XIV WORLD FORESTRY CONGRESS, Durban, South Africa, 7-11 September 2015

Evaluation of carbon sequestration service of forests – A Russian case-study

Anatoly Shvidenko[1], *Dmitry Schepaschenko*[1], *Sabine Fuss*[2], *Florian Kraxner*[3], *Michael Obersteiner*[1]

[1]International Institute for Applied Systems Analysis, Laxenburg, A-2361 Austria, shvidenk@iiasa.ac.at
[2]Mercator Research Institute on Global Commons and Climate Change (MCC), 10829 Berlin, fuss@iiasa.ac.at

Abstract

Prerequisites of a system methodology of evaluation of carbon sequestration service of forests (CSS) *inter alia* include: 1) need of assessment of the CSS in biophysical terms, in form of the Full Verified Carbon Account (FCA); 2) an ultimate proxy indicator of the FCA is Net Ecosystem Carbon Budget of forest ecosystems (NECB); 3) need of explicit spatio-temporal distribution of the service (in biophysical and economic terms) and estimation of uncertainties; 4) taken into account that the FCA is a fuzzy (underspecified) system, NECB and its major components are assessed by complimentary use of major methods of carbon accounting (landscape-ecosystem approach; process-based models; eddy covariance; and inverse modelling) with following harmonizing and mutual constraints of the independent estimates. Economic evaluation is provided based on quantitative models of ecosystem services, i.e. ecological production functions, and potential cost under different assumptions. This methodology has been realized for Russian forests for 2007-2009. The NECB was estimated based on an Integrated Land Information System, a multi-layer GIS, where the forest mask was developed at a spatial resolution of 1km by an aggregation of 12 recent remote sensing products, geographically weighted regression and crowdsourcing. Because interactions between ES are different (from synergetic to neutral to competitive to exclusive), economic evaluation of an individual service may not be directly used in integrated assessment of all services within the multipurpose paradigm of forest management. We reconsider the most complete Russian classification of forest ecosystem functions (totally of 75) within 4 classes of ES (provisioning, regulated, cultural, and supporting) and developed a matrix of interactions between CSS and other services that allows to define the range of economic estimates of the CSS under different prices for sequestered carbon and different regimes of forest management.

Keywords: Russian forests, evaluation ecosystem services, natural capital

Introduction, scope and main objectives

Ecosystem services (ES) represent a significant direct and indirect contributions of ecosystems to human well-being and the natural capital, often larger than the contribution of marketed goods andservices (The Heredia Declaration on Payments for Ecosystem Services, Farley and Costanza 2010; Burkhard et al. 2012). Ecological economists provide a difference between ecosystem processes and functions, from one side, and ecosystem services, from another. Ecosystem functions describe biophysical relationships and exist regardless of whether they contribute to human well-being, while ES cannot be defined outside of human well-being (de Groot et al. 2002). Following such a point of view, we consider carbon cycling as a function which together with other numerous functions of forest ecosystems (productivity, soil formation etc.) generate the ecosystem service – carbon sequestration - as a direct impact on composition of greenhouse gases in the atmosphere and eventually – on stability of the Earth System.

Forests play a crucial role in the global carbon budget providing almost all the carbon sink of terrestrial ecosystems (Pan et al. 2011; Le Querry et al. 2014). CSS of forest ecosystems is considered as one of crucial indicators in both Montreal and European systems of criteria and indicators of sustainable forest management. Development of carbon market, increasing general interest of public, stakeholders and policy-makers to biospheric and protective role of forests generate a need for development of methodology of assessment– in a transparent and reliable way – not only how much carbon is held in landscapes today, and how storage and sequestration will change under climate change and different management options (Conte et al., 2011), but which resources the society is ready to spend for maintenance and enhancement of the CSS in a changing world.

The vast extent of Russian forests makes them a phenomenon of global meaning: they comprise almost 800 million hectare (M ha), more than 20% of the global forest area. An interplay of specific features of Russian forests and forest management in the country (large amount of protective and unmanaged forests – forests that are allocated for industrial use comprise only 45% of the total forest area; actual harvest does not exceed one third of the Annual Allowable Cut, a norm of sustainable final felling; wide distribution of disturbances, particularly fire and insects outbreaks; decrease of both governance and protection of forests during the last three decades; unfavourable successions and impoverishment of forests in large territories etc.) provide complicated impact on CSS of the country's forests.

On-going climate change that is already observed in Russia accelerate problems of country's forest management. The trend of warming in Russia is more than two times higher than the global one (0.40 versus 0.17°C/10 years in 1976-2014). While the average amount of precipitation over the country is slowly growing, dryness of climate is increasing in vast south-west regions of the country and Asian part of Russia. Variability of seasonal weather has been dramatically growing. Dry and prolong heat waves become more often and severe. The heat wave of 2010 that affected the central part of European Russia with a summer temperature anomaly of above 3°C over an area of ~200 M ha caused the economic losses above USD10 billion, widespread forest mortality and decreased seasonal NPP about half (Bastos et al. 2014). Dangerous meteorological phenomena demonstrate a stable growth in frequency and severity. During the period of 2000-2012 the average area of wild fire comprised 12 million ha per year, including two third of this area on forest land and half – in closed forests where about 3 M ha burnt forests died annually (Shvidenko, Schepaschenko 2014). The area of wild fire had a positive trend of 0.3 M ha yr^{-1} during the last decade. It is expected that these tendencies will substantially accelerate in future. The most dramatic climatic change over the globe is expected in the forest zone of Russia. Recent climatic forecasts reported that probability of realization of the most critical RCP8.5 scenario, which predicts the global warming by 2100s above 4.0°C, exceeds 0.4. For major part of Russia it means the regional warming from 7 to 11°C that would generate substantial risks of transforming Russian forests in the tipping element (Lenton et al., 2008) that will dramatically increase mortality in forests and their death on vast territories. Overall, it is expected that the carbon sink of Russia's forests will slightly decline during the next 20 years and might switch over to a sink by end of the century ((FAO 2012; DeLuca, Boisvenue 2012).

The main objective of this paper is providing the evaluation of current CSS of Russian forests that includes three items: 1) presenting major components of the carbon budget of Russia's forest ecosystems in biophysical terms in spatially and temporally explicit way; 2) assessing uncertainties of the account; and 3) evaluating CSS in economic terms.

Methodology

The initial stage of valuation of any ecosystem service is presenting this in measured biophysical terms. While different indicators were used for quantification of CSS of forests, e.g., Net Primary Production as important indicator of Ecosystem Potential Index for Canada, or carbon stock change (Good Practice… 2003), the most informative proxy of CSS is Net Ecosystem Carbon Budget (NECB), an indicator which accumulates the eventual impact of ecosystems on concentration of greenhouse gases in the atmosphere and finally – on the Earth system as a whole (Chapin et al. 2005). Conceptually, only a full and verified carbon account (FCA) presents comprehensive information about the interaction of forests with the global carbon cycle. A full C budget of terrestrial ecosystems encompasses all components and processes of ecosystems and should be applied continuously in time (Steffen et al., 1998). Experiences show that the uncertainty of interaction of terrestrial ecosystems with the global carbon cycle are high (Shvidenko et al. 2010) that requires reliable and – to a possible extent - comprehensive estimation of uncertainties at all stages and for all modules of the account. Uncertainty is understood as an aggregation of insufficiencies of studied system output, regardless of whether these insufficiencies result from lack of knowledge, the intricacies of system or other causes (Nilsson et al., 2007).

However, the FCA is an underspecified (fuzzy) system, whose membership function is in essence stochastic. It means that any individually used methods of carbon account is able to assess only uncertainties “within a method”, but not structural uncertainties. The methodology developed by the International Institute for Applied Systems Analysis (IIASA) takes into account the fuzzy character of the FCA (Shvidenko et al. 2010). It is based on system integration of major methods used for understanding carbon cycling of forest ecosystems (landscape-ecosystem method; direct measurements of carbon exchange with the atmosphere mostly by eddy-covariance; models of different types; inverse modelling and multi-sensor applications of remote sensing methods). Landscape-ecosystem approach (LEA), an integration of all relevant empirical and semi-empirical information about landscapes and ecosystems is used for the system designing the accounting scheme. FCA by the LEA is provided by complimentary use of flux-based and pool-based approaches. The information background of the LEA is presented in form of an Integrated Land Information System – a multi-layer and multi-scale GIS with basic resolution of 1 km. The forest land cover map was developed based on integration of 12 remote sensing products, geographically weighted regression and crowdsourcing; the accuracy of the forest mask controlled by an independent set of data was estimated at 97% (Schepaschenko et al. 2015). Assessment of organic carbon stocks (live biomass, dead wood, soil) and fluxes (NPP, heterotrophic respiration, HR, fluxes caused by disturbances, lateral fluxes) was provided by-pixel based on methods described in Shvidenko et al. (2007), Schepaschenko et al. (2013), Mukhortova et al. (2015). Uncertainties within LEA was estimated in the following way: 1) assessment of precision based on the formal use of error propagation theory; and 2) transformation of precision in uncertainties using Monte-Carlo simulations for varied input data and intermediate results. Independent results received by other methods were used for harmonizing and mutual constrains of major intermediate and final results using the Bayesian approach (Shvidenko, Schepaschenko 2014). This procedure requires availability of statistical indicators describing uncertainty of the results received of independent methods.

Relevant economic mechanisms for evaluation of and payment for ecosystem services are now under development (e.g., Costanza et al. 1998; 2014; Farley, Costanza 2010; Burkhard et al. 2012; de Groot 2012). It has been shown (e.g., OECD 2013) that carbon pricing is economically preferable among different policies (such as feed-in tariffs, industry regulation and subsides) with respect to cost-effectiveness of alternative policies to reduce greenhouse gas emissions. There are two major approaches – (1) explicit payments in form of carbon taxes or prices of emission allowances in GHG trading schemes and (2) implicit reflection on the cost to society paid per tonne of CO2-eqv. in form of effective carbon prices abated as a result of any type of policy measure that influence GHG emissions.

Addressing the reader to discussions about strengths and limitation of the above approaches (e.g.,OECD 2013), one could note that effective carbon prices reflect the objective situation in national economics, directly connect to natural, built, human and social (including financial) capital assets and present the most economically solid mechanism among others. Because aggregated information on effective carbon prices is absent for Russia, we used results of OECD study that have been reported for 15 countries as of 2010. Taking into account clearly redundant use of energy in the Russian economy and availability of substantial possibilities for improvements of the technological level of the country's industry with following decreasing the carbon emissions, we used a conservative estimate 25 USD per 1 tonne CO_2-eqv. In our opinion, such an approach has an advantage over the use of average prices (established or expected) from existing GHG trading schemes because the approach does not depend on momentary political tendencies and market conjuncture that might be very dynamic and far from real cost of required actions by countries.

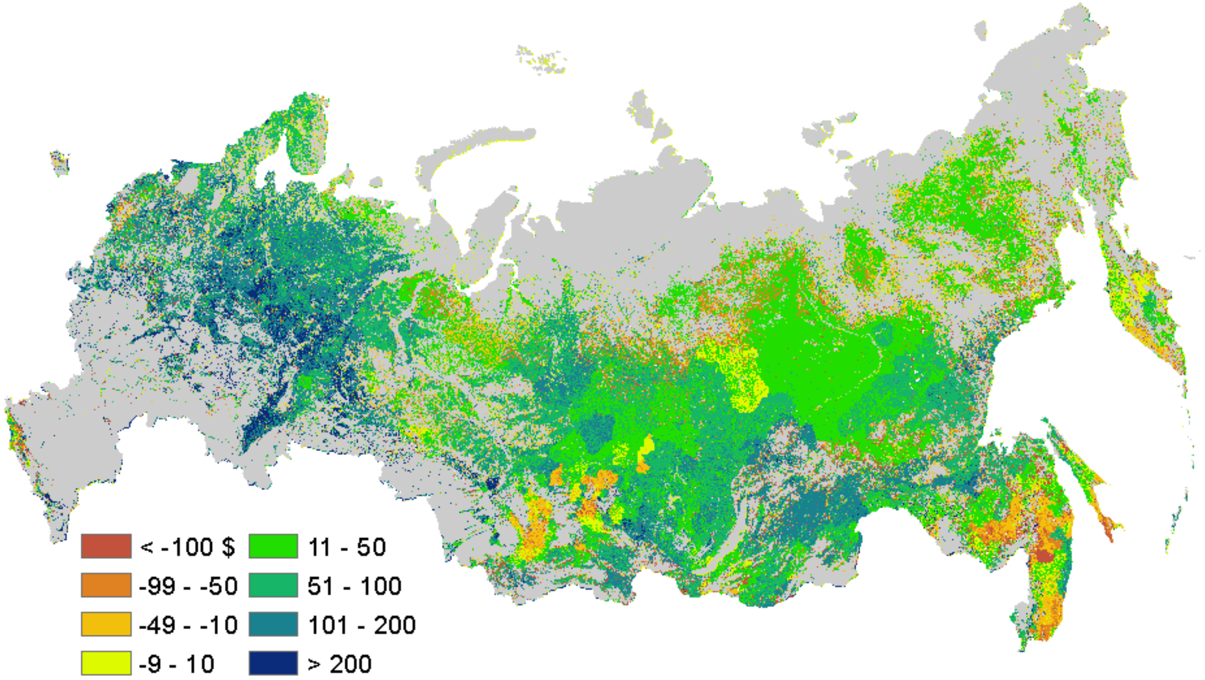

Fig. 1: Cost of carbon sequestration service of Russia's forests. Units – US Dollars / ha^{-1}

Results

The total pool of organic carbon (here and below average values for 2007-2009) is estimated to be 192.3 Pg C, including 37.5±1.5 Pg C (19.5% of the total) in live biomass and 10.3±1.0 Pg C (5.4%) in dead wood. Almost two-thirds of the live biomass is above ground. The stock of soil carbon that includes on-ground organic layer and 1m top layer of soil is 144.5 ±10.1 Pg C (75.1% of the total organic carbon of forest ecosystems), i.e. the ratio between soil and biomass carbon is about 3:1. The substantial uncertainty of the estimate of soil carbon limits practical application of the pool-based approach in the FCA.

Net Primary Production (NPP) comprised 2610 Tg C yr^{-1} (or 319±19 g C m^{-2} yr^{-1}) and Heterotrophic Respiration (HR) - 1688 Tg C yr^{-1} (206 g C m^{-2} yr^{-1}). It gives the ratio of HR : NPP equal to 0.67 with substantial difference for the European and Asian parts (respectively 0.53 and 0.70). Fluxes due to disturbances comprised 126.7 Tg C yr^{-1}, including 44.7% generated by fire, 30.1% – by biogenic factors, mostly outbreaks of pests, and 25.7% - by harvest and use of wood. Finally, the flux to the hydrosphere and lithosphere was estimated at 33.8 Tg C yr^{-1} (Shvidenko, Schepaschenko, 2014; Mukhortova et al., 2015).

The above data resulted in the average Net Ecosystem Carbon Budget (NECB) in 2007-2009 at 546±120 Tg C yr^{-1}, or 66 g C m^{-2} yr^{-1}, including 143 g C m^{-2} yr^{-1} in the European and 47 g C m^{-2} yr^{-1} in Asian parts of Russia. The Bayesian approach applied to the results of the LEA, inverse modelling and pool-based approach presented the closed value, providing the net sink of 560±117 Tg C m^{-2} yr^{-1}, or about 20% of NPP for this period. This result is presented in carbon units and includes 1.26 Tg C-CH_4 yr^{-1} (this is basically the flux from forests on peat soils and from fire emissions). However, under the high average sink over the country, substantial areas, basically on permafrost and on areas of disturbed forests served a net carbon source. Recalculation for the period 2000-2012 by administrative regions of the country showed that the annual NECB was in range of 500-600 Tg C yr^{-1} with a weekly declined trend, particularly after middle of 2000s. Several reasons for this could be indicated. During the last 10 years, an acceleration of fire regimes was observed; it resulted in the positive trend of increasing both burnt areas (+0.3 M ha yr^{-1}) and severity of fires. This, as well as several waves of drying of dark coniferous forests in different regions substantially increased mortality. The total area of Russian forests (the national Russian definition of forest is used) has decreased at 27 M ha in 2000-2010. This does not provide any large impact on decreasing the sink because the major loss of forested areas was observed in remote low productive forests of high latitudes, while the substantial areas of abandoned agricultural land (totally18 million ha, of which 12 million ha are in the European part of the country) were revegetated by forests.

The total cost of the carbon sequestration service of Russian forests is estimated to be USD 4,282 million, or USD 52.13 ha^{-1} in 2007-2009. The spatial distribution of the cost (Figure 2) shows a large spatial variability which corresponds to the sign and magnitude of the NECB. Another reason of variability is a different regional composition of carbon contained components of the NECB (mostly CO_2 and CH_4). Uncertainty of evaluation depends on uncertainties of the NECB (about 22% for the country's average, CI 0.9) and selection of the shadow prices.

Discussion

In spite of many debates on possibility and relevance of economic valuation of ecosystem services, many authors argue that suitably specified valuation of ecosystem services flows and natural capital stocks are conceptually solid and can have many potential uses (Howarth and Farber 2002, Costanza et al. 2014), even if virtual non-market prices and incomes are considered. This study clearly supports this concept. In our conservative estimate, cost of the CSS of forest ecosystems comprises 0.2% of the reported Russia's GDP, while the total current contribution of the Russian forests sector to the national GDP is 1.3%. Evidently, the overall estimate completely depends on the level of shadow prices. We used the method which results in the most conservative estimate, at most approximated to current economic realities. In the seminal paper by Constanza et al. (1997), additive monetary value of 17 ecosystem services for boreal and temperate forests was estimated at 417 USD ha^{-1} yr^{-1} and recently, based on updated information (Costanza et al., 2014), at 3137 USD ha^{-1} yr^{-1} for 2011 (prices of 2007).

Valuation of an individual ecosystem service may have a limited importance within the paradigm of multipurpose forest management. The most complete national classification of ecosystem services of Russian forests (Sheingauz, Sapozhnikov 1983, 1989) accounts for 4 classes, 14 subclasses, 29 groups, and 75 basic services. The suggested classes and subclasses – the class of primary goods (with sub-classes food, fodder, industrial forest products and fuel); landscape-stabilized class (including water regulating, soil protected, air regulated, and biota-regulated subclasses); social (recreation, sanitary and hygienic, scientific, and defence); and economy-ecological supporting class (with two subclasses of ecology-supporting and biota-supporting) in an evident way could be transformed in 4 internationally used classes of ecosystem services – provisioning, regulated, cultural and supporting. Legislatively, Russian forests are divided by major functional destination in 1) protective forests (which in turn are divided in 18 protective categories with different regimes of forest management), 2) forests available for industrial harvest and 3) unused (reserve) forests. We developed an expert matrix of interaction between CSS and the mentioned above 14 ES subclasses using four types of interaction of ecosystem functions: synergetic, neutral, competitive and exclusive. Such a matrix allows providing the total economic valuation of all diversity of ecosystem services according to the actual input of each of them within major functional destination of different management regimes. Particularly this is important for the long-run valuation when interactions between different ecosystem services should be presented explicitly for the period close to the length of rotation cycles. However, the substantial problems remain. Climate change may substantially impact functioning of forest ecosystems and their ecosystem services; thus, results of long-period evaluation would critically depend on reliability of climatic predictions and understanding of feedbacks and responses of forest ecosystems. Uncertainties of that are high. Quantitative estimates of partial inputs of each service depends on the regimes of forest management, but is regionally specific. Finally, there are a number of unresolved theoretical questions, e.g., how to reasonably apply the principle of equal meaning but not equal value of ecosystem services (Sheingauz, Sapozhnikov 1989).

Conclusion

This study corroborates a relevance of using effective carbon prices for evaluation of the CSS in a country with almost exclusive state property of forests. Development of an Integrated Land Information System as an unified information background presents possibility for future integrated consideration of all relevant ecosystem services in biophysical and economic terms.

Acknowledgements

References

1. Bastos A., Gouvenia C.V., Trigo R.V. 2014. Analysing the spatio-temporal impacts of the 2003 and 2010 extreme heatwaves on planr producyivity in Europe. Biogeosciences 11: 3421-3435.
2. Burkhard B., Groot de, R., Costanza R., Seppelt R., Jorgenson S.E., Potschin M. 2012. Solutions for sustaining natural capital and ecosystem services. *Ecological Indicators*, 21: 1-6.

3. Chapin F.S., Woodwell G.M., Randerson J.T. et al. 2005. Reconciling carbon-cycle concepts, terminology and methodology. *Ecosystems*, 9: 1041-1050.

4. Costanza R., d’Agre R., de Groot R., Farber S., Grass M., Hannon B. 1997. The value of the world’s ecosystem services and natural capital. *Nature*, 387: 253-260.

5. Cosanza R., de Groot R., Sutton P., van der Ploeg S., Anderson S., Kubiszewski I., Farber S., Turner R.K. 2014. Changes in the global value of ecosystem services. *Global Environmental Change,* 26: 152-158.

6. Conte M.N., Ennaanay D., Mendoza G., Walter M.T., Wolny S., Nelson E. 2011. Vegetation retention of nutrients and sediment. In Daily G., Kareiva P., Ricketts T. (eds.) *Natural*

Capital: Theory and Practice of Mapping Ecosystem Services. New York, Oxford University Press.

7. De Groot R.S., Wilson M.A., Boumans R.M.J. 2002. A typology for the classification, description and valuation of ecosystems functions, goods and services. *Ecological Economics,* 41: 393-408.

8. de Groot R., Brander L., Ploeg van der, S., Costanza R., Bernard F., Braat L. et al. 2012. Global estimate of the value of ecosystems and their services in monetary units. *Ecosystem Services*, 1: 50-61.

9. DeLuca T.H., Biosvenue C. 2012. Boreal forest soil carbon. Distribution, function and modelling. *Forestry*, 85(2): 161-184.

10. FAO. 2012. *The Russian Federation Forest Sector. Outlook Study to 2030*. Food and Agriculture Organization of the United Nations, Rome, 84 pp.
11. Farley J., Costanza R. 2010. Payments for ecosystem services: from local to global. *Ecological Economics*, 69: 2060-2068.

12. *Good Practice Guidance for Land-use, Land-Use Change and Frestry*, edited by J. Penman, M. Gytarsky, T. Hirashi et al. 2003. Japan, IPCC, 590 pp.

13. Howarth R.B., Farber S.F. 2002. Accounting for the value of ecosystems services. *Ecological Economics*, 41: 421-429.

14. Le Quéré, C., Moriarty, R., Andrew, R.M., Peters, G.P., Ciais, P., Friedlingstein, P. et al. 2014. Global carbon budget 2014. *Earth Syst. Sci. Data Discuss.* 7, 521–610. doi:10.5194/essdd-7-521-2014

15. Mukhortova L., Schepaschenko D., Shvidenko A., McCallum I., Kraxner F. 2015. Soil contribution to carbon budget of Russian forests. *Agricultural and Forest Meteorology*, 2015: 97-108.

16. Nilsson S., Shvidenko A., Jonas M., McCallum I., Thomson A., Balzter H. 2007. Uncertainties of a regional terrestrial biota full carbon account: A systems analysis. *Water, Air, and Soil Pollution: Focus*, 7: 425-441.

17. Pan Y., Birdsey R.A., Fang J., Houghton R., Kaupi P.E., Kurz W.A. et al. 2011.A large and persistent carbon sink in the world’s forests. *Science*, 333: 988-993.

18. Schepaschenko D.G., Mukhortova L.V., Shvidenko A.Z., Vedrova E.F. 2013. The pool of organic carbon in the soils of Russia. *Eurasian Soil Science*, 46(2): 107-116.

19. Schepascheno D.G., Shvidenko A.Z., Lesiv M.Y., Ontikov P.V., Schepaschenko M/V., Kraxner F. 2015. Area of Russia’s forests and its dynamics based on synthesis of remote sensing products. *Forest Science (Lesovedenie)*, 3: 163-174.

20. Sheingauz A.S., Sapozhnikov A.P. 1983. Classification of functions of forest resources. *Forest Science*, 4: 3-9 [in Russian].

21. Sheingauz A.S., Sapozhnikov A.P. 1989. Estimation of combination of functions of forest resources- a background of organization of multipurpose forest use. *Forest Science*, 1: 3-8 [in Russian].

22. Shvidenko A., Schepaschenko D., Nilsson S., Bouloui Y. 2007. Semi-empirical models for assessing biological productivity of Northern Eurasian forests. *Ecological Modelling*, 204: 163-179.

23. Shvidenko A., Schepaschenko D., McCallum I., Nilsson S. 2010. Can the uncertainty of full carbon accounting of forest ecosystems be made acceptable for policy makers? *Climatic Change*, 102: 137-157.

24. Shvidenko A.Z., Schepaschenko D.G. 2014. Carbon budget of Russia's forests. *Siberian Journal of Forest Science*, 1: 69-92 [in Russian].

25. Steffen W., Canadell J., Apps M. et al. 1998. The terrestrial carbon cycle: Implication for the Kyoto Protocol. *Science* 280: 1393-1394