Supporting Information

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A.1. List of provinces/states in Fig. 1

The total number of provinces/states in the six countries Canada (CAN), Finland (FIN), Norway (NOR), Sweden (SWE), Russia (RUS) and the United States (USA) is 182. Data from 167 provinces where forest area is greater than 15% of the land area (10% in RUS) were used in the regression analysis (Sweden for two time periods). These are listed below (outliers shown in Fig. 1; British Columbia, California, Oregon and Washington are not listed).

RUSSIA (57 of 71; listed in the same order as in 1)
Kaliningrad Oblast, Arkhangel'sk Oblast, Vologoda Oblast, Mumansk Oblast, Rep. of Karelia, Rep. of Komi, Leningrad Oblast, Novgorod Oblast, Pskov Oblast, Bryansk Oblast, Vladimir Oblast, Ivanov Oblast, Tver' Oblast, Kaluga Oblast, Moscow Oblast, Ryazan' Oblast, Smolensk Oblast, Tula Oblast, Yaroslavl' Oblast, Nizhniy Novgorod Oblast, Kirov Oblast, Rep. of Mari EI, Rep. of Mordvinia, Rep. of Chuvashia, Tambov Oblast, Samara Oblast, Penze Oblast, Ul'yanovsk Oblast, Rep. of Tatarstan, Krasnodar Kray, Rep. of Kabardino-Balkaria, Rep. of North Osetia, Rep. of Checheno-Ingushetia, Kurgan Oblast, Perm' Oblast, Sverdlovsk Oblast, Chelyabinsk Oblast, Rep. of Bashkortostan, Rep. of Udmurtia, Altai Kray, Kemerov Oblast, Novosibirsk Oblast, Omsk Oblast, Tomsk Oblast, Tyumen' Oblast, Krasnoyarsk Kray, Irkutsk Oblast, Chita Oblast, Rep. of Buryatia, Rep. of Tuva, Khabarovsk Kray, Amur Oblast, Kamtchatka Oblast, Magadan Oblast, Sakhalin Oblast, Rep. of Yakutia (Sakha).

NORWAY (17 of 17)
Akershus, Aust-Agder, Buskerud, Hedmark, Hordland, Møre Og Romsdal, Nord-Trondelag, Nordland, Oppland, Østfold, Rogaland, Sogn Og Fjordane, Sør-Trøndelag, Telemark, Troms, Vest-Agder, Vestfold.

FINLAND (8 of 9)
Lappi, Oulu, Pohjanmaa, Kymi, Pohjois-Karjala, Pohjois-Savo, Keski-Suomi, and one region which is a combination of Mikkeli, Hame, Turku Ja Pori, and Uusimaa.

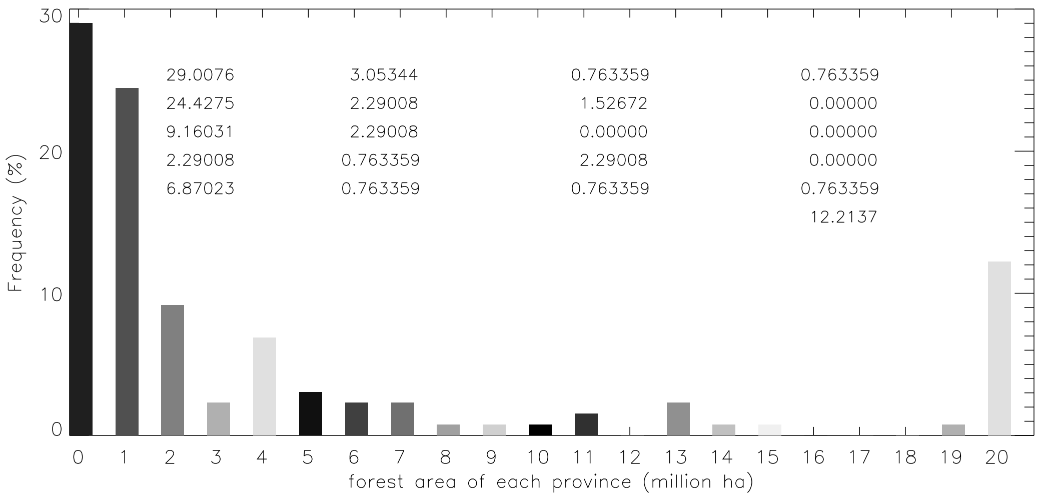
SWEDEN (21 of 23)
Älvsborg, Blekkinge, Gävleborg, Göteborg, Halland, Jämland, Jönköping, Kalmar, Kopparberg, Kronoberg, Norrbotten, Örebro, Östergötland, Skaraborg, Södermanland, Stockholm, Uppsala, Värmland, Västerbotten, Västernorrland, Västmanland.

CANADA (11 of 12; listed in the same order as in 2)
Newfoundland, Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan, Alberta, Yukon Territory, Northwest Territories

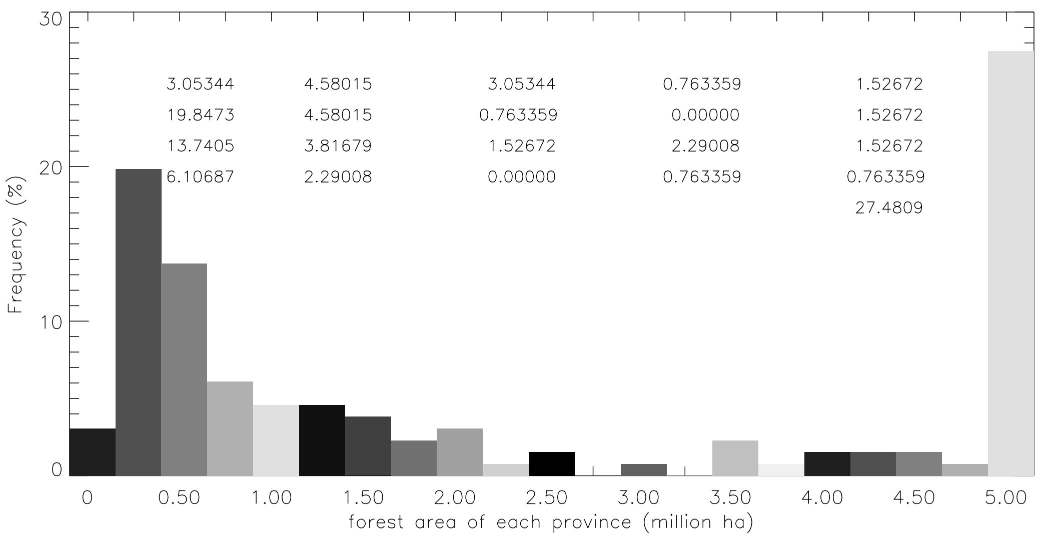
USA (32 of 50; listed in the same order as in 3)
% needle forest < 40: Connecticut, Massachusetts, Rhode Island, Vermont, Delaware, Maryland, New Jersey, New York, Pennsylvania, West Virginia, Michigan, Minnesota, Wisconsin, Indiana, Kentucky, Missouri, Ohio, Virginia, Tennessee
% needle forest ≥ 40: Maine, New Hampshire, North Carolina, South Carolina, Florida, Georgia, Alabama, Mississippi, Arkansas, Louisiana, Idaho, Montana, Colorado

A.2. Distribution of provincial/state forest areas

The distribution of provincial forest area in the six countries CAN, FIN, NOR, SWE, RUS and the USA is shown below. About 54% of the provinces had forested area less than 1.5 million ha (37% less than 625 thousand ha). About 27% had areas greater than 5 million ha (12% greater than 20 million ha).



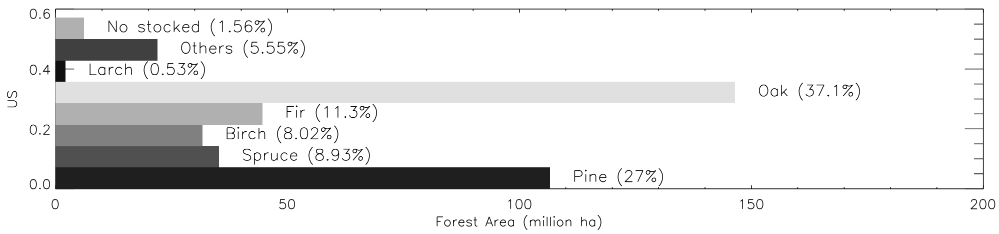
0 -- less than 0.5 million ha
1 -- between 0.5 and 1.5 million ha
....
20 -- above 20 million ha

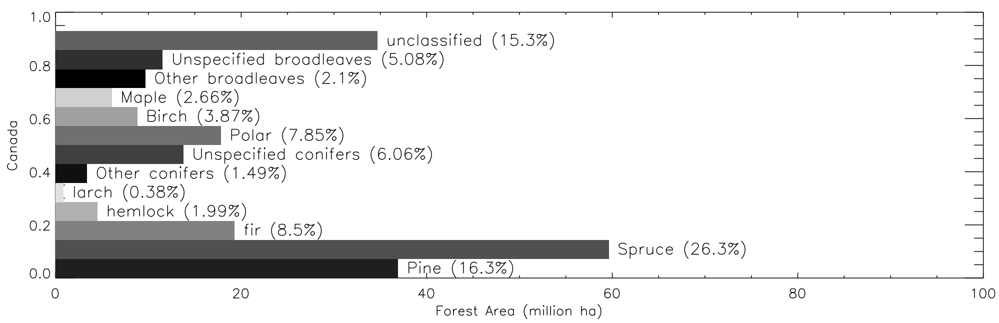


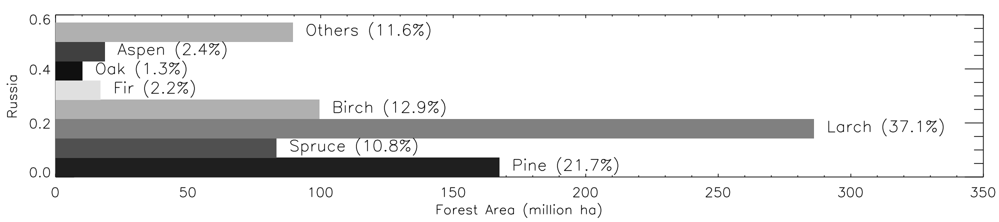
0 -- less than 125 thousand ha
0.25 -- between 125 and 375 thousand ha
0.5 -- between 375 and 625 thousand ha
0.75 -- between 625 and 875 thousand ha
1 -- between 875 and 1125 thousand ha
....
5 -- above 5 million ha

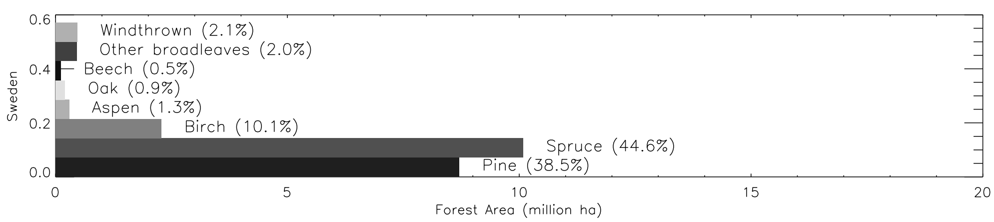
A.3. Distribution of forest area by genus.

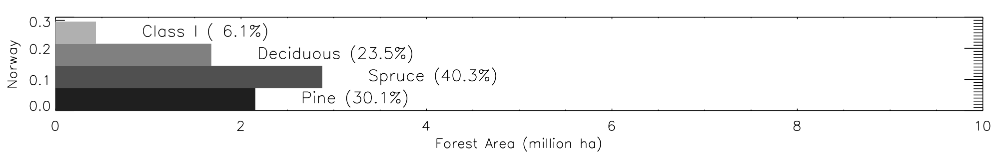
The dominant forest type is needle leaf (spruce, pine, fir and other conifers in CAN, > 60%; larch, pine, spruce in RUS, > 70%; spruce and pine in FIN, NOR and SWE, 70–90%). The area of broad leaves (mostly oak) in the USA is comparable to that of needle leaves (pine, fir, and spruce), about 40%.

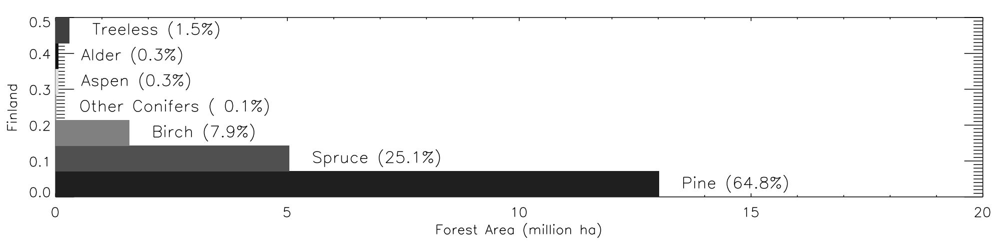






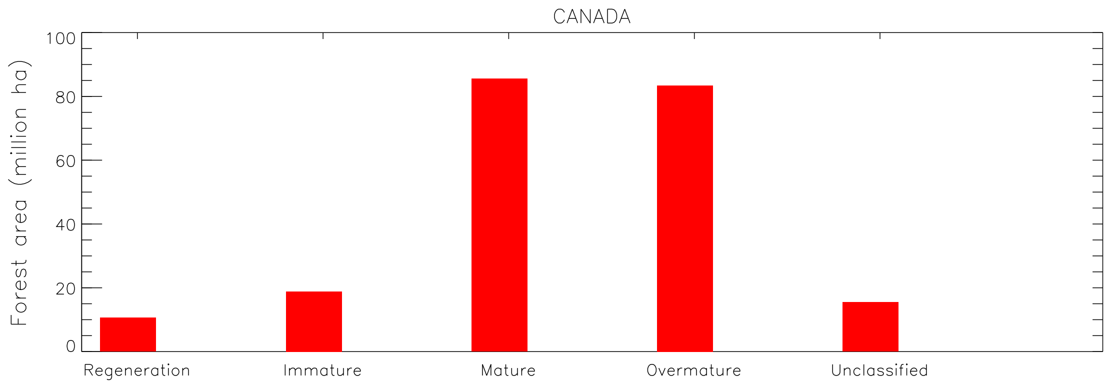


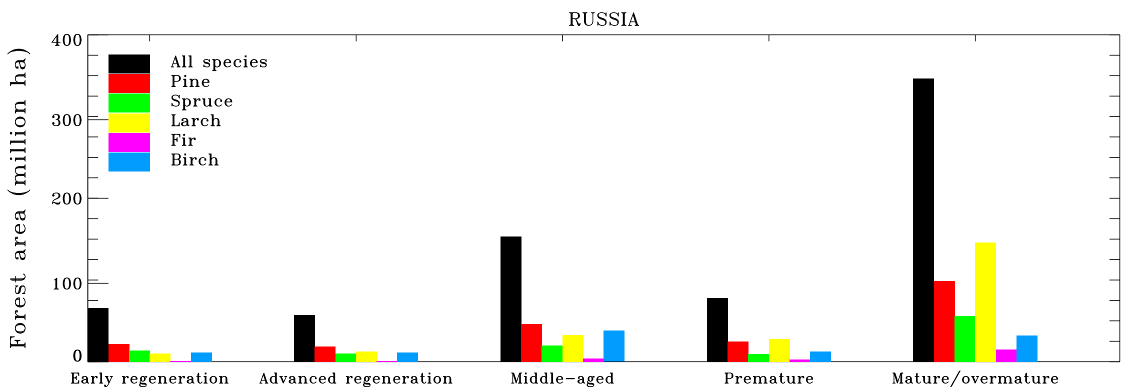


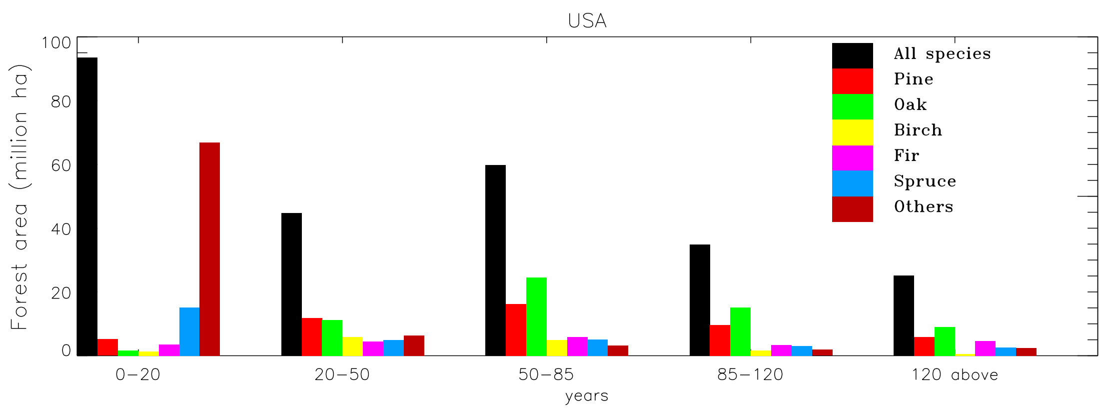


A.4. Age structure of forest

About 40% of the forest area in Canada and 55% in Russia is under mature and over mature forests. The area under immature forests in Canada is about 30% (23% middle-aged forests in Russia). The forest area under regeneration is less than 10% in Canada (20% in Russia). Thus, in a broad sense, the Canadian and Russian forest age structures are comparable. In the United States, fully three-fourths of the forest area is under forests younger than 85 years.







A.5. Evaluation of biomass from inventory of wood volume data

Above-stump biomass is estimated as:

$$AB(P) = \frac{N_{cf}(C)WV_N(P) + B_{cf}(C)WV_B(P)}{FA(P)}$$

- AB: Above-stump Biomass *(tons/ha)*
- N_{cf} : Conversion factor for conifers *(tons biomass/m^3 stem wood)*
- B_{cf} : Conversion factor for broad leaves *(tons biomass/m^3 stem wood)*
- WV_N : Wood volume of needleleaf forest *(m^3)*
- WV_B : Wood volume of broadleaved forest *(m^3)*
- FA: Forest area *(ha)*
- C: Country based function
- P: Province based function

Total biomass is estimated as:

$$TB(P) = AB(P)[1 + (\frac{FF_N(P)}{N_{cf}(C)} + \frac{FF_B(P)}{B_{cf}(C)})R_{cf}(C)]$$

- TB: Total Biomass *(tons/ha)*
- FF_N : Forest fraction of conifers *(% of pixel area)*
- FF_B : Forest fraction of broad leaves *(% of pixel area)*
- R_{cf} : Conversion factors for root *(tons biomass/m^3 stem wood)*

The conversion factors are country specific and given in TBFRA-2000 (4).

A.6. Matching Inventory and Remote Sensing Data: An Example

The relation between biomass and cumulative growing season NDVI data shown in Fig. 1 requires matching inventory data to remote sensing data, such that the growing season NDVI totals are evaluated from forest land cover pixels only. The methodology is illustrated here, using Sweden as an example.

Sweden spans a latitude range of about 55N to 70N, with 24 provinces for which the inventory data are available (Fig. A.6.1). The provinces are of different land and forest areas. The data reported are stem wood volume in cubic million meters and forest area in thousand hectares for various tree types and trunk size classes. Data are published in a series of statistical handbooks (5, 6). We utilized data from two periods (1982-1986 and 1993-1997).

To match these provincial inventory estimates to NDVI data, the distribution of forest area in each of the provinces, not just the total forest area, is required, because the NDVI data are 8×8 km pixel data. Therefore, we use a remote sensing land cover map, shown here in Fig. A.6.2. This map is at a spatial resolution of 1x1 km (7). For each province, in a Geographical Information System, we evaluate the cumulative growing season greenness from NDVI data layers, by averaging over forest pixels, as identified from the land cover map. Forests are defined as the following remote sensing land covers: broad leaf and needle leaf forests, mixed forests, and woody savannas. This assures that the resulting provincial cumulative growing season greenness is assembled from NDVI data of forested regions only. Also, the degree to which total forest area estimates from inventory and remote sensing match, provides some confidence in both inventory and remote sensing data. This is shown in Fig. A.6.3. The inventory stem wood volume data are converted to total and above stump biomass, as described elsewhere in this document and then plotted against the provincial growing season cumulation NDVI, as in Fig. A.6.4. A similar plot for Russia is shown in A.6.5.

Fig. A.6.1 Sweden administritive map

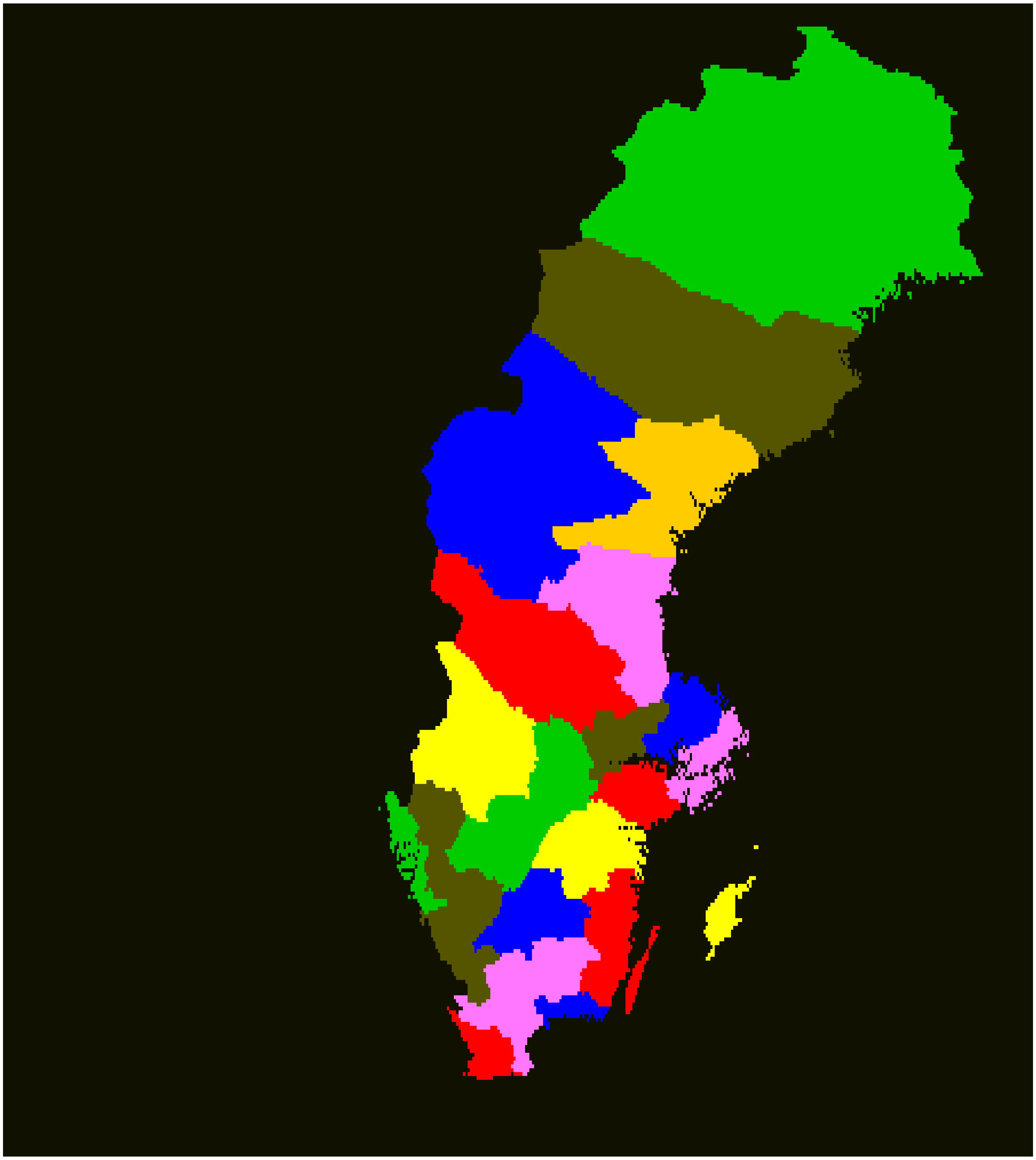


Fig. A.6.2. Sweden Landcover Map

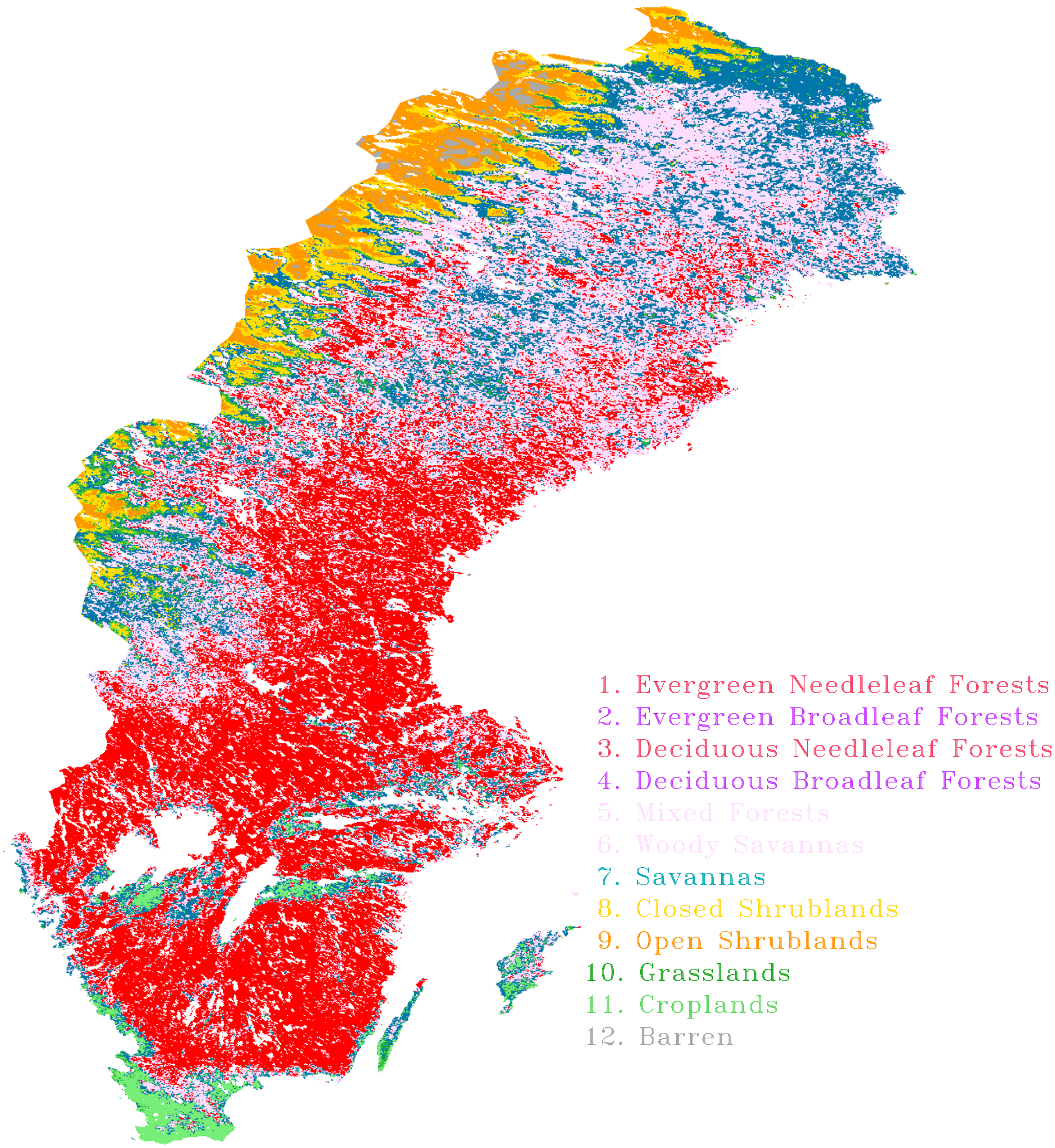
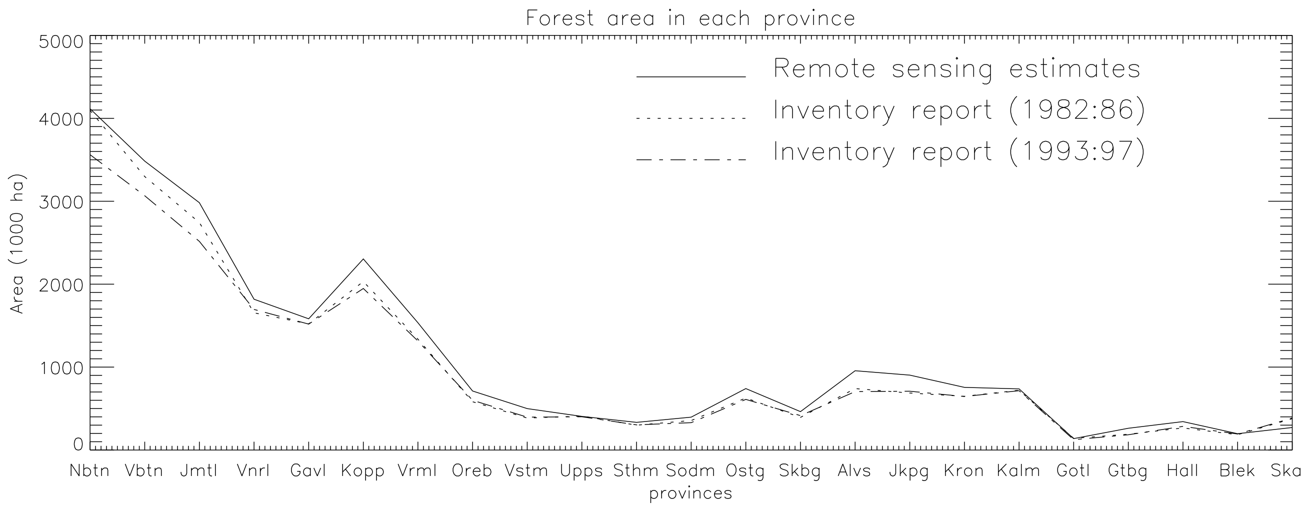


Fig. A.6.3


Forest area in each province
Remote sensing estimates
Inventory report (1982:86)
Inventory report (1993:97)
Area (1000 ha)
0
1000
2000
3000
4000
5000
Nbtn Vbtn Jmtl Vnrl Gavl Kopp Vrml Oreb Vstm Upps Sthm Sodm Ostg Skbg Alvs Jkpg Kron Kalm Gotl Gtbg Hall Blek Skan
provinces

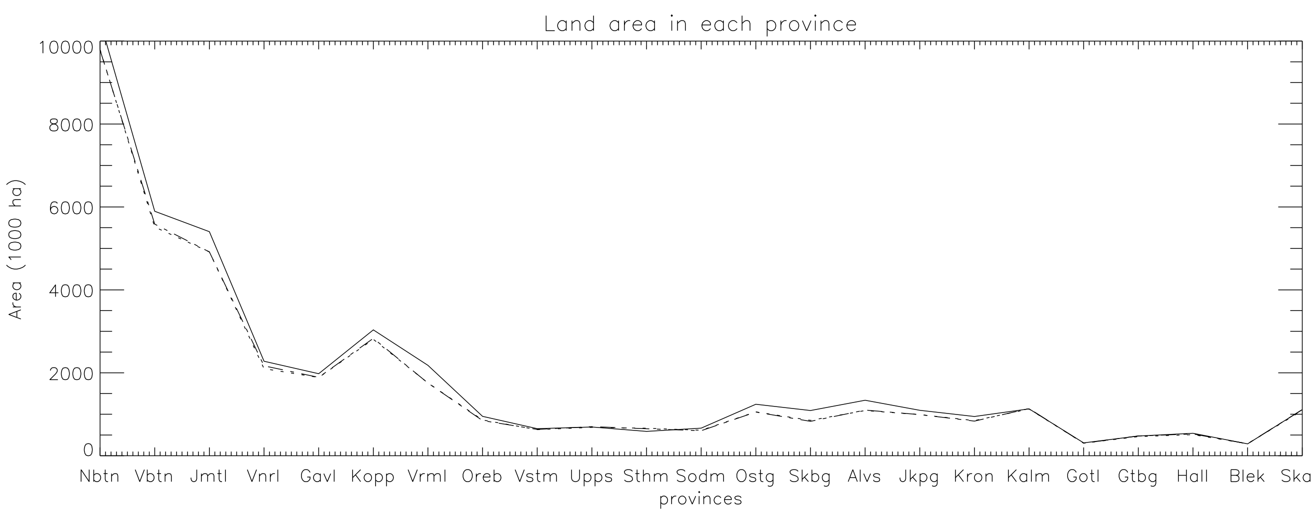

Land area in each province
Area (1000 ha)
0
2000
4000
6000
8000
10000
Nbtn Vbtn Jmtl Vnrl Gavl Kopp Vrml Oreb Vstm Upps Sthm Sodm Ostg Skbg Alvs Jkpg Kron Kalm Gotl Gtbg Hall Blek Skan
provinces

Fig. A.6.4

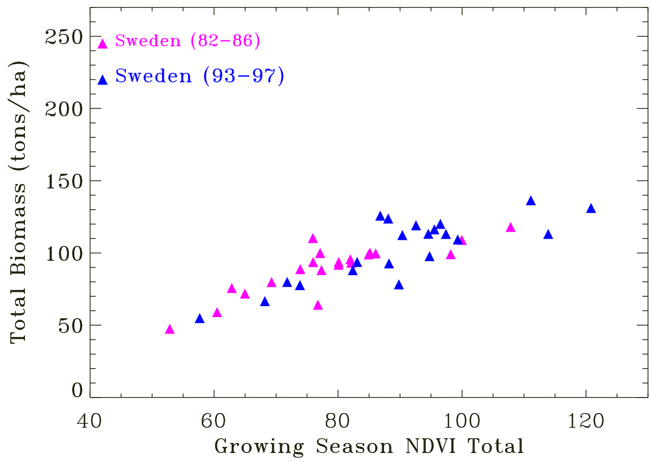
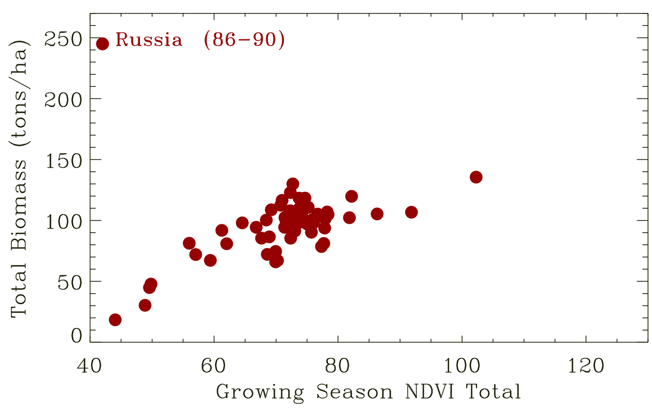


Fig. A.6.5



B. Regression Analysis of Biomass and Satellite Greenness Data

The equation that is used to calculate biomass from NDVI (the biomass-NDVI equation--see caption for Fig. 1) is estimated with data from seven samples; samples from a single period for five nations (Canada, Finland, Norway, Russia, Sweden, and the United States) and two periods for Sweden (1982-1986 and 1995-1999). Using these samples to estimate the relation between biomass and NDVI for all of North America and Eurasia begs two related questions: (i) does the relation between biomass and NDVI vary across spatial, temporal, and ecological scales; (ii) if the relation does vary, can Eq. **1** be used to generate accurate estimates for biomass (and changes in biomass) in countries where there are no forest inventory data to generate country-specific relations?

Estimating the biomass-NDVI equation from pooled data implies that the relation between biomass and NDVI does not vary among the seven samples. That is, the relation between biomass and NDVI in Russia is the same as the relation between biomass and NDVI in the USA (i.e., $\beta_{Russia} = \beta_{USA}$). Making this assumption to estimate the biomass-NDVI equation and using the resultant equation to calculate biomass in nations not in the regression sample implies that the value of β represents the relation between biomass and NDVI for all spatial scales, time periods, and biomes in North America and Eurasia.

As noted previously, the data used to estimate the biomass-NDVI equation represent a wide variety of inventory practices, provincial forest acreage, ecosystem types, age structures, management practices, fire and insect dynamics, and time periods (part A of supporting information). These differences could cause the biomass-NDVI equation to indicate a relation between NDVI and biomass when in fact no relation exists and/or could bias the statistical estimates for the regression coefficients (for a discussion of potential pitfalls, see 8). Such problems would affect the reliability of our estimate for biomass and ultimately, the carbon sink.

One way to evaluate the ability of the biomass-NDVI equation to represent the relation between biomass and NDVI across spatial, temporal, and ecological scales is to test the null hypothesis that regression coefficients do not vary across the seven samples used to estimate the equation. This null hypothesis is evaluated by comparing a restricted model, in which the value of the regression coefficients do not vary among samples, against an unrestricted model, in which the values of the regression coefficients are allowed to vary. From this perspective, the biomass-NDVI equation can be considered to be a restricted model:

$$1/\text{Biomass} = \alpha + \beta\,[(1/\text{NDVI})/\text{Latitude}^2] + \gamma\,\text{Latitude}, \qquad \textbf{[1]}$$

in which biomass is a measure of total biomass obtained from inventories, NDVI is the cumulative growing season NDVI averaged over a 5-year period before inventory date, latitude is the centroid of the area sampled by forest inventory in a province, and α and β are regression coefficients that are the same across the seven samples.

We test the null hypothesis that the values of the regression coefficients do not vary across the seven samples (ecological and temporal scales, broadly speaking) with a *F* test. This test compares a restricted model, in which the values of the regression coefficients are not allowed to vary, against an unrestricted model, in which the values of the regression coefficients are allowed to vary.

First, we test the assumption that the intercepts (α) do not vary by comparing an unrestricted model, in which the intercepts are allowed to vary across the seven samples (Eq. **3**) against a restricted model in which the intercept is not allowed to vary across the seven samples (Eq. **2**):

$$1/\text{Biomass} = \alpha + \beta\,[(1/\text{NDVI})/\text{Latitude}^2] + \gamma\,\text{Latitude}, \qquad \textbf{[2]}$$

$$1/\text{Biomass} = \sum_{i=1}^{7} \alpha_i + \beta\,[(1/\text{NDVI})/\text{Latitude}^2] + \gamma\,\text{Latitude}, \qquad \textbf{[3]}$$

in which i corresponds to the seven samples.

The set of restrictions that equalizes the values of α is tested with a test statistic (ω), which is given by Eq. **4**:

$$\omega = \frac{(RSS_R - RSS_U)/s}{RSS_U\ /(T-K)}, \qquad \textbf{[4]}$$

in which T is the number of observations (167), K is the number of regressors in the unrestricted equation, s is one less than number of coefficients restricted to be equal (in this case, 6) , RSS_R is the residual sum of squares from the restricted model (Eq. **2**) and RSS_U is the residual sum of squares from the unrestricted version of equation (Eq. **3**). The test statistic ω is distributed as a F with s and (T-K) degrees of freedom in the numerator and denominator, respectively. If the αs vary across the seven samples, Eq. **3** will fit the data better than Eq. **2**. If the improved fits is sufficiently large, ω will exceed the critical value and indicate that the residual sum of squares for the restricted model increases in a manner that is statistically significant at the relevant level of significance relative to the residual sum of squares for the unrestricted model, in which case we reject the null hypothesis that the regression coefficients are equal across the seven samples. The results indicate that we can strongly reject the set of restrictions that equalize the values of α [$F(6,158) = 7.53$; $P < .0001$]. Although the value of α varies by sample, this will have little effect on the estimate for the carbon sink. The carbon sink is calculated by subtracting the biomass estimates for 1982-1986 from the biomass estimates for 1995-1999. This subtraction eliminates the value of α (and the value of γ that is associated with latitude).

For the purpose of evaluating the change in carbon storages, we test whether the relation between NDVI and biomass varies among the seven samples. We do so by comparing an restricted model (Eq. **5**), in which α varies across the seven samples, against an unrestricted version of the model (Eq. **6**), in which both α and β vary across the seven samples.

$$1/\text{Biomass} = \sum_{i=1}^{7} \boldsymbol{\alpha}_i + \beta\,[(1/\text{NDVI})/\text{Latitude}^2] + \gamma\,\text{Latitude}, \qquad \textbf{[5]}$$

$$1/\text{Biomass} = \sum_{i=1}^{7} \boldsymbol{\alpha}_i + \sum_{i=1}^{7} \boldsymbol{\beta}_i\,[(1/\text{NDVI})/\text{Latitude}^2] + \gamma\,\text{Latitude}. \qquad \textbf{[6]}$$

The set of restrictions that equalizes the values of β is tested with the ω statistic (Eq. **4**). The results indicate that we reject the null hypothesis that we reject this restriction level [$F(6,151) = 2.59$; $P > 0.03$], but much less strongly than we rejected the previous restriction.

This result implies that the values for β vary among nations. To assess this variation, we estimate Eq. **1** seven times. For each, we include only those points for an individual nation and/or period. For each set of regression results, we evaluate the relation between NDVI and biomass with a *t* statistic that tests the null hypothesis $\beta = 0$. If we cannot reject this null, the result indicates that there is no relation between NDVI and biomass. Conversely, rejecting this null hypothesis would indicate that there is a statistically meaningful relation between NDVI and biomass.

The results indicate that there is a statistically meaningful the relation between NDVI and biomass in nearly every nation and sample period (Table 3). For Finland, the relation is significant at the $P < 0.10$ level, but not at the $P < 0.05$ level. This result is not surprising given the small sample from Finland (the regression equation estimated from the Finnish data has only 5 degrees of freedom). For the United States, there is no relation statistically meaningful relation between NDVI and biomass. This failure is due to a single observation. If we remove this observation and reestimate Eq. **1**, there is a statistically meaningful relation between NDVI and biomass ($P < 0.01$). Together, these results indicate that there is a statistically significant correlation between NDVI and biomass within nations.

Variations in β among nations could affect our estimate for the change in the carbon pool if the differences are systematically associated with NDVI or latitude (i.e., the size of β_1 depends on either the value of NDVI or latitude). Figs. 1 and 2 seem to indicate that there is no relation between NDVI and biomass for values of NDVI that are greater than 80 (this comment was raised independently by two reviewers). For ease of exposition, Figs. 1 and 2 plot biomass as a function of NDVI. But Eq. **1** specifies a more complex relation. Therefore, judging the relation between biomass and NDVI based on a two-dimensional plot of the untransformed values may be misleading.

Nonetheless, it is important to evaluate the potential for changes in the relation between biomass and NDVI statistically. One way to evaluate the relation between biomass and NDVI is to estimate Eq. **1** by using a subsample that includes values of NDVI equal to or greater than 80 (and the corresponding values of biomass). For this subsample, we can evaluate whether there is a relation between biomass and NDVI by testing the null hypothesis $\beta = 0$. Rejecting this null hypothesis would indicate that there is a relation between NDVI and biomass for values of NDVI greater than 80. This hypothesis can be tested with a t statistic. The t statistic for a regression estimated with the subsample (NDVI > 80) is 3.16, $P < 0.003$. This result indicates that $\beta \neq 0$, which means that there is statistically meaningful relation between biomass and NDVI for values of NDVI that exceed 80.

We can go one step further by asking the question is the relation between NDVI and biomass for values above 80 the same as the relation between NDVI and biomass for values below 80. We evaluate this question by defining a dummy variable (DUM) that is equal to 1 for values of NDVI above 80 and equal to zero for values of NDVI equal to 80 or below. We use this dummy variable to modify Eq. **1** as follows:

$$1/\text{Biomass} = \alpha_1 + \alpha_2 * \text{DUM} + \beta_1 * [(1/\text{NDVI})/\text{Latitude}^2] + \beta_3 * \text{DUM} * [(1/\text{NDVI})/\text{Latitude}^2] + \beta_2 \text{ Latitude} \quad \textbf{[7]}$$

The DUM variables allow the relation between NDVI and biomass to change at 80. That is, if the regression coefficient α_2 is statistically significant, such a result indicates that the intercept for the relation between NDVI and biomass is α_1 for values of NDVI equal to or less than 80 and $\alpha_1 + \alpha_2$ for values of NDVI greater than 80. Similarly, if the regression coefficient β_3 is statistically significant, it implies that the slope for the relation between NDVI and biomass is β_1 for values of NDVI less than 80 and $\beta_1 + \beta_3$ for values of NDVI equal to or greater than 80. We can test hypotheses about the dummy variable that modifies the intercept and/or slope individually or jointly. An *F* test that DUM*α_2 is equal to zero cannot be rejected [$F(1,162) = 0.71$; $P<0.40$]. Nor can an *F* test that DUM*β_3 is zero be rejected [$F(1,162) = 0.04$; $P < 0.84$). Finally, an *F* test that DUM*α_2 AND DUM*β_3 are zero cannot be rejected [$F(2,162) = 2.88$, $P < 0.06$]. Together, these results indicate that there is a relation between NDVI and biomass for values above 80 and that the relation between NDVI and biomass for values of NDVI above 80 is not statistically different from the relation between NDVI and biomass for values of NDVI equal to or less than 80.

The focus on 80 as a threshold, which is suggested by two reviewers, is somewhat restrictive — the relation between NDVI and biomass could break down at a threshold other than 80. To explore this possibility, we look for changes in the relation between NDVI and biomass at every possible threshold between 47 and 127 (the minimum and maximum values for which there are enough degrees of freedom to do the statistical tests). First, we test whether there is a statistically meaningful relation between NDVI and biomass in subsamples defined by values for NDVI. To do so, we estimate Eq. **1** with a subsample of data that includes observations with a value for NDVI of 127 or greater and progressively lower the threshold by one unit. Line 4 in Fig. B.1 shows the significance level of the *t* statistic for the test $\beta = 0$. The value that corresponds to a value of 100, 0.03, indicates that estimating Eq. **1** with a subsample that includes values for NDVI of 100 or greater generates a statistically meaningful value for β_1 as indicates by a threshold of $P < 0.05$ (line 3) or $P < 0.1$ (line 2). A value above either line indicates that β_1 is not statistically different from zero at threshold of $P < 0.05$ or $P < 0.1$ (i.e. there is no relation between NDVI and biomass). Notice that line 4 moves above line 3 when the regression equation includes values of NDVI equal to or greater than 113. At this point, the regression sample has less than 23 degrees of freedom (line 1), which reduces the reliability of the statistical estimation. These results indicate that there is a relation between NDVI and biomass for nearly all values for NDVI.

We also can repeat the analysis of the stability of the regression results by estimating Eq. **7** with the 0/1 threshold for the dummy variable for every possible value between 47 and 127. As indicated by line 5 in Fig. B.2, we cannot reject the null hypothesis that the value for DUM*β_3 in Eq. **7** is zero, for nearly every value for the 0/1 threshold (except for a threshold of 63 or 64). Similarly, line 4 in Fig. B.2 indicates that we cannot reject the null hypothesis that DUM*α_2 is equal to zero except for a few thresholds between 100 and 115. As indicated by line 1, we are unable to reject the null hypothesis that both DUM*α_2 AND DUM*β_2 for thresholds above 70 and below 80. This range generates subsamples that are approximately equal, which generate the most reliable results. As indicated by line 2 in Fig. B.2, about 25% of the sample has a value for NDVI below 70 while about 40% of the observations have a value for NDVI above 80. Together, these results indicate that the relation between NDVI and biomass is stable over a wide range of subsamples.

Alternatively, the relation between NDVI and biomass may vary over latitude. We can explore the effect of latitude on the relation between NDVI and biomass by estimating Eq. **1** with subsamples that are defined by latitude (rather than by NDVI). The data used to estimate Eq. **1** include observations between 29^{o}N and 69^{o}N. To see whether there is a relation between NDVI and biomass within latitudinal bands, we use data from these latitudinal bands to estimate Eq. **1** and test whether β is statistically different from zero. The first subsample includes all observations north of 67^{o}N. The next subsample includes all observations north of 66^{o}N. We repeat this expansion of the latitudinal band until all observations are included. We also repeat this process starting with observations from low latitudes, such that the first subsample includes observations from 29^{o}N to 31^{o}N, the second from 29^{o}N to 32^{o}N, and so on. Regardless of the latitude that is used to truncate the sample, we strongly reject ($P < 0.01$) the null hypothesis that β is equal to zero. The consistent rejection of this null hypothesis indicates that there is a statistically meaningful relation between NDVI and biomass, regardless of latitude.

Eq. **1** specifies the effect of NDVI on biomass [(1/NDVI)/Latitude^2] such that the relation between biomass and NDVI can vary across space. Over large spatial scales, biomes vary by latitude, with low biomass boreal forests at high latitudes and high biomass hardwood forests at mid latitudes. This latitudinal variation probably is not linear. Biomass increases slowly with latitude as latitude increases beyond 25°-30°, where most of the world's deserts are located. To capture this nonlinear variation, we divide NDVI by the square of latitude. This specification implies that the amount of biomass that is associated with a given level of NDVI varies with latitude with the largest values in temperate latitudes (Fig. B.3). Similarly, the relation between biomass and NDVI varies with latitude (Fig. B.4).

There is no *a priori* evidence to indicate whether the effect of latitude on the relation between biomass and NDVI is nonlinear (as represented by the square of latitude) or linear. The use of a linear specification can be evaluated statistically by estimating the following model:

$$1/\text{Biomass} = \sum_{i=1}^{7} \boldsymbol{\alpha}_i + \sum_{i=1}^{7} \boldsymbol{\beta}_i \ [(1/\text{NDVI})/\text{Latitude}] + \gamma\, \text{Latitude}, \qquad \textbf{[8]}$$

and testing whether the slopes (β_i) in Eq. **7** are the same across the seven samples. The ω statistic clearly rejects the null hypothesis that the slopes (β_i) in Eq. **7** are the same [$F(6,152) = 6.72$, $P < 0.00001$]. Similar results [the slopes (β_i) vary across nation] are obtained for an equation in which NDVI is not modified by latitude [$F(6,152) = 8.79$, $P < 0.0000001$]. Together, these results indicate that much of the variation in slopes (β_i) across samples is associated with latitude and that this effect is represented more accurately by the square of latitude.

Finally, we explore the possibility that the temporal relation between biomass and NDVI is different from the spatial relation between biomass and NDVI. To test whether spatial variation in NDVI and biomass is different from the temporal variation in NDVI and biomass, we use observations for Sweden only to estimate the following equation:

$$1/\text{Biomass} = \alpha_1 + \alpha_2 * \text{DUM8286} + \beta_1 * [(1/\text{NDVI})/\text{Latitude}^2]$$
$$+ \beta_3 * \text{DUM8286} * [(1/\text{NDVI})/\text{Latitude}^2] + \beta_2 * \text{Latitude} \qquad \textbf{[9]}$$

in which DUM8286 is a dummy variable that is equal to 1 for observations for Sweden from the 1982 to 1986 and is equal to 0 for observations for Sweden from 1995 to 1999. If the spatial relation between NDVI and biomass during the 1982–1986 and 1995-1999 periods is different from the temporal relation between NDVI and biomass between these two periods, DUM*α_2 and/or

DUM*β_3 will not be equal to zero. Conversely, if the spatial relation between NDVI and biomass during the 1982–1986 and 1995-1999 periods is the same as the temporal relation between NDVI and biomass between these two periods, DUM*α_2 and/or DUM*β_3 will be zero.

We test whether DUM*α_2 and/or DUM*β_3 are equal to zero with an *F* test. Tests indicate that we cannot reject the null hypothesis that DUM*α_2 is equal to zero [$F(1,36)= 0.005$, $P < 0.95$], DUM*β_3 is equal to zero [$F(1,36) = 0.01$, $P < 0.91$], and DUM*α_2 and DUM*β_3 are equal to zero [$F(2,36) = 0.07$, $P < 0.94$]. Together these results indicate that the spatial relation between biomass and NDVI is not statistically different from the temporal relation between biomass and NDVI.

Next, we estimate the effect of uncertainty regarding the relation between biomass and NDVI on the estimate for the carbon sink by running a Monte Carlo simulation. Ideally, this Monte Carlo experiment would be simulated with the entire data set. For each pixel and period in North America and Eurasia, we would use the values of NDVI to calculate a value for biomass that includes an error. This error would be determined by an estimate for the variance of the biomass estimate, which can be derived from the regression results. This process would be repeated 1,000 times to generate a confidence interval for our point estimate of the carbon sink. Unfortunately, this process is not computational feasible because the North American and Eurasian data set includes tens of millions of pixels.

To avoid these difficulties, we use Monte Carlo techniques to evaluate the change in the carbon storage that is generated by the uncertainty in biomass-NDVI equation alone. To do so, we create a hypothetical landscape of 10,000 pixels (640,000 km^2) where NDVI is identical for each pixel for both periods. We use statistical techniques to calculate the variance associated with the point estimate for biomass that is generated by the biomass-NDVI equation (Eq. **1**). This variance increases as the values of NDVI and latitude move away from the sample mean (83 and 54°, respectively). This variance is multiplied by a normally distributed random variable that has a mean value of zero and a variance of 1. The resultant estimate for the regression error is added to the point estimate to calculate a value of biomass for each pixel. This process is repeated for each pixel to generate a second value for biomass for each pixel. These two values are subtracted from each other and divided by two to calculate each pixel's change in carbon pool. These values are summed over the 10,000 pixels to calculate the total change in the carbon pool in the hypothetical landscape. The total is divided by 10,000 to calculate the mean change in carbon storage per pixel. This process is repeated 1,000 times. We use these 1,000 observations to calculate a mean (and standard error) change in the carbon pool for the 640,000 km^2 hypothetical landscape where NDVI does not change.

The results (Table 4) indicate that the mean estimate for the per-pixel change in the carbon pool is statistically indistinguishable from zero and that the standard error of this mean is 1 or 2 orders of magnitude smaller than the positive per-ha change in carbon pool (sink) reported in the text (0.48 ton C/ha per year). The small size of the standard error relative to the per pixel carbon sink does not vary greatly if we change the values for latitude and/or NDVI that are associated with the hypothetical 64,000 km^2 landscape (the size of standard error decreases as we increase the number of pixels included in the Monte Carlo simulation). The generality of this result indicates that it is highly unlikely that the size the carbon sink reported in the text is a statistical artifact of uncertainty regarding the relation between biomass and NDVI.

We also estimate an equation for the relation between NDVI and above-stump biomass. The results are similar to those obtained for the relation between NDVI and total biomass. We reject restrictions that equalize the value of α across census [$F(6,158) = 2.73$; $P < 0.02$] and we reject restrictions that equalize the values of β across census [$F(6,152) = 2.74$; $P < 0.02$]. Similarly, tests indicate that the regression residual is heteroscedactic [$\chi^2(14) = 28.4$; $P < 0.02$]. Country-wise estimates of above-stump biomass are given in part E of Supporting Information.

Table 3. Regression results for the total biomass equation

	β_1	Standard error	*t* statistic	Degrees of freedom
Sweden 1982-1986	2836	968	**2.93** (*P* <0.004)	18
Sweden 1995-1999	2743	951	**2.89** (*P* <0.004)	18
Norway	9858	2038	**4.84** (*P* < 0.0001)	14
Finland	2793	1536	1.82 (*P* < 0.07)	5
Canada	1631	382	**4.27** (*P* < 0.0001)	8
Russia	8315.	2664	**3.12** (*P* < 0.002)	54
USA	747	562	1.33 (*P* < 0.19)	29
USA*	1371	527	**2.60** (*P* < 0.01)	28

Values that exceed the 0.01 threshold are in bold; Values that exceed the 0.05 threshold in italics
* Result for US when one outlier is removed.

Table 4. Monte Carlo simulation results

Latitude / NDVI	40	80	120
30°	2.57E-04 (.00246)	.000701 (.00671)	.00166 (.01582)
50°	4.85E-04 (.00468)	.000799 (.00772)	.00521 (.04979)
70°	1.89E-04 (.00184)	.000903 (.00871)	.00205 (.01962)

The number is mean per pixel changes in carbon pool (ton C/yr per pixel); the values in parenthesis are the standard errors for this estimate. NDVI here refers to total growing season NDVI.

Fig. B.1 The relation between NDVI and biomass for samples defined by NDVI. Line 4 gives the significance level for the *t* statistic associated with β_1 (Eq. **1**) estimated with data that include values of NDVI equal to or greater than the value given on the *x* axis. The degrees of freedom in these regressions in given by line 2. Line 3 represents the $P < 0.05$ significance level and line 4 represents the $p < 0.10$ significance level. Values of line 4 that exceed lines 2 and 3 indicate that there is no relation between NDVI and biomass for samples that include values of NDVI equal to or larger than the corresponding value on the *x* axis.

Fig. B.2 The stability of the relation between NDVI and biomass for samples defined by NDVI. Line 5 tests whether the slope (DUM*β_1—Eq. **7**) of the relation between NDVI and biomass differs between samples above and below a given threshold for NDVI. Line 4 tests whether the intercept (DUM*α_1—Eq. **7**) of the relation between NDVI and biomass differs between samples above and below a given threshold for NDVI. Line 1 tests whether the intercept and slope (DUM*α_1 and DUM*β_1— Eq. **7**) of the relation between NDVI and biomass differs between samples above and below a given threshold for NDVI. Line 2 represent the number of observations below a given level of NDVI. Line 3 represents the $P < 0.05$ significance level. Locations where lines 1, 4, or 5, dip below line 3 identify values of NDVI where the relation between NDVI and biomass differs between the two subsamples.

Figure B.1

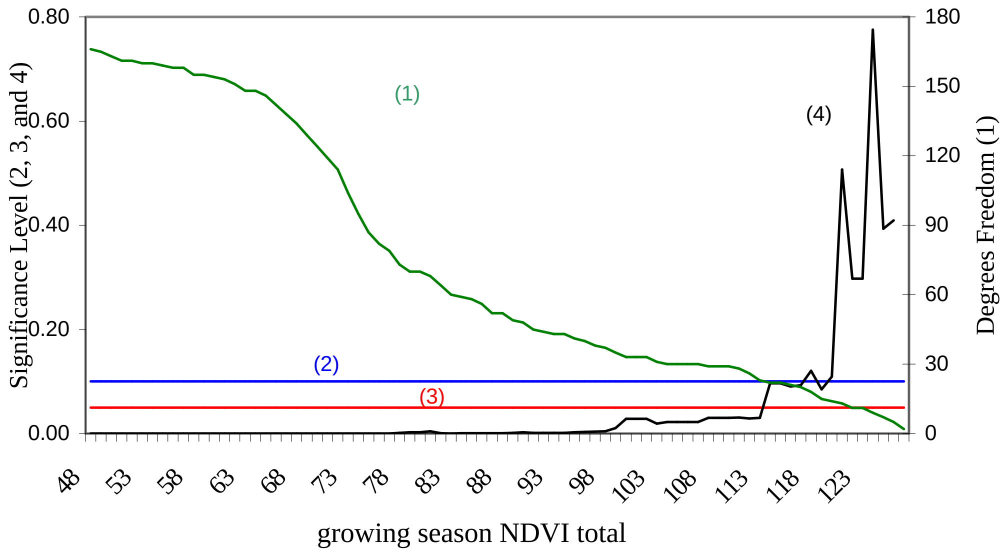
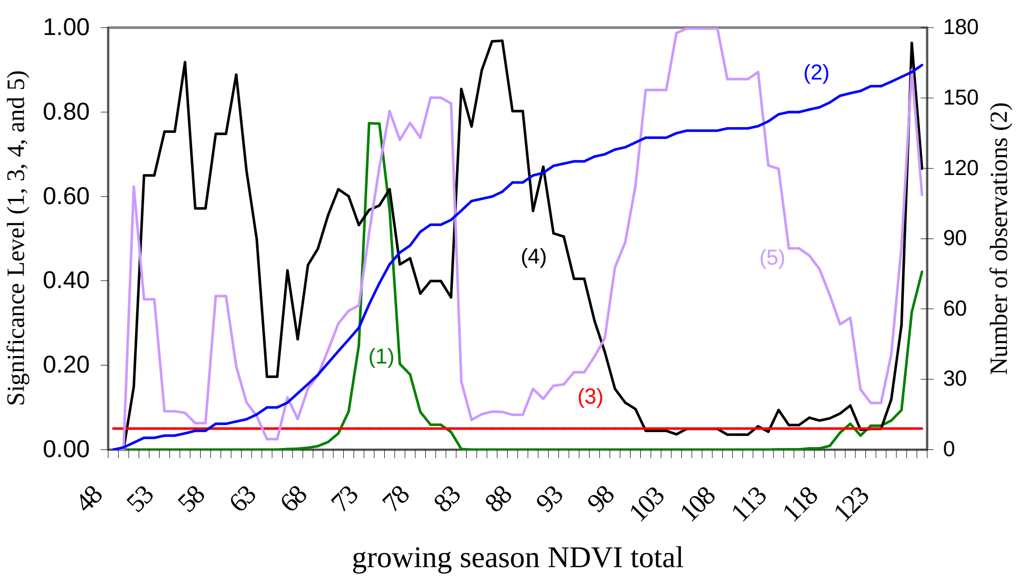


Figure B.2



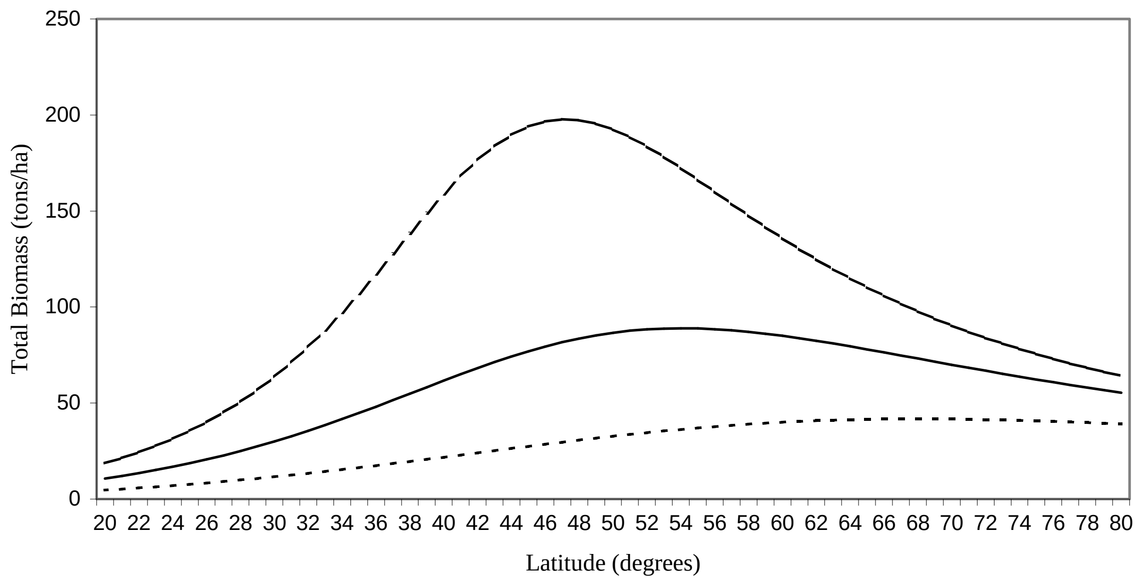


Figure B.3: The relation between total biomass and latitude at three levels of growing season NDVI (40 -- dotted line); (80 -- solid line); (120 -- dashed line).

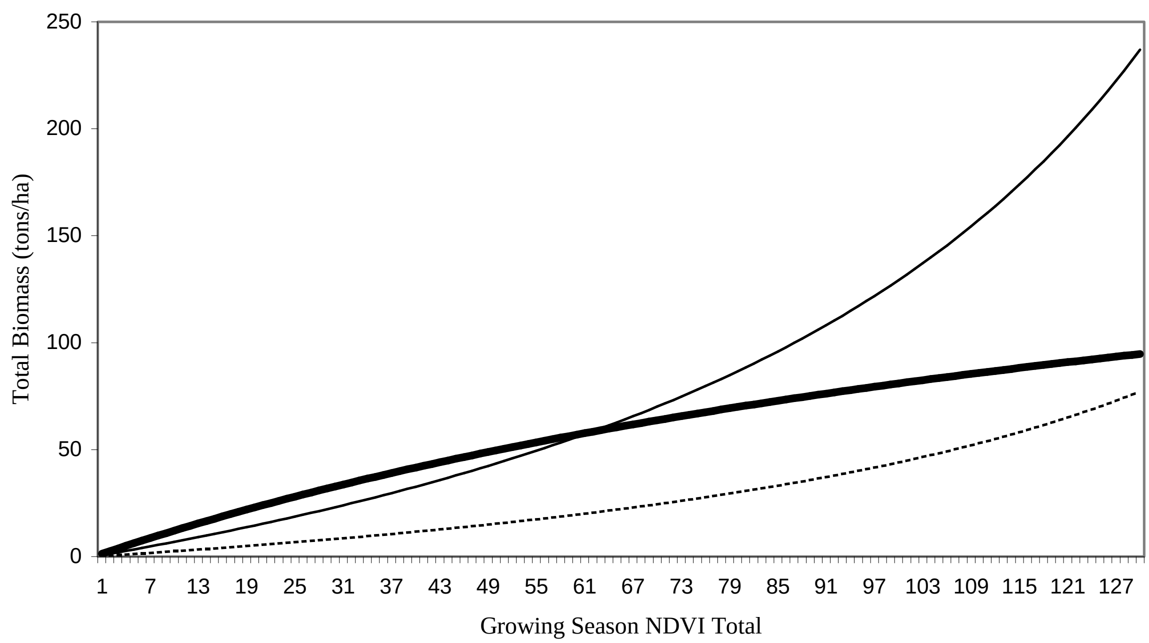


Figure B.4: The relation between total biomass and total growing season NDVI at three latitudes (30^0 -- dotted line); (50^0 -- solid line); (70^0 -- heavy solid line).

C.1. Forest fraction map

Color-coded map of forest fraction expressed as the fraction of each quarter degree pixel area under the following land covers of the high resolution (1x1 km) satellite vegetation map (7): broad leaf and needle leaf forests, mixed forests and woody savannas.

C.1. Forest fraction map

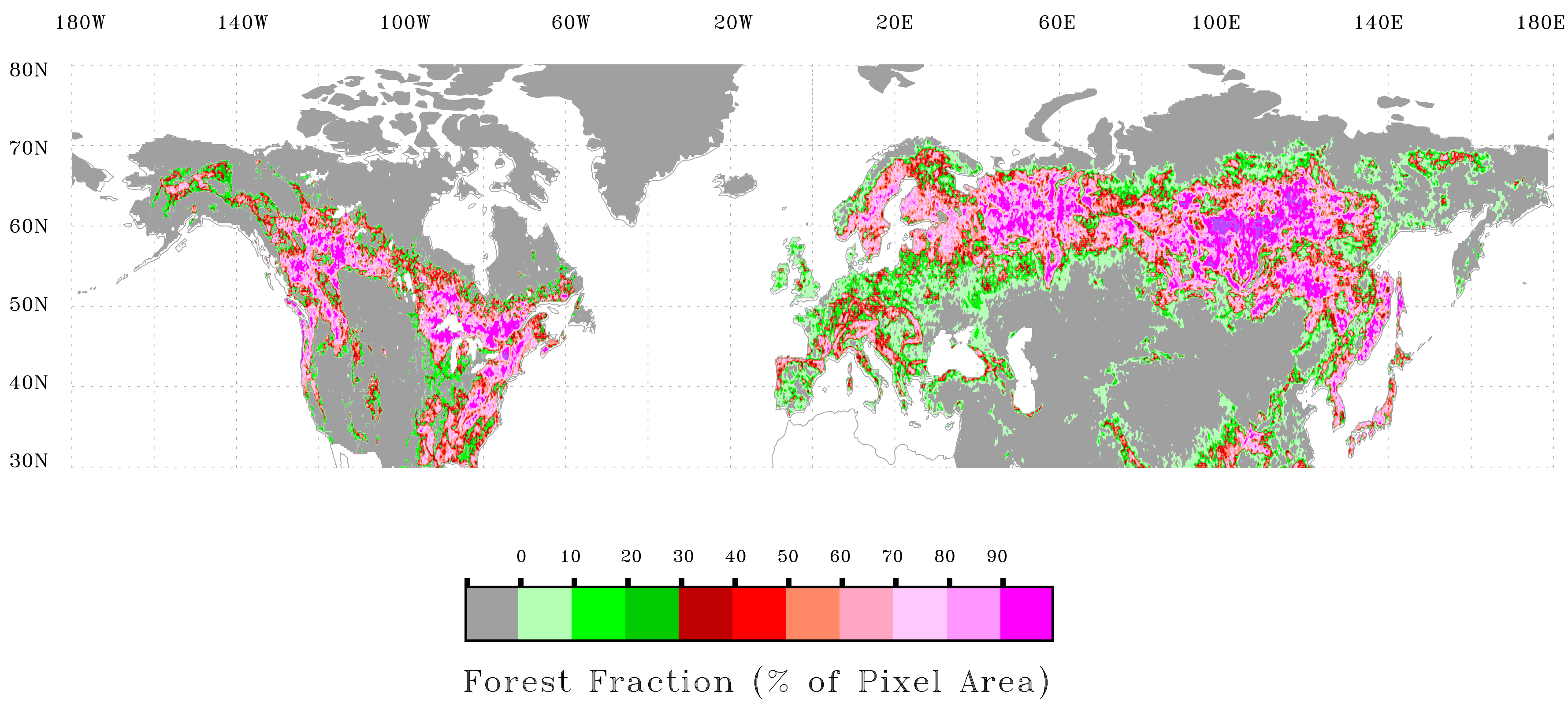


Figure C.1 (Myneni & Dong et al., 2001)

C.2. Map of changes in climatological cumulative growing season NDVI

Color-coded map of changes in climatological growing season NDVI totals north of 30N. Growing season is defined as the period when composite (15-day) NDVI values are greater than 0.1. The map shows the difference between two time periods, 1995-1999 and 1982-1986, for all vegetated regions.

C.2. Changes in NDVI Total

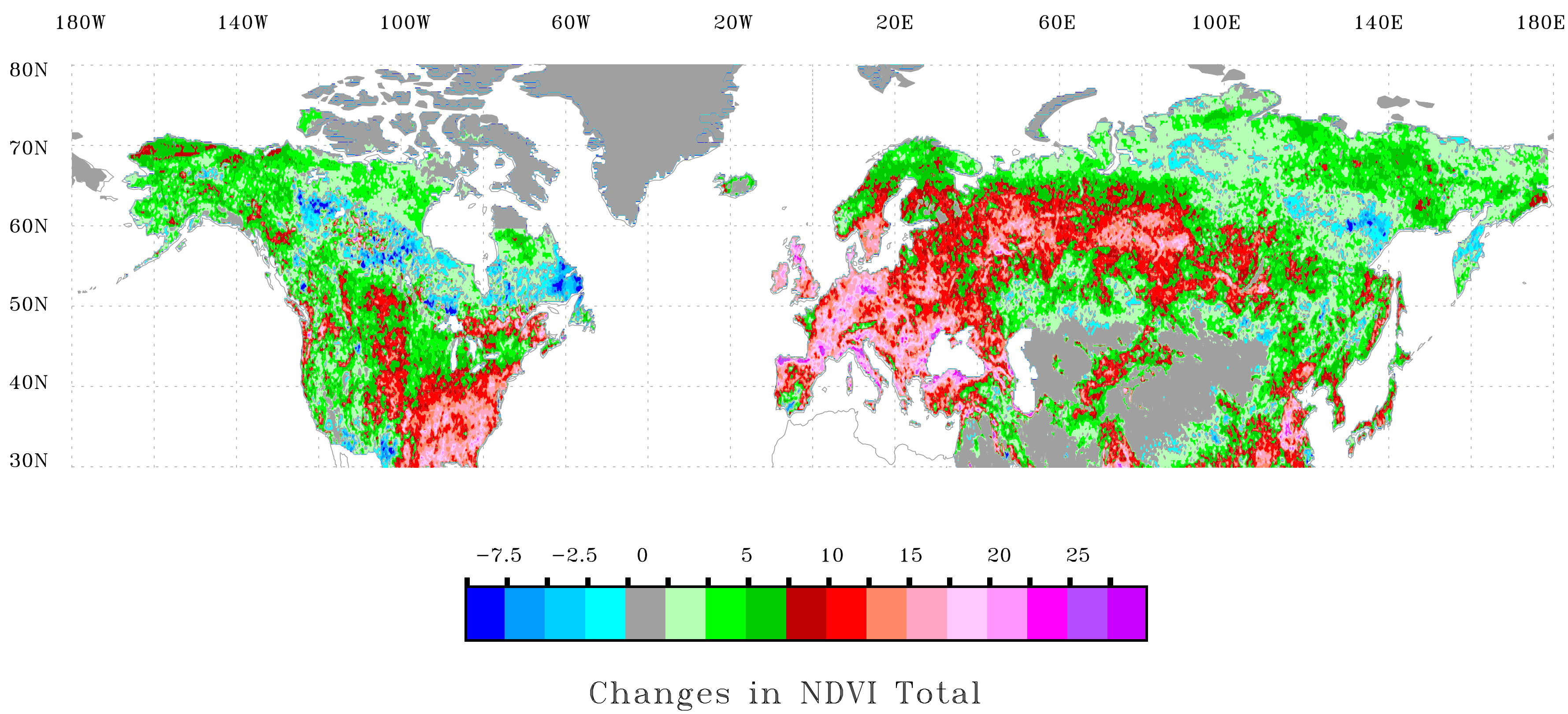


Figure C.2 (Myneni & Dong et al., 2001)

C.3. Detailed maps of changes in the carbon pool

The following pages show larger versions of Fig. 2*a*. They depict the rate of change of mass of carbon in the woody biomass of forests estimated as the difference in predicted pool size for two periods (1995-1999 and 1982-1986), expressed on an annual basis.

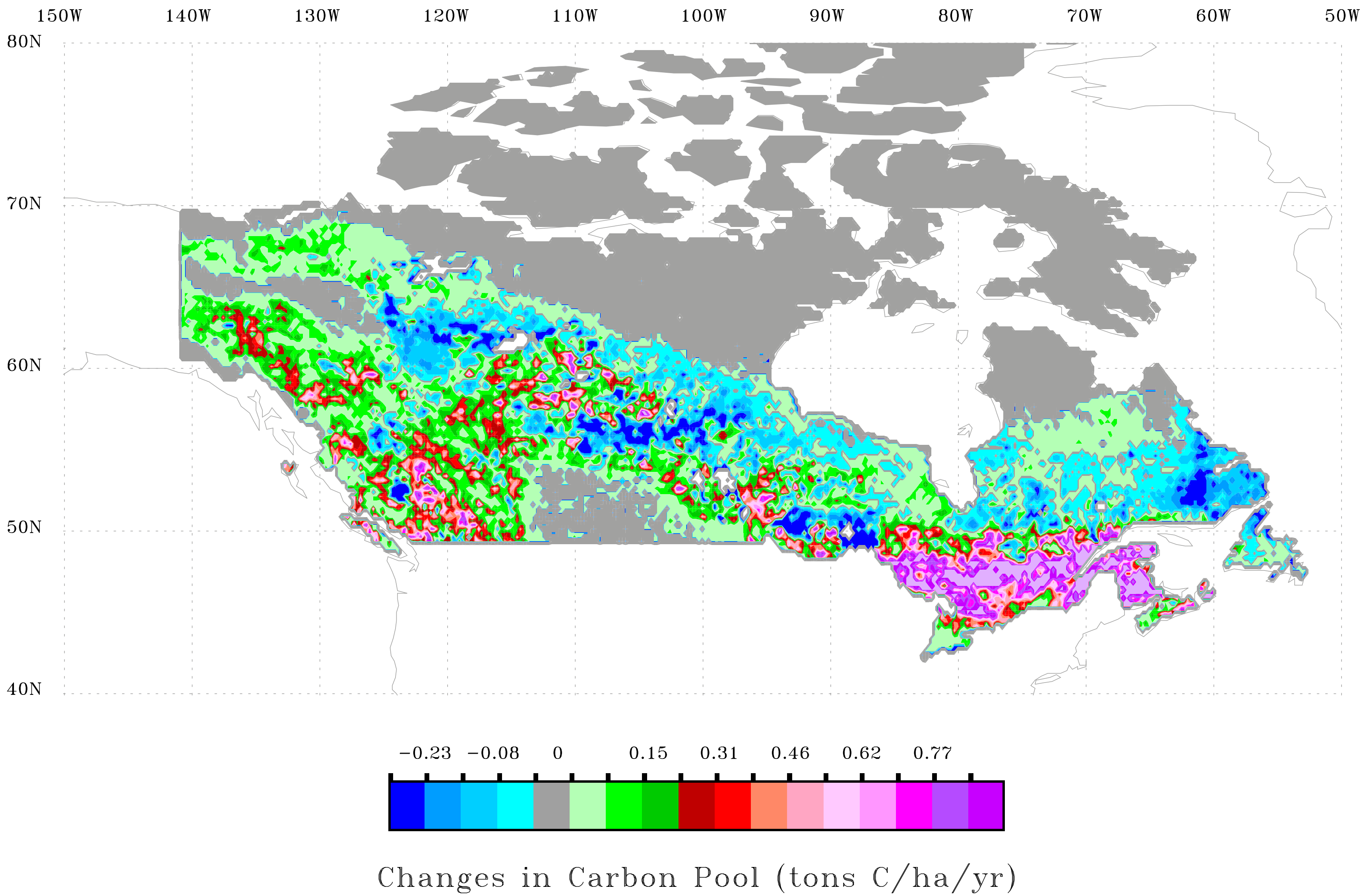


Figure C.3 Canada (Myneni & Dong et al., 2001)

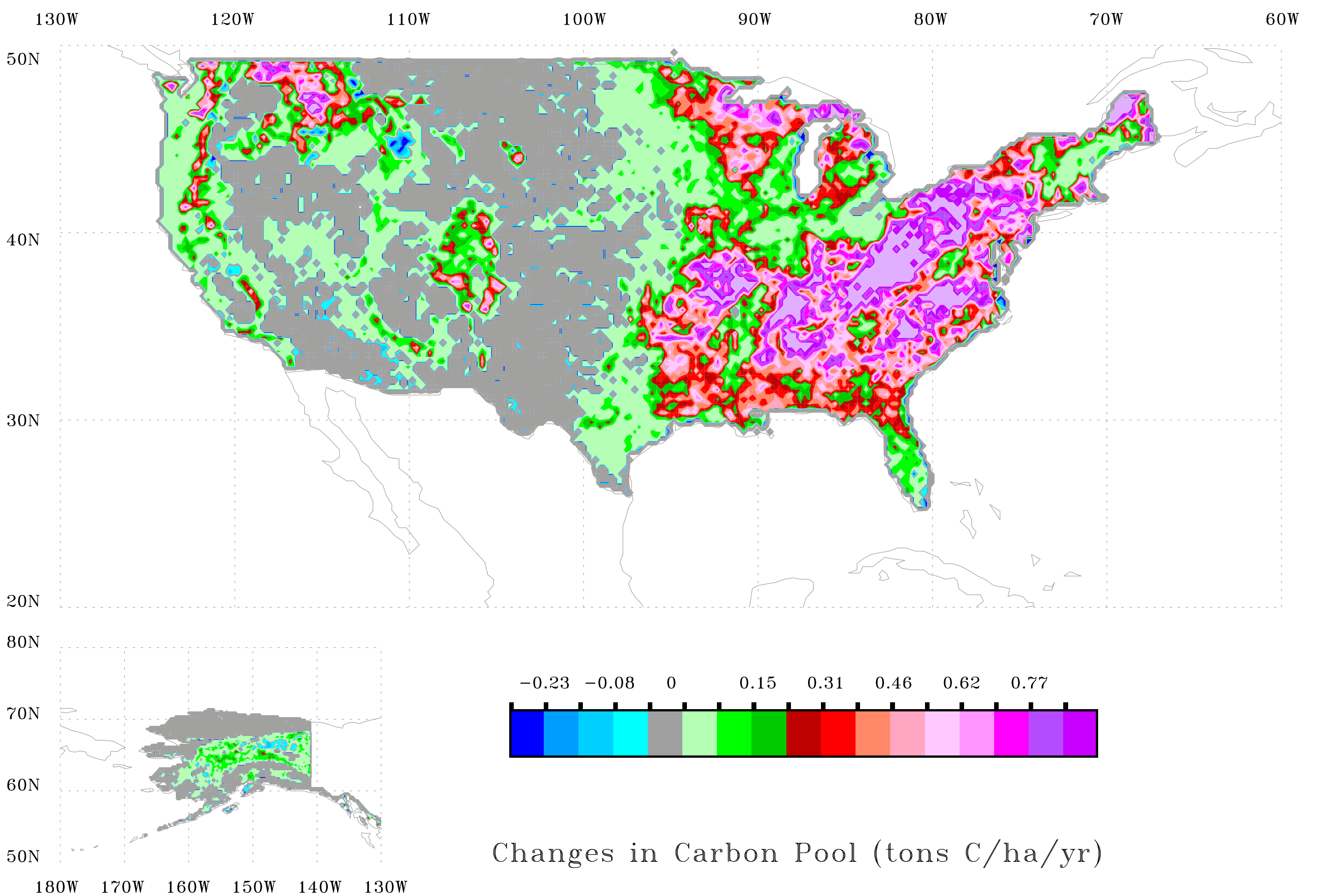


Figure C.3 USA (Myneni & Dong et al., 2001)

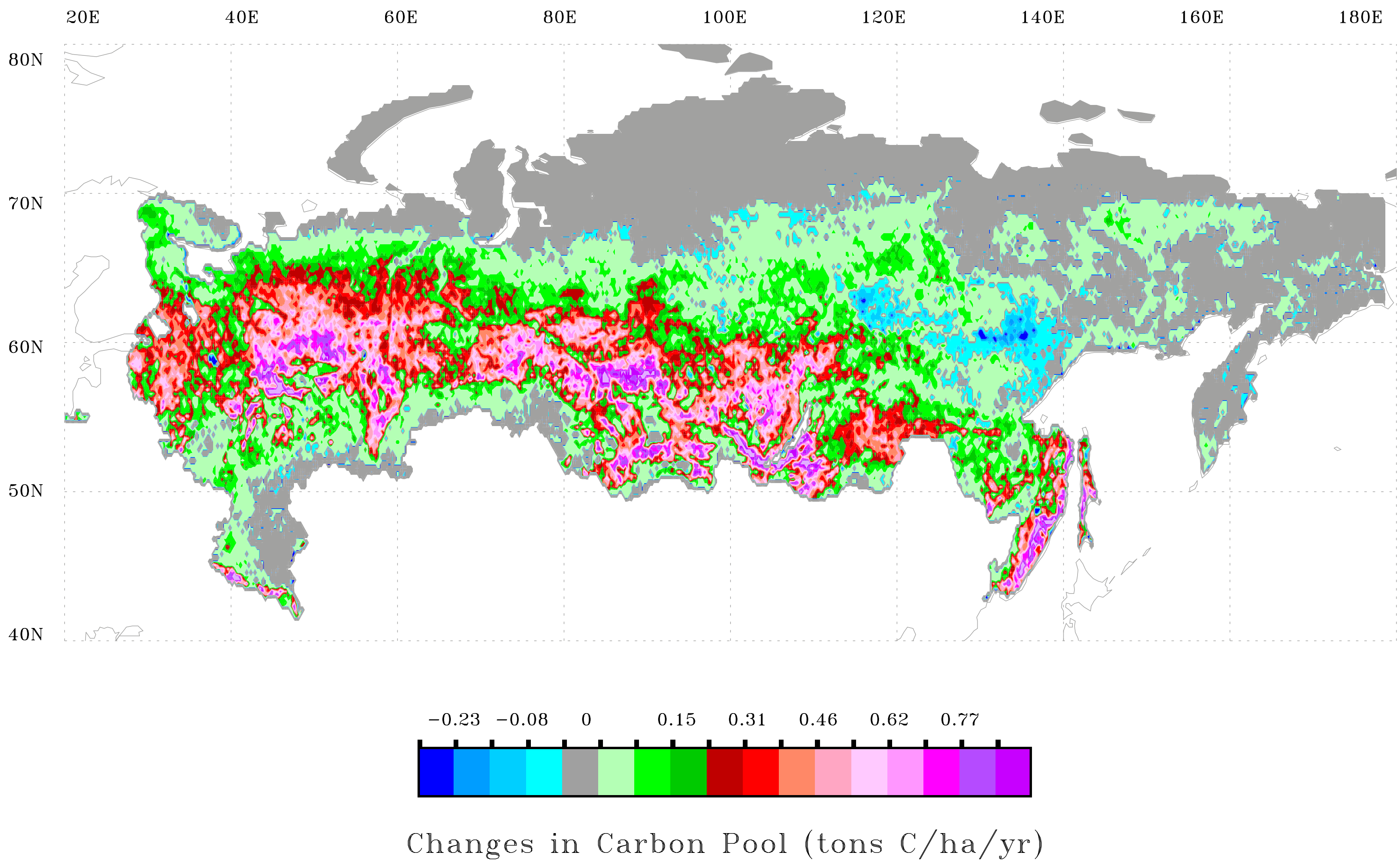
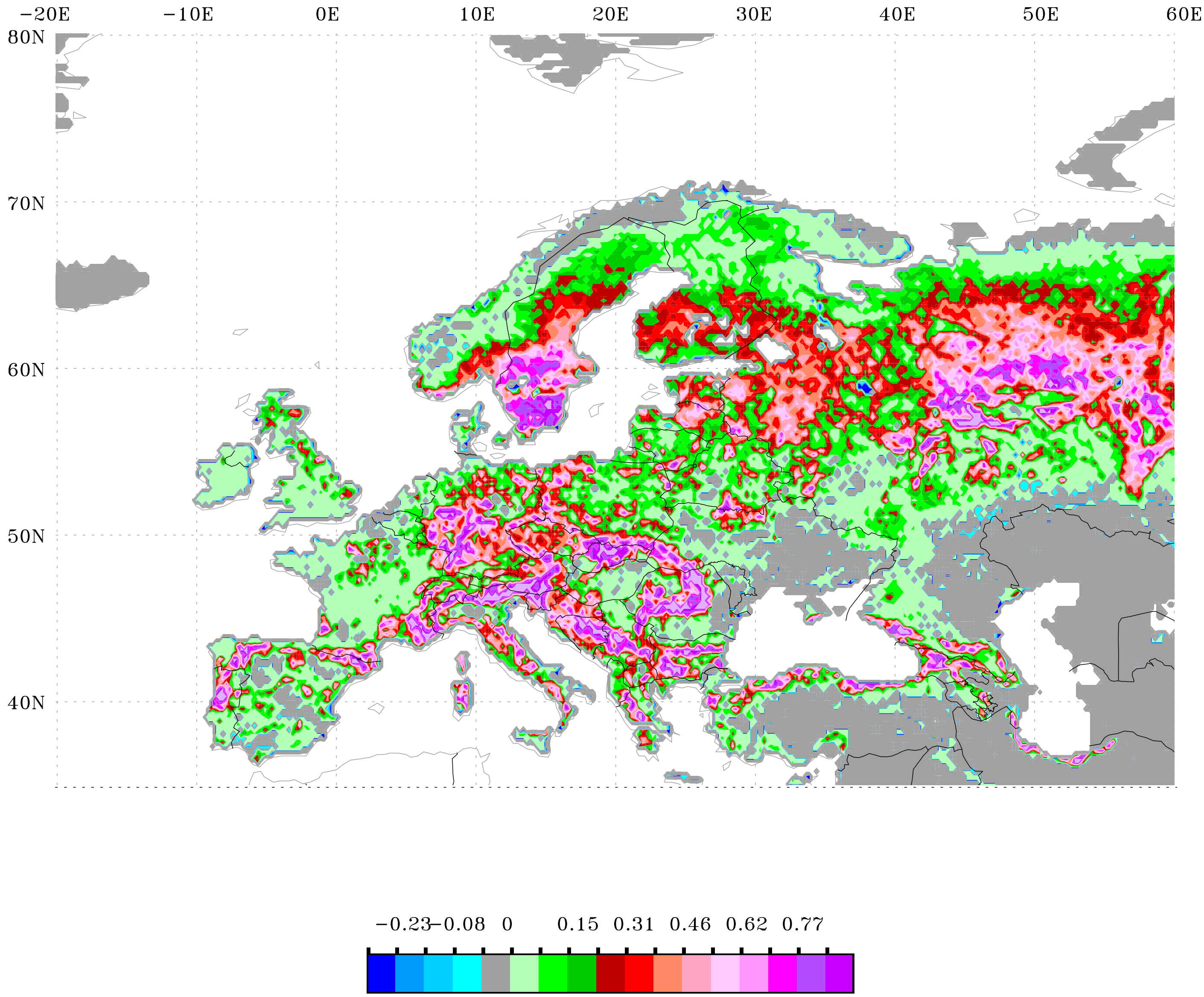


Figure C.3 Russia (Myneni & Dong et al., 2001)



Changes in Carbon Pool (tons C/ha/yr)

Figure C.3 European Countries (Myneni & Dong et al., 2001)

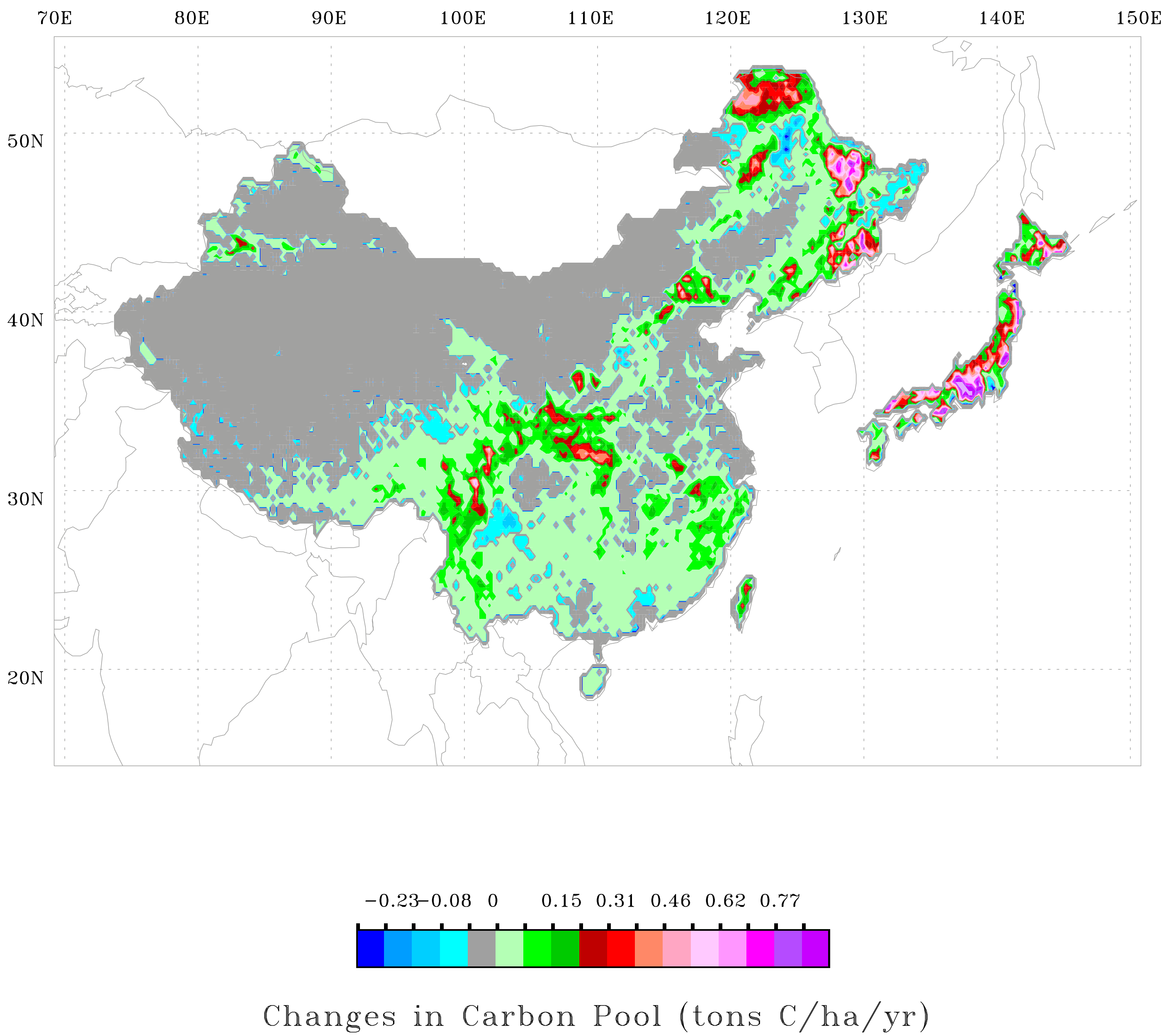


Figure C.3 China & Japan (Myneni & Dong et al., 2001)

D.1. List of provinces, states and countries in Fig. 3*a*

The following provincial (Canada), state (USA) and national data were used in Fig. 3*a*.

CANADA (11 provinces, 2)

Alberta, Manitoba, New Brunswick, Newfoundland, Northwest Territories, Nova Scotia, Ontario, Quebec, Saskatchewan, Yukon Territory.
Not included: British Columbia

USA (46 states, 3)

Alabama, Alaska, Arizona, Arkansas, Colorado, Connecticut, D. Columbia, Delaware, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, West Virginia, Wisconsin, Wyoming.
Not included: California, Hawaii, Oregon, Washington

EURASIAN COUNTRIES from TBFRA-2000 (37 countries, 4)

Albania, Armenia, Austria, Azerbaijan, Belgium, Bosnia, Bulgaria, Byelarus, Croatia, Czech, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Ireland, Italy, Japan, Kazakhstan, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom.
Countries not included:
(1) Russia and China are given in Table 1
(2) Kyrgyzstan, Macedonia and Uzbekistan: Sink data not given in TBFRA-2000
(3) Cyprus, Iceland, Israel, Luxemburg, Moldova, Turkmenistan, and Uzbekistan: Forest area less than 0.1 million ha

USA (10)

Arkansas (1988, 1995), Florida (1987, 1995), Georgia (1989, 1997), Mississippi (1987, 1994), North Carolina (1984, 1990), South Carolina (1986, 1993), Texas (1986, 1992), Virginia (1986, 1992), Wisconsin (1983, 1996).

http://srsfia.usfs.msstate.edu/ewman.htm

D.2. List of provinces, states and countries in Fig. 3*b*

The following provincial (Sweden), state (USA) and national data were used in Fig. 3*b*.

USA (9)

Arkansas (1988, 1995), Florida (1987, 1995), Georgia (1989, 1997), Mississippi (1987, 1994), North Carolina (1984, 1990), Texas (1986, 1992), Virginia (1986, 1992), Wisconsin (1983, 1996).
South Carolina not included because of shows decrease in biomass.

http://srsfia.usfs.msstate.edu/ewman.htm

EURASIAN COUNTRIES From TBFRA-2000 (37 countries, 4)

Albania, Armenia, Austria, Azerbaijan, Belgium, Bosnia, Bulgaria, Byelarus, Croatia, Czech, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Ireland, Italy, Japan, Kazakhstan, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom.
Countries not included:

(1) Russia and China are given in Table 1
(2) Kyrgyzstan, Macedonia and Uzbekistan: Sink data not given in TBFRA-2000
(3) Cyprus, Iceland, Israel, Luxemburg, Moldova, Turkmenistan, and Uzbekistan: Forest area less than 0.1 million ha

http://www.unece.org/trade/timber/fra/welcome.htm.

SWEDEN (22 provinces, 5, 6)

Älvsborg, Blekinge, Gävleborg, Göteborg, Gotland, Halland, Jämtland, Jönköping, Kalmar, Kronoberg, Norrbotten, Örebro, Östergötland, Skän, Skaraborg, Södermanland, Stockholm, Uppsala, Värmland, Västerbotten, Västernorrland, Västmanland.
Not included: Kopparberg because of data quality issues

D.3. Analysis of bias in remote sensing estimates

If the estimates for biomass generated by the remote sensing/statistical methodology are unbiased relative to those generated from inventory data, the data in Fig. 3 will lie along the 45^o line. By definition, this 45^o line has an intercept of zero and a slope of 1. To test this hypothesis, we estimate the following equation:

$$\text{Inventory} = \alpha + \beta \text{ Remote Sensing} + \mu \qquad \textbf{[1]}$$

in which Inventory is the forest inventory biomass estimate from forest inventories in Fig. 3, Remote sensing is the remote sensing/statistical methodology biomass estimate generated in Fig. 3, α and β, are regression coefficients, and μ is a normally distributed random error term.

To test the null hypothesis that the intercept (α) is equal to zero, we use a *t* statistic. This test statistic will reject the null hypothesis if its value exceeds the value associated with the $P < 0.05$ threshold. Failing to exceed this threshold would indicate that the intercept is not statistically different than zero. To test the null hypothesis that β equals 1.0, we use an *F* test. This test statistic will reject the null hypothesis if imposing a value of 1 on β causes the residual sum of squares for Eq. **1** to increase in a statistically significant fashion relative to the version of Eq. **1** in which β is allowed to assume the value that minimizes the residual sum of squares for Eq. **1**. Failing to exceed this threshold would indicate that β is not statistically different from one. Lastly, both of these hypotheses ($\alpha = 0$, $\beta = 1$) can be tested jointly with an *F* statistic. This test statistic will reject this null hypothesis if imposing the restrictions on α and β cause the residual sum of squares for Eq. **1** to increase in a statistically significant fashion relative to the version of Eq. **1** in which α and β is allowed to assume the value that minimizes the residual sum of squares for Eq. **1**.

Failing to exceed this threshold would indicate that α is not statistically different zero and β is not statistically different from 1.0.

Results indicate that we fail to reject any of these hypotheses. The intercept of a line fit to data in Fig. 3*a* is not statistically different from zero (t = 0.83, P < 0.42). Similarly, the slope of the line is not statistically different from 1.0 [$F(1,112) = 0.40$; P < 0.53]. Finally, we cannot reject the null hypothesis ($\alpha = 0$, $\beta = 1$) for the data in Fig. 3*a* [$F(2,112) = 0.35$; P < 0.71]. Similar results are obtained for the data in Fig. 3*b*. The intercept of a line fit to data in Fig. 3*b* is not statistically different from zero (t = 0.05; P < 0.97). Similarly, the slope of the line is not statistically different from 1.0 [$F(1,66) = 1.28$; P < 0.27]. Finally, we cannot reject the null hypothesis ($\alpha = 0$, $\beta = 1$) for the data in Fig. 3*a* [$F(2,66) = 1.07$; P < 0.35]. Together, these results indicate that the biomass estimates generated by the remote sensing/statistical methodology are unbiased relative to the biomass estimates generated from inventory data.

E.1. Country-wise estimates of the carbon pool and sink in the woody biomass of temperate and boreal forests

Country	Carbon pool, Mt C	Carbon sink, Mt C/yr	Forest area, Mha
Albania	28.274	0.558	0.532
Armenia	14.386	0.426	0.328
Austria	263.196	4.039	4.359
Azerbaijan	43.706	1.287	0.841
Belgium	34.708	0.226	0.471
Bosnia	178.236	3.297	2.516
Bulgaria	160.584	4.095	2.531
Byelarus	171.241	3.339	3.366
Canada	10560	73.123	239.500
China	3675.311	38.62	142.600
Croatia	127.828	1.982	1.787
Czech	154.151	3.245	2.971
Denmark	6.29	0.133	0.106
Estonia	109.006	1.234	2.294
Finland	601.369	5.558	17.243
France	1136.249	8.518	15.666
Georgia	142.365	3.234	2.384
Germany	622.256	12.262	9.354
Greece	111.421	2.72	1.981
Hungary	47.017	1.02	0.746
Italy	585.941	10.835	8.489
Japan	897.967	11.915	18.965
Kazakhstan	117.732	2.025	3.087
Kyrgyzstan	16.658	0.385	0.658
Latvia	176.342	2.406	3.543
Lithuania	87.933	1.235	1.819
Macedonia	41.205	0.837	0.640
Netherlands	10.847	0.16	0.157
Norway	259.108	2.782	6.958
Poland	322.26	6.946	6.361
Portugal	122.716	2.57	2.032
Romania	355.547	7.926	5.378
Russia	24393.805	283.589	642.221
Slovakia	138.065	3.427	2.077
Slovenia	89.37	1.668	1.219
Spain	588.747	7.344	10.424
Sweden	1054.516	13.859	26.455
Switzerland	107.971	1.247	1.734
Turkey	296.043	6.91	5.454
Turkmenistan	0.18	0.004	0.016
United Kingdom	204.827	4.353	1.864
Ukraine	132.258	1.325	3.702
United States	12480	141.528	215.500
Uzbekistan	0.289	0.001	0.030

E.2. Remote sensing and inventory estimates of the carbon pool and sink in above-stump woody biomass of temperate and boreal forests in Eurasia and North America

The above-stump biomass sink (0.64 Gt C/yr) is nearly identical to the total biomass sink (0.68 Gt C/yr). This is not surprising, and is to be expected, because these numbers are obtained from regression relations which are essentially black box representations. That is, they translate the observed changes in growing season NDVI totals to the dependent variables.

Country	Carbon pool, Gt C	Carbon Sink, Gt C/yr	Forest area, Mha
Canada	8.71	0.07079	239.5
USA	10.61	0.13435	215.5
North America	19.32	0.20514	455.0
China	2.86	0.03265	142.6
Finland	0.48	0.00493	17.2
Japan	0.74	0.01116	19.0
Norway	0.21	0.00251	7.0
Russia	19.68	0.26082	642.2
Sweden	0.86	0.01251	26.5
Other†	5.81	0.10706	117.4
Eurasia	30.63	0.43202	964.9
Total	49.95	0.63716	1419.9

† Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, France, Georgia, Germany, Greece, Hungary, Italy, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland, Tajikistan, Turkey, Turkmenistan, United Kingdom, Ukraine, Uzbekistan.

F.1. Comparison of estimates for Canada, Russia, and the United States

The three large countries, Canada, Russia, and the United States, account for 78% of the pool, 73% of the sink, and 77% of the forest area. Therefore, it is instructive to compare remote sensing estimates for these three countries with others estimates. But care is required in making these comparisons, in view of differences in definitions of forest areas, time periods for which the estimates are valid, and large uncertainties associated with all estimates. TBFRA-2000 below refers to Temperate and Boreal Forest Resources Assessment 2000 from the Food and Agriculture Organization. These estimates are generally for early to mid-1990s. Forest area is quoted below in Mha.

United States

Our sink estimate for the United States (0.142 Gt C/yr) is comparable to the TBFRA-2000 estimate (0.166 Gt C/yr). It is greater than estimates for the 1980s, from both inventory [0.063 Gt C/yr by Turner et al. (9), and 0.098 Gt C/yr by Birdsey and Heath (10)] and land-use change studies [0.02 Gt C/yr by Houghton et al. (11)].

Our pool (12.5 Gt C) and forest area (215 Mha) estimates for the late 1990s are comparable to the TBFRA-2000 estimates (13.85 Gt C for the pool and 217 Mha for forest area).

Canada

The Canadian forests were reported to be subject to disturbances since the 1970s from fires and insect damage (12), which is consistent with carbon losses seen in Fig. 2*a*. Our sink estimate, 0.073 Gt C/yr, is of comparable magnitude to both the TBFRA-2000 estimate (0.093 Gt C/yr) and the Canadian Forest Service estimate (13) (about 0.085 Gt C/yr for the 1981-1991). Our estimate is slightly higher than that inferred by Chen et al. (14) for the total terrestrial sink in Canada (0.053 Gt C/yr) for the 1980-1996.

Our pool (10.6 Gt C) and forest area (239 Mha) estimates for the late 1990s are also comparable to the TBFRA-2000 estimates (11.9 Gt C and 244 Mha).

Russia

The remote sensing estimate of Russian forest area, 642 Mha, is lower than estimates by TBFRA-2000 (816 Mha), Alexeyev and Birdsey (771 Mha) and Nilsson et al. (764 Mha). These differences are possibly due to definitions.

Forest and other wooded land in the Food and Agriculture Organization statistics is equal to what is called in Russia "forest land" which consists of "forested area" and "unforested area" in Russian classification. Forested area is area that meets Russian stocking density requirement. Unforested area is area on which stocking density is temporarily below that requirement. In 1993, forest land was 887 Mha, forested area 764 Mha and unforested area 123 Mha.

Estimates by Alexeyev and Birdsey (1) and Nilsson et al. (15) possibly covered forested area only, which is not comparable to remote sensing definition of forests. These Fig.s fluctuate time from time. For example, the area of stocked stands (forested area) was estimated as 771.2 Mha in 1988, in 1993 as 763.5 Mha, and in 1998 as 769.8 Mha.

The remote sensing estimate of 642 Mha is possibly due to the coarse resolution of satellite data (8x8 km). It may be unsuitable for detecting tree stands in forest-tundra of Russia, where small lots of sparse, open larch stands with extremely low growing stock (30-50 m3/ha) are distributed between the vast peatlands. In addition, Russia has about 35 Mha of dwarf shrub communities (Betula nana and others) which are counted as forests in inventory studies. The total area of plain and mountain forest-tundra forests is about 108 Mha, which is possibly not detected as forest land cover in remote sensing data (recent unpublished analysis of V. A.). There is an additional 20-30 Mha difference between remote sensing and inventory estimates.

It is not clear why the TBFRA-2000 estimate for forest area (816 Mha) is different than the remote sensing estimate, considering that the two agree well for Canada, United States, and other countries.

When expressed on a per-ha forest area basis, the various pool estimates are comparable (38-43 ton C/ha). The difference in sink estimates between remote sensing and TBFRA-2000 is smaller (0.44 vs. 0.53; in ton C/ha per year).

Nilsson et al.'s (15) estimate for the biomass sink, 0.058 Gt C/yr, is lower than our (0.284 Gt C/yr) and TBFRA-2000 estimates (0.423 Gt C/yr). They did not derive the sink estimate from stem wood volume data because the increment quoted by them (816 Mm^3/year) on 760 Mha of forested area in 1990 is comparable to TBFRA-2000 estimate of 1134 Mm^3/year on 886 Mha of forest and other wooded land area about the same period. If they did, the three sink estimates would be comparable on a per-unit forest area basis. Alexeyev and Birdsey (1) did not provide a sink estimate.

References

1. Alexeyev, V. & A. Birdsey, R. A. (1998) *Carbon storage in forests and peatlands of Russia* (U.S. Department of Agriculture Forest Service, Northeastern Research Station, Radnor, Pennsylvania), General Technical Report, NE-244.
2. Penner, M., Power, K., Muhairwe, C., Tellier, R. & Wang, Y. (1997) *Canada's forest biomass resources: Deriving estimates from Canada forest inventory* (Pacific Forestry Centre, Victoria, B.C., Canada), Information Report BC-X-370.
3. Powell, D. S., Faulkner, J. L., Darr, D. R., Shu, Z. & MacCleery, D. W. (1993) *Forest statistics of the United States* (U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado), Gen. Tech. Rep. RM-GTR-234, 132 p.
4. Liski, J. & Kauppi, P. (2000) in *Forest Resources of Europe, CIS, North America, Australia, Japan and New Zealand (industrialized temperate/boreal countries), United Nations-Economic Commission for Europe/Food and Agriculture Organization Contributions to the Global Forest Resources Assessment 2000* (United Nations, New York), pp. 155-171.
5. Statistical Yearbook of Forestry 1988 (1988) *Official Statisticas of Sweden National Board of Forestry* (Jönköping, Sweden) ISBN 91-85748-71-4.
6. Statistical Yearbook of Forestry 1999 (1999) *Official Statisticas of Sweden National Board of Forestry* (Jönköping, Sweden) ISBN 91-88462-40-4.
7. Hansen, M. C., DeFries, R. S., Townshend, J. R. G. & Sohlberg, R. (2000) *Int. J. Remote Sens.* **21**, 1331-1364.
8. Hsiao, C. (1986) *Analysis of Panel Data*, Cambridge, Cambridge University Press.
9. Turner, D. P., Koerper, G. J., Harmon, M. E. & Lee, J. J. (1995) *Ecological Applications* **5**, 421-436.
10. Birdsey, R. A. & Heath, L. S. (1995) in *Productivity of America's Forest and Climatic Chan*ge, Ed. Joyce, L. A. (U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado), General Technical Report RM-GTR 271, 56-70.
11. Houghton, R. A., Hackler, J. L. & Lawrence, K. T. (1999) *Science* **285**, 574-578.
12. Kurz, W. A. & Apps, M. J. (1999) *Ecological Applications* **9**, 526-547.
13. Canadian Forest Service (1993) *The State of Canada's Forests 1993, Nat. Resour.* (Ottawa, Ontario, Canada).
14. Chen, J., Chen, W., Liu, J. & Cihlar, J. (2000) *Global Biogeochem. Cycles* **14**, 839-849.
15. Nilsson, S., Shivdenko, A., Stolbovoi, V., Gluck, M., Jonas, M. Obersteiner, M. (2000) *Full carbon account for Russia* (International Institute for Applied Systems Analysis, Laxenburg, Austria), Interim Report IR-00-021.