Assessment of NTSG MODIS NPP product for forests in Kurzeme region, Latvia

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Abstract. The space-borne Moderate Resolution Imaging Spectroradiometer (MODIS) data based net primary production (NPP) product from Numerical Terradynamic Simulation Group (NTSG) was tested in the Kurzeme region, Latvia using a stand-wise forest inventory database. The NPP product has been validated globally and found to have no overall bias. In this study the NPP product was compared with stem biomass increment and soil fertility in respect to distance from the Baltic Sea coast. For each MODIS NPP product pixel we calculated forest cover, share of coniferous trees, average stem biomass increment and average site fertility (growth potential estimate). Then, 2432 pixels with a forest cover over 75% were selected for analysis. The results indicated that MODIS NPP decreased with distance from Baltic Sea coast but stem biomass increment and site fertility indicated a trend of increase. There was no functional relationship between MODIS NPP and stem biomass increment. Analysis of the landcover map used by NTSG for MODIS NPP product showed that the classes "Evergreen needleleaf" and "Mixed forests" differentiated only 10% by mode value of coniferous proportions in species composition. A non-natural jump was detected in the MODIS NPP values at a longitude of 22.5 degrees east corresponding to the border of the coarse scale meteorological dataset (NCEP Reanalysis (R2)) data representation unit. According to the results the MODIS NPP product is not applicable for regional level planning but can probably provide only rough average estimates of NPP for the Baltic region.

Key words: MODIS NPP, validation, Baltic region, forest.

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Introduction

Woody biomass from forests is gaining importance as a CO_2-neutral energy source (Berndes, 2012). However, Holtsmark (2013) shows that the conclusions about CO_2-neutrality of using woody biomass from boreal forests depend on the assumptions of the modelling framework. Hence, high quality and wide spatial coverage measurements of the physical quantities, e.g absorbed photosynthetically active radiation that drive photosythesis in plant canopies and involving process based models into the decision making is probably the solution for the future.

For bioenergy management strategic planning at country or regional level spatially explicit information is required to account for potentially available woody biomass, biodiversity, logistic options and other aspects. Prediction of forest characteristics and potentially available biomass in the long term is usually based on current data of forests, forest growth models and forest management models (Vanclay, 1994; Kangur *et al.*, 2007; Shvidenko *et al.*, 2007). Forest data are collected using a regular

stand-wise inventory (RFI) (Krigul, 1972) or a statistical sampling based inventory (NFI) (Tomppo *et al.*, 2010). Modern NFI-s use remote sensing data to improve estimation accuracy and to provide estimates as digital maps (McRoberts & Tomppo, 2007). However, experiences from the MODIS project indicate that if space-borne remote sensing is combined with process-based modeling then ecosystem net primary production can be estimated without forest inventory data (Running *et* al., 1999). The NPP estimate includes woody biomass accumulation in tree stems. The MODIS sensor is designed for global coverage and MODIS data based products have usually 500m or 1000m spatial resolution (Running *et al.*, 2004; Friedl *et al.*, 2010). Such spatial resolution is applicable to regional level estimations of available biomass if random errors in the NPP predictions are not too large and there are no systematic errors and the landscape is not too fragmented.

The MODIS near real time NPP product is provided by NASA and yearly recalculated NPP data by NTSG (Zhao *et al.*, 2005). The MODIS NPP product is based on absorbed photosynthetically active radiation, light use efficiency and meteorological factors, including water vapor pressure deficit and air temperature that influence photosynthesis (Heinsch *et al.*, 2003). Turner *et al.* (2006) evaluated MODIS NPP and GPP products using data from nine BigFoot test sites from different parts of the Earth and found no overall bias. MODIS NPP depends on landcover classes (Heinsch *et al.*, 2003; Zhao *et al.*, 2005) as the light use efficiency for the NPP model is obtained from lookup table according to the landcover class. The MODIS landcover data are obtained by supervised classification, however there are no nearby training sites for the Baltic states (Friedl *et al.*, 2010). Quaife *et al.* (2008) converted different global landcover maps from Great Britain into plant functional type maps and found that estimated NPP varied significantly in heterogeneous landscapes. Zhao *et al.* (2005)

show that interpolation and temporal filling of coarse scale meteorological data used for NTSG NPP products does significantly improve NPP estimates. However, Eenmäe *et al.* (2011) still found a significant systematic influence of coarse scale meteorological variables on NTSG MODIS NPP product in Estonia.

The net primary production estimate in the MODIS NPP product for forests is a summary of all ecosystem components. Hasenauer *et al.* (2012) used data from permanent NFI sample plots in Austria and found that MODIS NPP agreed well with allometric models based tree layer NPP after corrections for stand density were applied. Hence, MODIS NPP could be interpreted as NPP potential for forest tree layer (Hasenauer *et al.*, 2012) and could be used for a long term woody biomass accumulation prognosis. Regular forest inventory data as well as NFI data do not contain estimates of biomass fractions - leaves, branches, roots, but mean tree height, stem diameter at breast height and total stem volume per hectare. NFI and RFI data have both their merits: NFI data are precisely measured on systematically distributed small sample plots and intended for regional or country wide statistics. Stand-wise RFI databases, on the other hand, provide information for each stand in an area of interest; only the estimation errors for stand characteristics are bigger. Information from RFI databases can easily be used for biomass estimation if suitable models similar to Shvidenko *et al.* (2007) exist. Thomlinson *et al.* (1999) conclude that best available local landcover maps must be used to evaluate global landcover maps. We can extend this to the MODIS NPP validation and consider the RFI as best available dataset in the absence of flux-tower data (Turner *et al.*, 2006) or of NFI data (Hasenauer *et al.*, 2012).

Poorter *et al.* (2012) show in their review paper that biomass accumulation into stems is proportional to the accumulation in other parts of a woody plant. According to Gower *et al.* (2001) and Turner *et al.* (2004)

the mean aboveground biomass increment can be used to validate the MODIS NPP product. RFI databases contain usually an estimate of stem wood volume increment which is a significant share of total biomass accumulation according to the allometric biomass models (Marklund, 1988; Repola, 2008, 2009).

Another common variable in RFI data is site fertility which is estimated using stand mean height and age (Vaus, 2005). Since site fertility corresponds in general to the site growth potential, it can be used to validate MODIS NPP product similar to Hasenauer *et al.* (2012).

In this paper we validated the NTSG MODIS NPP Collection-5 product using regular forest inventory data to evaluate the applicability of the MODIS NPP product for the assessment of the forest bioenergy potential in the Kurzeme region, Latvia. Species composition data from forest inventory records were used to validate MODIS landcover map forest classes. Stem volume increment was converted to biomass by using wood density and compared to MODIS NPP average for period 2000–2010. Distance from the Baltic Sea coast was calculated for each MODIS grid pixel and used to study possible trends in MODIS NPP, stem biomass increment and site fertility.

Material and methods

Kurzeme region

Kurzeme region (Figure 1), also known as Courland, is situated in the western Latvia between 55° 45′ and 57° 45′ North and 21° and 27° East with total area of 13 607 km². The climate in the research area is determined by temperate climate zone with significant maritime features since Kurzeme comprises Kurzeme peninsula. The landscape has generally a low and hilly character, with flat and marshy coastlands (Rutkis, 1960). In the east, the test area reaches the western side of Jelgava plain, which is fertile (thus has mostly agricultural land) and

is densely inhabited. Approximately half of the area of Kurzeme is covered by forests. Latvia lies on the border between two different forest types: the northern coniferous and the broad leaved trees of the temperate zone, and characteristic tree species for both forest types can be found in the landscape (Znotiņa, 2002). The forested areas form a mosaic landscape with agricultural land, lakes and urban areas (Saliņš, 2002).

Coniferous trees are represented by four species, but deciduous by 17 tree species. While coniferous trees often form pure stands, the deciduous trees are found almost exclusively in the mixed stands. The most dominant tree species in Kurzeme region are Scots pine (*Pinus Sylvestris* L.) and Norway spruce (*Picea Abies* (L.) Karst.) due to both climate related and economic factors. The most common deciduous tree species are birch (*Betula pendula* Roth. and *Betula pubescens* Ehrh.), black alder (*Alnus glutinosa* (L.) Gaertn.), aspen (*Populus tremula* L.) and grey alder (*Alnus incana* (L.) Moench) (Bušs, 1987). In contrast to the small number of tree species, forest structure diversity in Latvia is very high. Tree species compositions, density, age and volume vary a lot even in small geographical regions.

Forest inventory database

The regular forest inventory database was obtained from Latvian state owned company "Latvijas valsts mezi". The database contained data and digital vector map for 649889 stands covering 8363.8 km² in the Kurzeme region. Site fertility (measured as Orlov's site index (Orlov, 1915), *Bon*) class in database was converted to site fertility index $H_{100} = 35.5 - 4Bon$ corresponding to stand height at age of 100 years. Stem volume current annual increment in cubic meters per hectare per year was calculated with model (Metsakorralduse, 2009) for each stand using information about species, site fertility, stand age and stand relative density. An average wood density value of 500 kg m⁻³ was used to calculate
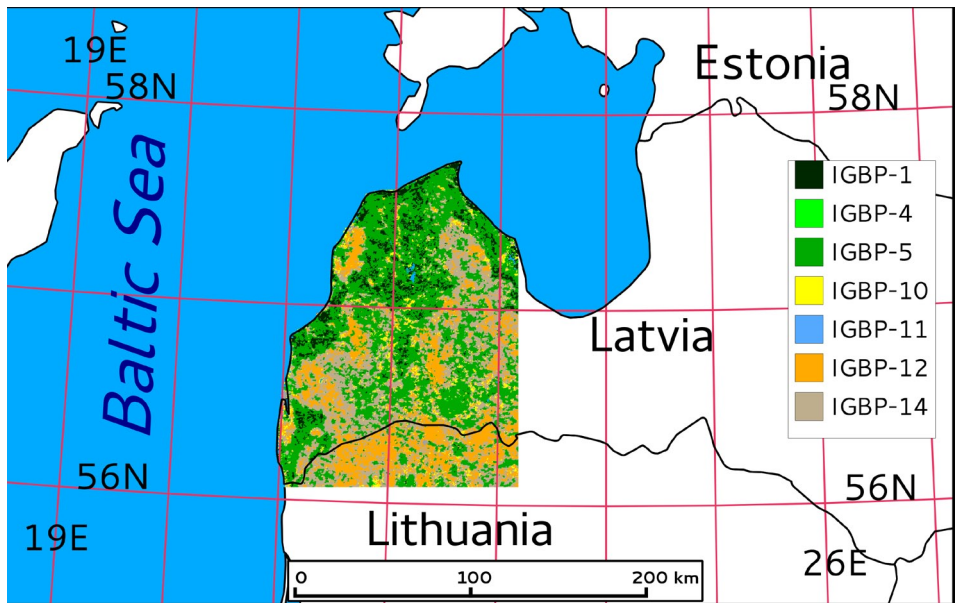
Figure 1. Location of the Kurzeme test site. The image overlay corresponds to the MODIS IGBP type landcover (Loveland and Belward, 1998) map. IGBP classes: 1) Evergreen Needleleaf forest, 4) Deciduous Broadleaf forest, 5) Mixed forest, 10) Grasslands, 11) Permanent wetlands, 12) Croplands, 14) Cropland/Natural vegetation mosaic.

Joonis 1. Kuramaa testala asukoht, mille taustaks on NTSG MODIS NPP produktis kasutatav IGBP klassifikatsiooni maakattekaart. Klassid: 1) igihaljad okaspuumetsad, 4) heitlehised lehtpuumetsad, 5) segametsad, 10) rohumaad, 11) märgalad, 12) põllumajanduslik maa, 14) klassi 12 ja loodusmaastiku segu.

tree stem biomass increment Z. We did not have information about dependence of wood density on the distance from Baltic Sea in Kurzeme region. It was assumed that species specific differences in wood density do not have much influence at the MODIS NPP product pixel level.

NTSG MODIS NPP data
The Collection 5 yearly NPP data from Numerical Terradynamic Simulation Group (NTSG) website were downloaded and projected to the Latvian state coordinate system LKS92 using nearest neighbour sampling. Tan *et al.* (2006) analysed MODIS observation geometry and observation gridding process and showed that MODIS pixels in archived image overlap only about 33% with original observation. To avoid the inevitable half pixel error corresponding to 500 m for the 1000 m MODIS NPP product and to better match with stand polygon map, a 20m pixel size was selected for the projected NPP images. This resulted in skewed 1 km^2 areas with similar NPP value from the original MODIS NPP pixels. The NPP images were visually inspected for the possible NPP zones as reported by Eenmäe *et al.* (2011) for Estonia due to the NCEP-NCAR (R2) coarse resolution meteorological data (National Center, 2013). Such an unnatural jump in NPP values was detected at longitude of 22.5°E that corresponds to the NCEP-NCAR (R2) meteorology dataset 1.25° cell and the Kurzeme region was divided into two zones.

Data processing and queries
Forest data cover within each MODIS 1 km^2 pixel was calculated using stand maps. The 2432 pixels with a forest cover over 75% were selected for further study. For each

pixel the distance from Baltic Sea coast was calculated. From the forest inventory database the average proportion of coniferous in the species composition, the average site fertility index H_{100} and the average current annual stem biomass increment Z were calculated for each pixel of the MODIS NPP product. The IGBP landcover class (Loveland and Belward, 1998) from the landcover map used in the NTSG MODIS NPP product was queried for each selected pixel. Data processing and analysis was done with GRASS (GRASS Development Team, 2012) and QGIS (QGIS Development Team, 2012) spatial analysis programs, the statistical software R (R Core Team, 2012) and partially with our own developed software to query raster data.

Results and discussion

A comparison of landcover classes "Evergreen needleleaf" and "Mixed forest" according to their share of coniferous trees in the species composition revealed only a small difference (Figure 2). The mode value of actual proportions (classified using 5% interval) of conifers was 80% for Mixed forest class and 90% for Evergreen needleleaf class. The histograms of both classes overlap in a great extent. This hints at possible errors in the MODIS NPP product since the landcover class is used for ecosystem light use efficiency lookup table in the NPP model.

The MODIS NPP decreased with distance from the Baltic Sea coast. Scatterplot of MODIS NPP as a function of distance to the coast (Figure 3) showed a clear decreasing trend and revealed at least two distinct groups of pixels. We found that the group with higher NPP values corresponded to the landcover class Mixed forest and the group with lower NPP values was part of Evergreen needleleaf class.

Contrary to MODIS NPP, stem biomass increment and site fertility did not exhibit such a decreasing trend with distance to coast of Baltic Sea (Figure 4). Vice versa, Z and H_{100} increased slightly within 20 km distance to the Baltic Sea coast, levelled off within a distance of 20–50 km from coast and then started to increase again.

We expected that the MODIS NPP is an increasing function of the current annual stem mass increment. However, the MODIS NPP and current annual stem wood mass increment Z did not have the expected functional relationship (Figure 5) but formed four distinct groups of pixels in the scatterplot. These groups were formed due to errors in the landcover map as found in
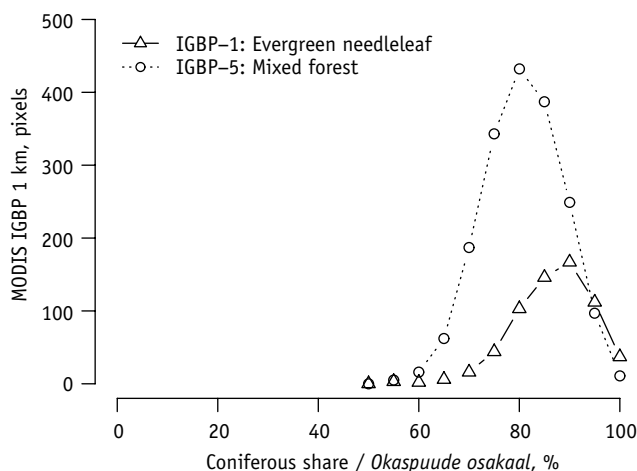

Figure 2. Share of conifers according to the forest inventory data in the MODIS IGBP landcover map classes "Evergreen needleleaf" and "Mixed forest" in the Kurzeme region. The histograms show that the classes are not different.

Joonis 2. NTSG MODIS NPP algoritmis kasutatava maakattekaardi klasside "Evergreen needleleaf"="Okaspuud" ja "Mixed forests"="Segametsad" jagunemine okaspuude osakaalu järgi metsakorralduse andmete põhjal. Selgub, et tegelikult need klassid Kurzeme piirkonnas omavahel oluliselt ei erinegi.

Figure 3. The NTSG MODIS NPP in forest pixels depending on the distance from the Baltic Sea coast.

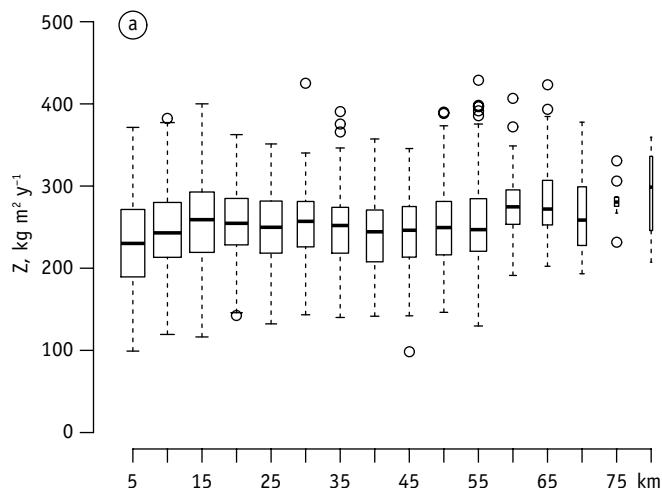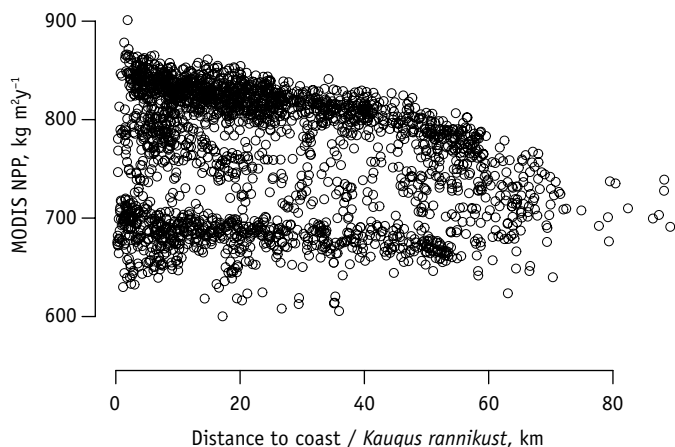*Joonis 3. NTSG MODIS NPP sõltuvus Balti mere ranniku kaugusest.*

Figure 4. In the Kurzeme test area a) stem wood accumulation (Z) and b) site fertility (H_{100}) increased with the distance from Baltic Sea coast. The widths of the boxes in the figure depend on the number of MODIS pixels in each 5km distance class.

Joonis 4. Kuramaa testalal kasvas Balti mere rannikust kaugenedes nii a) puistute tüvepuidu juurdekasv (Z) kui ka b) kasvukoha viljakus (H_{100}). Kastide laiused joonisel sõltuvad vastavas 5 km laiuses tsoonis olevate MODISe 1 km² pikslite arvust.

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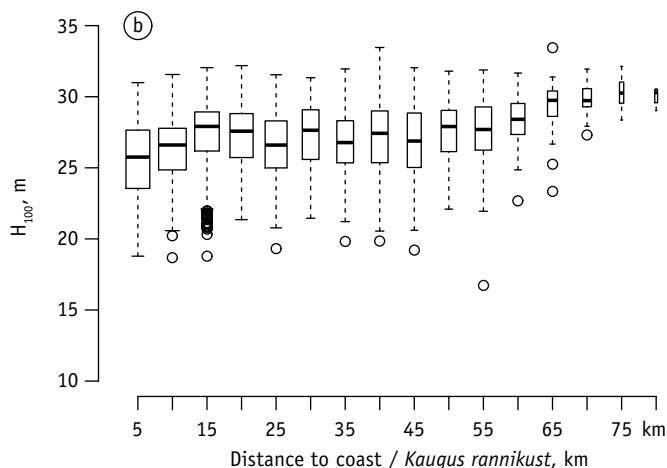
this study and due to the influence of the NCEP-NCAR (R2) meteorological dataset (Eenmäe *et al.*, 2011) used by NTSG to create the MODIS NPP product. In the western zone that is closer to the Baltic Sea, MODIS NPP is higher compared to the zone that starts from the longitude of 22.5 degrees east.

We analysed the NTSG MODIS NPP product using regular forest inventory database and found the product not applicable to regional level forest biomass growth estimations. It was expected that general growth trends in the Kurzeme region detectable from the forest database also exist in the MODIS NPP product. However, the MODIS NPP did not have any relationship with stem biomass increment which is a rather good estimator of total forest NPP. The allocation of NPP into roots may depend on soil fertility, since in poor soils trees have to invest more to build root system (Finér *et al.*, 2007). In such case site fer-

tility would be a better variable to assess the MODIS NPP. However, site fertility in the Kurzeme region had exactly the opposite trend compared to MODIS NPP in respect to distance from the Baltic Sea coast.

The MODIS NPP product has been found to have no global systematic bias (Turner *et al.*, 2006) and also to be in concordance with stand density corrected tree layer NPP estimates in Austria (Hasenauer *et al.*, 2012). However, in Estonia (Eenmäe *et al.*, 2011) and in the Kurzeme region, Latvia, significant inconsistencies of MODIS NPP were found using regular forest inventory databases. There is no reason to believe that such stand-wise forest databases are entirely free from errors, however, these data are used in daily decision making and management in forestry and therefore regularly updated and checked. On the other hand, the MODIS NPP algorithm relies on landcover map that can have significant errors and even contradictions with sim-
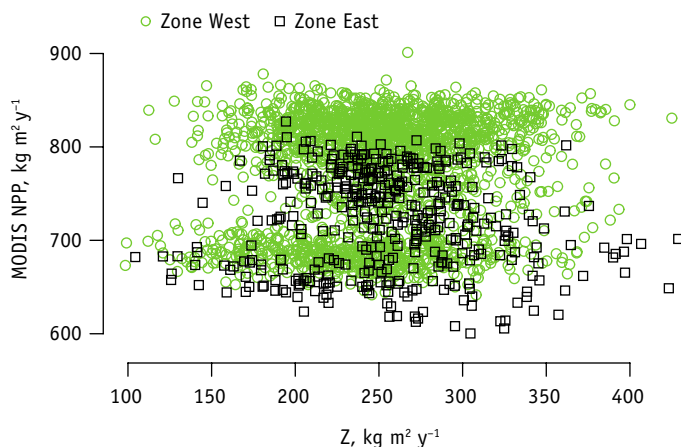

Figure 5. Relationship between the MODIS NPP and stem wood accumulation (Z). Zones were separated after the detection of abrupt change in the MODIS NPP values at longitude of 22.5 degrees East which corresponds to the cell boundaries of the NCEP-NCAR (R2) meteorological data set. Two distinct clouds within the zones correspond to different landcover classes in the map.

Joonis 5. Tüvepuidu juurdekasvu (Z) ja MODIS NPP seos. Tsoonid eristati järsu ebaloomuliku muutuse järgi MODIS NPP kaardil. Tsoonidevahelise piiri asukoht 22.5° idapikkust vastab MODIS NPP algoritmis kasutatava NCEP-NCAR (R2) ilmastikuandmete baasi vaatlusühiku piirile. Tsoonide sees tekivad pikslite rühmad erinevate maakatteklasside tõttu.

ilar purpose maps (Figure 6). The impact of coarse resolution meteorological data on MODIS NPP algorithm adds additional systematic errors as found in current study and by Eenmäe *et al.* (2011). Considering the results from the MODIS NPP product validation in Estonia and in the current study in the Kurzeme region, Latvia, we conclude that the product can provide grand average NPP estimate for Baltic region within about 300 km wide zone from the Baltic Sea coast, but it is not usable for regional analyses.

The use of local meteorological data (Nilson *et al.*, 2012) and better light use efficiency estimates for the MODIS NPP algorithm (Olofsson *et al.*, 2007) will probably ensure consistent NPP estimates in the Baltic region. An alternative approach for NPP estimation and mapping could be the use of National Forest Inventory data, Landsat Thematic Mapper type satellite images and k-Nearest Neighbour classification technique in similar to Härkonen
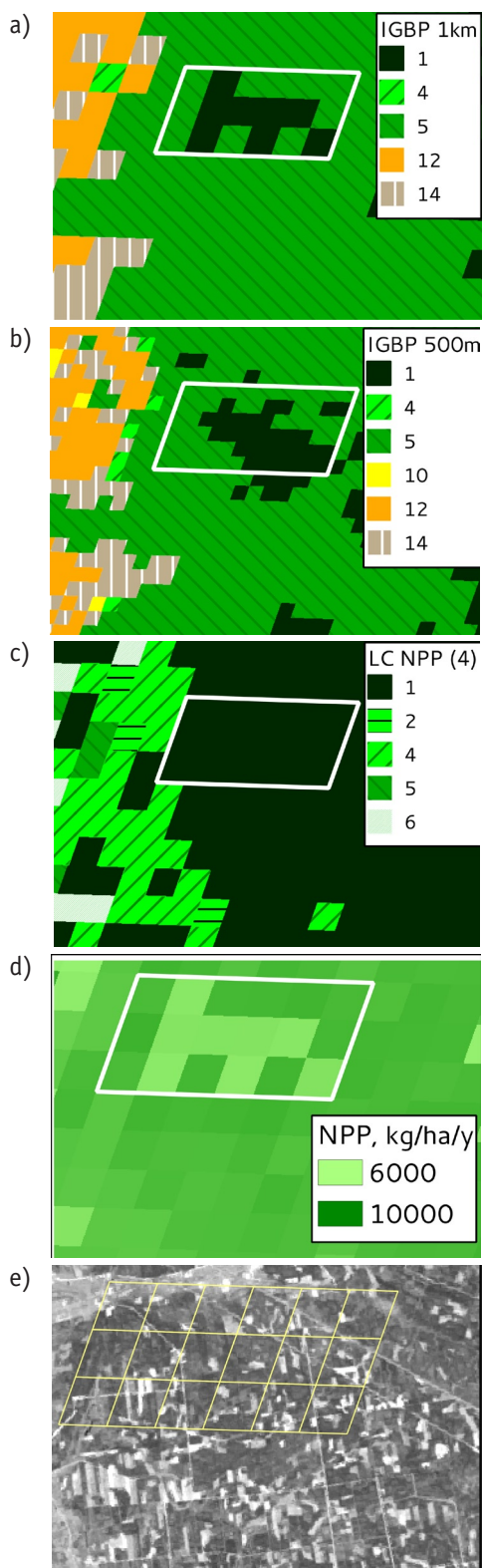
Figure 6. Possible errors in the landcover map influence MODIS NPP estimates (d). In the surrounded pixels the proportion of coniferous is over 71% but IGBP landcover map (a, b) indicates mostly mixed forests (class 5). The NASA NPP landcover map (c) shows "Evergreen needleleaf vegetation" (class 1, see also Figure (1)). The Landsat-5 TM5 image over the same area does not indicate any abrupt changes in landscape but characteristic pattern of managed forests (e).

Joonis 6. Vead MODIS NPP algoritmis kasutataval maakatteklasside kaardil mõjutavad oluliselt NPP hinnangut (d). Joonega piiritletud alal oli metsakorralduse andmete järgi okaspuude osakaal üle 71%, aga IGBP maakatteklasside kaardil (a, b) on alale määratud palju segametsi (klass 5). NASA NPP algoritmis kasutataval maakattekaardil (c) on sama ala määratud okasmetsaks (klass 1, vt ka joonis (1)). Landsat-5 TM5 pildi järgi (e) on alal tavaliselt majandatavad ja omavahel sarnased metsad.

et al. (2011) who used satellite images only for up-scaling from plot level NPP estimates. The next modifications of forest NPP models shall combine the satellite borne measurements of absorbed photosynthetically active radiation, local meteorological data (Olofsson *et al.*, 2007), soil fertility as suggested by Nilson *et al.* (2012) and sample plot based estimates (Härkonen *et al.*, 2011).

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Kuramaa metsade primaarproduktsiooni hindamisest NTSG MODIS NPP andmestiku abil

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Kokkuvõte

Skanneri Terra MODIS mõõtmisandmetel koostatakse regulaarselt globaalse katvusega taimkatte primaarproduktiooni NPP hinnanguid (Heinsch *et al.*, 2003, Zhao *et al.*, 2005; Turner *et al.*, 2006), mis on kasutajatele kättesaadavad tavaliste rasterkaartidena. Selline andmestik võiks olla väga väärtuslik metsast saadava biomassi hulga hindamiseks, mis on vajalik CO_2-neutraalse energiamajanduse strateegilises planeerimises (Berndes, 2012).

Käesolevas uurimuses testiti Numerical Terradynamic Simulation Group (NTSG) poolt välja antavat MODIS NPP produkti Lätis Kuramaal (joonis 1) metsakorralduse andmestikus oleva puidu juurdekasvu ja kasvukoha viljakuse andmete abil. Igale MODIS NPP produkti $1 \, km^2$ suurusele pikslile arvutati metsasus, kaugus Balti merest, okaspuude osakaal puistu liigilises koosseisus, keskmine tüvemassi juurdekasv (Z, tüvemahu juurdekasvu (Metsakorralduse, 2009) järgi, puidu tihedus $500 \, kg \, m^{-3}$) ja kasvukoha viljakuse hinnang $H_{100} = 35.5–4Bon$, kus Bon on andmestik salvestatud boniteet Orlovi järgi. Analüüsiks valiti 2432 pikslit, millel metsasus oli üle 75%. Eeldati, et tüvemassi aastane juurdekasv on heas seoses puistute primaarproduktsiooniga, tuginedes allomeetrilistele biomassi võrranditele (Marklund, 1988, Repola, 2008, 2009), NPP ja metsa maapealse biomassi keskmise juurdekasvu seostele (Gower *et al.*, 2001; Turner *et al.*, 2004) ning biomassi allokatsiooni seaduspärasustele taimede maapealse ja maa-aluse osa vahel (Poorter *et al.*, 2012).

Selgus, et MODIS NPP arvutamisel kasutatava IGBP süsteemi maakattekaardi klassid *Mixed forest* (segametsad) ja *Evergreen needleleaf* (okasmetsad)*, mille järgi määratakse tabelist fotosünteetiliselt aktiivse kiirguse kasutustõhusus taimekooslustes, ei erine tegelikkuses oluliselt okaspuude osakaalu poolest (joonis 2). MODIS NPP hinnang kahanes süstemaatiliselt Balti mere rannikust kaugenedes (joonis 3), aga tüvepuidu juurdekasv Z ja kasvukoha viljakus H_{100} pigem kasvasid (joonis 4). Tüvepuidu juurdekasv ja MODIS NPP hinnang polnud omavahel seoses (joonis 5), samas ilmnesid süstemaatilised vead, mille põhjuseks olid maakattekaardil klasside vale määrang (joonis 6) ja madala ruumilise lahutusega ilmastikuandmete kasutamine NTSG MODIS NPP algoritmis (Eenmäe *et al.*, 2011). Kokkuvõtteks järeldati, et globaalseteks hinnanguteks mõeldud NTSG MODIS NPP produkt võib sobida Balti regiooni kohta üldise keskmise taimkatte primaarproduktsiooni hinnangu saamiseks, kuid ei kõlba lokaalsete süstemaatiliste vigade tõttu regionaaluuringuteks.