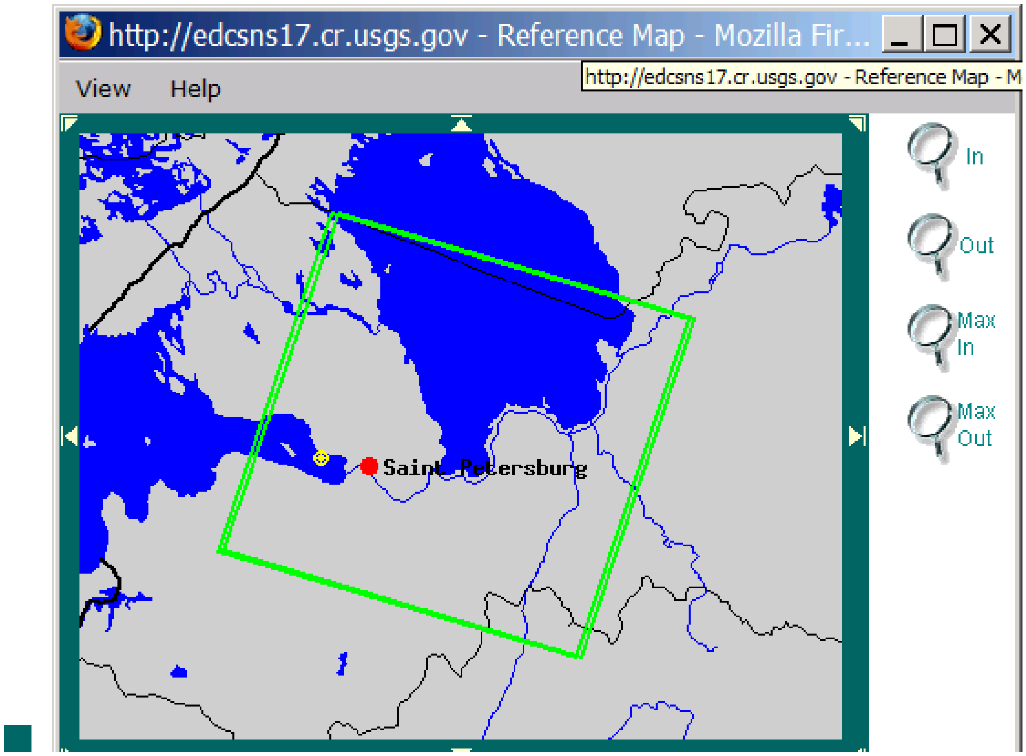
# NELDA TEST SITE REPORT

## Site 1 -- St. Petersburg, Russia

## Table of Contents

## 1) Site location

a) ***Country, State, Province*** -- Russian Federation, central part of St. Petersburg Region (Leningradskaya oblast) and small northern part of Novgorod region




b) ***Center coordinates --*** 60°05'24.00"N, 31°17'24.00"E (Landsat 184/18)

*c)* ***General characteristics of terrain --*** The site is a part of the East-European Plain with elevations between 0 and 250 m a. s. l. The terrain is mostly flat and rests on ancient sea sediments covered by a layer of moraine deposits. The region was completely glaciated during the Ice Age, and contains numerous glacial features. Soils are mostly of the podzol type on deep loamy to sandy sediments. Numerous sites in the northwestern part of the region have very thin sandy soils and exposed granite bedrock, whereas the southern and eastern parts have deep silty soils and numerous expansive peat bogs. The natural vegetation belongs to southern taiga type; major conifer species include Scots pine (*Pinus sylvestris L.*) and Norway spruce (*Picea abies (L.) Karst.*) both growing in pure and mixed stands. After disturbance, these species are often replaced by northern hardwoods including birch (*Betula pendula Roth.*) and aspen (*Populus tremula L.*). The climate is cool maritime with cool wet summers and long cold winters. The mean temperature of July ranges from +16° to +17° C, and the mean temperature of January is -7° to -11° C; mean monthly temperatures are negative November through March, and annual precipitation is 600-800 mm. A large agricultural region stretches south and west from St. Petersburg, a city of over 5 million people. There are numerous towns, villages, and summer cottages throughout the site.

*d)* ***Major types of vegetation disturbance and land cover change –*** During 18-19 century conversion of forest and shrub lands to agriculture was the main type of land-cover change. Remaining forests were used for timber and firewood production. Clearcuts became the main type of wood harvest in the 20 century and at present few (if any) forest stands remain undisturbed by humans.

i) Clearcut harvest occurs on 0.5-1% of forest lands annually. The common size of a clearcut parcel is 100x500 m in conifers and 250x1000 in hardwoods; clearcuts tend to cluster together.

ii) Clearcuts normally regenerate within 2-3 years, often by hardwood species.

***iii)*** A significant portion of clearcut area is planted with conifers (spruce and pine, mostly spruce after 1980-ies). The planted stands often have a significant proportion of natural regeneration present and most young stands are mixed.

***iv)*** Partial harvest and different types of thinning occur on about the same area as clearcuts. Thinning removes 20-40% of tree canopy but the transition from closed-canopy to open-canopy condition seldom exceeds 2-3 years as the canopy recovers. The main long-term effect of thinning is the increased proportion of evergreen-needlleaf cover and reduction of hardwood cover.

v) Other types of forest disturbance (insect outbreaks, windthrow, flooding, etc.) occur infrequently and do not exceed a few hundred ha.

***vi)*** Burning of agricultural lands is rare; forest area burned varies year-to-year. In extreme fire years the area burned can be similar to the clearcut area, but commonly it is much lower (long-term average is about 500 ha/yr). The last extreme fire year occurred in 2001 (? check). Timber is salvaged on a large portion of burned forest.

***vii)*** Slash burning gradually went out of use in 1980ies.

***viii)*** Many peat lands are drained, mostly between 1960-1990, peat was excavated in several locations producing permanently flooded and bare land. Herbaceous and shrub cover regenerates very gradually and bare land condition persists for many years. Some drained peatlands were converted to agriculture; others increased tree cover (mostly pine) as tree growth often improves.

***ix)*** Expansion of summer cottage construction started in 1970'ies and continues at present.

***x)*** Pastures and abandoned fields gradually regenerate with broadleaf shrub and eventually with mixed trees. Significant agricultural abandonment occurred during mid-1990's.

## 2) Satellite Imagery

a) Landsat imagery is the primary source; the stack includes 8 images and covers the time period from 1978 to 2006.; the 9$^{th}$ image is auxiliary for use in the overlapping part. (T:\Groups\Cellar\Larse\Russia\NELDA_Images\1_StPete).

i) Landsat MSS (200/18); Imagine; 1978-May-21 (Wispy clouds in the northern region)
ii) Landsat TM (184/18); hdf; 1988-Jun-27 (Missing data in a big stripe across lower part of image).
iii) Landsat TM (184/18); GeoTiff; 1992-May-19 (Missing data in a big stripe across lower part of image).
iv) Landsat TM (184/18); hdf; 1994-May-19 (10% clouds)

v) Landsat TM (184/18); GeoTiff; 1995-Jul-9

vi) Landsat ETM (184/18); GeoTiff; 2000-Oct-2

vii) Landsat TM (184/18); hdf; 2002-Jun-2

viii) Landsat ETM - SLCoff-GapFilled (184/18); GeoTiff; 2006-Jun-13 (Gap filled using 2004-Jul-9)

ix) Landsat ETM – SLCoff (185/18); GeoTiff; 2006-Jun-13; (Overlap scene used for pixel replacement of gap-fill)

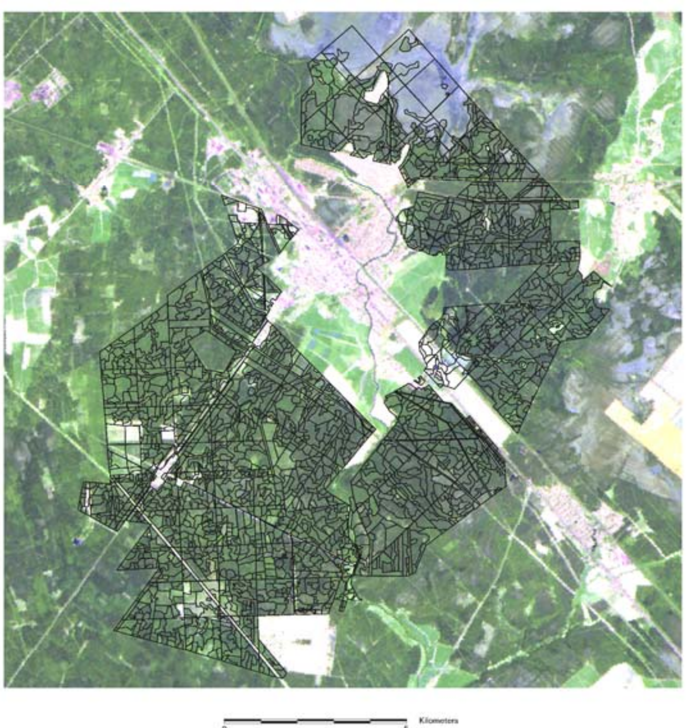
b) Quickbird image (2002-July-13, nw60.3$^{o}$,30.0$^{o}$;se60.2$^{o}$,30.2$^{o}$) was used to supplement land cover classes that were poorly represented in the ground data set.

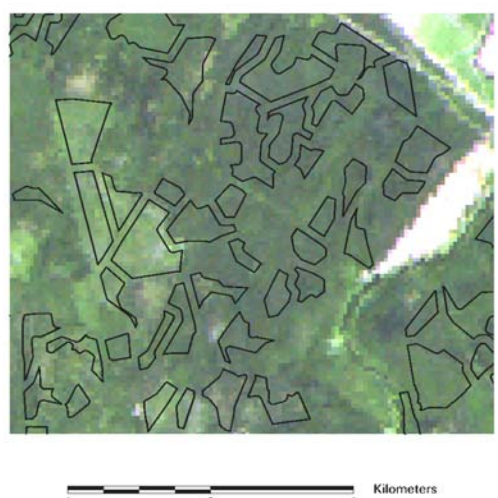
c) Google Earth was used for general geographic context

## 3) Ground Data

a) Forest inventory data: for three separate locations within the site, we obtained a digital map of forest polygons (stands) and the inventory data characterizing each polygon. Data included, for each polygon: area, land cover type as defined by forest inventory (e.g. forest, wetland, clearcut, pasture, etc.) and a set of attributes that varied by land cover class. For forests the attributes included dominant tree species, tree species composition, tree stand age, height, stocking density, volume of live stem wood (growing stock), and volume of snags and logs. For wetlands the attributes included presence of trees, species and percent cover, type of vegetation (dominated by mosses, sedges or reeds). Altogether, for three sites, we used information for 2227 polygons, covering a total area of 8698 ha. The ground data were collected by the Northwestern Forest Inventory Enterprise in 1992 and were updated to match the 2002 image (forest polygons under age 15 were “aged” based on local growth tables, disturbed polygons were removed from the set, other polygons were assumed not to change significantly).

b) Hand-digitized additional polygons using Quickbird (105 polygons) and Google Earth (70 polygons) for classes which were under-represented in forest inventory data.



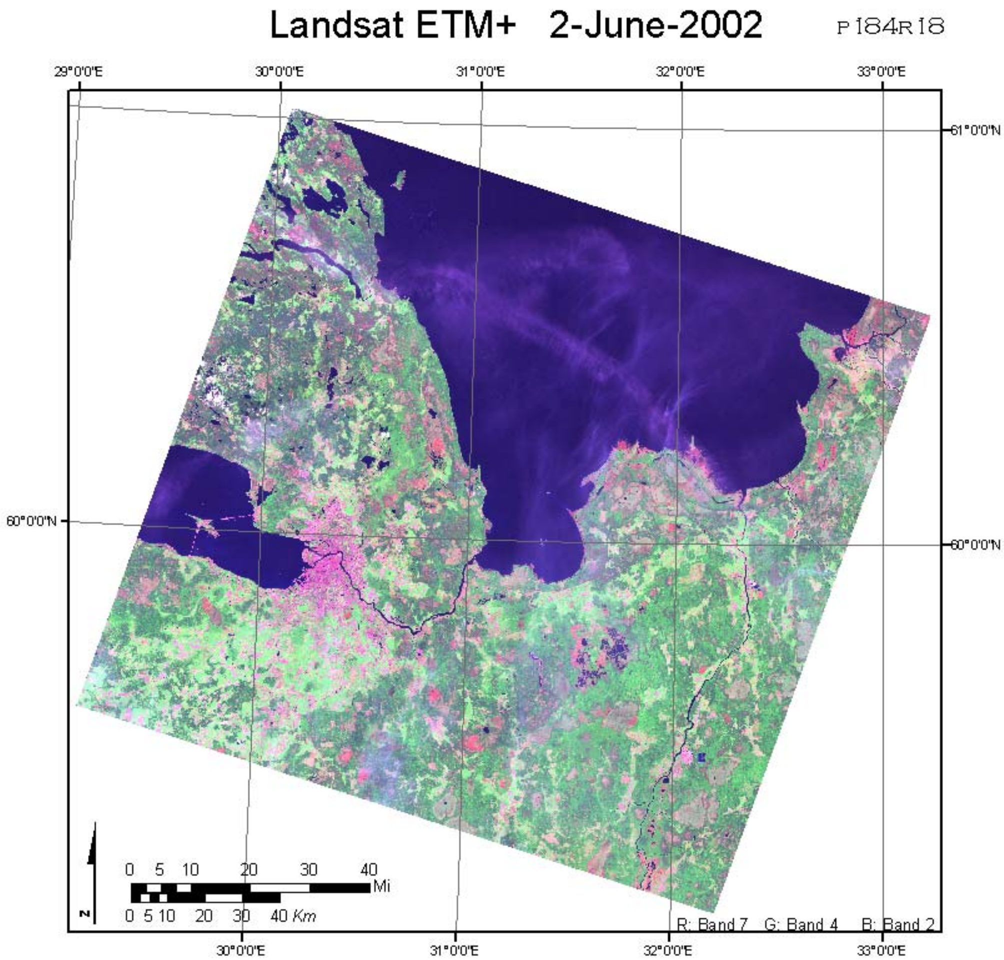



## 4) Land Cover Map

### *a) Map Legend*

| Class (bold is primary class) | Code | Definition |
|---|---|---|
| **Water** | W | Perennial natural water bodies where water is present over 11 months per year. |
| **Bare Land** | B | Primarily non-vegetated areas containing less than 15% vegetation cover during at least 10 months per year. |
| **Bare Land**.Built Up | BB | Buildings or man-made structures cover more than 15% of the area |
| **Bare Land**.Wetland | BW | Primarily drained or mined peat bogs |
| **Herbaceous** | H | Main layer consists of herbaceous vegetation with less than 15% tree crown cover. |
| **Herbaceous**.Cultivated | HC | Areas used for the production of graminoid (wheat, barley, oats, and rice) and non-graminoids (corn, soybeans, vegetables). |
| **Herbaceous**.Wetland | HW | Herbaceous 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. Closed** | TBDC | Vegetation height greater than 3m with the main layer consisting of broadleaved deciduous woodland with a crown cover greater than 65%. |
| **Tree.Broadleaved.Deciduous. Open** | TBDO | Vegetation height greater than 3m with the main layer consisting of broadleaved deciduous woodland with a crown cover 15-65%. |
| **Tree.Mixed.Closed** | TMC | Vegetation height greater than 3m with no dominant woodland type and crown cover greater than 65%. |
| **Tree.Mixed.Open** | TMO | Vegetation height greater than 3m with no dominant woodland type and crown cover 15-65%. |
| **Tree.Needleleaved.Evergreen. Closed** | TNEC | Vegetation height greater than 3m with the main layer consisting of needleleaved evergreen woodland with a crown cover greater than 65%. |
| **Tree.Needleleaved.Evergreen. Closed.Wetland** | TNECW | Vegetation height greater than 3m with the main layer 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. Open** | TNEO | Vegetation height greater than 3m with the main layer consisting of needleleaved evergreen woodland with a crown cover 15-65%. |
| **Tree.Needleleaved.Evergreen. Open.Wetland** | TNEOW | Vegetation height greater than 3m with the main layer 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). |

## b) *Imagery pre-processing*




The 2-June-2002 Landsat ETM+ scene (Path 184, Row 18) used for land cover mapping was acquired at level 1G processing with a 28.5-m spatial resolution and UTM projection (zone 36N, WGS84). We used an automated tie-point program from Kennedy and Cohen (2003) to geometrically rectify the image to an orthorectified Landsat scene (Tucker et. al. 2004) with an RMSE within a half-pixel. A cloud-free 19-May-1994 TM image was first converted to at-satellite radiance using parameters from Chander and Markham (2003) and then to surface reflectance using the COST radiometric correction model (Chavez Jr. 1996). The 2002 ETM+ scene was then radiometrically normalized to the atmospherically corrected TM image using the multiple alteration detection calibration algorithm from Canty (2004). Finally, the six ETM+ reflectance bands were transformed into Tasseled Cap indices of brightness, greenness, and wetness (Crist 1985).

Chavez Jr., P.S. 1996. Image-based atmospheric corrections – revisited and improved. Photogrammetric Engineering & Remote Sensing 62: 1025-1036

Canty, M.J., Nielsen, A.A., & Schmidt, M. 2004. Automatic radiometric normalization of multitemporal satellite imagery. Remote Sensing of Environment, 91: 441-451.

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

Kennedy, R.E., & Cohen, W.B. 2003. Automated designation of tie-points for image-to-image coregistration. International Journal of Remote Sensing, 24: 3467-3490.

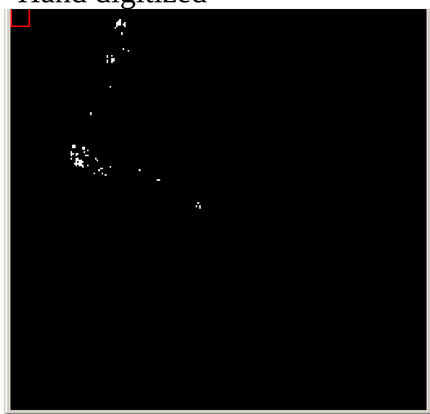
Tucker, C.J., Grant, D.M., & Dykstra, J.D. 2004. NASA's Global Orthorectified Landsat Data Set. Photogrammetric Engineering & Remote Sensing.: 70 (3): 313–322.

***c) Masks***

i. Background – thresholding

*F:\NELDA\NELDA_Sites\1_StPete\classifications\masks\mask_NELDA_StPete_2002_background*

ii. Clouds/Shadows – Hand digitized



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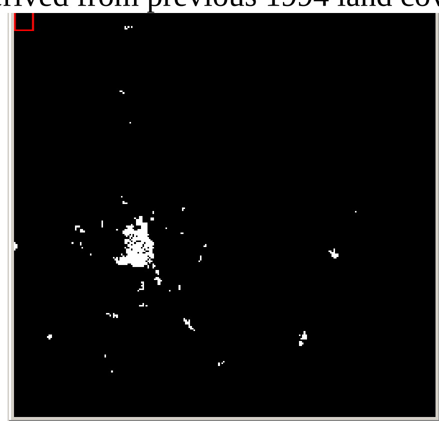
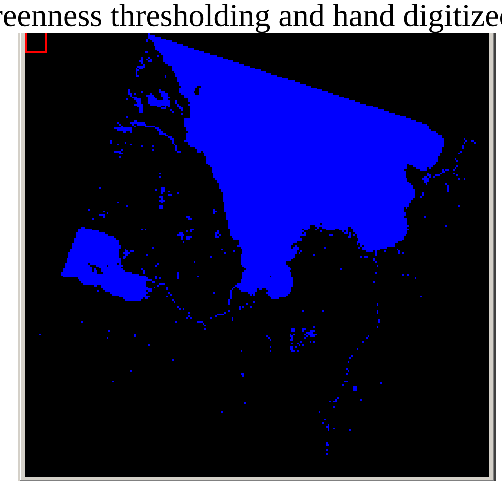
ii. Urban Cities – Derived from previous 1994 land cover map (Oetter et. al. 2001)



*F:\NELDA\NELDA_Sites\1_StPete\classifications\masks\mask_NELDA_StPete_1994_urban*

Oetter, D.R., Krankina, O.N., Cohen, W.B., and Majersperger, T.K.: Using landsat thematic mapper data to map land cover and biomass in a Russian forest for regional carbon storage inventory, Global Change Open Science Conference, Amsterdam, The Netherlands, 10-13 July,2001.

iii. Water – TC Greenness thresholding and hand digitized shallow rivers



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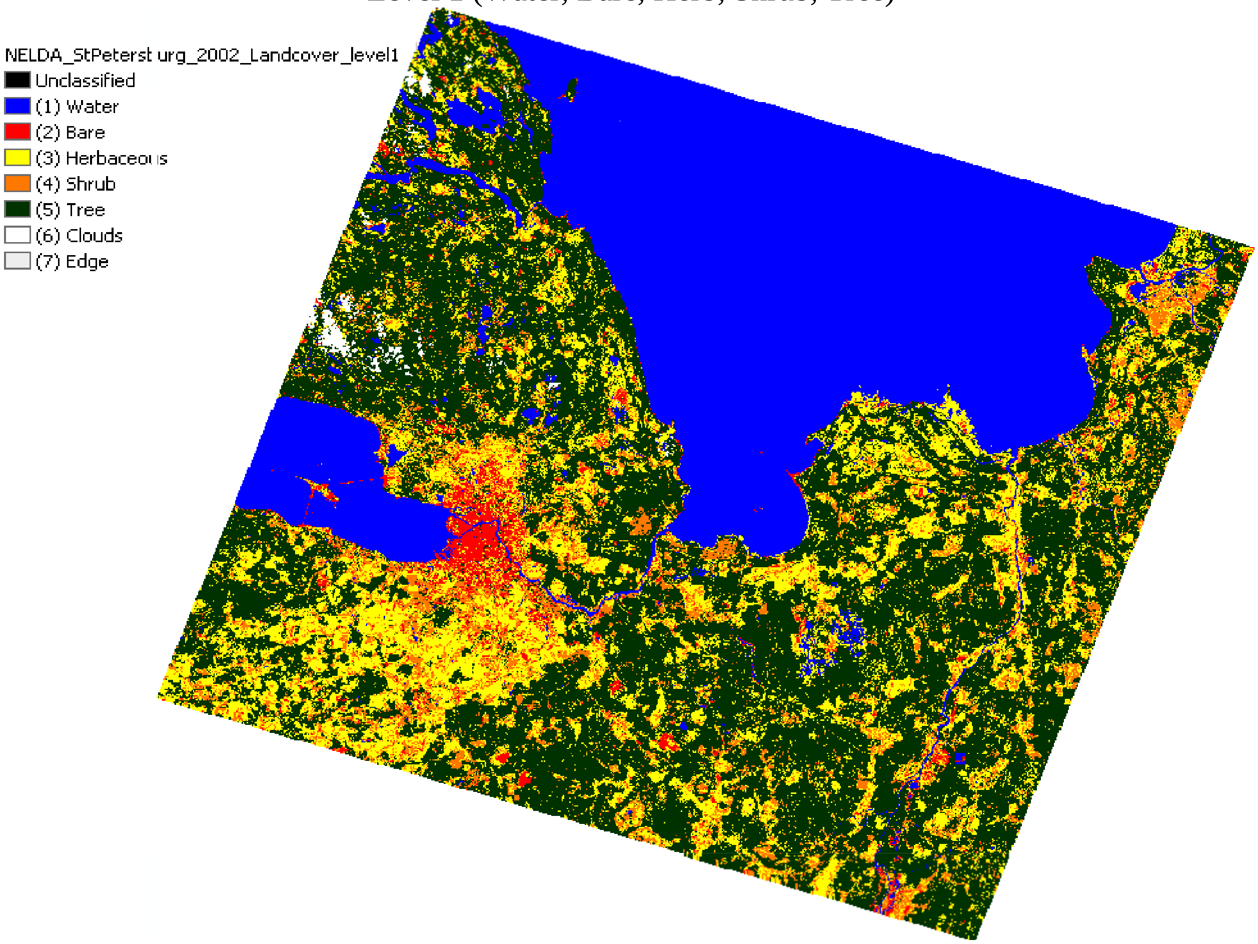
### *d) Unsupervised classification*

The 2002 Tasseled Cap image was classified into 14 land cover classes using multiple iterations of ISODATA unsupervised classification after applying the masks.

Level 1 (Water, Bare, Herb, Shrub, Tree)

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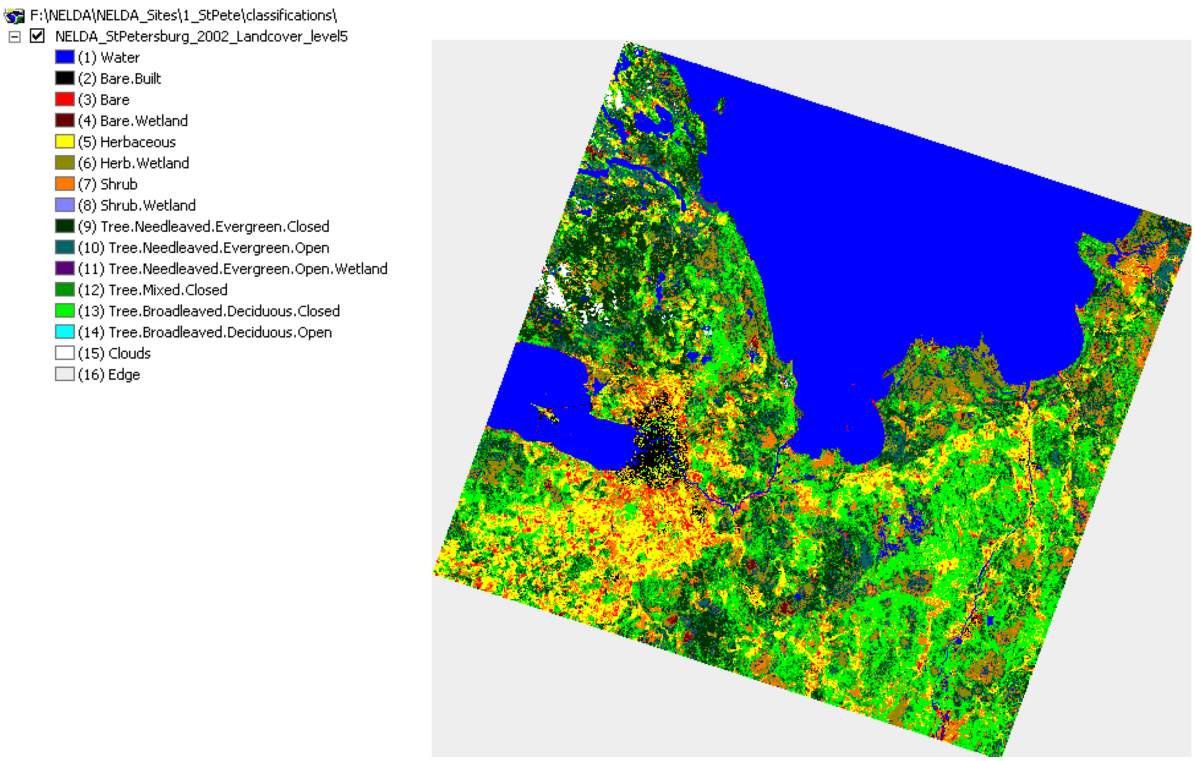
Filter to minimum mapping unit ~1 ha (12 pixels)

1 pixel * (28.5m*28.5m) = 812.25 $m^2$ *12 pixels = 9747 $m^2$

Level 5

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### *e) Accuracy assessment*

Using forest inventory polygon data and hand digitized reference polygons, error matrices were created to assess the quality of the raster land cover maps. Mid-points of percent cover values for each class found within a polygon were used to determine average percent of relevant cover types and based on those percents map-based classes were assigned to each polygon.

Error matrix for Level 1 (Water, Bare, Herb, Shrub, Tree)

| Level 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Count of Polygons | Reference | | | | | | |
| Classification | B | H | S | T | W | Total | Commission |
| B | 380 | 5 | 1 | | | 386 | 1.6% |
| H | 1 | 58 | 5 | 6 | | 70 | 17.1% |
| S | 1 | 6 | 44 | | | 51 | 13.7% |
| T | | 18 | | 2176 | | 2194 | 0.8% |
| W | | | | | 116 | 116 | 0.0% |
| Total | 382 | 87 | 50 | 2182 | 116 | 2817 | |
| Ommission | 0.5% | 33.3% | 12.0% | 0.3% | 0.0% | | |
| | | | | | | | |
| | | | Overall Accuracy = | 2774 | / 2817 = | 98.5% | |
| | | | | | kappa = | 0.959 | |
| | | | | | | Almost perfect agreement | |

**B** = Bare **H** = Herbaceous **S** = Shrub **T** = Tree **W** = Water

Error matrix for Level 2

| Level 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Count of Polygons | | | | Reference | | | | | |
| Classification | B | H | S | TB | TM | TN | W | Total | Commision |
| B | 379 | 5 | 1 | | | | | 385 | 1.6% |
| H | 1 | 58 | 5 | 6 | | | | 70 | 17.1% |
| S | 1 | 6 | 44 | | 1 | 1 | | 53 | 17.0% |
| TB | | 1 | | 672 | 176 | 6 | | 855 | 21.4% |
| TM | | 2 | | 140 | 193 | 50 | | 385 | 49.9% |
| TN | 1 | 15 | | 29 | 152 | 756 | | 953 | 20.7% |
| W | | | | | | | 116 | 116 | 0.0% |
| Total | 382 | 87 | 50 | 847 | 522 | 813 | 116 | 2817 | |
| Ommission | 0.8% | 33.3% | 12.0% | 20.7% | 63.0% | 7.0% | 0.0% | | |
| | | | | | | | | | |
| | | Overall Accuracy = | | 2218 | / 2817 = | 78.7% | | | |
| | | | | | kappa= | 0.721 | Substantial Agreement | | |

**B** = Bare **H** = Herbaceous **S** = Shrub **TB** = Tree.Broadleaved
**TM** = Tree.Mixed **TN** = Tree.Needleleaved **W** = Water

Error matrix for Level 4

| Level 4 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Count of Polygons | | | | | Reference | | | | | |
| Classification | B | H | S | TBDC | TMC | TNEC | TNEO | W | Total | Commision |
| B | 379 | 5 | 1 | | | | | | 385 | 1.6% |
| H | 1 | 58 | 5 | 6 | | | | | 70 | 17.1% |
| S | 1 | 6 | 44 | | 1 | 1 | | | 53 | 17.0% |
| TBDC | | 1 | | 672 | 176 | 6 | | | 855 | 21.4% |
| TMC | | 2 | | 140 | 193 | 49 | | | 384 | 49.7% |
| TNEC | 1 | 15 | | 29 | 152 | 426 | 3 | | 626 | 31.9% |
| TNEO | | | | | | 263 | 65 | | 328 | 80.2% |
| W | | | | | | | | 116 | 116 | 0.0% |
| Total | 382 | 87 | 50 | 847 | 522 | 745 | 68 | 116 | 2817 | |
| Ommision | 0.8% | 33.3% | 12.0% | 20.7% | 63.0% | 42.8% | 4.4% | 0.0% | | |
| | | | | | | | | | | |
| | | Overall Accuracy = | | 1953 | / 2817 = | 69.3% | | | | |
| | | | | | kappa = | 0.616 | | Substantial Agreement | | |

**B =** Bare **H =** Herbaceous **S=** Shrub **TBDC =** Tree.Broadleaved.Deciduous.Closed
**TMC =** Tree.Mixed.Closed **TNEC =** Tree.Needleaved.Evergreen.Closed
**TNEO** = Tree.Needleaved.Evergreen.Open **W** = Water

Error matrix for Level 5

| Count of Polygons | | | | | | Reference | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Classification | B | BB | BW | H | HW | S | TBDC | TMC | TNEC | TNEO | TNEOW | W | Total | Commision |
| B | 148 | | 3 | | 1 | | | | | | | | 152 | 2.6% |
| BB | | 183 | | | | | | | | | | | 183 | 0.0% |
| BW | 3 | | 41 | | 4 | 1 | | | | | | | 49 | 16.3% |
| H | 1 | | | 25 | | | 3 | | | | | | 29 | 13.8% |
| HW | | | | | 33 | 5 | 3 | 1 | | | 2 | | 44 | 25.0% |
| S | 1 | | | | 6 | 44 | | 1 | 1 | | | | 53 | 17.0% |
| TBDC | | | | | 1 | | 672 | 176 | 6 | | 2 | | 857 | 21.6% |
| TMC | | | | | 2 | | 140 | 192 | 49 | | | | 383 | 49.9% |
| TNEC | 1 | | | | 15 | | 29 | 152 | 426 | 3 | 1 | | 627 | 32.1% |
| TNEO | | | | | | | | | 263 | 19 | 7 | | 289 | 93.4% |
| TNEOW | | | 1 | | | | | | | | 34 | | 35 | 2.9% |
| W | | | | | | | | | | | | 116 | 116 | 0.0% |
| Total | 154 | 183 | 45 | 25 | 62 | 50 | 847 | 522 | 745 | 22 | 46 | 116 | 2817 | |
| Ommission | 3.9% | 0.0% | 8.9% | 0.0% | 46.8% | 12.0% | 20.7% | 63.2% | 42.8% | 13.6% | 26.1% | 0.0% | | |
| | | | | | | | | | | | | | | |
| | | | Overall Accuracy = | | 1933 | / 2817 = | 68.6% | | | | | | | |
| | | | | | | kappa = | 0.614 | | Substantial Agreement | | | | | |

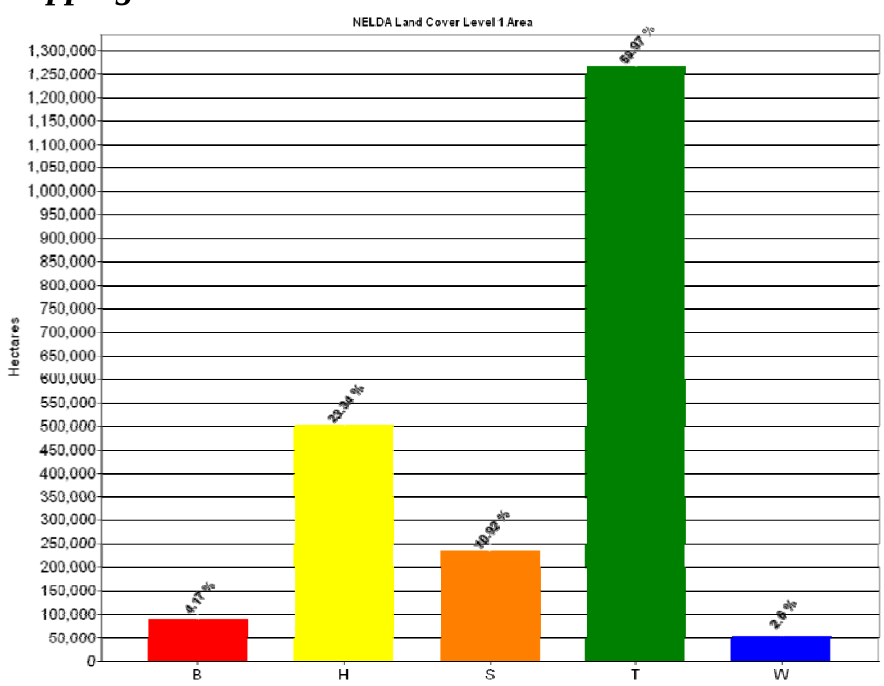
**B** = Bare **BB**= Bare.Built **BW** = Bare.Wetland **H** = Herbaceous **HW** = Herbaceous.Wetland
**S**= Shrub **TBDC** = Tree.Broadleaved.Deciduous.Closed **TMC** = Tree.Mixed.Closed
**TNEC** = Tree.Needleaved.Evergreen.Closed **TNEO** = Tree.Needleaved.Evergreen.Open
**TNEOW** = Tree.Needleaved.Evergreen.Open.Wetland **W** = Water

The transformation of the 6 Landsat bands into the Tasseled Cap spectral space of brightness, greenness, and wetness improves the identification and separation of different land cover types. For example, water can be identified through a combination of low brightness, low greenness, and high wetness values. Bare land has the characteristics of high brightness, low greenness, and low wetness values. Herbaceous tend to have the highest greenness values (although seasonality might affect this), higher brightness values, and low wetness values. Trees are identified as having moderate brightness (increasing as the canopy decreases), high greenness values, and high wetness values. Needleleaved trees have a lower greenness value compared to broadleaved trees. Shrubs tend to be a mix of high brightness, moderate greenness, and lower wetness due to the size of the leaf and background soil material.

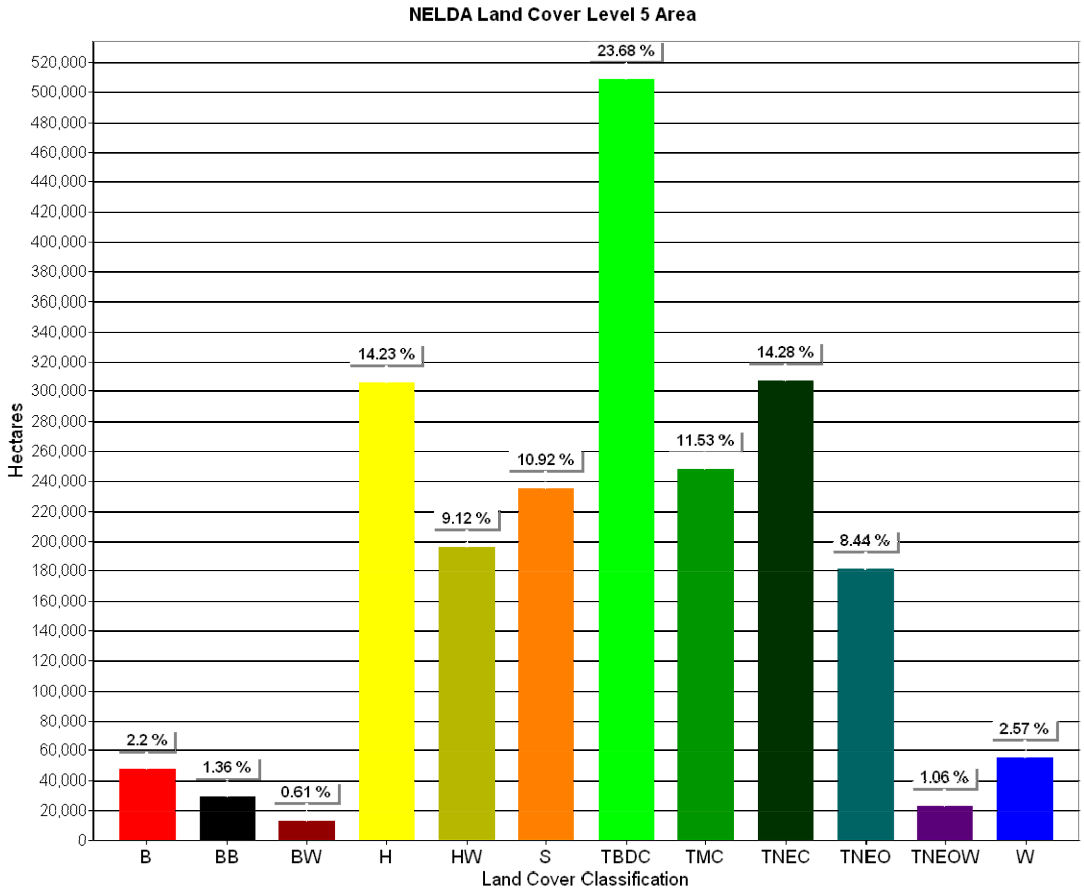
The greatest success delineating the St. Petersburg study site was greatest at NELDA level 1 classification of water, bare land, herbaceous cover, shrub cover, and tree cover. Upon further division of the tree cover into needleleaved, mixed, or broadleaved types there appears to be some misclassification when compared with polygon reference data although there is substantial agreement (overall accuracy = 78.7%, kappa = 0.72). Dividing the tree classes based upon crown cover of the area into opened or closed, had substantial agreement (kappa = 0.61) when compared to polygon reference data with a reduction in overall accuracy (69.9%). Finally, identifying wetlands within the study area was successful overall with substantial agreement (kappa = 0.61, overall accuracy = 60.6%) with reference polygons.

Separating the pure stands of Tree.Needleleaved from Tree.Broadleaved was successful because of the difference in Tasseled Cap greenness. Tree.Mixed class was less success when compared to 1992 reference forest inventory polygons. The Tree.Mixed class introduces the most error into the map with an omission rate of 63% and a commission rate of 49%.

## f) *Mapping results*

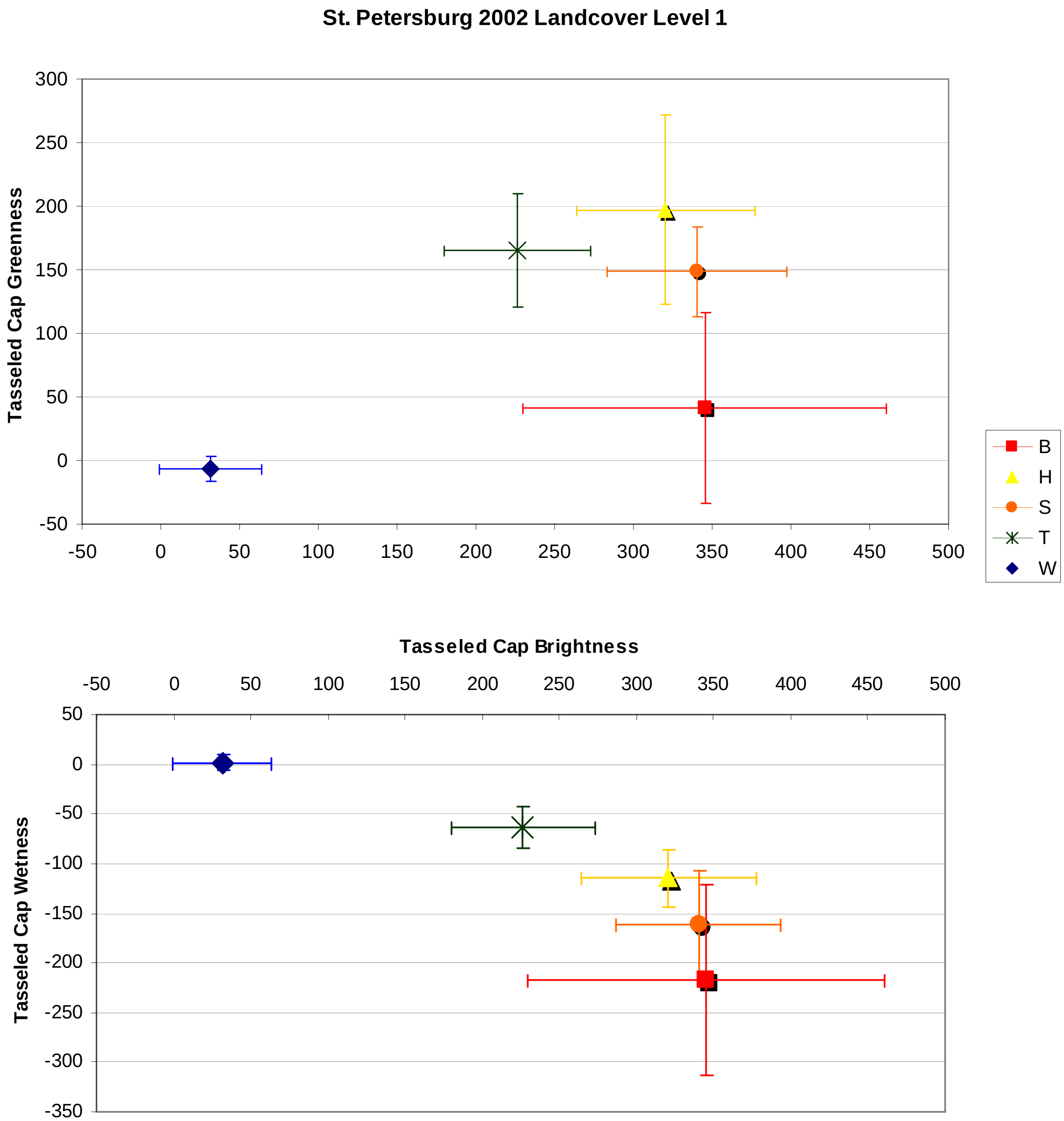



Level 1 classification (excluding the Baltic Sea and Lake Ladoga). **B** = Bare **H** = Herbaceous **S** = Shrub **T** = Tree **W** = Water

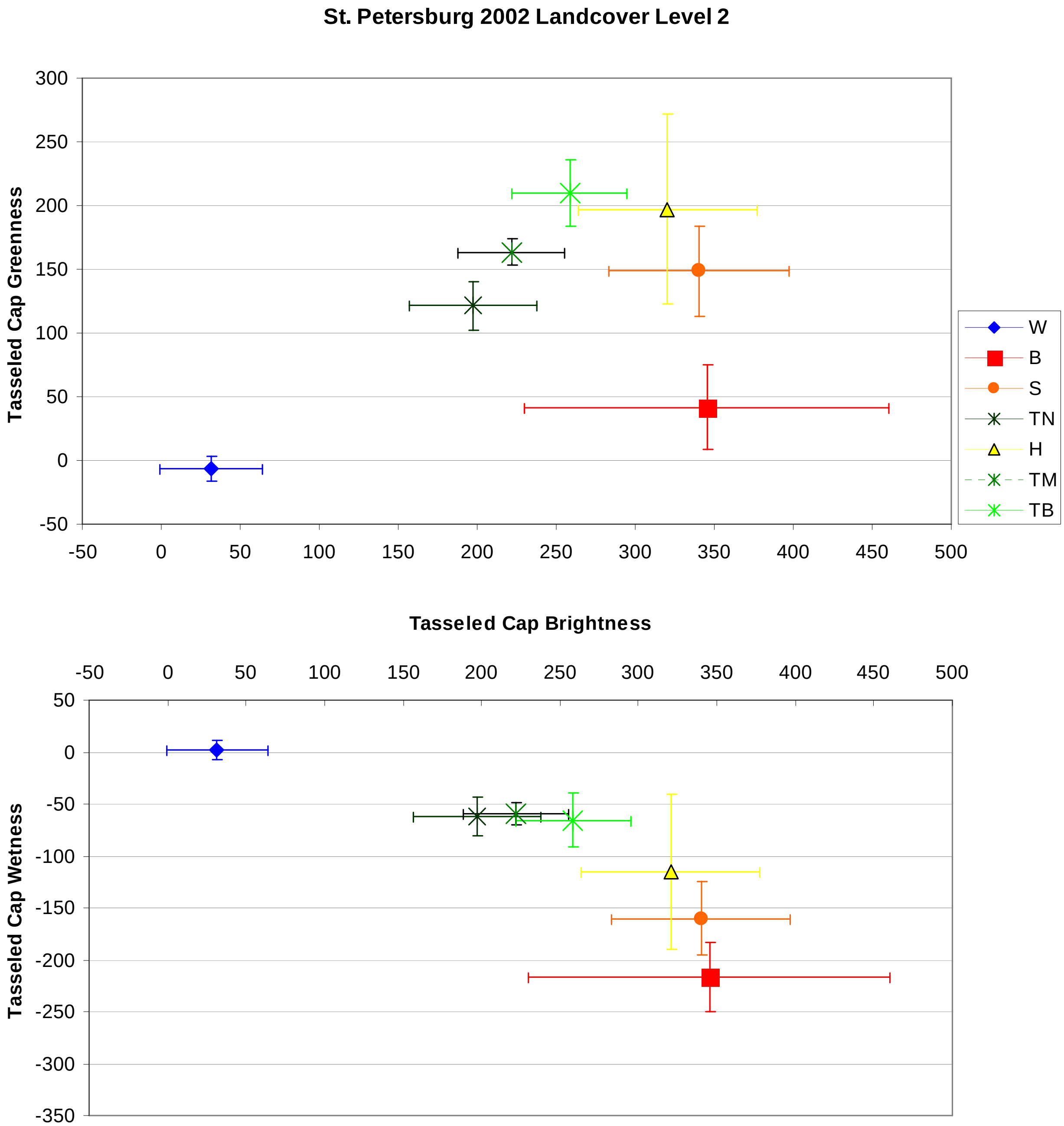



Level 5 (excluding the Baltic Sea and Lake Ladoga). **B** = Bare **BB**= Bare.Built
**BW** = Bare.Wetland **H** = Herbaceous **HW** = Herbaceous.Wetland **S**= Shrub
**TBDC** = Tree.Broadleaved.Deciduous.Closed **TMC** = Tree.Mixed.Closed
**TNEC** = Tree.Needleaved.Evergreen.Closed **TNEO** = Tree.Needleaved.Evergreen.Open
**TNEOW** = Tree.Needleaved.Evergreen.Open.Wetland **W** = Water

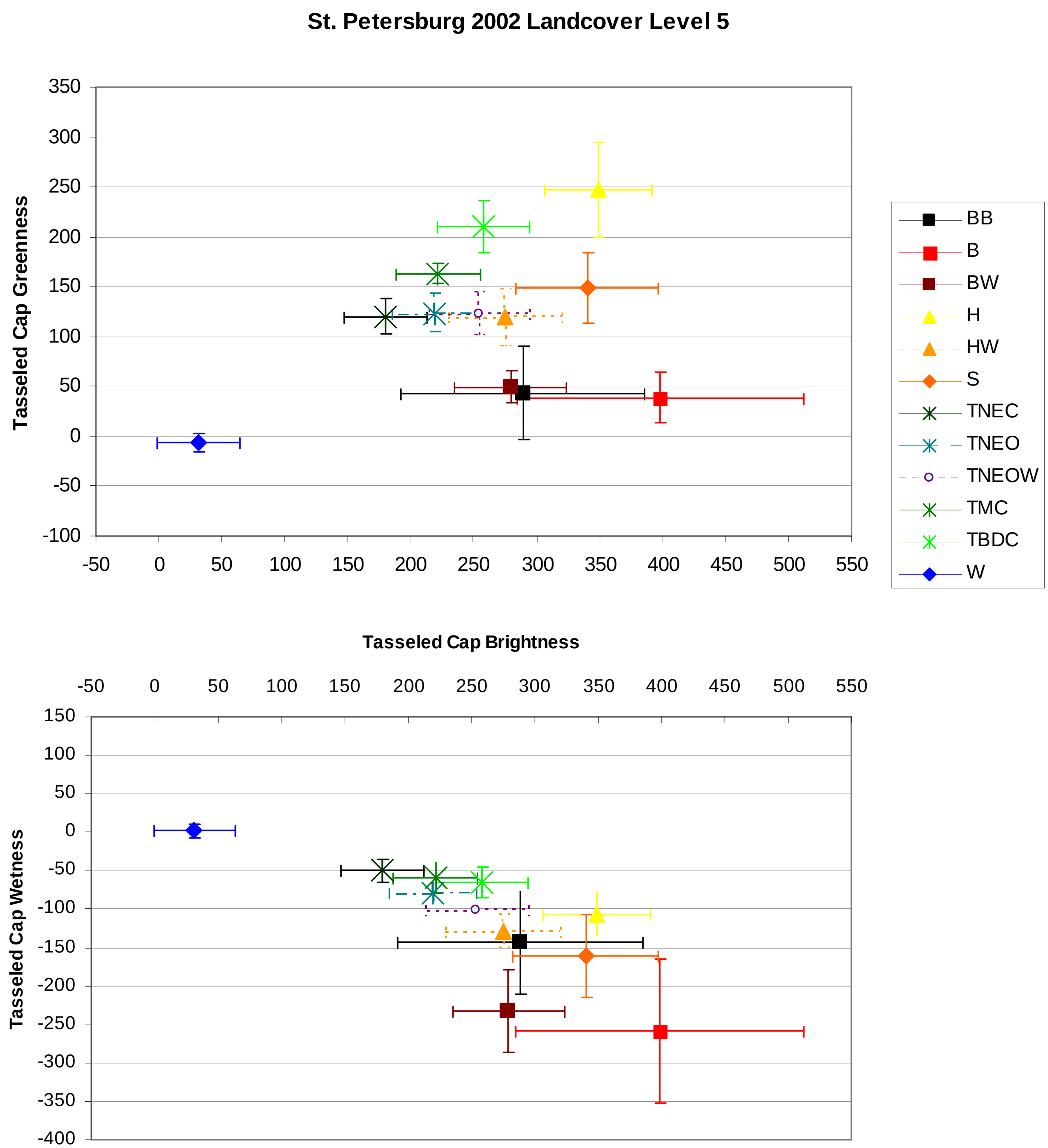
Spectral Separability of NELDA classes : Tasseled Cap mean values (+/- 1 standard deviation)




**B** = Bare **H** = Herbaceous **S** = Shrub **T** = Tree **W** = Water




Level 2 land cover classification. **B** = Bare **H** = Herbaceous **S** = Shrub **TB** = Tree.Broadleaved, **TM** = Tree.Mixed **TN** = Tree.Needleleaved **W** = Water




Level 5 land cover classification. **B** = Bare **BB**= Bare.Built **BW** = Bare.Wetland **H** = Herbaceous **HW** = Herbaceous.Wetland **S**= Shrub **TBDC** = Tree.Broadleaved.Deciduous.Closed **TMC** = Tree.Mixed.Closed **TNEC** = Tree.Needleaved.Evergreen.Closed **TNEO** = Tree.Needleaved.Evergreen.Open **TNEOW** = Tree.Needleaved.Evergreen.Open.Wetland **W** = Water

## 5) Land cover change (Tree cover loss)

Tree cover loss was created using two phases. The first phase was part of a larger project examining change from 1977-2000 within the larger St. Petersburg oblast which consisted of Landsat images from WRS2 path/row 186/17, 186/18, 185/18, 185/19, 184/18. The second phase was focused on changes between 2000-2006 in WRS2 path/row 184/18.

Steps

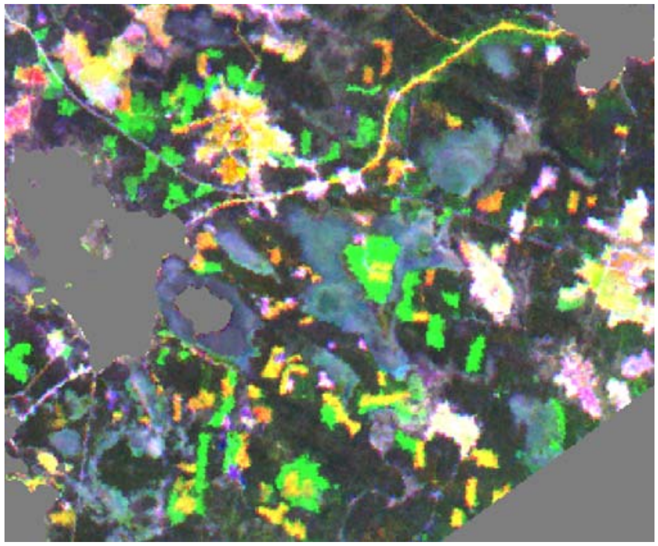
- Perform geometric alignment (ITP-Find) for images through time .
- Radiometric normalization (madcal) for images through time.
- Calculate Disturbance Index (Healey et al. 2005) for each scene using NELDA land cover level 1 “Tree” class to calculate mean and standard deviation of each Tasseled Cap component (Brightness, Greenness, Wetness).
- Standardize each year’s TC Brightness, TC Greenness, TC Wetness according to mean and standard deviation of “Tree” class
  - i) Brightness_std = (pixel – brightness_mean ) / brightness_standard deviation
  - ii) Greenness_std = (pixel – greenness_mean ) / greenness_standard deviation
  - iii) Wetness_std = (pixel – wetness_mean ) / wetnesss_standard deviation
- Disturbance Index = Brightness_std – (Greenness_std + Wetness_std)

### *Phase 1 change: 1977 - 2000*

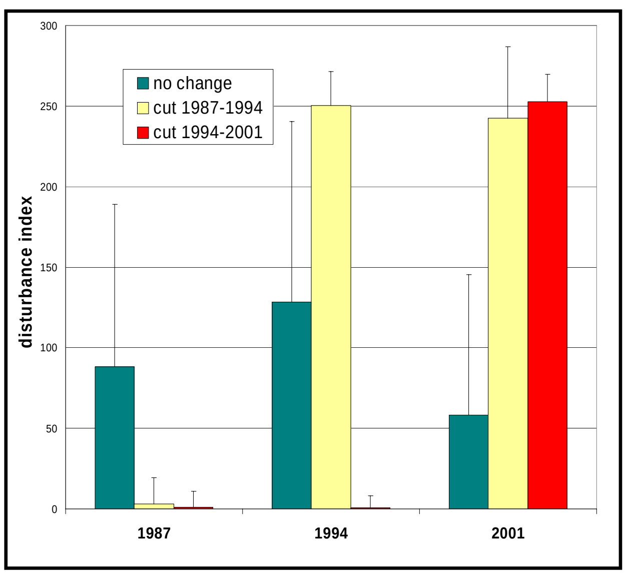
- Forest change analysis between 1977 to 2000 was done for the larger St Petersburg oblast covering WRS2 path/row 186/17, 186/18, 185/18, 185/19, 184/18 (Duane et al 2004). This image was subsequently clipped to the NELDA site boundary.

- For change detection for the time period 1977 – 1988, the Landsat MSS imagery was resampled from the original 60m pixel size to the matching 30m pixel size of the Landsat TM imagery. The Landsat MSS images were transformed into Tasseled Cap components brightness and greenness (*citation year* ). The Landsat TM images were converted into Tasseled Cap components brightness, greenness, and wetness (*citation year* ). The Tasseled Cap images were stacked into one image for supervised classification. Using the 1994 Landcover (Oetter et. al. 2001), water, built, agriculture, and bog developed were masked out of the stacked image to make change detection more effective. Then viewing the Tasseled Cap stacked image as Red: 5 (1988 Wetness), Green: 1 (1977 Brightness) , Blue: 2 (1977 Greenness) expertly identified training polygons were hand-digitized around change and no change areas for maximum likelihood supervised classification. Finally, post-classification the analyst hand recoded obvious false change errors. A minimum mapping unit of 1 ha was applied to the change results.

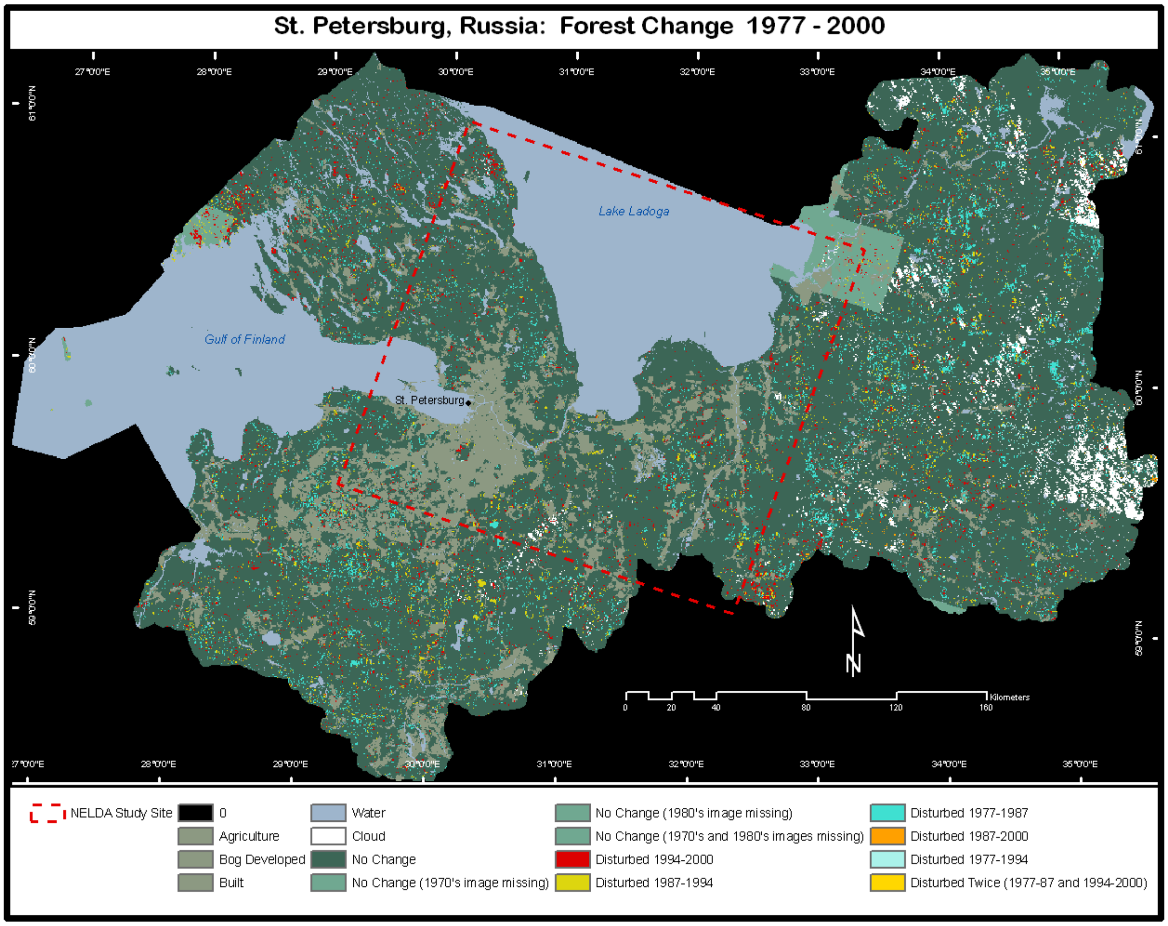
- For change detection for the time period 1988 -2000, the Landsat TM imagery for dates: 1988-Jun-27, 1992-May-19, 2000-Oct-2 were transformed into the Tasseled Cap components of brightness, greenness, and wetness (Crist 1985), The DI was calculated for the three images using the 1994 Landcover ‘Forest’ class for the normalization parameters. Using the 1994 Landcover (Oetter et. al. 2001) water, built, agriculture, and bog developed were masked out of the stacked image to make change detection more effective. Then viewing the DI stacked image as Red: DI 1988 Green: DI 1992 Blue: DI 2000, expertly identified training polygons were hand-digitized around change, no change, and false change areas for maximum likelihood supervised classification. Post-classification, the analyst hand recoded obvious false change errors. A minimum mapping unit of 1 ha was applied to the change results.



A pseudo-color image can be created by using 3 DI images loaded into different color registers (R: DI 1988 G: DI 1992 B: DI 2000). enables visual identification of changes from one year to another. In this figure, bright green highlights those areas that changed from 1988 to 1992. The yellow color shows areas disturbed from 1988 to 2000. Darker colors are those that do not have dramatic DI differences from year to year. (Duane et al 2004).



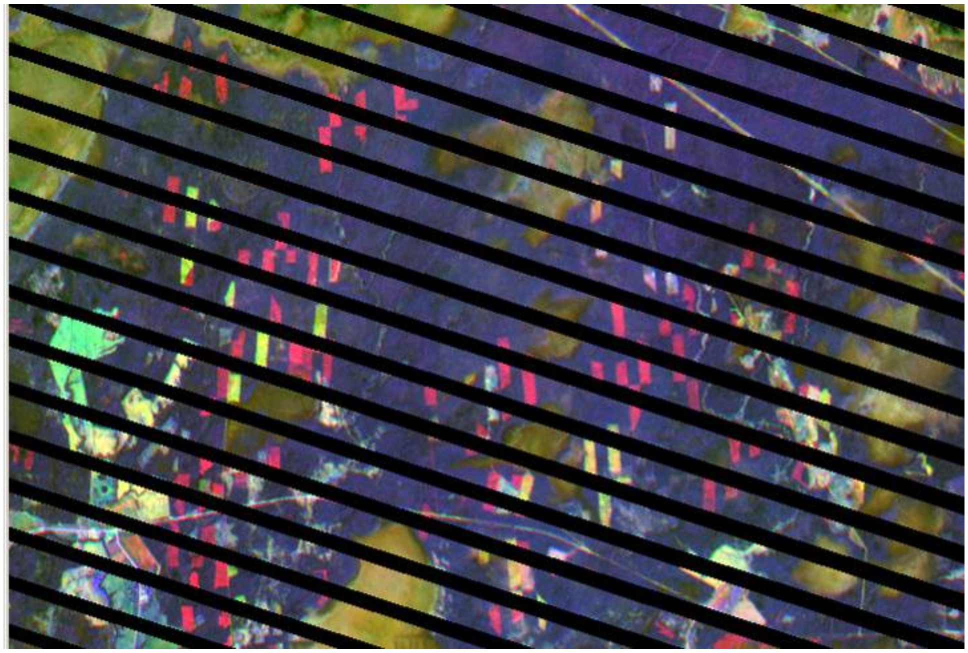

The Disturbance Index values for the training areas are different enough for use as training data in the maximum likelihood classification.




- Accuracy Assessment of Map
  -Stratified Random 150 points (minimum 250m apart) within 3 distinct regions centered around the city of St. Petersburg (southwest, northwest, east) to reflect the ecologically distinct regions.
- Clip St. Petersburg disturbance map 1977-2000 to NELDA study site boundary.

## *Phase 2 change: 2000 - 2006*

- For change detection for the time period 2000 -2006 we stacked the Disturbance Index for 2000, 2002, and 2006 into one file. Post-May, 2003, the Landsat ETM+ satellite produced imagery with gaps due to a satellite error (scan line corrector). Therefore, the amount of usable imagery was reduced 34.52% from the pre-2003 38,006,318 pixels to the post-2003 24,886,453 pixels. This reduced the amount of 2002-2006 'Tree' cover change analysis area 37% from 15,589,830 pixels in 2002 to 9,806,577 pixels in 2006. The missing 6,000,000+ pixels were masked out during the 2002-2006 classification.



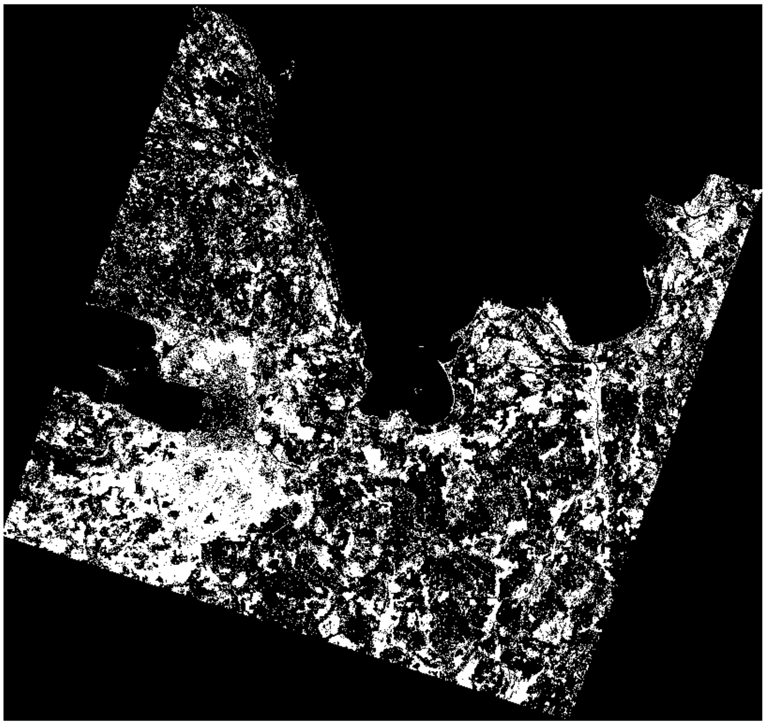
This figure shows the result of a pseudo-color image using the 3 DI images for 2000, 2002, 2006 loaded into different color registers (R: DI_2006 G: DI_2002 B: DI_2000). Bright red linear features highlight the 'Tree' removal from forestry practices between 2002 and 2006 while bright green features highlight the disturbances between 2000-2002. The black diagonal lines result from a gap in Landsat ETM+ satellite data due to sensor malfunction (scan line corrector) post 2003 resulting in a reduction of area for 2002-2006 change.

- Create training polygons for disturbance intervals and unchanged 'Tree'

| 2000-2006 Training Areas | Number of Polygons |
|---|---|
| 00-02 Disturbance | 35 |
| 00-02 Disturbance (2006 gap) | 18 |
| 02-06 Disturbance | 52 |
| Undisturbed Trees | 52 |

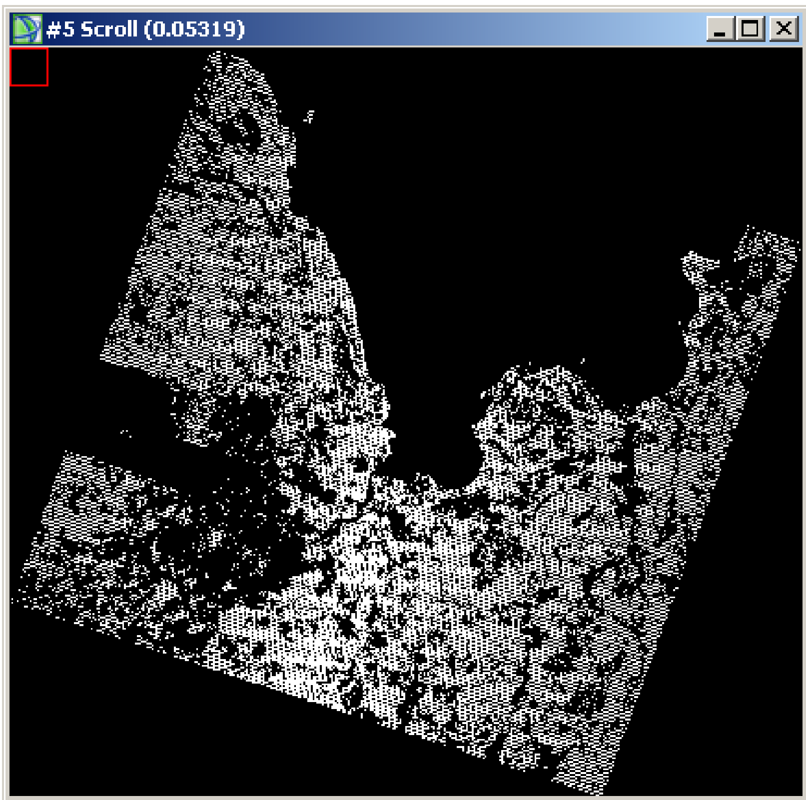
- Mask areas based on NELDA 2002 Landcover to reduce misclassification

  Training polygons for 2000-2002 disturbances were applied to a maximum likelihood classification of the stacked DI file to find NELDA land cover classes Bare, Herbaceous, Shrub which had previously been 'Tree' during the 2000-2002 period. It was limited to these land cover classes because the likelihood of such rapid 'Tree' recovery was quite low.



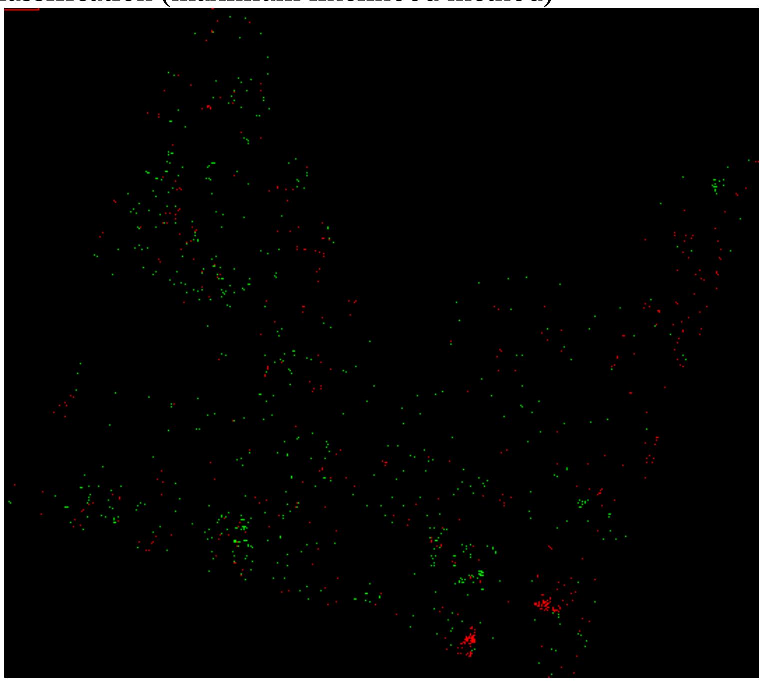
*Mask of NELDA landcover 2002 shrub, bare, herbaceous classes which were used in the classification of 'Tree' disturbance 2000-2002.*

Training polygons for 2002-2006 disturbances were applied only to the NELDA 2002 landcover 'Tree' pixels. The 2006 gap mask was also applied to insure there was not misclassification in these areas.

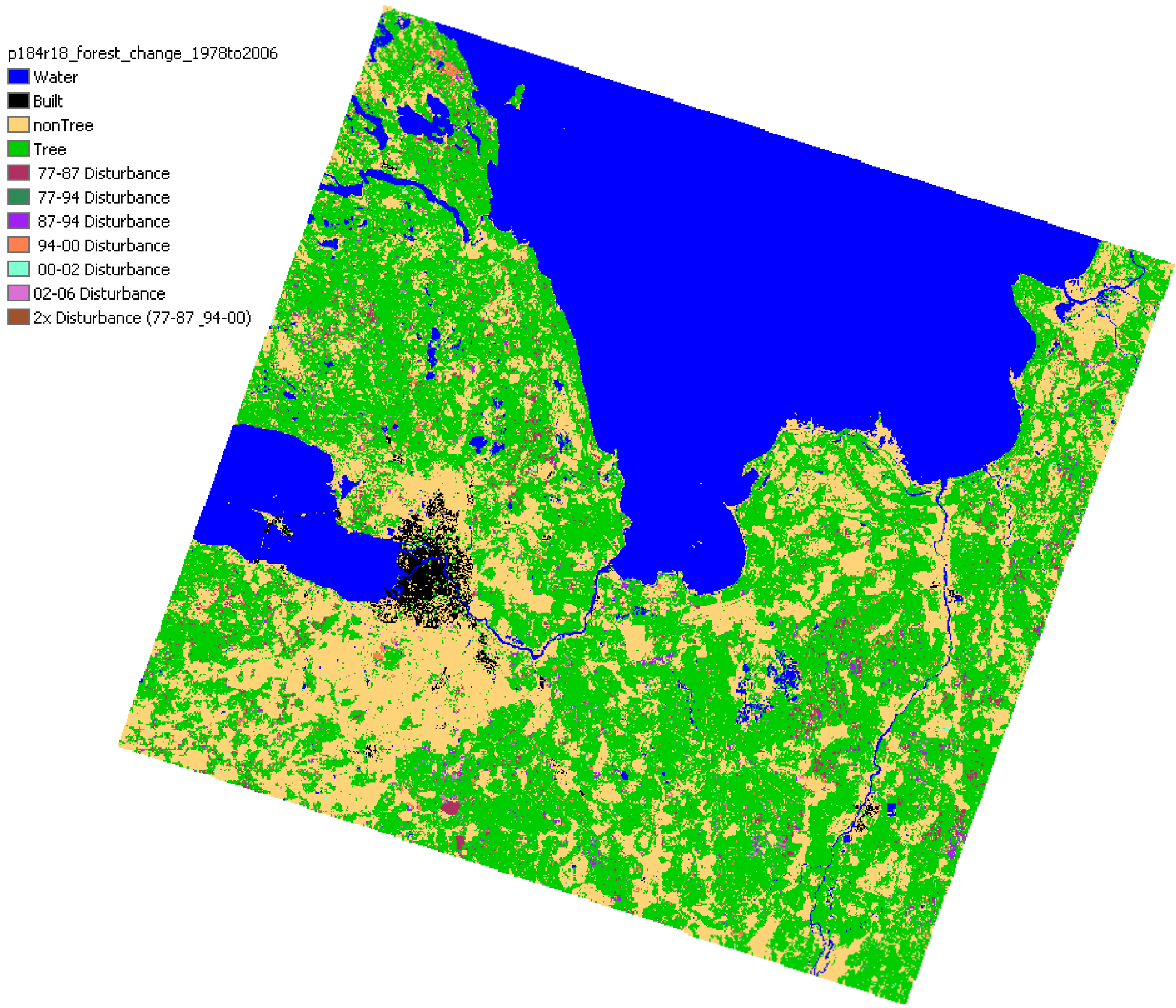


Mask showing areas of NELDA Landcover 2002 ‘Tree’ combined with the 2006 Landsat ETM+ slc-off gap mask.

- Supervised Classification (maximum likelihood method)



- Combine files to create ‘Tree’ Change 1978-2006




*F:\NELDA\NELDA_Sites\1_StPete\classifications\change_detection\p184r18_forest_change_1978to2006_finalversion6*

- Accuracy Assessment of Map (based on Cohen 2002)
  -Stratified Random 150 points (minimum 250m apart)

| Point Count | Reference | | | | |
|---|---|---|---|---|---|
| Classification | Undisturbed | 00-02 Disturb | 02-06 Disturb | Total | Commission |
| Undisturbed | 103 | 0 | 0 | 103 | 0% |
| 00-02 Disturb | 13 | 10 | 0 | 23 | 57.5% |
| 02-06 Disturb | 6 | 0 | 18 | 24 | 25% |
| Total | 122 | 10 | 18 | 150 | |
| Omission | 15.6% | 0% | 0% | | |

Overall Map Accuracy = 86.0%
Overall Kappa Statistic = 0.6008

For the overall accuracy assessment of change map, 150 random points are assigned to "no-change" class and the remaining 150 to change classes (intervals) in proportion to the area of change classes. Stratified random sampling of 150 change points within the 4 change classes.

Table shows the agreement between an independent data determination of change using a yearly time-series of Landsat MSS, TM, and ETM data from 1978 to 2008 using TimeSync (Cohen, 2009). Landsat dates of imagery used for change detection classification included: 1978-May-21, 1988-Jun-27, 1994-May-19, 2000-Oct-2, 2002-Jun-2, 2006-Jun-13.

| Count of Points | Accuracy Points | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Map Classification** | 1978 - 1987 | 1987 - 1994 | 1994 - 2000 | 2000 - 2002 | 2002 - 2006 | Stable Tree | Non Tree | Total | *Commission* |
| 1978 - 1987 | 36 | 2 | | | | 17 | | 55 | *34.5%* |
| 1987 - 1994 | | 20 | | | | 7 | 1 | 28 | *28.6%* |
| 1994 - 2000 | | 4 | 19 | 4 | | 13 | | 40 | *52.5%* |
| 2000 - 2002 | | | | 5 | | 4 | | 9 | *44.4%* |
| 2002 - 2006 | | | | | 14 | 2 | | 16 | *12.5%* |
| Stable Tree | | 3 | | | 1 | 57 | | 61 | *6.6%* |
| Non Tree | | 1 | | | | | 90 | 91 | *1.1%* |
| Total | 36 | 30 | 19 | 9 | 15 | 100 | 91 | 300 | |
| *Omission* | *0.0%* | *33.3%* | *0.0%* | *44.4%* | *6.7%* | *43.0%* | *1.1%* | | |

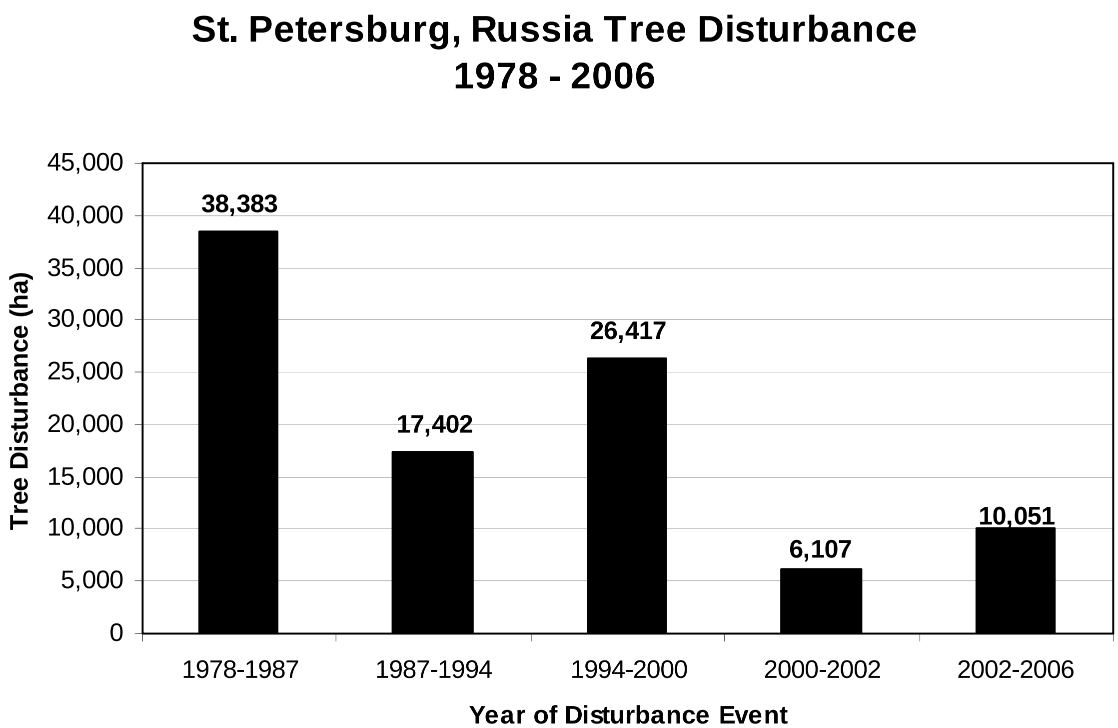
Overall accuracy = 241 / 300 = 80.3 %
kappa = 0.61 = substantial agreement

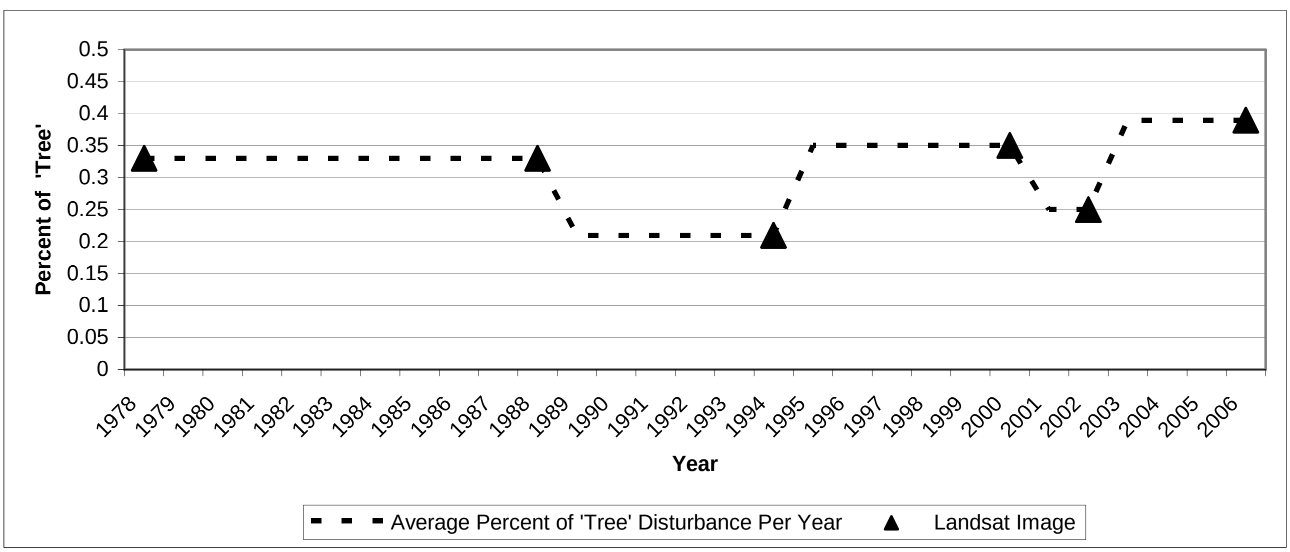
Substantial agreement occurs between an independent change detection analysis using TimeSync and the mapped 'Tree' change derived from a four date Disturbance Index supervised classification. 'Tree' disturbances occurring between 1978 and 1987 were successfully mapped with a low omission rate but with a moderate commission rate of stable forest (34.5%). Some of the stable forest commission errors occurred in 'Tree' covered bogs for this class. 'Tree' disturbances occurring between 1987 and 1994 had a moderate omission rate (33.3%) and commission rate (28.6%). Some of the omission error in this class may be explained by an initially low disturbance magnitude during the disturbance event with a prolonged loss of vegetative vigor. Identifying 'Tree' disturbances occurring between 1994 and 2000 was particularly challenging due to seasonal difference of the two images, May-1994 and October-2000. Indeed, the omission rate for this class is extremely low (0%) while the commission of 'stable forest' and disturbances during other time periods was the greatest (52.5%). The seasonal difference between the time interval October-2000 and Jun-2002 also created high omission (44.4%) and commission (44.4%) errors, particularly in bogs and hardwoods. The final time period from Jun-2002 to *-2006

Improving this map would require increased Landsat images to remove seasonal differences currently in the dataset. In addition, analyzing the highly spectral variable bogs separately would minimize the commission errors associated with these locations.

## *ANALYSIS*

In the NELDA study area, 'Tree' disturbance was detected on 98,190 ha between 1978 – 2006. Excluding Lake Ladoga and the Gulf of Finland, this is less than 0.47% of the St. Petersburg study area.

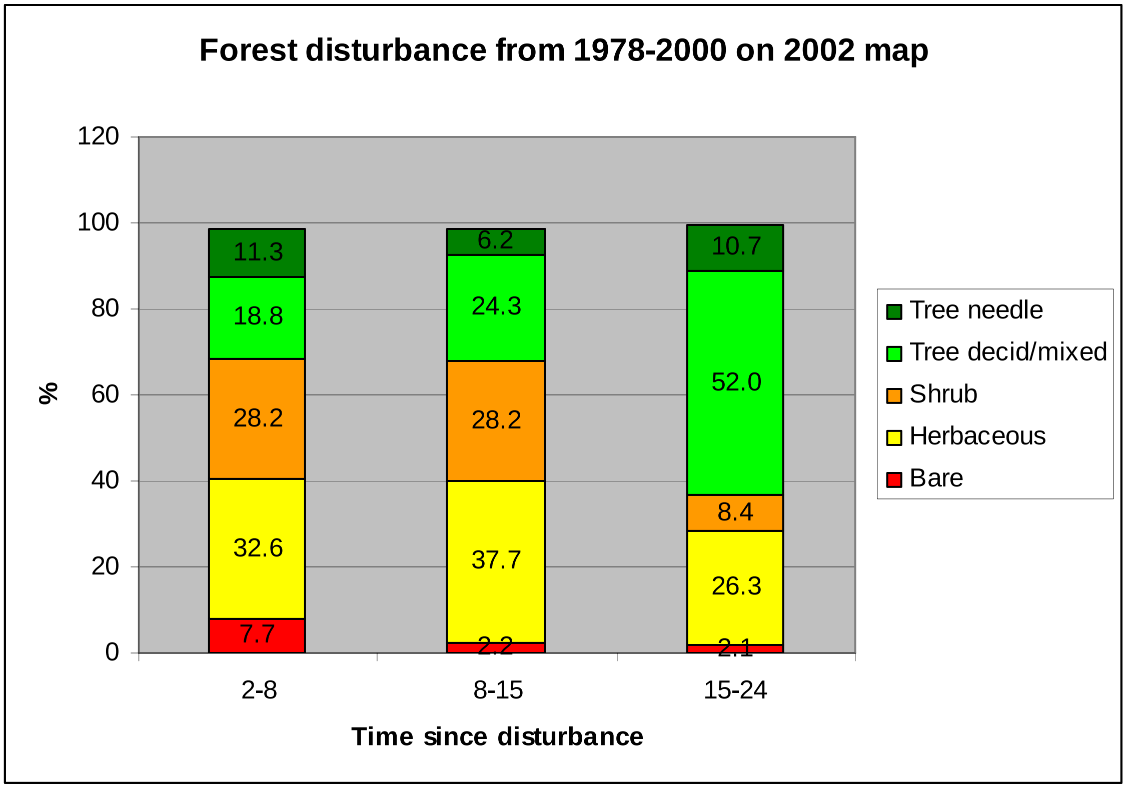



Intersecting the 1978-2002 ‘Tree’ disturbed raster with the NELDA 2002 land cover shows that 42% of the disturbed area has returned back to ‘Tree’. Nearly 53% of the area disturbed during 1978-2002 is shrub or herbaceous in 2002. Only 5% of the disturbed trees were converted to either bare ground or urbanized during this period.

Trees removed from 1978-1987 primarily returned back to trees (62%) and secondarily to herbaceous cover (26%) by 2002. Trees removed from 1987-1994 primarily were herbaceous and shrubs (65%) and secondarily broadleaved trees (18%) by 2002. Trees removed from 1994-2000 primarily were herbaceous and shrubs (60%) and secondarily trees (28%) by 2002, Trees removed from 2000-2002 primarily were herbaceous and shrubs (90%) and secondarily bare (9%) by 2002.

Classification of disturbed forest pixels on 2002 land cover map provides some indication of forest regeneration dynamics:



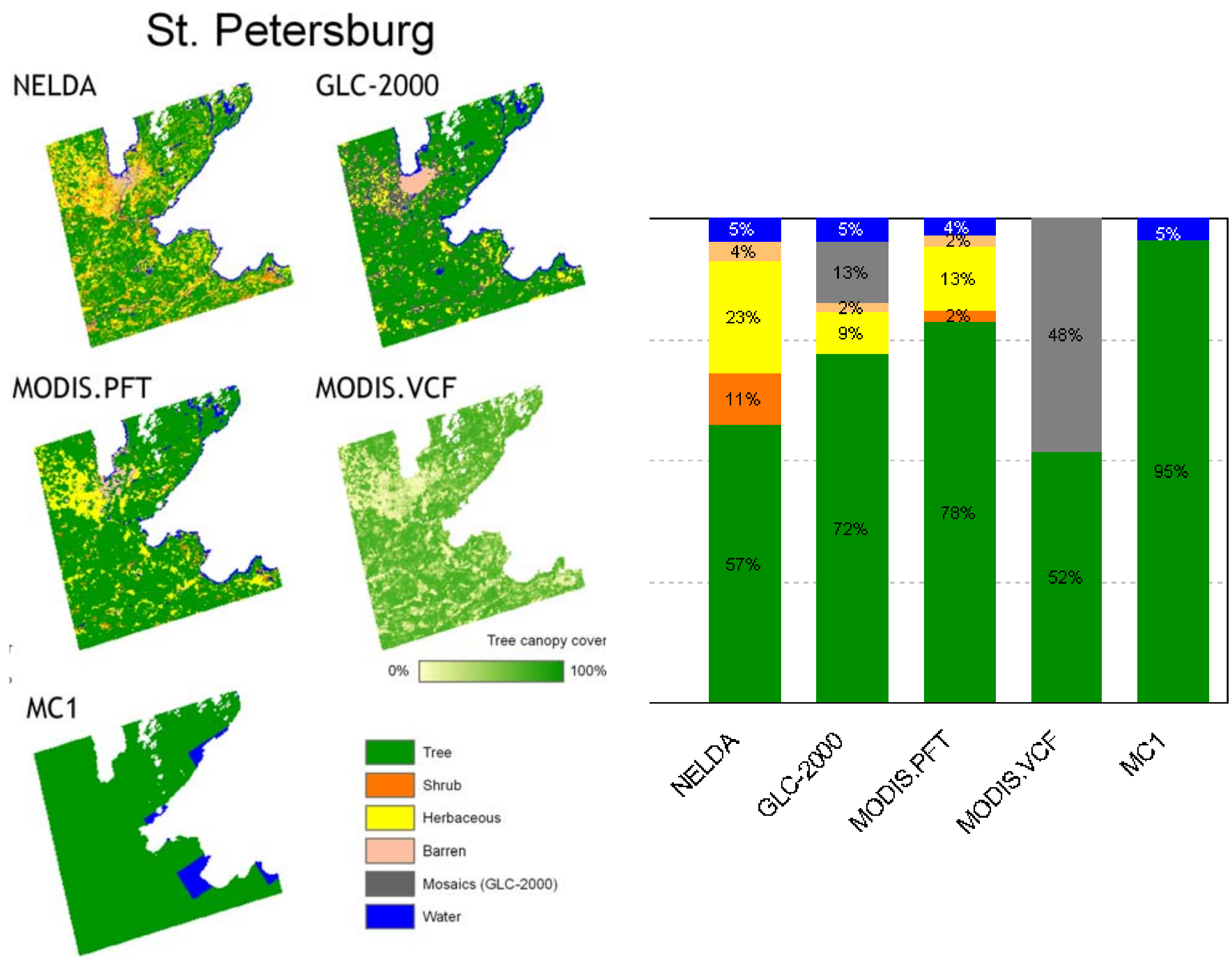

Disturbed pixels are quickly covered by herbaceous vegetation but 7% remains bare after 2+ years; apparently 2% of disturbed area never regains vegetation; some of it is mined peatland. About 1/3 of disturbed forest regains tree cover in less than 8 years, additional 1/3 regrows in 15+ years but the remaining lands apparently represent long-term loss of tree cover. While most of harvested forest is conifer-dominated, only 10% regrows as conifer.

## 6) Comparison with Coarse-resolution maps

Comparison with coarse-resolution maps is based on aggregation of Landsat-based maps to larger pixels and generalizing the legends to dominant vegetation types. Dominant vegetation cover from GLC-2000 and MODIS.PFT and crown cover from MODIS-VCF were compared with Landsat-resolution land cover maps. We also made comparison with the output of dynamic global vegetation model MC-1 at 0.5 °lat/long.

The overall agreement between GLC-2000 and MODIS PFT is high at 83%. The landscape if very fragmented and GLC-2000 mapped 13 % of the site as mosaics of tree, shrub and herbaceous (including croplands) vegetation possibly inflating the agreement with MODIS-PFT (Figure 4.4).

The tree cover is overestimated by the GLC-2000 map (72%) and MODIS.PFT map (78%) when compared to NELDA (57%). In comparison, the MODIS-VCF estimate of 52% tree canopy cover is in good agreement with NELDA, but the results for categorical maps and VCF are not directly comparable. By far the most common confusion type at the St. Petersburg site is between trees and herbaceous vegetation (8% of total area). One likely cause for this confusion is the significant presence of peatlands and other wetlands at the St. Petersburg site with their characteristic mix of open canopy tress, low shrubs, and moss-dominated herbaceous layer (Krankina et al. 2008). These complex plant assemblages fit poorly in class definitions of land cover maps (Frey and Smith 2007). Both GLC-2000 and MODIS PFT underestimate the extent of shrubs and herbaceous vegetation in the overall land cover of the St. Petersburg site.



## 7) Publications using the site data

### a) *NELDA – peer-reviewed papers*

i) D. Pflugmacher, O.N. Krankina, W.B. Cohen. 2007. Satellite-based peatland mapping: Potential of the MODIS sensor. Global and Planetary Change 56 (3-4): 248-257.

ii)

### b) *NELDA – selected other publications and presentations*

i) "The Challenge of Mapping Peatlands and the Potential of Remotely Sensed Data" (O.N. Krankina, K.C. McDonald, M. Friedl, W.B. Cohen, D. Pflugmacher, P. Nelson, A Baccini). Symposium Carbon in Peatlands, Wageningen, The Netherlands, 15-18 April, 2007

### c) *pre-NELDA – peer-reviewed papers only*

i) R.A. Houghton, D. Butman, A. Bunn, O.N. Krankina, P. Schlesinger, T.A. Stone. In press. Mapping Russian Forest Biomass with Data from Satellites and Forest Inventories. Environmental Research Letters.

ii) D. Pflugmacher, O.N. Krankina, W.B. Cohen. 2007. Satellite-based peatland mapping: Potential of the MODIS sensor. Global and Planetary Change 56 (3-4): 248-257.

iii) R.J. Alig, O.N. Krankina, A. Yost, J. Kuzminykh. 2006. Forest Carbon Dynamics in the Pacific Northwest (USA) and the St. Petersburg Region of Russia: Comparisons and Policy Implications, Climatic Change, Jan 2006, pp. 1-26, DOI 10.1007/s10584-006-9077-7, URL http://dx.doi.org/10.1007/s10584-006-9077-7

iv) S.P. Healey, W.B. Cohen, Y. Zhiqiang, O. Krankina. 2005. Comparison of Tasseled Cap-Based Landsat Data Structures for Use in Forest Disturbance Detection. Remote Sensing of Environment 97: 301 – 310.

v) O.N. Krankina, R.A. Houghton, M.E. Harmon, E.H. Hogg, D. Butman, M. Yatskov, M. Huso, R.F. Treyfeld, V.N. Razuvaev, G. Spycher. 2005. Effects of Climate and Disturbance on Forest Biomass across Russia. Can. J. For. Res. 35: 2281-2293.

vi) Y.V. Kuzminykh, R.J. Alig, O.N. Krankina, A.S. Yost. 2005. Social and Economic Aspects of Potential Carbon Flow to Forest Ecosystems (in Russian). Lesnoy Zhurnal (Forest Journal) 1-2:130-135.

vii) Krankina, O.N., M.E. Harmon, W.B. Cohen, D.R. Oetter, O. Zyrina, Duane, M.V. 2004. Carbon Stores, Sinks, and Sources in Forests of Northwestern Russia: Can We Reconcile Forest Inventories with Remote Sensing Results? Climatic Change 67(2-3):257-272.

viii) Turner, D.P., Ollinger, S., Smith, M.L., Krankina, O., Gregory, M. 2004. Scaling Net Primary Production to a MODIS Footprint in Support of Earth Observing System Product Validation. Int. J. Remote Sensing 25(10): 1961-1979.

ix) Bergen, K., Conard, S., Houghton, R., Kasischke, E., Kharuk, V., Krankina, O., Ranson, J., Shugart, H., Sukhinen, A., Treyfield, R. 2003. NASA and Russian scientists observe land-cover/land-use change and carbon in Russian forests. Journal of Forestry 101(4): 34-41. (I contributed the summary of results from my studies in Northwestern Russia).

x) Krankina, O. N., Harmon, M.E., Kukuev, Y.A., Treyfeld, R.F., Kashpor, N.N., Kresnov, V.G., Skudin, V.M., Protasov, N.A., Yatskov, M., Spycher, G., Povarov, E.D. 2002. Coarse woody debris in forest regions of Russia. Can. J. For. Res. 32:768-778.

xi) Treyfeld, R.F., and Krankina, O.N. 2001. Estimating volume and biomass of woody detritus using forest inventory data (Opredelenie zapasov i fitomassy drevesnogo

detrita na osnove dannyh lesoustroistva). Lesnoye Khoziajstvo (Forest Management) 4: 23-26. (In Russian).

xii) Krankina, O.N., R.F. Treyfeld, M.E. Harmon, G. Spycher, E.D. Povarov. 2001. Coarse woody debris in the forests of St. Petersburg region, Russia. Ecol. Bull. 49: 93–104.

d) Selected pre-NELDA – presentations

i) Duane, M. V., O. N. Krankina, S.P. Healey, J. Kuzminykh, and W. B. Cohen. Temporal and Regional Patterns of Disturbance in the St. Petersburg Region, Russia. 12th International Boreal Forest Research Association Conference, Fairbanks, Alaska, May 3-6, 2004. (Presentation)

## 8) List of contributors to site data and report

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Rudolf Treyfeld and Evgeny Povarov, St. Petersburg Forest Inventory, Russia
Tom Maiersperger, USGS
Doug Oetter

## 9) Acknowledgements

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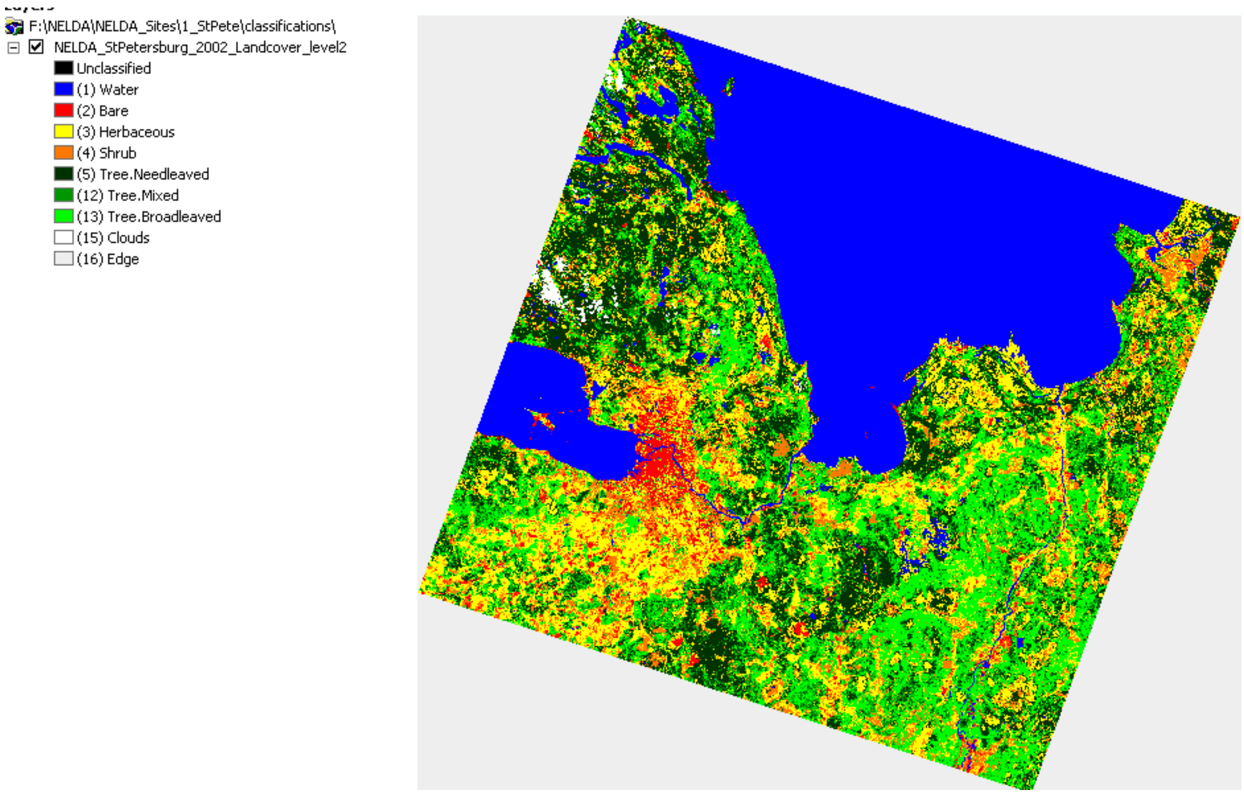
# APPENDICES

***a) NELDA legend: picture examples and colors***

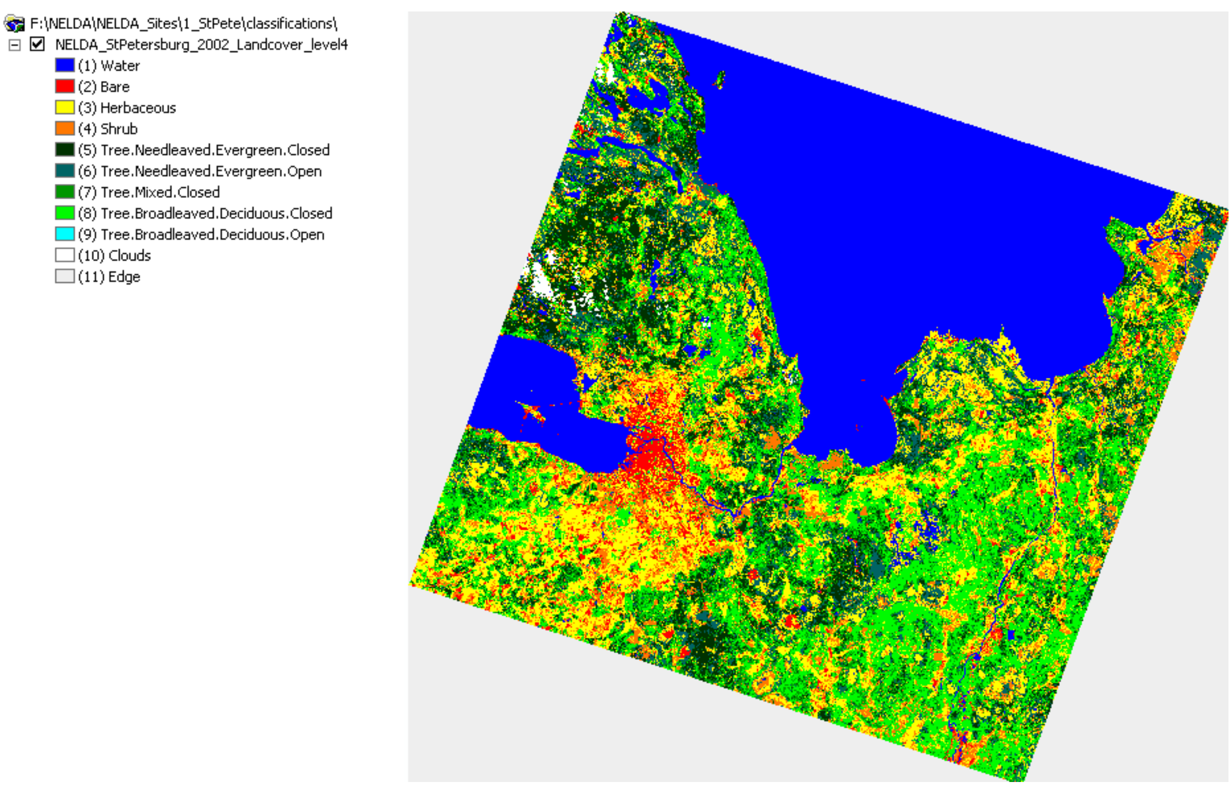
| NELDA Legend Class (bold is primary class) | Picture | Color |
|---|---|---|
| **Water** |  http://www.panoramio.com/photo/1134701 | |
| **Bare Land** |  http://www.panoramio.com/photo/1875390 | |
| **Bare Land**.Built Up |  http://www.panoramio.com/photo/2225183 | |
| **Bare Land**.Wetland | | |
| **Herbaceous** |  http://www.panoramio.com/photo/2082789 | |
| **Herbaceous**.Cultivated |  http://www.panoramio.com/photo/5070166 | |
| **Herbaceous**.Wetland | | |
| **Shrub** | | |
| **Shrub**.Wetland | | |

| | | |
|---|---|---|
| **Tree.Broadleaved.Deciduous.Closed** |  http://www.panoramio.com/photo/4559839 | |
| **Tree.Broadleaved.Deciduous.Open** | | |
| **Tree.Mixed.Closed** | | |
| **Tree.Mixed.Open** | | |
| **Tree.Needleleaved.Evergreen.Closed** | | |
| **Tree.Needleleaved.Evergreen.Closed.Wetland** |  http://www.panoramio.com/photo/7746300 | |
| **Tree.Needleleaved.Evergreen.Open** | | |
| **Tree.Needleleaved.Evergreen.Open.Wetland** | | |

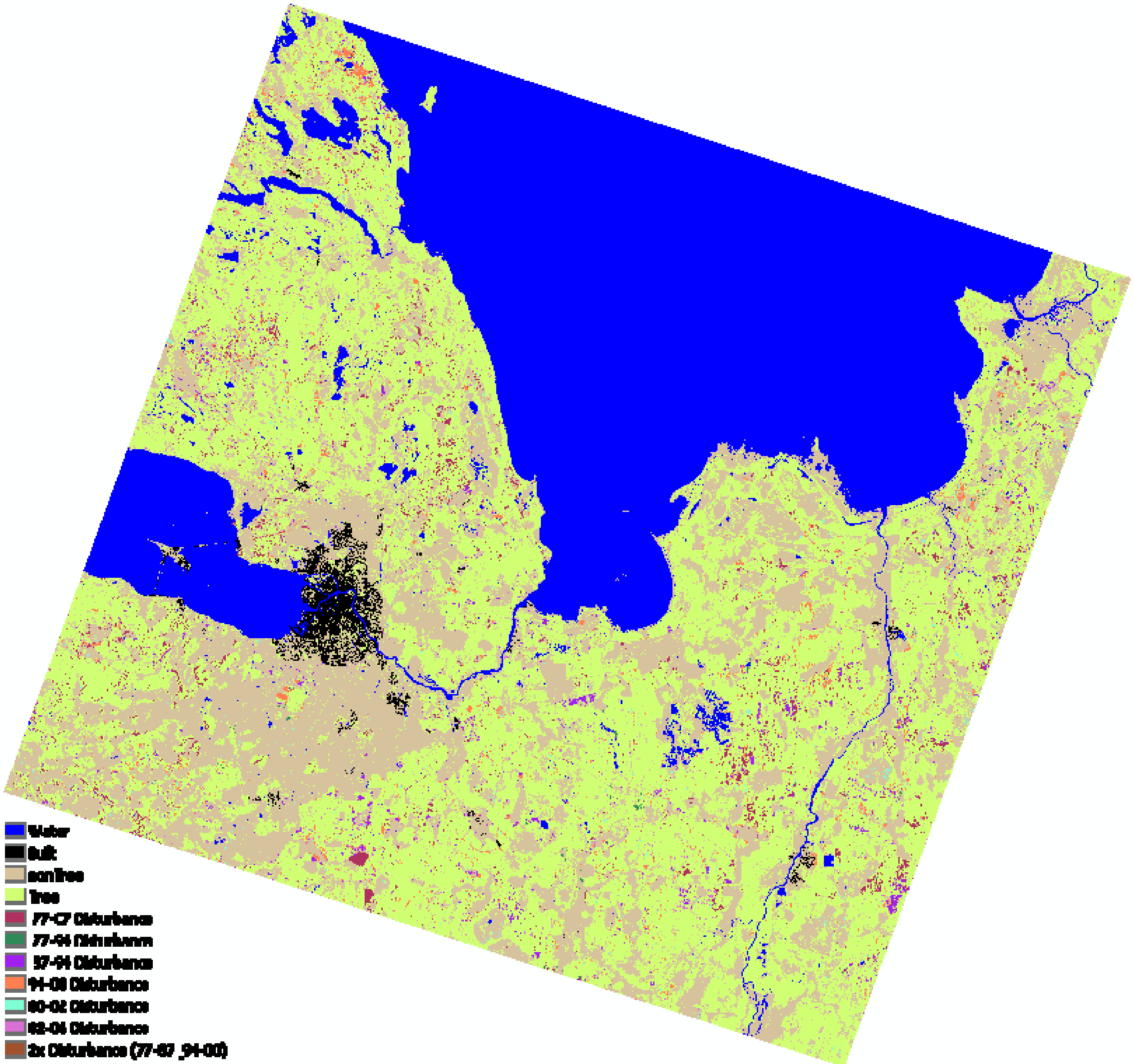
b) ***Unsupervised classification for Levels 2 and 4***




*F:\NELDA\NELDA_Sites\1_StPete\classifications\ NELDA_StPetersburg_2002_Landcover_level2*




*F:\NELDA\NELDA_Sites\1_StPete\classifications\ NELDA_StPetersburg_2002_Landcover_level4* *c) 'Tree' disturbance change detection 1977-2006*



*F:\NELDA\NELDA_Sites\1_StPete\classifications\change_detection\p184r18_forest_change_1978to2006_finalversion6*