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Soil inventory and soil classification in Croatia: historical review, current activities, future directions

S. HUSNJAK[A], D.G. ROSSITER[B], T. HENGL[B] & B. MILOŠ[C]

[A]*Soil Science Department, Faculty of Agriculture, University of Zagreb, Svetosimunska 25, 10000*

[B]*International Institute for Geo-Information Science & Earth Observation (ITC), P.O. Box 6, 7500 AA Enschede*

[C]*Institute for Adriatic Crops and Karst Reclamation. Put Duilova 11. PO box 288. 21000 Split*

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Summary

An historical overview of soil survey and soil classification activities in Croatia - including correlation between the Classification of Yugoslav Soils (CYS) and the World Reference Base for Soil Resources (WRB). From 1964 to 1986 a national project to produce a *Basic Soil Map of Croatia* (BSMC) at 1:50 000 on a topographic base created a purely pedological map by air photo-interpretation and field checks of one full profile and 10 to 30 augerings per 1000 ha; the mostly compound map units refer to the sub-types of the CYS, which is a six-level hierarchy influenced by earlier European systems; keys and class descriptions are mostly qualitative; also, 10 800 geo-referenced profile descriptions with standard laboratory data were recorded. All polygons and profile locations have been digitised; data from 2198 profiles have been systematized in a digital database. The BSMC has been generalised to a *Map of Soil Suitability for Cultivation* (1:300 000) and *Soil Map of Croatia* (1:1M) using the FAO 1990 legend. Land use planning in Croatia is most active at the level of the 21 counties, eight of which are developing Land Information Systems at 1:100 000, including the digital BSMC newly-interpreted by soils specialists. Increasing demand can be partly met by re-interpretation and augmentation of the BSMC with a revised soil classification but may, also, require a new survey initiative.

Introduction

Many Eastern European countries invested in soil surveys that can serve as raw material for useful multi-purpose soil geographic databases. In particular, Croatia assembled extensive data in a long running project to create the *Basic Soil Map of Croatia* (BSMC). Though suffering from a lack of consistent standards, this is a valuable resource. These data have been only sparingly used for land use planning and management for reasons intrinsic to the data as well as to the form in which they are presented.

This document gives an overview of soil survey and classification in Croatia, focusing on the BSMC, and gives insight into the current status and future prospects of soil inventory, soil classification, and soil geographic databases. We also present a rough correlation between the CYS and the *World Reference Base for Soil Classification* (WRB) (FAO, 1998).

History of soil survey in Croatia

Soil science has a long tradition in Croatia. Already in 1877, when Croatia formed part of the Austro-Hungarian empire, the first textbook on soil science in Croatia was published (Kišpatic, 1877) at the request of the Royal Croatian Higher School for Agronomy and Forestry. The first exploratory soil surveys in Croatia were conducted at the beginning of the 20th century by Šandor, a professor of Pedology at the Royal Forestry Academy in Zagreb (Šandor, 1912; Šandor, 1914). Subsequently, when Croatia was part of the Kingdom of Yugoslavia, Gracanin produced several soil survey monographs (Bogunovic *et al.*, 1998). With the establishment of the Federal People's Republic of Yugoslavia (including Croatia) in 1945 a comprehensive state-run soil survey was established - part of a large-scale investment in the agricultural sector following the abandonment of collectivisation in 1953 and subsequent land reform. The first systematic survey was an agro-pedological map of Eastern Slavonia at 1:200 000 scale (Jugo *et al.*, 1953). During the late 1950s, Yugoslavian soil scientists were interested in systemising existing knowledge on soils and producing detailed soil maps of the entire federal republic. A national soil survey project was established to produce a *Basic Soil Map of Yugoslavia*. This project was divided among the republics and their local soil institutions. The Croatian portion was known as the *Basic Soil Map of Croatia* (BSMC). Mapping began in 1964 under the leadership of Kovacevic. The project was scheduled for seven years, but it soon became clear that it would require much more effort then originally planned (Škoric, 1976). In the event, the project lasted for 23 years, finally ending in 1986 (Bogunovic et al., 1998).

The project was divided in two periods, the first lasting until 1972, during which 22% of Croatia, exclusively in the Sava River plains to the south and east of Zagreb, was mapped by the Institute for Soil Science and Soil Technology (a government agency) in Zagreb, using the survey methodology described by Kovacevic and Jakšic (1964) and the classification system developed by Kovacevic *et al.* (1967). In the second period, the project bureau was expanded, and co-ordinated by Prof. Škoric of the Soil Science Department of the University of Zagreb (Škoric et al., 1975). The authors also used the Yugoslav soil classification systems that had evolved in the early 1980's (Škoric et al., 1985). The project was conducted as a series of more or less independent sub-projects under different surveyors, each 15'?15' topographic map sheet covering approximately 20 km ? 27.5 km (Figure 1) on a Gauss-Krüger projection on the Bessel 1841 ellipsoid and scale factor of 0.9999 at the central meridian, in two 3º-wide zones centred on 15ºE (zone 5, false easting 550000) and 18ºE (zone 5, false easting 650000). There was no correlation, either in mapping concepts or legends; although a common classification system was used, it was applied according to each mapper's judgement; soil boundaries from adjacent sheets often do not match.

Reports were published for upper Posavina (middle Sava river plain) at 1:50 000 (Kovacevic *et al.*, 1972), Slavonia and Baranja at 1:200 000 (Škoric, 1977), and Istria at1:150 000 (Škoric, 1987). An attempt was made to establish standards for converting the BSMC, as well as the maps from the rest of Yugoslavia, to a national digital database (Ciric and Miloš, 1978), but this project had not advanced very far by the time Yugoslavia dissolved.

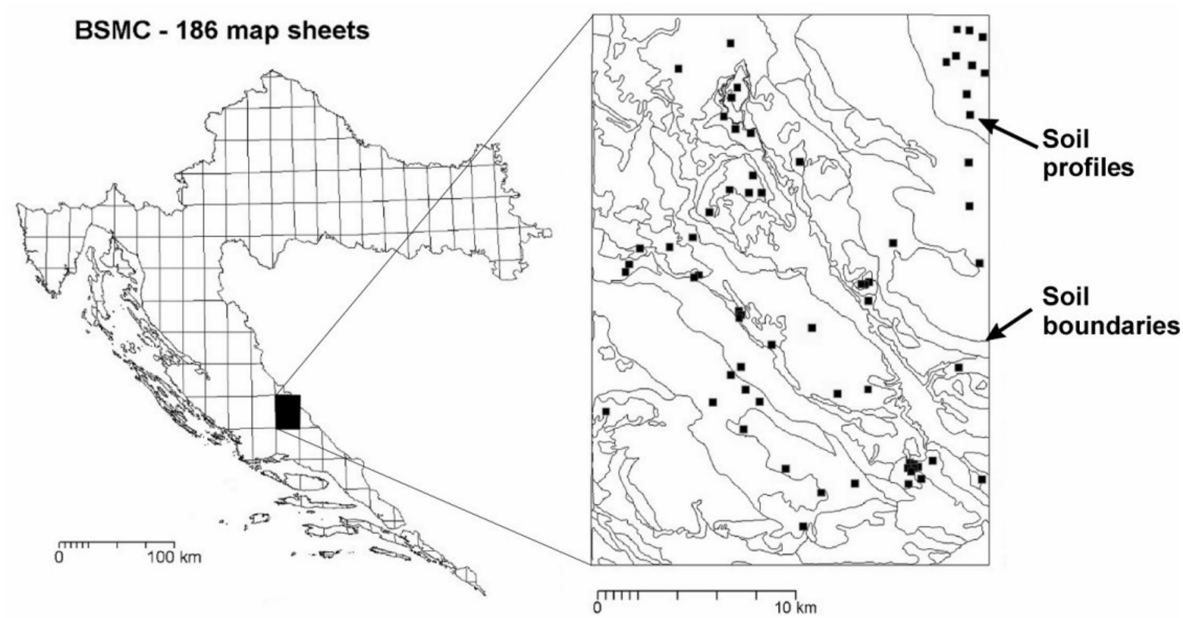

Figure 1. Croatia: 1:50 000 map sheets (left) and example of a digitised map sheet with soil profiles.

In 1991 Croatia separated from Yugoslavia. The Croatian Ministry of Civil Engineering and Environmental Protection established a comprehensive project called the Croatian Environmental Protection Information System, part of which was a GIS database of the soil cover. As part of this project, soil boundaries and profile locations of all map sheets from the BSMC were digitised by the Department of Photogrammetry and Department of Soil Science in Zagreb (Bogunovic and Rapaic, 1993). A new Croatia-wide grid coordinate system was devised known, from its central meridian (16º 30'E), as "16 30"; it uses a Gauss-Krüger projection on the Bessel 1841 ellipsoid but with a false easting of 2 500 000 and scale factor of 0.9997. The digitised sheets were not used as a database in themselves, but rather as input for other projects.

The first derived product was the *Map of Soil Suitability for Cultivation* at 1:300 000 (Bogunovic *et al.*, 1997) produced by merging the separate digitised sheets, edge matching, generalisation of original soil boundaries and elimination of smaller polygons of neighbouring polygons, and legend simplification (Bogunovic *et al.*, 1998). The chosen scale shows that the authors were aware that the effective scale of the original BSMC is smaller than the nominal 1:50 000. Another product based on the BSMC was the *General Soil Map of Croatia* at scale 1:1M (Špoljar, 1999), derived from the 1:300 000 map, further generalised and correlated to the FAO's revised legend for the soil map of the world (FAO, 1990).

During this period, a group led by Dr. Martinovic from the Croatian Forestry Institute in Jastrebarsko organised the original laboratory data and profile descriptions of the BSMC into a paper database (Martinovic and Vrankovic, 1997). They selected 2198 profiles (20% of the total) which had full descriptions and laboratory analysis, each with about 50 descriptive and analytical parameters, and entered these into a digital database. These were geo-referenced (by estimating grid coordinates with a ruler placed on the paper map) but otherwise not integrated with digital maps. The soil database was used to derive average or characteristic attributes of each soil type for a monograph on Croatian soils (Martinovic, 2000).

Characteristics of the *Basic Soil Map of Croatia* (BSMC)

The BSMC project produced 186 1:50 000 manuscript map sheets on standard 15’?15’ topographic quadrangles (some partial), 165 manuscript reports, and about 10 800 profile descriptions with standard laboratory characterisations. Locations of sampled profiles are shown on the maps by 4 mm² squares corresponding to 100 m ? 100 m on the ground, which is consistent with the field location methods used, and eight times coarser than the maximum location accuracy at this map scale. In fact, the profiles were located to a higher accuracy, probably 50 m ? 50 m, but the squares were drawn four times this size for legibility. Only 109 map sheets and 50 reports were published; the rest are still in manuscript stored in the Soil Science Department, University of Zagreb. Most (83%) of Croatia is covered by published maps, but less than half (42%) by published reports.

Mapping and legend concepts were quite different in the two phases of the BSMC. In the first, mapping was carried out directly on topographic maps, without airphoto interpretation; observations were exclusively profiles (no supplementary augerings), two full pits and two to three semi-pits per 200 ha. Boundaries were based on the physiographic analysis in the field and interpolation of the profile observations, and plotted directly on the maps. Only soil profile morphology was considered in constructing map units.

In the second phase, air photo-interpretation became standard technique using 1:14 000 to 1:33 000 panchromatic and 1:10 000 to 1:17 000 infrared photos (Bogunovic, 1983). At first, single photos were interpreted for clues to soil texture, moisture, rock outcrops and other easily-visible or inferable physiographic features; later some surveyors used stereoscopic landform analysis, but surveyors did not use a formal system of soil-landscape interpretation. Boundaries were drawn manually on 1:50 000 topographic sheets with a 20 m contour interval. The inspection density was adjusted to one full profile and 10 to 30 augerings per 1000 ha, with the aim of reducing survey costs and accelerating the survey. On some sheets it is difficult for an experienced mapper not familiar with area to infer on what basis some of the boundaries were drawn. There was no attempt to standardise cartographic concepts to respect the 1:50 000 nominal scale.

The soil mapping units were almost always compound, each having several genetic soil types with the proportions estimated. There were no transect or grid studies to estimate map unit composition. In most, but not all sheets, the map unit also has indicated (1) general texture; (2) parent material; (3) rock outcrops class; (4) slope class, and in some cases (5) drainage class (although this latter is usually implicit in the soil type). These were not criteria for mapping, only for characterisation. For example, a major slope break did not by itself warrant a boundary, unless the genetic soil type or composition of the compound map unit changed at that feature. It is not clear from this construction of the legend whether some of the genetic soils correspond to one part of the range or all of it. A symbol such as:

g		*v*
	RI(v)	
r1-2		*1*

does not show composition of the mapping unit, although this is given in the legend (Figure 2). Here, the generalised texture is shown in the upper left (*g*), the parent material in the upper right (*v*), the rock outcrops in the lower left (*r1-2*), and the slope class in the lower right (*1*). It is not stated which of the three soil types named in the legend has rock outcrops class 1 and which 2, or whether the stated range applied to the entire map unit.

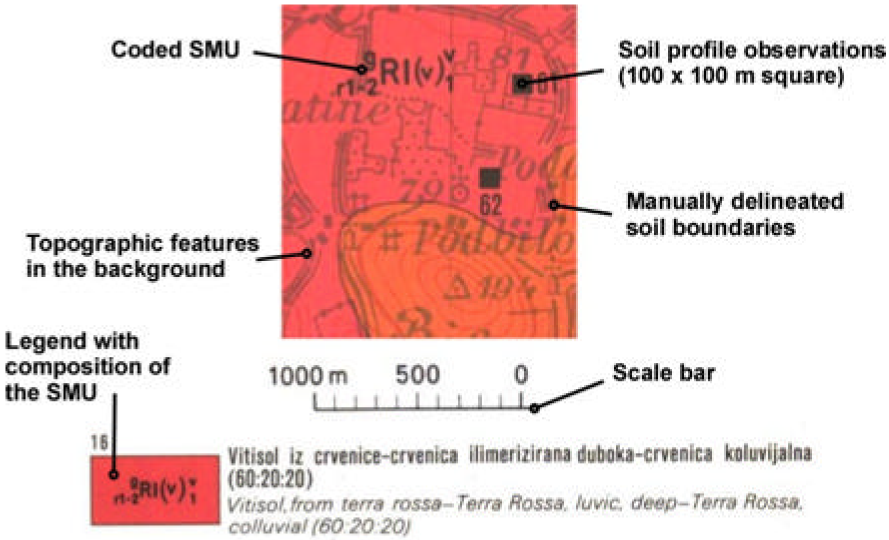

Figure 2. Part of the soil map with associated legend.

Sometimes the context allows the user to guess; in this example, the Vitisols probably don't have significant rock outcrops, the deep (luvic) Terra Rossas probably have class 1 outcrops and the colluvial Terra Rossas class 2. But this is not trivial when systematising the database, and requires inference by someone who usually did not participate in the original survey. Even more intricate symbols may be used, e.g.

$$ {}^{g,\,i}_{r0\text{-}1}\,R - DS\,{}^{v,\,d}_{2\text{-}3} $$

with two genetic soil types, two parent materials, two rock outcrop classes and two slope classes. The four modifiers can apply to one or all components and the values of the other modifiers. That is, the modifier ranges or multiple classes may apply to the whole map unit or to just some components, and this can not be determined from the symbol or descriptive legend.

In the accompanying reports, each map unit was described according to its soil types, percent of each type, type of landscape pattern (e.g. topo-sequence, drainage sequence, litho-sequence, or a mosaic, i.e. complex), and degree of contrast between the soils (Bogunovic, 1994). This last item is especially interesting to the map user: if the contrast is low, a land evaluation can safely be performed on the dominant soil and applied without too much risk to the whole map unit; if the contrast is high, components must be evaluated separately and carefully located in the field.

Classification of Yugoslav Soils (CYS)

The key issue in reading the BSMC, apart from understanding the soil survey principles and legend, is to understand the soil type names. In the former Yugoslavia, the Classification of Yugoslav Soils (CYS) was developed especially for the purpose of national inventory, as the basis for production agriculture, and to foster understanding of the soil resource. Its authors were influenced mainly by the Russian school, including Sibircev and Glinka; the main focus is given to the evolution of soil horizons under the influence of genetic processes (Škoric et al., 1985). Although Croatia is a relatively small country (56 538 km²), its soil variability is comparable to the entire Balkan region, so almost all CYS classes can be found in Croatia (Bognar, 1996).

In the 1930s the first classification system was developed, based on Russian principles and adjusted to the local soils. This was modified by Gracanin (1950) and then again in 1963, leading to the first official version of the CYS, which was presented internationally in 1964 at the 8th International Congress of Soil Science (Filipovski *et al.*, 1964). This version was also influenced by ideas from Kubiëna (1953) and the German system (Mückenhausen and Vogel, 1962). The CYS was revised three more times: in 1964, 1973 and 1985 (Škoric et al., 1985). A separate system (not CYS) was developed for the first phase of the BSMC by Kovacevic *et al.* (1967). Once the decision was made to continue with the second phase of the BSMC, this system had to be correlated to the new CYS system (Bogunovic, 1993), which was easily accomplished. The most recent version of the CYS (Škoric et al., 1985) is still in use in all republics of the former Yugoslavia, although there have been proposals to modify or abandon it in Croatia (Bogunovic and Racz, 2001) and Serbia & Montenegro (Antonovic and Protic, 1997).

Basic concepts of the CYS system

The CYS system has six hierarchical levels: division, class, type, sub-type, variety and form (Figure 3), with levels of detail similar to the German soil classification (Arbeitskreis für Bodensystematik, 1998). There are four divisions, based on the over-riding moisture environment: automorphic (hydrological weathering is limited to rainfall), hydromorphic (formed under the influence of fresh water), halomorphic (formed under the influence of saline water) and subaquic soils (formed in lakes, swamps and tidal zones); the influence of Kubiëna (1953) is obvious here. The classes reflect pedogenetic environments and states of development. The soil types and subtypes are most used in general mapping, and roughly correspond to the WRB reference groups, often with one or two 2nd level modifiers. They are defined mainly on the evidence of soil morphology. An overview of divisions, classes, and soil (sub)types is given in Table 1, along with a correlation to the most likely WRB reference group, if possible with 2nd level-modifiers. There is no key to CYS soil types, only descriptions out of which the best must be chosen. Subtypes are chosen with a within-type key. Class and horizon descriptions rely on the judgement of the classifier so the correspondence with the WRB can only be approximate, based on central concepts; it is not implied that all soils of a particular CYS type would classify as the given WRB group.

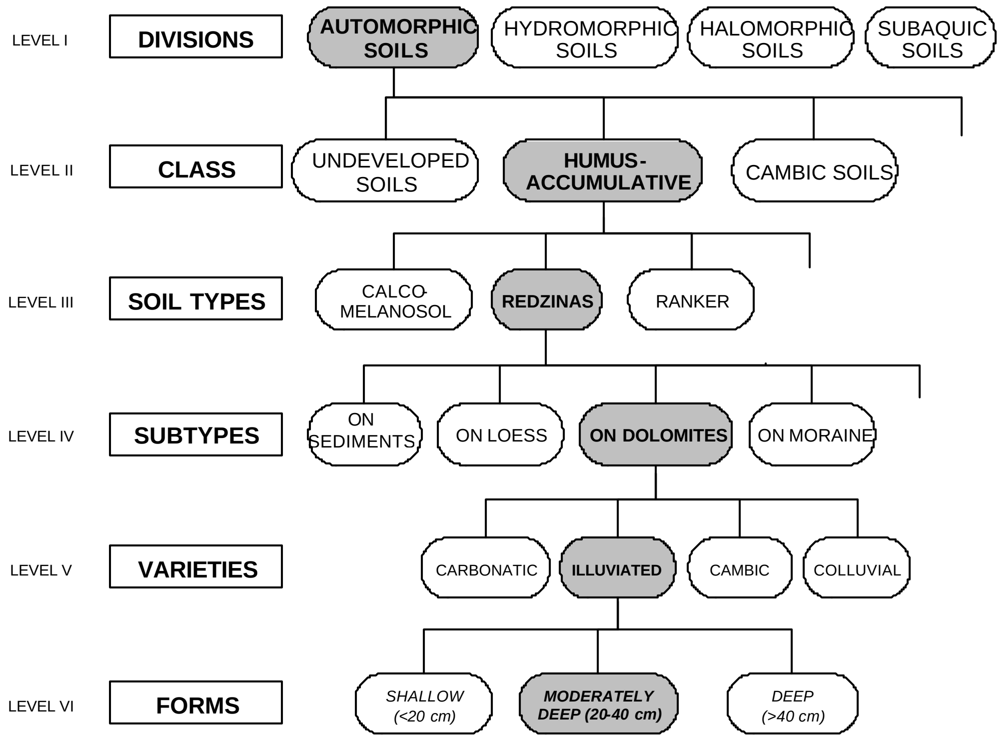

Figure 3. An example of hierarchical levels of the CYS system: Rendzina, on dolomites, illuviated, moderately deep.

Table 1. Divisions, classes and principal soil types in the CYS and corresponding WRB groups.

CYS			WRB soil group
Division	**Soil Class**	**Type or Subtype**	
Automorphic soils	Undeveloped	Lithosols	Lithic and Haplic Leptosols
		Regosols	Haplic Regosols
		Arensols	Arenosols
		Colluvial soils	Regosols (not Lithic)
	Humus-accumulative	Calcomelanosols	Humic Leptosols
		Rendzinas	Rendzic Leptosols
		Rankers	Humic Leptosols
		Chernozems	Kastenozems
		Vertisols	Vertisols
	Cambic	Eutric Cambisols	Eutric Cambisols
		Dystric Cambisols	Dystric Cambisols
		Calcocambisols	Calcic Cambisols
		TerraRossa	Rhodic Cambisols
	Eluvial-illuvial	Luvisols	Luvisols
		Podzols	Haplic Podzols
		Brunipodzols	Umbric Podzols
	Anthropogenic	Rigosols	Regi-hortic Anthrosols
		Hortisols	Hortic Anthrosols (not Regic)
	Technologenic	Deposols	Spolic Regosols
		Aerial precipitation soils	Haplic Regosols
		Flotisols	Spolic Regosols; Fluvisols
Hydromorphic soils	Pseudogleyic	Pseudogleys	Stagnic Gleysols
	Undeveloped alluvial	Fluvisols	Calcaric Fluvisols
	Semigley	Humoluvisols	Gleyic Fluvisols
	Gleyic	Humogleys	Humic Gleysols
		Eugleys	Haplic Gleysols
		Pseudogley-Gleysols	Gleysols
	Peat bogs (Histosols)	Low-moor peats	Sapric Histosols
		High-moor peats	Fibric Histosols
	Anthropogenic hydromorphic	Hydromeliorated soils	Gleysols (drained)
Halomorphic soils	Saline non-sodic	Solonchaks	Solonchaks
	Sodic	Solontez	Solontez
Subaquic soils	Undeveloped subaqual	Protopedon	Gleysols
	Developed subaqual	Gyttja	Histic Fluvisols
	Anthropogenic subaqual	Hydromeliorated soils	Gleysols (drained)

The lower classification levels are not as consistent as in WRB and USDA *Soil Taxonomy* (Soil Survey Staff, 1999a). For some soil types, different parent material classes are used to separate different sub-typesl; in other cases, pedogenetic properties are used. To separate the lowest levels, i.e. different forms or variants, soil texture, depth to bedrock or thickness of topsoil are used. These classification criteria are not defined explicitly, as in the case of WRB, so depend on the classifier's interpretation. In mapping, these lower levels were sometimes used, but not consistently even within individual map sheets.

Correlation of the CYS with other systems

Špoljar (1999) correlates the CYS to the 1990 FAO revised legend for the soil map of the world (FAO, 1990) and, then, used it to build a legend for the 1:1M FAO Soil map of Croatia (Bogunovic and Špoljar, 2001). Correlation with WRB is more difficult because WRB requires the (mostly quantitative) identification of diagnostic horizons and properties. The level of correlation is the CYS class to the WRB reference group, or the CYS soil type or possibly subtype to the WRB second level. The same difficulty applies to correlation between CYS and USDA *Soil Taxonomy* (Soil Survey Staff, 1999b), where correlation can be from the CYS form to the Soil Taxonomy family. In both cases, the most reliable procedure is to re-classify each pedon separately; correlation of whole classes is not possible because of the discrepancies in definitions and the vagueness of the CYS.

The main difference between the WRB and CYS systems for application in Croatia is that in the CYS some soil processes, notably gleying and illuviation, are described in more detail. There are a number of soil names used in the CYS that are not found in the WRB: hypogleys, amphigleys, pseudogleys, humogleys, which depend on the source and nature of gleying. Nonetheless, these concepts often have a counterpart, if not the same name, in the WRB.

Current activities

Land use planning in Croatia is most active at the level of the 21 counties. Eight of these are developing Geographic Land Information Systems (GLIS), typically at 1:100 000 scale. These include interpreted soil information which is being supplied by soils specialists using the BSMC map, legend, and pedon database, and polygon geometry directly from the digitised 1:50 000 map sheets (Husnjak and Bogunovic, 2002). Interpretations include: (1) soil physical and chemical properties; (2) landform properties; (3) derived soil-related land qualities such as suitability for irrigation; (4) measures required for land improvement for intensive agriculture (lime and fertilizer requirement, erosion protection, drainage and supplementary irrigation); (5) land suitability for various general land use types. In this way much value is being added to the original surveys; however the problems of coarse scale, non-standard cartography, and compound map units limits the accuracy of these interpretations (Hengl, 2003; chapter 8).

At the national level, the 1:300 000 soil map is being used for teaching of soil geography at universities and schools, by the Ministry of Environmental Protection and Physical Planning for devising national soil protection plans, and for national-level water management. A different 1:300 000 soil map is included in Martinovic's monograph (2000) but not georeferenced or digitised.

The BSMC (maps, reports, profiles, and digital products) are being used by various university researchers for individual projects. These include new volumes in the series of regional soil monographs: Dalmatia, the central mountainous regions, and middle Croatia at scale 1:200 000. Other projects include special studies for municipalities (Zagreb, Rijeka) and environmental impact studies for hydroelectric projects and river management projects.

Future directions

Regional soil monographs covering all of Croatia will be published with soil maps at scale 1:200 000 and a unified legend over the next few years. To further integration with world and regional soil databases, there are plans to create a SOTER (van Engelen and Wen Ting-tiang, 1995) map and database for Croatia with the technical support of ISRIC - World Soil Information. More generally, there is a for a comprehensive digital information system for land resources in the Republic of Croatia, complying with criteria and standards of medium-scale maps for the immediate users of land resources, policy and decision makers, and government departments involved in soil protection and development of physical plan.

One possibility is a project to systematise the existing BSMC into a seamless digital map at its effective scale, 1:200 000, as well as digitising the remaining 8000 soil profiles. This would add value to the existing 1:300 000 *Map of Soil Suitability for Cultivation* and would increase its spatial resolution, but would not answer the needs for detailed, location-specific soils information. It might be possible to enhance the precision of such a product by combining the point data, environmental co-variates, and related digital coverages, especially digital elevation models and coarse-resolution multi-temporal remote sensing (Dobos *et al.*, 2000).

There is also need for detailed soil maps (1:25 000) with map units at the soil form level, especially in intensively-used agricultural and urban areas. There are many detailed maps with manuscripts commissioned by cooperatives and state enterprises during the socialist period, which were produced by local soil scientists according to widely-divergent concepts and delivered directly to the client, but never published (Bogunovic *et al.*, 1998). Rescuing these data is not contemplated at present, due to the inaccessibility of the manuscripts and the difficulty in bringing them to a common standard. Still, they could be used as supplementary information in a new survey.

A new project to produce a detailed map would use more tightly-defined map units and modern mapping methods, as well as existing digital products such as digital topographic maps, digital cadastre, orthophotos or high-resolution satellite imagery, digital elevation models (McKenzie *et al.*, 2000), geological maps, and land cover maps. In addition, such a detailed inventory may require new investigations into detailed soil-landscape relations to allow the construction of predictive models of soil distribution.

In such a new survey, the main concepts of the inventory should be adjusted to the clients' needs (Bouma, 1999; Dalal-Clayton and Dent, 2001), starting from the planning objectives, then the required land qualities, and finally the diagnostic land characteristics needed to evaluate the land qualities. In addition, the required categorical spatial precision should be specified. This then would lead to the survey methodology. In this case, there are four types of clients for interpreted soils data that might contribute to such a needs assessment: 1) land use planning offices working at county level, producing semi-detailed land zoning maps; 2) nature protection agencies working at regional and sub-continental level and with a wide range of chemical and physical indicators of environmental quality especially of 'hot spots' and critical areas for intervention; 3) agricultural extension offices working at district and farm level; and, in case precision agriculture becomes popular, 4) farmers working at (sub-)field level. Three fundamental problems must be addressed before such a project could be realised: 1) institutional co-ordination among surveyors, 2) quantification and perception of the value of interpreted soils information by decision-makers at the several scales, leading to political support, and 3) financial support.

There is also a need to modify the CYS soil classification, to make it quantitative and objective, and to include some soils that are not well-classified by the current system. Alternatively, the WRB could be used, augmented by locally-defined families or series as is being proposed in the Germany – Czech Republic – Poland border area (Jahn et al., 2004).

As Croatia continues towards full membership in the European Community, the need for understandable, high-quality, soil geographic databases at several scales can only increase.

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