References

Arino, O., Bicheron, P., Achard, F., Latham, J., Witt, R. & Weber, J.L. 2008. The most detailed portrait of Earth. *ESA Bulletin* (European Space Agency), 136: 24–31.

Asner, G. P. 2001. Cloud cover in Landsat observations of the Brazilian Amazon. *Environmental Studies*, *22*(18), 3855–3862. DOI:10.1080/01431160010006926.

Avissar, R. & Werth, D. 2005. Global hydroclimatological teleconnections resulting from tropical deforestation. *J. Hydrometeorology*, 6(2): 134–145. DOI: 10.1175/JHM406.1.

Baatz, M. & Schappe, A. 2000. Multiresolution segmentation: an optimization approach for high quality multi-scale image segmentation. *In* J. Strobl, T. Blaschke & G. Griesebner, eds. *Angewandte geographische informations-verarbeitung XII*. Karlsruhe, Germany, Wichmann Verlag. pp. 12– 23.

Bartolev, S. 2012. Unpublished data on accuracy of FRA RSS land cover classification compared to high spatial resolution satellite imagery.

Beuchle, R., Eva, H.D., Stibig, H.-J., Bodart, C., Brink, A., Mayaux, P., Johansson, D., Achard, F. & Belward, A. 2011. A satellite data set for tropical forest change assessment, *Int. J. Remote Sens.* DOI: 10.1080/01431161.2011.611186.

Bodart, C., Eva, H.D., Beuchle, R., Raši, R., Simonetti, D., Stibig, H.-J., Brink, A., Lindquist, E. & Achard, F. 2011. Pre-processing of a sample of multi-scene and multi-date Landsat imagery used to monitor forest cover changes over the tropics. *ISPRS J. Photogram. Remote Sens.* 66: 555–563.

Broich, M., Hansen, M.C., Potapov, P., Adusei, B., Lindquist, E. & Stehman, S.V. 2011. Time-series analysis of multi-resolution optical imagery for quantifying forest cover loss in Sumatra and Kalimantan, Indonesia. *Int. J. Appl. Earth Obs. and Geoinformation*, 13(2): 277–291. DOI: 10.1016/j.jag.2010.11.004.

Broich, M., Stehman, S.V., Hansen, M.C., Potapov, P. & Shimabukuro, Y.E. 2009. A comparison of sampling designs for estimating deforestation from Landsat imagery: a case study of the Brazilian Legal Amazon. *Remote Sens. Environment*, 113(11): 2448–2454. DOI: 10.1016/j.rse.2009.07.011.

Carroll, M.L., Townshend, J.R., DiMiceli, C.M., Noojipady, P. & Sohlberg, R. 2009. A new global raster water mask at 250 m resolution. *Int. J. Digital Earth*, 2(4): 291–308. DOI: 10.1080/17538940902951401.

Czaplewski, R. 2002. *FRA 2000: On sampling for estimating global tropical deforestation*. Forest Resources Assessment Programme, Working Paper 60, Rome, FAO.

Desclée, B., Bogaert, P., Defourny, P. 2006. Forest change detection by statistical object-based method. *Remote Sens. Environment*, 102: 1–11.

Duveiller, G., Defourny, P., Desclée, B. & Mayaux, P. 2008. Deforestation in Central Africa – estimates at regional national and landscape levels by advanced processing of systematically distributed Landsat extracts. *Remote Sens. Environment,* 112: 1969–1981.

Eva H., Carboni S., Achard F., Stach N., Durieux L., Faure J-F. & Mollicone D. 2010. Monitoring forest areas from continental to territorial levels using a sample of medium spatial resolution satellite imagery. *ISPRS J. Photogram. Remote Sens.*, 65: 191–197.

FAO. 2001. *Global forest resources assessment 2000*, Main report, FAO Forestry Paper 140. Rome.

FAO. 2010. *Global forest resources assessment 2010*, Main report, FAO Forestry Paper 163. Rome.

FAO. 2012. Global ecological zones for FAO forest reporting: 2010 Update. FRA working paper 179. Rome.

Feddema, J.J., Oleson, K.W., Bonan, G.B., Mearns, L.O., Buja, L.E., Meehl, G.A. & Washington, W.M. 2005. The importance of land-cover change in simulating future climates. *Science*, 310(5754): 1674-8. DOI: 10.1126/science.1118160.

Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M., Holmgren, P., Ramankutty, N. & Foley J.A. 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proc. Nat. Acad. Sci. USA*, 107: 16732–16737.

Gillis, M.D., Omule, A.Y. & Brierley, T. 2005. Monitoring Canada's forests: the national forest inventory. *Forestry*, 81.

Gutman, G., Byrnes, R., Masek, J., Covington, S., Justice, C., Franks, S. & Kurtz, R. 2008. Towards monitoring land cover and land use changes at a global scale: the global land survey 2005. *Photogram. Eng. and Remote Sens.*, 74: 6–10.

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., Carroll, M., Dimiceli, C. & Sohlberg, R.A. 2003. Global percent tree cover at a spatial resolution of 500 meters: first results of the MODIS Vegetation Continuous Fields algorithm. *Earth Interactions*, *7*(10).

Hansen, M.C., Roy, D., Lindquist, E., Adusei, B., Justice, C. & Altstatt, A. 2008. A method for integrating MODIS and Landsat data for systematic monitoring of forest cover and change in the Congo Basin. *Remote Sens. of Environment*, 112: 2495–2513.

Hoffhine, E. & Sader, S.A. 2002. Detection of forest harvest type using multiple dates of Landsat TM imagery. *Remote Sens. Env.*, 80, 385–396.

Homer, C., Huang, C., Yang, L., Wylie, B. & Coan, M. 2004. Development of a 2001 national land-cover database for the United States. *Photogram. Eng. and Remote Sens.*, 70(7): 829–840.

Horler, D.N.H., & Ahern, F.J. 1986. Forestry information content of Thematic Mapper data. *Int. J. Remote Sens.*, 7(3): 405–428. DOI: 10.1080/01431168608954695.

JRC. 2010. P. Kennedy, ed., *Science for the environment*, Luxembourg, Joint Research Centre (available at http://ies.jrc.ec.europa.eu/).

Ju, J. & Roy D.P. 2008. The availability of cloud-free Landsat ETM+ data over the conterminous United States and globally. *Remote Sens. Env.*, 112(3): 1196–1211. DOI: 10.1016/j.rse.2007.08.011.

Kuemmerle, T., Olofsson, P., Chaskovskyy, O., Baumann, M., Ostapowicz, K., Woodcock, C.E., Houghton, R.A., Hostert, P., Keeton, W.S. & Radeloff, V.C. 2011. Post-Soviet farmland abandonment, forest recovery, and carbon sequestration in western Ukraine. *Global Change Biology*, *17*(3), 1335–1349. DOI: 10.1111/j.1365-2486.2010.02333.x.

Kurz, W.A. 2010. An ecosystem context for global gross forest cover loss estimates. *Proc. Nat. Acad. Sc. USA*, 107(20): 9025–6. DOI:10.1073/pnas.1004508107.

Lambin, E., Turner, B., Geist, H., Agbola, S., Angelsen, A., Bruce, J., Coomes, O., Dirzo, R., Fischer, G. & Folke, C. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Env. Change*, 11(4): 261–269. DOI: 10.1016/S0959-3780(01)00007-3.

Lambin, E. F., & Meyfroidt, P. 2011. Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(9), 3465–72. DOI: 10.1073/pnas.1100480108.

Lindquist, E.J., D'Annunzio, R., MacDicken, K., Hansen, M.C., Bodart, C., Raši, R., Achard, F. & Gerrand, A. Submitted. Object-based land cover and land use classification for a global systematic sample of Landsat from 1990–2000–2005: the FAO methods for the FRA-2010 Remote Sensing Survey. Submitted to IEEE JSTARS, 2012.

Liu, M., & Tian, H. 2010. China's land cover and land use change from 1700 to 2005: Estimations from high-resolution satellite data and historical archives. *Global Biogeochemical Cycles*, *24*(3). DOI:10.1029/2009GB003687.

Matthews, E. 2001. *Understanding the FRA 2000*, World Resources Institute Forest Briefing No. 1 (available at http://pdf.wri.org/fra2000.pdf).

Mayaux P., Holmgren, P., Achard, F., Eva, H.D., Stibig, H.-J. & Branthomme, A. 2005. Tropical forest cover change in the 1990's and options for future monitoring. *Phil. Trans. B*, 360: 373–384.

Pan Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S.W., McGuire, D., Piao, S., Rautiainen, A., Sitch, S. & Hayes, D. 2011. Large and persistent carbon sink in the world's forests. *Science*, 333: 988–993.

Paustian, K., Ravindranath, N.H. & van Amstel, A. 2006. Forest land. *In* H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara & K. Tanabe, eds. *IPCC guidelines for national greenhouse gas inventories*, Volume 4. Hayama, Japan, Institute for Global Environmental Strategies (also available at www.ipcc-nggip.iges.or.jp).

Picquelle, S.J. & Mier, K.L. 2011. A practical guide to statistical methods for comparing means from two-stage sampling. *Fisheries Research* 107(1–3): 1–13. DOI: 10.1016/j.fishres.2010.09.009.

Potapov, P., Hansen, M., Stehman, S., Loveland, T., & Pittman, K. 2008. Combining MODIS and Landsat imagery to estimate and map boreal forest cover loss. *Remote Sens. Env.*, 112(9): 3708–3719. DOI:10.1016/j.rse.2008.05.006.

Potapov, P., Hansen, M.C., Gerrand, A.M., Lindquist, E.J., Pittman, K., Turubanova, S. & Loyche-Wilkie, M. 2010. The global Landsat imagery database for the FAO FRA remote sensing survey. *Int. J. Digital Earth*, 4(1): 2–21.

Potapov, P., Turubanova, S., & Hansen, M.C. 2011. Regional-scale boreal forest cover and change mapping using Landsat data composites for European Russia. *Remote Sens. Env.*, 115(2): 548–561. Doi: 10.1016/j.rse.2010.10.001.

Raši, R., Bodart, C., Stibig, H.-J., Eva, H.D., Beuchle, R., Carboni, S., Simonetti, D. & Achard, F. 2011. An automated approach for segmenting and classifying a large sample of multi-date Landsat-type imagery for pan-tropical forest monitoring, *Remote Sens. Env.*, 115 (12):3659–3669. DOI: 10.1016/j.rse.2011.09.004.

Ridder, R. 2007. *Global Forest Resources Assessment 2010: options and recommendations for a global remote sensing survey of forests*. Forest Resources Assessment Programme, Working Paper 141, Rome, FAO, ftp://ftp.fao.org/docrep/fao/010/ai074e/ai074e00.pdf.

Seebach, L., Strobl, P., Vogt, P., San-Miguel-Ayanz, J., Kempeneers, P., Sedano, F. & Gerrand, A. 2010. *Pilot study in Europe for the Global Forest Remote Sensing Survey,* JRC Technical Reports, EUR 24488 EN. Luxembourg, Publications Office of the European Union(also available at http://forest.jrc.ec.europa.eu/publications).

Simonetti, D., Beuchle, R. & Eva, H.D. 2011. *User manual for the JRC land cover/use change validation tool*, p 21. Joint Research Centre, Institute for Environment and Sustainability, Luxembourg, Publications Office of the European Union. DOI: 10.2788/18205.

Stehman, S.V., Sohl, T.L., & Loveland, T.R. 2005. An evaluation of sampling strategies to improve precision of estimates of gross change in land use and land cover. *Int. J. Remote Sens.*, 26: 4941–4957.

Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D., Hirsch, K.G., Logan, K.A., Martell, D.L. & Skinner, W.R. 2002. Large forest fires in Canada, 1959–1997. *J. Geophys. Res.* 108(D1): 5/1–5/12. Doi: 10.1029/2001JD000484.

Toivonen, T., Kalliola, R., Ruokolainen, K., & Naseem Malik, R. 2006. Across-path DN gradient in Landsat TM imagery of Amazonian forests: a challenge for image interpretation and mosaicking. *Remote Sens. Environment*, 100(4): 550–562. DOI: 10.1016/j.rse.2005.11.006.

Vogelmann, J., Howard, S., Limin, Y., Larson, C., Wylie, B., & Van Driel, N. 2001. Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogram. *Eng. & Remote Sens*., 650–662.

Williams, D.L., Goward, S., & Arvidson, T. 2006. Landsat: yesterday, today, and tomorrow. *Photogram. Eng. & Remote Sens*., 72(10): 1171–1178.

Woodcock, C.E., Allen, R., Anderson, M., Belward, A., Bindshadler, R., Cohen, W., Gao, F., Goward, S.N., Helder, D.L., Helmer, E.H., Nemani, R., Oreopoulos, L., Schott,

J.R., Thenkabail, P.S., Vermote, E.F., Vogelmann, J.E., Wulder, M.A., and Wynne, R. 2008. Free access to Landsat imagery. *Science*, 320(May).

Wulder, M.A., Dechka, J.A., Gillis, M.D., Luther, J.E., Hall, R.J., Beaudoin, A. & Franklin, S.E. 2006. Operational mapping of the land cover of the forested area of Canada with Landsat data: EOSD land cover program. *The Forestry Chronicle*, 79(6): 1075–1083.

Annex 1

Country-specific review-and-revision methodologies

Every effort has been made to produce consistent results at a global scale. Some countries, however, used unique methods to review and revise land-cover and land-use classifications. Those methods are described here.

CANADA

Data for Canada were derived using the classification methodology described in the main body of this report but applied across the Canadian National Forest Inventory (NFI) photo-plot grid system (Gillis, Omule and Brierley, 2005). The NFI uses 2 km × 2 km plots with 20 km horizontal and vertical spacing (i.e. a 20 km systematic grid), producing more than 18 000 individual plots. For the purposes of RSS 2010, a 25 percent sample of the plots (i.e. every fourth plot) was selected for initial analysis (Figure 1). In total, 4 052 2 km × 2 km plots were analysed across Canada.

At each plot location, level-1 segments from imagery captured in 2000 were directly assigned land-cover labels based on the Canadian Earth Observation for Sustainable Development of Forests (EOSD) dataset (Wulder *et al.*, 2006). The EOSD dataset is a 25 m spatial resolution, Landsat-based, 23-class land-cover classification for the forested areas of Canada. The 23 EOSD classes were aggregated into the simple 5-class legend, and level-1 segments for 2000 were assigned a value based on the majority land cover of the underlying EOSD data. The full methodology, as described in the main body of this report, was used where no EOSD data existed (i.e. in largely non-forested portions of Canada) and to classify 1990 and 2005 segments.

The initial conversion of land cover to land use was completed following the survey conversion rules, as described in the main body of this report. Next, a series of automated re-coding procedures was implemented in the review-and-revision phase of land-use validation. These procedures involved re-coding polygons to forest land use in cases where commercial timber harvest activity was indicated from NFI photo-plot data, where a forest fire occurred during the period of analysis (as indicated in the Canadian National Fire Database; Stocks *et al.*, 2002), or where no known deforestation (on the basis of NFI land-use and deforestation information) had occurred. Remaining sites were examined by image interpreters to ensure the accuracy of the final land-use classification.

Parameter estimates were calculated separately for Canada and integrated into analyses of FRA regions and FAO climatic domains.

RUSSIAN FEDERATION

The Russian Federation used a stratified sample of 300 RSS sample sites to estimate forest area and forest area change for the three survey periods. A total of 1 961 complete RSS sample sites were contained within the Russian Federation. Landsat data were available for 1 219 of these for all three time periods; this incomplete coverage is due to the lack of satellite data acquisitions for the eastern part of the Russian Federation in 1990. Although all 1 961 sample sites were processed to the extent possible using the methods described in the main body of this report, expert review and revision of all sample sites in the Russian Federation was not possible in the timeframe of the study.

Cloud-free, seasonal 250 m spatial resolution data from MODIS were used, along with vegetation change indices, to create 23 strata according to percentage forest cover and amount of indicated change in forest cover. A probability-based selection process was implemented to select

the final plots for review and revision based on a minimum separating distance (i.e. plots were preferred to be further apart within any single stratum) and minimum number (ten) per stratum. A total of 282 RSS sites were expertly interpreted for land-cover and land-use classification.

The parameter estimates and statistical variance of the stratified sample were incorporated with those of the systematic sample for Europe and used in analyses of the boreal climatic domain.

UNITED STATES OF AMERICA

RSS results for the United States of America were derived from the National Land Cover Dataset (NLCD) (Vogelmann *et al.*, 2001; Homer *et al.*, 2004). The NLCD is a 21-class land-cover product for the conterminous United States based on Landsat satellite data. The 21 classes were reduced to the five simple land-cover classes required for RSS 2010. Level-2 segments for 1990, 2000 and 2005 were assigned land-cover labels directly from the NLCD dataset for each survey period. Land-cover labels were adjusted to land use using the automated conversion rules described in the main body of this report. A probability-based sample of sites, by FAO climatic domain, was selected for review and revision for continental United States and Alaska. At each review-and-revision site, the accuracy of the land-use call was evaluated against the NLCD and high-resolution aerial photography. The results of the accuracy assessment were used to adjust the overall area of land-use category for the United States in its entirety and for each FAO climatic domain.

Annex 2

Survey sites processed vs analysed

The table below lists, by region or country-specific grouping, the number of sample sites processed (grand total), analysed and not analysed. The main reason that survey sites were not analysed was missing data in one or more time periods due to cloud cover, a lack of satellite image acquisitions, or other data anomalies.

Region/country	Analysed	Not analysed	Grand total
Africa	2 322	196	2 518
Asia	2 863	184	3 047
Canada	3 737	315	4 052
Europe	625	55	680
Oceania	769	29	798
Russian Federation	282	1 679	1 961
South America	1 372	129	1 501
North & Central America	1 096	126	1 222
Grand Total	**13 066**	**2 713**	**15 779**

Annex 3

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Summary of national and regional review-and-revision workshops

Area of interest	Location	Date	No. countries	No. experts	Female	Male
Brazil	São José dos Campos	September 2009	1	2	0	2
Central Africa	Brazzaville	February 2010	8	16	1	15
North America	Salt Lake City	March 2010	3	3	1	2
South Africa	Cape Town	March 2010	8	16	3	13
West Europe	Rome	March 2010	14	14	3	11
Central America	Panama City	July 2010	7	12	5	7
Southeast Asia	Bangkok	August 2010	14	23	5	18
East Asia	Beijing	September 2010	3	16	3	13
South America	Valdivia	November 2010	7	14	2	12
France	Nogent	November 2010	1	1	0	1
East Africa	Nairobi	December 2010	6	11	1	10
West Africa	Dakar	March 2011	13	18	1	17
New Zealand	Rome	March 2011	1	1	0	1
Australia	Canberra	April 2011	1	2	1	1
East Europe	Budapest	May 2011	9	14	1	13
Ireland/Latvia	Teleconference	May 2011	2	2	0	2
Sudan	Khartoum	May 2011	1	18	5	13
Brazil	Campinas	June 2011	1	9	3	6
Italy	Rome	June 2011	1	5	1	4
West Asia, North Africa	Rome	July 2011	5	5	0	5
Russian Federation	Moscow	September 2011	1	2	0	2
Total			**107**	**204**	**36**	**168**

Annex 4

Details of calculation

1. For every sample site, the following variables were extracted from the PostGreSQL database:
   - tile unique ID (*rss_id*)
   - latitude (*lat*) and longitude (*lon*) of the centre of the tile
   - climatic domain (*domain*)
   - region (*continent*)
   - total tile area (*total*)
   - water area (*water*)
   - no data area (*nodata*)
   - forest area in 1990, 2000 and 2005 (*forest90, forest00, forest05*)
   - area of gains and losses of forest in 1990-2000 and 2000-2005 (*gain9000, loss9000, gain0005, loss0005*)
   - Julian date of image acquisition for 1990, 2000, 2005 (*jdate90, jdate00, jdate05*)

2. Then, the following variables were calculated:
   - Area of land within the tile (*gla*)

Eq. 1
$$gla = total - water - nodata$$

   - Latitude correction factor (*corrlat*)

Eq. 2
$$\begin{cases} if\ lat \leq 60° \ then\ corrlat = cos\ (lat) \\ if\ lat > 60° \ then\ corrlat = 2 * cos\ (lat) \end{cases}$$

NB: The number of samples was reduced to include only even degrees of longitude above 60 degrees latitude (Figure 1 shows the thinning of samples at high northern latitudes).

   - Weight of the sample i (w_i)

Eq. 3
$$w_i = \frac{gla_i * corrlat_i}{\Sigma_j gla_j * corrlat_j}$$

   - Proportion of forest in 1990, 2000 and 2005 (*pfor90, pfor00, pfor05*)

Eq. 4
$$\begin{cases} pfor90 = \dfrac{forest90}{gla} \\ pfor00 = \dfrac{forest00}{gla} \\ pfor05 = \dfrac{forest05}{gla} \end{cases}$$

- Annualized proportion of gains, losses and net change for 1990–2000 (*pagain9000*, *paloss9000*, *panet9000*)

Eq. 5

$$\begin{cases} pagain9000 = \dfrac{gain9000}{gla * (jdate00 - jdate90)} \\ paloss9000 = \dfrac{loss9000}{gla * (jdate00 - jdate90)} \\ panet9000 = pagain9000 - paloss9000 \end{cases}$$

NB: *pagain0005*, *paloss0005* and *panet0005* are calculated in the same way

3. For any subset S of samples (e.g. one climatic domain), average value ($\bar{x}$) and standard deviation (std) of *pfor90*, *pfor00*, *pfor05*, *pagain9000*, *paloss9000*, *panet9000*, *pagain0005*, *paloss0005* and *panet0005* were calculated with the survey package of R[3] using the following formula:

Eq. 6

$$\bar{x} = \frac{\Sigma_{i \in S} W_i * x_i}{\Sigma_{i \in S} W_i}$$

Eq. 7

$$std = \sqrt{\frac{\Sigma_{i \in S} W_i * (x_i - \bar{x})^2}{\Sigma_{i \in S} W_i}}$$

4. Final values (e.g. of annual loss in forest area between 1990 and 2000 in a given climatic domain) were obtained by multiplying the average and the standard deviation by the area of the region (A):

Eq. 8

$$loss = \overline{paloss9000} * A \pm 1.96 * \frac{std(paloss9000)}{\sqrt{N}} * A$$

[3] http://cran.fhcrc.org/web/packages/survey/index.html.

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Global forest land-use change 1990–2005

This report presents the key findings on forest land use and land-use change between 1990 and 2005 from FAO's 2010 Global Forest Resources Assessment Remote Sensing Survey. It is the first report of its kind to present systematic estimates of global forest land use and change.

The ambitious goal of the Remote Sensing Survey was to use remote sensing data to obtain globally consistent estimates of forest area and changes in tree cover and forest land use between 1990 and 2005. Overall, it found that there was a net decrease in global forest area between 1990 and 2005, with the highest net loss in South America. While forest area increased over the assessment period in the boreal, temperate and subtropical climatic domains, it decreased by an average of 6.8 million hectares annually in the tropics. The survey estimated the total area of the world's forests in 2005 at 3.8 billion hectares, or 30 percent of the global land area.

This report is the result of many years of planning and three years of detailed work by staff at FAO and the European Commission Joint Research Centre, with inputs from technical experts from more than 100 countries. Many of these contributors now constitute a valuable global network of forest remote sensing and land-use expertise.

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