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Estimation of soil organic carbon stocks and stock changes in Croatia (1980–2006) – use of national soil database and the Corine Land Cover

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Abstract

Background and Purpose: *In this study, estimation of soil organic carbon (SOC) stocks for the LULUCF categories is provided together with assessment of spatial and temporal trend of soil carbon density (SCD) for the 1980–2006 period in Croatia.*

Materials and Methods: *Calculations of soil carbon stocks was based on data of soil organic carbon from the national (pedon) database of Croatian soils that consisted of 2351 soil profiles and Corine Land Cover inventories in 1980, 1990, 2000 and 2006.*

Results and Conclusions: *The total estimated soil organic carbon stock in Croatia for all CLC categories relevant for the LULUCF sector (93% of the total country area in 2006) is 618,77 Mt. Forests and areas with natural vegetation with 348,11 Mt contribute most of all categories, of which managed forests (broad-leaved, coniferous and mixed) contain 241,93 Mt and other natural vegetation classes 106,18 Mt. Estimated soil carbon stock in agricultural land is 270,46 Mt, of which 166,99 Mt contain classes of intensive agriculture (arable land, permanent crops and complex cultivation patterns). Total change in SC stock between 1980 and 2006 equals +1,91 Mt and is mostly due to changes in agricultural practices in rural*

List of abbreviations:

IPCC	– Intergovernmental Panel on Climate Change
LULUCF	– Land use, land-use change and forestry
GHG	– greenhouse gas
GPG-LULUCF	– The Good Practice Guidance for Land Use, Land-Use Change and Forestry
SSURGO	– Soil Survey Geographic database
STATSGO	– State Soil Geographic database
NCSS	– National Cooperative Soil Survey
SGDBE	– Soil Geographical Database of Europe
AFSS	– Austrian Forest Soil Survey
HWSD	– Harmonized World Soil Database
SOC	– soil organic carbon
SCD	– soil carbon density
OPK-RH	– Basic soil map of Republic of Croatia
CLC	– Corine Land Cover
GAMs	– Generalized Additive Models
mgcv library	– Mixed GAM Computation Vehicle with GCV/AIC/REML smoothness estimation and GAMs by REML/PQL

areas (abandonment of intensive grazing and conversion of pastures into natural grasslands). Changes in the forestry sector during the considered period were less noticeable but were also present, particularly for broad-leaved forest class (–2,73 Mt C). Trends of SC stock changes in LULUCF categories represent good indices of demographic and socio-economic processes in Croatia where three distinctive moments were evident: (I) decrease of SC stock in the 1980–1990 period mostly due to urban sprawl; (II) increase of SC stock in the 1900–2000 period due to the decline of agricultural activities in rural areas during and after war period; (III) decline of SC after 2000 due to more intensive urbanization and infrastructural development.

INTRODUCTION

Land use, land-use change and forestry (LULUCF) is defined by the United Nations Climate Change Secretariat as »a greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities« *(1)*. Activities in the LULUCF sector can provide a relatively cost-effective way of offsetting emissions, either by increasing the removal of greenhouse gases from the atmosphere (e. g. by planting trees or managing forests), or by reducing emissions (e. g. by curbing deforestation). The Good Practice Guidance for Land Use, Land-Use Change and Forestry, GPG-LULUCF *(2)* provides supplementary methods and good practice guidance for estimating, measuring, monitoring, and reporting on, carbon stock changes and greenhouse gas emissions from LULUCF activities under the Kyoto Protocol. The methodologies of carbon estimation inside GPG-LULUCF are organized, first, by land-use categories and, second, by broad pools. GPG-LULUCF describes six broad land-use categories for reporting national inventories under the Convention: forest land, cropland, grassland, wetlands, settlements and other land. The main carbon pools are living biomass (above and below ground), dead organic matter (dead wood and litter) and soils (soil organic matter).

Organic carbon sequestrated in soils can contribute to mitigation of greenhouse gas emissions in the frame of LULUCF. To evaluate this potential, baseline data on soil carbon stocks are critical for understanding current conditions and the quantity of soil carbon that could be sequestrated both in natural and managed forest and agricultural systems. The use of information from existing soil surveys and pedon (soil profile) databases is very common in preliminary soil carbon inventories and uncertainties of these baseline soil carbon stock estimations are mostly related to a scale at which soil survey is performed. As an example, the basic information of soil carbon stocks in the USA *(3)* can be obtained from the Soil Survey Geographic Database (SSURGO) which includes non-federal lands in the USA at scales of 1:12000 to 1:24000 and consists of soil attribute data, including organic C, $CaCO_3$ equivalent, bulk density and fragment content for layers of different soil components of each map unit. In the areas of federal land, less precise (1 : 250,000) data are available in the State Soil Geographic Database (STATSGO). In addition to the pedo-cartographic units, National Cooperative Soil Survey (NCSS) pedon database contains measured soil property data for horizons to 1 m or greater depth for more than 30000 sites from across the country, sampled and analyzed over the last 60 years. In China, 1:4,000,000 vegetation and soil maps were used as base maps to display the spatial distribution of soil carbon extent, with a total of 388 pedons of the second national soil survey *(4)*. Inventory of carbon stock of forest soils at European scale was performed at 16 km × 16 km survey grid (5269 plots) established in the frame of the International Co-operative programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) and Soil Geographical Database of Europe (SGDBE) with a scale of 1:1,000,000 *(5)*. At a national scale, Austrian Forest Soil Survey (AFSS) records detailed chemical and physical soil properties in a 8.7 x 8.7 km^2 sampling grid, which makes a total of 514 permanent AFSS plots for the whole Austria *(6)*. Swedish soil inventory of forest land and grassland consists of around 11,000 plots *(7)*. Global estimates of soil organic carbon (SOC) stocks have been produced based on the Harmonized World Soil Database (HWSD) *(8)*. The comparative evaluation of HWSD has demonstrated that bulk density is the most important factor for estimating SOC stocks and mainly responsible for differences between estimates. Estimates that are most affected by the variability in bulk density are SOC stocks which are high in organic carbon.

Inventory of soils in Croatia has been undertaken through long term activities on producing of the basic soil map of Republic of Croatia (OPK-RH), which were intensively taking place between 1964 and 1985. Within this project, coverage of almost all land territory of Croatia was accomplished with pedo-cartographic maps 1 : 50,000 together with completion of pedon database containing around 2351 soil profiles *(9)*. Pedon database contains basic chemical and physical data together with description of locations and pedogenetic factors: geographic position (latitude/longitude), elevation, aspect, slope, vegetation type and land use, parent material, hydrology (dominant source of moisture and drainage), soil type and subtype, name and depth of horizon, textural class, structure of aggregates, percentage of textural fractions, pH, organic matter, nitrogen, phosphorus, potassium and carbonates. Drawback in the OPK-RH is that measurements of soil bulk density, which is a required parameter for recalculation of total quantity of any chemical element given in percentage, were undertaken only on a limited number of soil profiles (about one hundred); this requires construction of pedo-transfer functions to be applied on the database as a whole. Some of the most significant studies concerning the OPK-RH aimed to evaluate adequacy and usability of produced soil maps *(10)* and to model spatial distribution of the major soil groups *(11)*.

For the estimation of carbon stocks, emissions and removals of GHG associated with LULUCF activities, information about land area and land area classes is essential. GPG-LULUCF defines remote sensing techniques and ground based surveys as suitable methodological approaches for collection of data about land area. One of the drawbacks of using ground surveys in Croatia for representation of area for LULUCF sector is temporal and spatial inconsistency of various available datasets, such as census data from country statistics, forest managerial plans, etc. This is mainly due to the usage of differing sampling methodology and inconsistent definitions in country legislative (i. e., there is disagreement between various complementary acts in respect to definition of agricultural and forest areas). One of the most consistent approaches to gather unique information of land use properties over space and time and all over the whole country area is Corine Land Cover which is based on remote sensing. Corine means 'coordination of information on the environment' and represents an inventory of land cover in 44 classes operationally available for most areas of Europe *(12)*. Disadvantage of Corine Land Cover (CLC) is that it is not applicable, due to its coarse scale of 1 : 100,000, for GHG inventory under LULUCF which requires the smallest units to be 0.05 ha. CLC inventory of land surface of Croatia was produced for four consecutive decades, i. e. 1980, 1990, 2000 and 2006 *(13)*. However, It provides very useful information of changes in land areas and accordingly it makes possible to perform country scale assessment of trends of carbon stocks in soils.

Up to the present, according to the authors' knowledge, no country scale assessment of soil organic carbon stock and stock changes due to alterations in land-use practices has been carried out during the past few decades in Croatia. Reporting of carbon stock in Croatian soils has been involved very rough »expert judgement« approach, it has not been based on accurate quantitative methodology which takes into account huge regional varieties of soil properties and land cover types. In accordance to the above, the main aims of this study were: (a) to provide baseline estimation of carbon stocks in soils for various land cover types in Croatia by using available information from existing pedon database (OPK-RH) and Corine land Cover (CLC); (b) to determine uncertainties of estimation, assess spatial variations of soil carbon and regional characteristics; (c) to assess changes in soil carbon quantity due to changes in land use practices in the 1980–2006 period.

MATERIAL AND METHODS

Estimation of carbon stock from available soil data

The computation of SOC stock is based on a few parameters that must be measured in the field, determined in laboratory or taken from other sources (e. g., cadastral information on plot location and area). The list of parameters includes: carbon content in soil, bulk density, the thickness of a soil layer, the content of coarse fragments and the area of a plot *(14)*.

$$SCD_{site} = -(SOC_{content} * BulkDensity * Depth * (1\text{-}frag))$$

SCD_{site} is aSOC content in % of mass (kgC/kgSoilx100); Bulk Density is soil bulk density (kgSoil/dm^3); Depth is the thickness of a sampled layer (dm); frag is the volume of coarse fragments, % of mass or (m^3Stone/m^3Soil).

Estimation of soil bulk density

Total pore space and pore size distribution in soil are controlled by soil physical properties such as texture, structure and organic matter content. Saxton *et al. (15)* estimated generalized bulk densities and soil-water characteristics from texture and developed a set of equations from which soil-water characteristic equations for a number of soil textural classes can be derived. In a recent study of Kobal *et al. (16)*, local pedotransfer functions were developed that estimate bulk density from organic carbon for Slovenian soils. In our study, bulk density was estimated from organic matter content from a limited number of available samples (89) in soil pedon database, using Generalized Additive Models method (GAMs). The advantage of GAMs in respect to other methods, such as generalized linear models, is that the shape of the relationship between response and explanatory variables could be captured without prejudging any particular parametric form *(17)*. GAMs extend the range of application of generalized linear models by allowing non-parametric smoothers in addition to parametric forms, and these can be associated with a range of link functions. Bulk density GAMs computations in this study were performed using R mgcv library (Mixed GAM Computation Vehicle with GCV/AIC/REML smoothness estimation and GAMs by REML/PQL) provided by Wood *(18,19)*.

Estimation of coarse fragments in soils

The percentage of coarse fragments in soils is not provided in the soil pedon database and therefore additional assessment had to be performed to acquire this parameter. For this purpose, we used description of coarse fragments from field manuals of soil profile description. For each of the stony soil type *(Leptosol, Regosol, Phaeozem, Cambisol,)* the percentage of coarse fragments was estimated from field sketches. The distribution of coarse fragments, assumed as a random variable whose value is subject to variations due to chance, was then attributed to stony soil profiles in the database.

Uncertainty of carbon stock estimates

The IPCC Good Practice Guidance *(2)* defines uncertainty as a parameter associated with the result of measurement that characterizes dispersion of values that could be reasonably attributed to the measured quantity. Uncertainty, i. e., the inaccuracy of the SOC stock estimation for a particular plot or soil/land use class is characterized by the standard error of changes. For construction of confidence intervals, normal distributions are used to approximate sampling distributions. The assumption of normal distribution of soil data is most

TABLE 1

Summary table of GAM bulk density prediction parameters from soil organic carbon content (OC).

Formula:			Family: gaussian	
log(density) ~ s(OC)			Link function: identity	
	Parametric coefficients:			
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	**0. 26889**	**0. 02599**	**10. 35**	**<2e-16 *****
	Approximate significance of smooth terms:			
	edf	Ref. df	F	p-value
s(OC)	**6. 508**	**7. 668**	**8. 741**	**9. 02e-09 *****
Signif. codes: 0 '***' 0. 001 '**' 0. 01 '*' 0. 05 '.' 0. 1 ' ' 1				
R-sq. (adj) = 0. 42		Deviation explained = 46. 3%		
GCV score = 0. 065644		Scale est. = 0. 060107		n = 89

often a wrong practice because soil parameters could have asymmetric distributions and may have more than one mode. The spatial distribution of soil parameters, such as organic carbon content, is not strictly random across an area, yet soil parameters are influenced by distribution and interaction of Jenny's *(20)* five factors: climate, organisms, topography, parent material and time. Soils are also spatially correlated and behave under »neighborhood law« which means that soil at some location depends on geographic coordinates and on the soil at neighboring locations *(21)*. Due to this, we used a Bootstrap method for constructing confidence intervals which draws samples from the empirical distribution of data. 95% confidence interval is obtained by taking 2.5% and 97.5% quartiles of replications as a lower and upper limit, respectively. Also, BCa (Bias-corrected and accelerated) method was used to adjust for skewed distributions of soil samples inside CLC classes *(22)*. The calculations of bootstrapped confidence intervals in this study were performed by using R function *boot. ci (23)*. The visual insight of distribution of carbon stock for each of the considered CLC class was also provided graphically through construction of appropriate histograms.

Spatial prediction of soil carbon

To predict values of estimated organic carbon content over the whole area of interest, there is currently a variety of applicable geostatistical methods. Geostatistical prediction, in respect to conventional mapping, is based on application of quantitative statistical techniques, most often various Kriging methods which completely rely on the use of actual measurements and algorithms *(24)*. For the spatial prediction of soil carbon at a country scale, we used Universal Kriging interpolation. Spatial representations for interpolated soil carbon content were made by using percentile class limits of 10 (0–10, 10–20, 20–30,…, 90–100).

RESULTS

The results of GAMs model outputs for the prediction of bulk density are presented in Table 1. The results of prediction confirm strong significant contribution of organic carbon content in explanation of bulk density variations. However, relatively smaller explained deviations and coefficient of determination (Rsq=0.42) suggest that further stratification of data sample is necessary in production of local pedotransfer function. Unexplained variations are most probably due to the inclusion of the disturbed agricultural soil samples into the model and to a rather large heterogeneity of soil types and properties in Croatia. Similar research performed only in forest sites in the neighboring Slovenia *(16)* confirms that, by use of segmented regression, nearly 80% of the variability of bulk density can be explained by organic carbon content. Kobal *et al. (16)* also suggest improvement of prediction by using data according to each unique soil type. Nevertheless, we assumed the obtained results to be satisfactory for the purpose of this study and used them for further calculations.

The estimates of soil carbon density (SCD) for considered CLC classes, together with uncertainty estimation, are given in Table 2. The estimate of the bias is given by the difference between the mean of bootstrap values and the initial estimate, and BCa represents the intervals calculated using the adjusted bootstrap percentile (BCa) method. From the obtained results, the evidence of differences between CLC classes is clearly distinguishable. The largest average carbon stocks are attributed to agricultural CLC classes, annual crops with permanent crops (176.53 T/ha) and fruit trees and berry plantations (163.92 T/ha). Somewhat lower values of SCD are attributed to forest and natural area classes, with largest SCD stock in the class of natural grassland (134.74 T/ha) and coniferous forest (126.53 T/ha), the latter being slightly higher than for broad-leaved forest (117.8 T/ha). The shapes of SCD distribution of considered CLC classes, with approximated normal distribution, sample average (full vertical line) with 2.5% and 97.5% quartile range of uncertainty (dashed vertical lines) can be assessed visually through histograms in Figure 1. It is evident from the histograms that distributions of SCD for practically each of CLC classes are skewed with shift of the majority of data to the left. Relatively narrow confidence interval (good estimation) was obtained in classes with a significant number of samples, i. e. for classes of non-irrigated arable land, vineyards and pastures in agricultural areas and in particular for forests, broad-leaved, coniferous, mixed and transitional woodland shrub. Significantly worst estimation of SCD was obtained for classes with a smaller number of samples and large internal heterogeneity of data such as moors and heathlands, sparsely vegetated areas, green urban areas and mixed classes such as the class of principal agriculture, significant areas of natural vegetation. These classes also have bimodal distribution of data and strong decline from normality.

The obtained calculations of SCD are comparable to results from similar studies. Global estimates of carbon

TABLE 2

C stock in soil (SCD) and uncertainty of SCD estimates for CLC categories.

CLC level 1	CLC level 2	CLC level 3	N	Mean (T C/ha)	std. Error	bias	BCa (2,5%)	BCa (97,5%)
Artificial surfaces	*Artificial, non-agricultural vegetated*	Green urban areas	29	**115,18**	10,58	0,6691	96,5	138,3
Agricultural areas	*Arable land*	Non-irrigated arable land	629	**114,29**	2,75	0,0014	109,2	120,1
	Permanent crops	Vineyards	137	**135,3**	6,24	–0,3980	123,5	150
		Fruit trees and berry plantations	40	**163,92**	15,79	–0,2991	135,9	197,5
		Olive groves	15	**121,62**	13,97	0,0325	93,9	148,1
	Pastures	Pastures	97	**104,96**	6,59	–0,0137	92,8	119
	Heterogeneous agricultural areas	Annual crops with permanent crops	21	**176,53**	18,37	–0,2041	140,7	211,8
		Complex cultivation patterns	21	**114,2**	11,45	–0,4922	94,6	138,7
		Principally agriculture, significant areas of natural vegetation	10	**137,52**	25,63	–0,5473	89,1	188,1
Forest and semi natural areas	*Forests*	Broad-leaved forest	723	**117,08**	2,75	–0,0690	111,5	122,4
		Coniferous forest	103	**126,53**	9,81	–0,7670	108,9	148,4
		Mixed forest	142	**117,88**	6,45	0,2899	105,3	130,5
	Schrub and/or herbaceous vegetation associations	Natural grassland	259	**134,74**	5,27	0,1307	124,6	146,3
		Moors and heathland	8	**121,95**	38,30	0,5409	69,8	236
		Transitional woodland-scrub	94	**110,47**	8,50	–0,0114	95,3	129,6
	Open spaces with little or no vegetation	Sparsely vegetated areas	7	**100,69**	21,52	–0,7085	65,6	150,8

stock in soil organic matter for temperate forests and plantations (up to one meter depth) of 122.7 T/ha *(25)* is very close to our calculations of 117.08 T/ha for broad-leaved and 126.53 T/ha for coniferous forests. Lettens *et al. (26)* obtained slightly higher values of 148 T/ha for broad-leaf, 155 T/ha for coniferous and 152 T/ha for mixed forests for more temperate conditions in Belgium, also within a soil depth of one meter. Estimation of SCD for land use categories in Spain up to 75 cm depth *(27)* shows significantly lower values than those obtained in our study, i. e. 52.2 T/ha for permanen0t crops, 47.8 T/ha for forest and 58.3 T/ha for arable land, which could be explained by scarcity of Mediterranean soils in that region. Determined differences of SCD between the above-mentioned regional studies can be explained by differences in climatic properties across EU which influence soil carbon stock. When moving from a warmer to a cooler climate, the SCD tends to increase because overall trend in the decomposition of organic matter is accelerated in warm dry climates, while a lower rate of decomposition is the case for cool and moister regions *(28)*.

The dominant CLC class in Croatia are forest and woodland areas which occupy 46.8% of 5. 658. 465 ha total land, followed by heterogeneous agricultural areas with 32.6%, shrubs and herbaceous vegetation 8.4%, arable land and permanent crops 7.8%, artificial surfaces 3.1%, wetlands 0.4%, and freshwater areas 1,0% (Figure 2). Kriging interpolation (Figure 3) provides insight in spatial variations of SCD over the whole country area where particular spots with excessive carbon stock could be distinguishable. In particular, increased SCD is in the continental northern part of the country related to areas of wetland floodplain forests (Spačva complex in eastern part and Posavina area in western part) and Kopački rit wetland area in the north-eastern region. In the continental agricultural region, decreased SCD is clearly distinguishable. In transitional mountainous part of the country, increased SCD is related to particular forested and extensive agricultural areas including pastures with natural vegetation. In part of the carstic forested areas, somewhat less successful spatial interpolation of SCD was obtained (nugget effect) due to the strong variation in geomorphology. In Mediterranean coastal part, there is significant increase of SCD in agricultural classes, in particular on Islands, which is related to increased carbon content in permanent crops CLCs such as vineyards and olive groves.

Urban area, Swamps, Wetland, Intensive agriculature, Extensive agriculture, Seminatural vegetation, Forests and underbrush

For represented land areas, IPCC GPG describes three approaches starting from identification of only the total

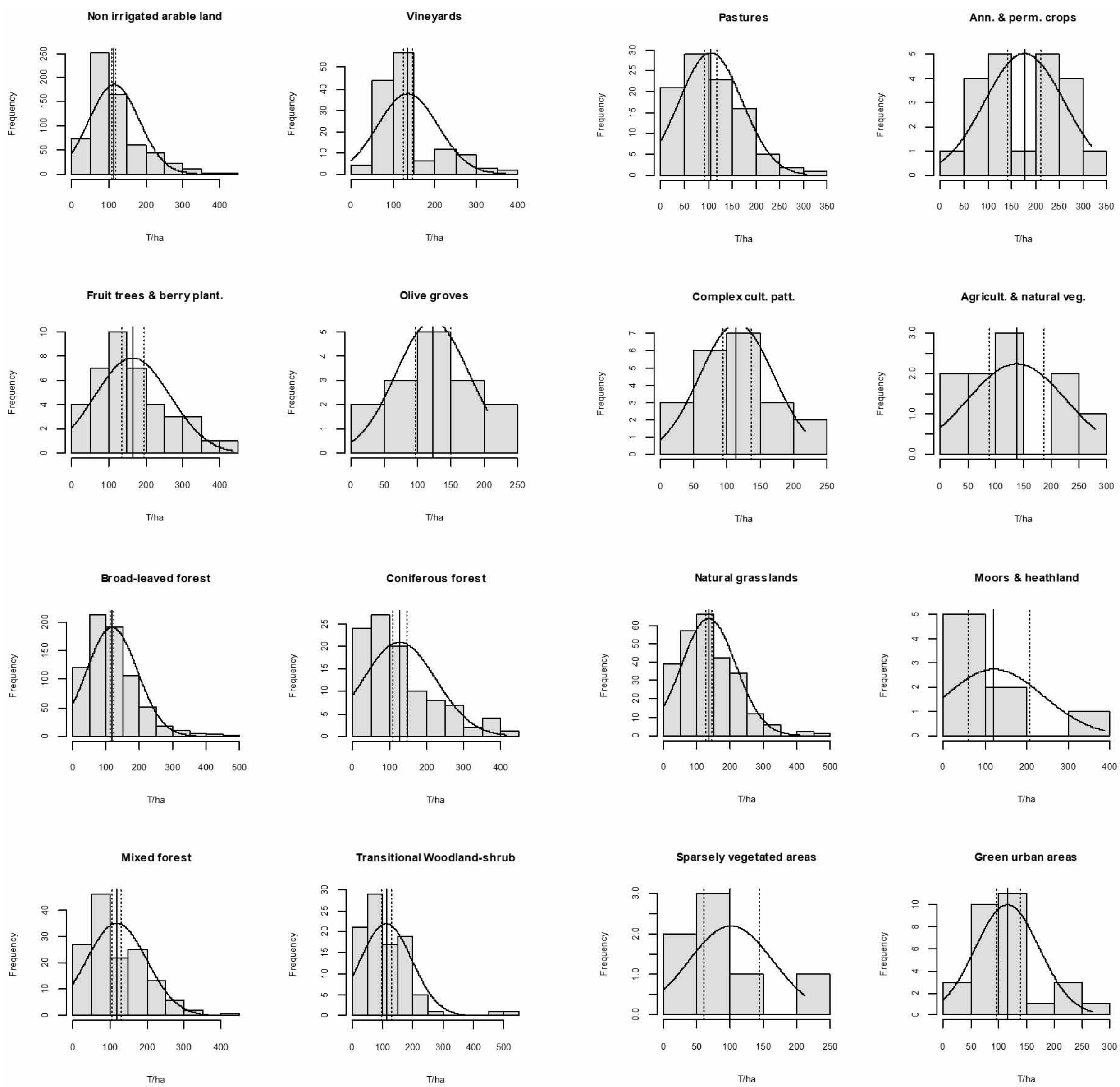

Figure 1. *Histograms of soil carbon distribution (SCD) in various CLC classes in respect to normal distribution, average SCD value (solid line), 95% confidence of the mean (dotted line).*

area for each individual land-use category without providing insight in changes between categories, followed by an approach that introduces tracking of land-use change between categories, and ending up with an approach that allows land-use changes to be tracked on spatial basis. Using regionalized variables such as SCD and CLC, i. e. combining national soil inventory and remote sensing such as presented in this study, all three approaches can be implemented at a country scale. CLC land cover inventories were compiled for decadal periods in Croatia from 1980 to a present time and they can provide insight in changes in soil carbon stock due to changes in land use in spatial sense. The IPCC GPG relies on basic default assumptions that land use changes have a linear impact on soil organic matter for 20 years after a new equilibrium is reached, with possible successions of 20-year periods to deal with longer time constants in temperate and boreal zones. In accordance to this assumption, we made calculation of changes in carbon stocks in soils for the 1980-2006 period on the basis of changes in CLC land cover categories and obtained a surplus of 1.91 Mt C/ha which was sequestrated in Croatian soils during that period. This result is only for illustrative and indicative purpose, and the aim of this study is not to evaluate the national GHG inventory *(29)* but to provide more advanced conceptual framework for future improvements of national GHG inventory in respect to IPCC GPG. Carbon stock of particular CLC classes for consecutive periodic inventory, together with stock changes, are provided in Table 3.

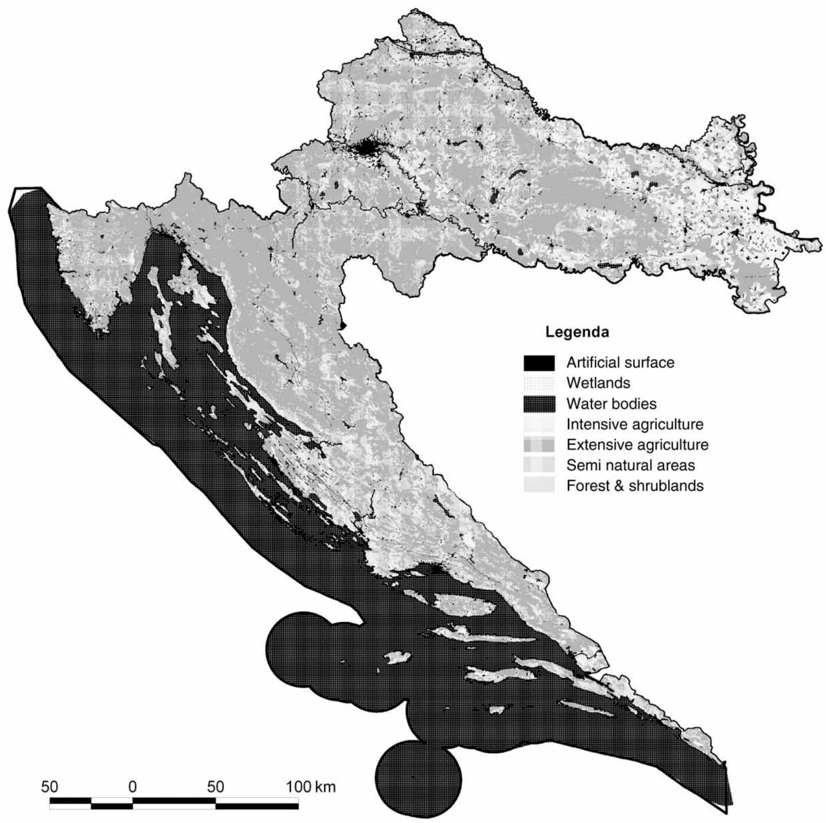

Figure 2. *Spatial distribution of main Corine Land Cover categories in Croatia (13).*

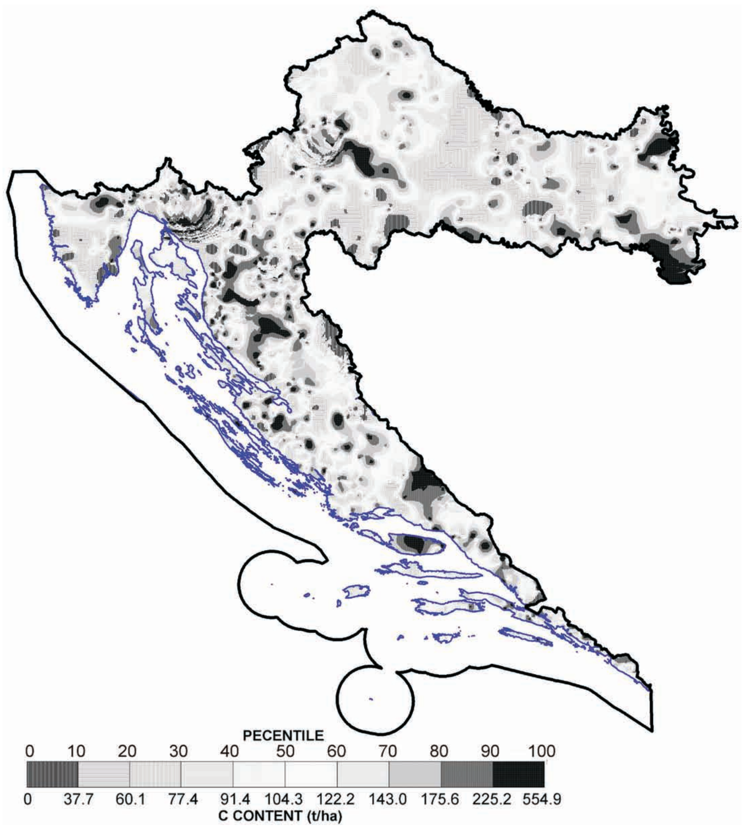

Figure 3. *Spatial Universal kriging prediction of soil organic carbon density (50 cm depth).*

TABLE 3

Changes of carbon stock in soils in respect to changes of CLC categories during 1980-2006.

CLC level 3	N	Mean (TC/ha)	CLC 1980 (ha)	CLC 1990	CLC 2000	CLC 2006	CLC 1980 (Mt C)	CLC 1990	CLC 2000	CLC 2006	Δ (CLC 2006 – CLC 1980) (Mt C)
Green urban areas	29	**115,18**	1812	1812	1782	1724	0,21	0,21	0,21	0,20	–0,01
Non-irrigated arable land	629	**114,29**	385633	378430	368974	370262	44,07	43,25	42,17	42,32	–1,76
Vineyards	137	**135,3**	28200	28193	28925	29055	3,82	3,81	3,91	3,93	0,12
Fruit trees and berry plantations	40	**163,92**	9760	9410	9548	9574	1,60	1,54	1,57	1,57	–0,03
Olive groves	15	**121,62**	18759	18705	20223	20197	2,28	2,27	2,46	2,46	0,17
Pastures	97	**104,96**	475815	477566	307296	298950	49,94	50,13	32,25	31,38	–18,56
Complex cultivation patterns	21	**114,2**	1034844	1026779	1017238	1022051	118,18	117,26	116,17	116,72	–1,46
Principally agriculture, significant areas of natural vegetation	10	**137,52**	515282	510822	523509	524202	70,86	70,25	71,99	72,09	1,23
Broad-leaved forest	723	**117,08**	1706194	1695356	1695495	1682078	199,76	198,49	198,51	196,94	–2,82
Coniferous forest	103	**126,53**	105473	102496	105702	102528	13,35	12,97	13,37	12,97	–0,37
Mixed forest	142	**117,88**	273533	275465	272522	271624	32,24	32,47	32,12	32,02	–0,23
Natural grassland	259	**134,74**	77147	77103	252102	252781	10,39	10,39	33,97	34,06	23,66
Moors and heathland	8	**121,95**	6892	6916	4114	4421	0,84	0,84	0,50	0,54	–0,30
Transitional woodland-scrub	94	**110,47**	567840	591160	579824	592532	62,73	65,31	64,05	65,46	2,73
Sparsely vegetated areas	7	**100,69**	65329	63989	61061	60807	6,58	6,44	6,15	6,12	–0,46
Total of above CLC categories			**5272513**	**5264202**	**5248315**	**5242786**	**616,86**	**615,64**	**619,41**	**618,77**	**1,91**
Total country land area acording to CLC			5657456	5657984	5658451	5658465					
Percentage of Country			93	93	93	93					

DISCUSSION

Three significant temporary processes in LULUCF sector in Croatia *(13)* can be distinguished which had consecutive impact on changes of total carbon stocks in soils. In the 1980 – 1990 period, before the homeland war activities, there was a declining trend in total carbon stocks in soils mostly due to the spreading of areas under human influence, particularly in coastal region and in short proximity of larger cities, i. e. urban sprawl. The above-mentioned period of time was also characterized by a process of abandoning rural agricultural areas. The war activities after 1990 caused intensification of natural processes and further desertion of rural areas, which contributed to accumulation of carbon stock in total. In the 2000-2006 period there were significant increase of man-made activities (rapid extension of highway network, spreading of settlements, recultivation of abandoned agricultural land, establishment of new areas suitable for agriculture…) that have again caused decline in total carbon stock. However, a decline in soil carbon for productive forest categories is evident in forestry sector, most evidently in the area of broad-leaved forest, and an increase of carbon stock in the management of extensive woodland-shrub areas.

The total estimated soil organic carbon stock in Croatia for all CLC categories relevant for the LULUCF sector (93% of the total country area in 2006) is 618,77 Mt. Forests and areas with natural vegetation with 348.11 Mt contribute most of all categories, of which managed forests (broad-leaved, coniferous and mixed) contain 241.93 Mt and other natural vegetation classes 106,18 Mt. Estimated soil carbon stock in agricultural land is 270.46 Mt, of which 166.99 Mt contain classes of intensive agriculture (arable land, permanent crops and complex cultivation patterns).

Total change in SC stock between 1980 and 2006 equals +1.91 Mt and is mostly due to changes in agricultural practices in rural areas (abandonment of intensive grazing and conversion of pastures into natural grasslands). Changes in the forestry sector during the observed period were less noticeable but also present, particularly for broad-leaved forest class (-2,73 Mt C).

Trends of SC stock changes in LULUCF categories represent good indices of demographic and socio-economic processes in Croatia where the following three distinctive moments were evident: (I) decrease of SC stock since the 1980-1990 period mostly due to the urban sprawl; (II) increase of SC stock since the 1900 – 2000 period due to the decline of agricultural activities in rural areas during and after the war period; (III) decline of SC after 2000 due to more intensive urbanization and infrastructural development.

The pedon database was confirmed as a relatively good source of information about SC stock, in particular for the most dominant CLC classes. Therefore, relative accurate estimation of SCD was provided for agricultural classes such as non-irrigated arable land, vineyards and pastures and particularly for managed forests. Estimation was somewhat less accurate for complex land patterns such as classes of heterogeneous agriculture and transitional agricultural and forest areas influenced by natural vegetation.

Due to the variability of SCD in forest and natural land use categories, further stratification according to the major forest types or vegetation groups is desirable, with the aim of improvement of GHG inventories in LULUCF sector.

Soil bulk density and percentage of coarse fragments in soils are issues where significant improvements could be achieved in future through construction of more robust local pedotransfer functions, possibly stratified according to major soil types and land use categories.

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