МН	S	SW	TBDC	TMC	ТМСМ	ТМОМ	TNEC	TNECW	TNEOW	Totals
В	32	0	0	0	0	0	0	0	0	0	0	0	0	32
w	0	24	0	0	0	0	0	0	0	0	0	0	0	24
Н	1	0	30	0	2	0	0	1	0	0	0	0	0	34
нพ	0	0	0	22	1	7	0	0	0	0	0	0	0	30
S	0	0	1	0	24	0	2	0	0	0	0	0	0	27
SW	0	0	0	2	0	21	0	1	0	0	0	0	4	28
TBDC	0	0	0	0	2	0	34	1	0	0	0	0	0	37
тмс	0	0	0	0	1	0	0	31	6	3	0	2	0	43
тмсw	0	0	0	2	0	0	0	0	22	6	0	2	0	32
тмоw	0	0	0	0	0	0	0	0	1	21	0	3	1	26
TNEC	0	0	0	0	0	0	0	2	0	0	27	1	0	30
TNECW	0	0	0	0	0	0	0	0	3	2	1	24	2	32
TNEOW	0	0	0	0	0	0	0	0	0	0	0	3	20	23

Table 2. Accuracy assessment.

Total	33	24	31	26	30	28	36	36	32	32	28	35	27	398
Correct	32	24	30	22	24	21	34	31	22	21	27	24	20	332
Accuracy	97.0	100	96.8	84.6	80	75	94.4	86.1	68.8	65.6	96.4	68.6	74.1	83.4

## f) Classes distribution

Tables 3, 4 and Figure 5 show distribution of land cover classes at the studied area. The main part of the studied area is occupied by tree dominated classes (66%). It should be noted that wetlands occupy about 43% of the area. Wetlands are the specific landscape type. It is strongly differs from the other types by the structure of vegetation and ecosystem functioning. It should exist as a on of the basic classes, such as tree-dominated of herb-dominated.

Class	Pixel	Area, ha	Area, %
В	145 064	11 783	0.37
W	237 335	19 278	0.60
Н	3 763 971	305 729	9.51
HW	2 998 052	243 517	7.57
S	1 870 603	151 940	4.72
SW	4 565 543	370 836	11.53
TBDC	5 431 509	441 174	13.72
ТМС	8 444 959	685 942	21.33
TMCW	929 338	75 486	2.35
TMOW	1 822 805	148 057	4.60
TNEC	3 094 160	251 323	7.81
TNEDC	2 273 566	184 670	5.74
TNEOW	4 017 012	326 282	10.15
Total	145 064	11 783	0.37

Table 3. Distribution of land cover classes.

Table 4. Distribution of basic land cover classes.

Class	Pixel	Area, ha	Area, %
В	145 064	11 783	0.37
W	237 335	19 278	0.60
н	6 762 023	305 729	9.51
S	6 436 146	522 776	16.26
TBD	5 431 509	441 174	13.72
ТМ	11 197 102	909 485	28.28
TNE	9 384 738	762 275	23.70



Figure 5. Distribution of land cover classes.

#### 5) Analysis of Land Cover Change

Two additional images 1990 and 2007 were corrected as described above (see 4b section). Cloud masks were constructed for each image. Tasseled caps processing was performed. Disturbance index (DI) was calculated for each tasseled cap image normalized, as described in [Healey S.P., Cohen W.B., Zhiqiang Y., Krankina O.N. Comparison of Tasseled Cap-based Landsat data structures for use in forest disturbance detection // Remote Sensing of Environment. 2005. v.97. #3. p. 301-310.] for forested areas. All disturbance index images were stacked into a one DI image (see Appendix D). Unsupervised classification of the DI image was made and 32 classes were revealed.

Distribution of classes in phase space DI-1990 – DI-1999 – DI-2007 is shown on figure 6. Some classes have changes significantly the disturbance index. A group of classes with high values of DI (20, 23, 27-32) have highest changes in disturbance index. These classes are likely related to changes in herb vegetation at grasslands and meadows. Disturbance indexes of classes 4, 12 and 16 are decreased with time. These classes are corresponds to changes in the central parts of bogs due to variations in water table level. Classes 17 and 10 have a moderate values of DI in 1990 and have significant increase in DI in 1999 and 2007, consequently. These changes are correspond to disturbances in forested areas.



Figure 6. Classes revealed at disturbance index map analysis in phase space DI-1990 – DI-1999 (a) and DI-1990 – DI-2007 (b).

350 points were randomly generated for accuracy assessment analysis: 200 points of undisturbed classes and 75 points for each class related to disturbed at different time periods. The visual comparison of different time images was done for detection of changes at all reference points. The areas with significant changes in forest cover are clearly identified by changes in color, texture and sharp boundaries of cut sites. Accuracy assessments analysis have shown, that classes 10 and 17 are clearly corresponds to the disturbed areas. The overall accuracy is about 75%.

	Changes 1990-1999	Changes 1999-2007	Unchanged
Changes 1990-1999	58	1	0
Changes 1999-2007	0	55	0
Unchanged	17	19	150
Total	75	75	150
Correct	58	52	150
Accuracy	77.3%	73.3%	

Table 5. Accuracy assessments for classification of disturbed areas.



Figure 7. A fragment of forest disturbance map. Legend: 1 – Disturbed in 1990-1999, 2 – disturbed in 1999-2007, 3 – undisturbed forests, 4 – non-forested areas, 5 – water, 6 – clouds.

The image with forest areas eliminated in 1990-1999 and 1999-2007 is shown at figure 7 and Appendix E. The area of forests disturbed in 1990-1999 is equal to 12711 ha. The total forest area has reduced by 8148 ha in 1999-2007.

Decrease of forest area in 1990-1999 are primary occurs due to intense forest cutting for timber industry and local use (for house, road, etc construction). A strong wind have damaged forests between 1990 and 1999 in stripes up to 15x1 km oriented from south-west to north -east in the prevailing wind direction. Strong winds were registered at begin of the century (in 2003, 2005, and 2007) too. They made different wind throw areas. The strongest hurricane has destroyed and damaged forest in area 5 by 50 km.

Tree cutting in 1999-2007 was significantly smaller than in previous time due to depression in economical activity. Some small new cuts for the local purposes appeared in the basic dark coniferous forests and in old cuttings where roads exist.

Some invasion of young tree in to abandoned agricultural lands also can be found at comparison of 1999 and 2007 images. After 1999 many agricultural lands stopped to plug, transformed to unmanaged meadows (grassland) and now occupying by young birch. Small burned areas are exists on the studied territory primary at drainage peatlands but fires does not affect forests significantly. The high sustainability of the studied region to anthropogenic and natural impact are explained by high overall moisture of the territory (about a half of the area occupied by mires), weak population density, the prevailing of broadleaved forests with rich vegetation cover.

## 6) Publications using site data

Books

1. Dyukarev A.G. Landscape-dynamical aspects of soil formation in Taiga zone. Tomsk. Izd-vo NTL. 2005. 284 p. (in Russian)

Articles

2. Dyukarev E.A., Pologova N.N., Golovatskaya E.A. Technologies of remote sensing for study of spatial structure of forest-mire complexes at the key site "Bakcharskiy" // Journal of Siberian Federal University. Engineering & Technologies 2008. v.4. P. 334-345. (in Russian)

Conference abstracts

- Pologova N.N. Types of contacts of forest and mire landscapes and its reflecting in the soil structure // Proc. V all-russian congress of soil scientist society. Rostov-na-Donu. 2008. p.226. (in Russian)
- 4. Dyukarev A.G., Pologova N.N. Landscape-ecological monitoring in oil-gas-producing areas of Western Siberia // Environment protection at oil-gas condensate field development. Tomsk. 2008 p. 63-64. (in Russian)
- Dyukarev E.A., Pologova N.N., Golovatskaya E.A. Spatial structure and dynamics of forestmire complexes at the key area "Vasuganie" // International conference on observations, modeling and information systems: ENVIROMIS-2008, Tomsk, Russia. CNTI, 2008, p.116-117.
- 6. Golovatskaya E.A., Dyukarev E.A. Regional carbon balance assessments for mires of southern taiga zone in West Siberia // International conference on observations, modeling and information systems: ENVIROMIS-2008, Tomsk, Russia. CNTI, 2008, p.73-74.

- 7. Dyukarev A.G., Pologova N.N. Soil formation process at the interface between landscape zones // International conference on observations, modeling and information systems: ENVIROMIS-2008, Tomsk, Russia. CNTI, 2008, p. 68-69.
- 8. Alekseeva A.N., Polishuk Yu.M., Dyukarev A.G. Thematic mapping of vegetation cover at forest-bog areas of Vasjugan plain // International conference on observations, modeling and information systems: ENVIROMIS-2006, Tomsk, Russia. CNTI. 2006. p.16-20.
- 9. Pologova N.N. Types of forest-bog complexes and it's reflection at satellite images // // International conference on observations, modeling and information systems: ENVIROMIS-2006, Tomsk, Russia. CNTI. 2006. p.149.
- 10. Pologova N.N., Lapshina E.D., Bleuten W., Dyukarev E.A. Estimation of sub-recent carbon accimilation rates in West Sibirian peatlands // International conference on observations, modeling and information systems: ENVIROMIS-2006, Tomsk, Russia. CNTI. 2006. p.120.

## 7) List of Contributors to Site Data and Report

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## **APPENDICES:**

# Appendix A. Tasseled Cap image.



Appendix B. Classified image and map legend.



Legend: W - Water, B - Bare Land, H - Herbaceous, HW - Herbaceous.Wetland, S - Shrub, SW -Shrub.Wetland, TBDC - Tree.Broadleaved.Deciduous.Closed, TMC - Tree.Mixed.Closed, TMCW -Tree.Mixed.Closed.Wetland, TMOW - Tree.Mixed.Open.Wetland, TNEC - Tree.Needleleaved. Evergreen.Closed, TNECW - Tree.Needleleaved.Evergreen.Closed.Wetland, TNEOW -Tree.Needleleaved.Evergreen.Open.Wetland

## Appendix C. Table.

The compliance matrix. Correspondence of unsupervised classification results to ground data.

	В	3	т	МН	S	SW	TBDC	TMC	TMCW	TMOW	TNEC	TNECW	TNEOW	TOTAL
Class 1														0
Class 2	31													31
Class 3		2												2
Class 4		5												5
Class 5		14												14
Class 6		3												3
Class 7		7												7
Class 8		5												5
Class 9		5												5
Class 10		7												7
Class 11		38												38
Class 12	5													5
Class 13														0
Class 14														0
Class 15														0
Class 16														0
Class 17		5		1										6
Class 18		2												2
Class 10		5		1										6
Class 20	5	J												5
Class 21	Ű	1									12			13
Class 22			1	3		1					19			24
Class 23				2		9					13			11
Class 24			24	11										35
Class 25	27		1											28
Class 26	21		56											56
Class 20			28											28
Class 27			20 /1											20 /1
Class 20			20	5										25
Class 29			20	60										79
Class 30			9 19	09										70 51
Class 31			40	3	4	19								22
Class 32				1	4	20							2	23
Class 33			1	1	2	10				1			2	12
Class 34						10					27			27
Class 30			<u> </u>								21			24
Class 30			<u> </u>							36	24			24
Class 37			<u> </u>			1				30	<u> </u>		59	50
Class 30			<u> </u>							2	<u> </u>		70	70
			<u> </u>					16	40	2	<u> </u>		10	1Z 56
				4				10 EE	40					50
			4		4		4	35				26		90
			- 1	12								20		30
			/	13		22								20
					4.4	33	2	•						34
Class 45				2	14	15	3	3						3/
Class 46			1	3				18			1			21

Tatal	 	247	24.4		4.40	454	440	45	20		20	400	4040
Class 62	 1	L	I	30	1	I	1	I	I	I	I	L	30
Class 62				20									20
Class 61		18											18
Class 60				19		1							20
Class 59		58	34										92
Class 58				13	1								14
Class 57			2			31		1					34
Class 56			26		1								27
Class 55			8	1		34		3					46
Class 54						16							16
Class 53			29			21		1					51
Class 52			2	2	29								33
Class 51						22							22
Class 50		4	46		1								51
Class 49			27			1	19						47
Class 48						24							24
Class 47			23		1								24

Total	68	99	317	314	86	140	154	112	45	39	82	26	130	1612
Correct	68	98	293	233	62	134	127	73	40	36	51	26	128	1369
Accuracy	100.0	99.0	92.4	74.2	72.1	95.7	82.5	65.2	88.9	92.3	62.2	100.0	98.5	84.9



Legend: 1 – Disturbed in 1990-1999, 2 – disturbed in 1999-2007, 3 – undisturbed forests, 4 – non-forested areas, 5 – water, 6 – clouds.