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A LAND-COVER CLASSIFICATION FOR MODELING NATURAL LAND COVER WITHIN THE IIASA LUC PROJECT

Jelle G. van Minnen, Günther Fischer,
Vladimir Stolbovoi

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IIASA International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Telephone: +43 2236 807 • Fax: +43 2236 71313 • E-Mail: info@iiasa.ac.at

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CONTENTS

1. INTRODUCTION

Natural forces have always shaped the Earth's surface. More recently anthropogenic impacts have induced rapid changes, which dominate the natural impacts in many areas. Several studies and modeling activities have been initiated to analyze the driving mechanisms behind these changes and to assess their consequences (e.g. Townshend *et al.*, 1991; Steffen *et al.*, 1992; IGBP, 1994; Turner *et al.*, 1995). An important issue within these activities is an adequate description and classification of the terrestrial land cover. Although many vegetation and land-cover classifications have been proposed for quite some time, no generally accepted global-scale classification exists. Land-cover datasets (e.g. Küchler, 1949; Matthews, 1983; Olson, Watts & Allison, 1985) and compiled classification systems/map legends (e.g. Holdridge, 1967; Box, 1981; Post *et al.*, 1982; Budyko, 1986; UNESCO in Küchler & Zonneveld, 1988; Strong, Oswald & Downing, 1990; Prentice *et al.*, 1992; Melillo *et al.*, 1993) differ in definition, spatial resolution, purposes, and outcome (as, for example, reviewed by Leemans, Cramer & Van Minnen, 1995). A major reason for these differences is that the classifications use different principles. Eco-physiognomy (determining morphological characteristics and lifeforms of dominant or co-dominant species), environment or ecology (relating the appearance and behavior of vegetation to environmental conditions like climate, soils and landform) and floristics are the most frequently used principles (Box, 1981; Küchler & Zonneveld, 1988). Furthermore, the classifications differ because some datasets/classifications describe actual land cover while others deal with potential cover, and because of differences in spatial scale (some are set up especially for local scale, while others represent global distribution). Several studies have recently been initiated to explore the possibilities of harmonizing existing classifications and to develop a consistent and widely acceptable reference land-cover classification (UNEP/FAO, 1994; De Bie *et al.*, 1995; Turner *et al.*, 1995). According to these studies, a meaningful comparison of land-cover classifications requires a common set of suitable attributes that can be used to correlate different categories. Agreement on types and measurements of such attributes is seen as the most important step in developing a global reference land-cover classification. These attributes will also be useful within other studies, which, for example, derive land cover from satellite data (e.g. Running, Loveland & Pierce, 1994).

At the beginning of 1995, the project *Modeling land-use and land-cover changes in Europe and Northern-Asia* (LUC) was initiated at the International Institute for Applied System Analysis (IIASA) in cooperation with several institutes in Europe and Northern-Asia (Fischer *et al.*, 1995b). An important activity within the project is the compilation of a continental-scale land-cover database, using various mapped sources of vegetation, land categories and agro-regionalization (Fischer *et al.*, 1995a). Together with the databases for climate and land resources, the land-cover database forms the backbone of the land-evaluation part of the project. As part of the development of the land-cover database, a land-cover classification scheme was introduced (Fischer *et al.*, 1995a). The scheme describes the categories of the land-cover database by using several attributes, which can be used to generate quantified information. These attributes 1) can be derived from the basic data sources 2) are based on eco-physiognomic principles, following concepts, which have recently been widely used, e.g. in remote sensing (e.g. Running *et al.*, 1994) and the UNEP-FAO harmonization project (UNEP/FAO, 1994; Wyatt *et al.*, 1995). Using this approach makes it possible to have a clear and understandable classification, which can readily be compared with other land-cover classifications. The categories of the basic land-cover classification can be aggregated in several ways, depending on the purpose and requirements of an application.

The goal of this paper is to describe how a natural vegetation classification has been set up, which is suitable for the vegetation modeling component of the LUC project. Current and future functioning and distribution of (semi-)natural vegetation is important within the project, because:

* (semi-)natural vegetation is an important part of the global and continental land cover.
* (semi-)natural vegetation plays a critical role within most greenhouse gasses cycles (GHG), e.g. of carbon and nitrogen.
* (semi-)natural vegetation is an important component of certain land-use categories (e.g. agriculture and forestry), which are part of the LUC project.

In Section 2 we briefly present the set-up of the general land-cover classification, including our definition of land cover, the basic principles, basic sources of information, and a description of the most important attributes. We also describe how the natural land-cover classification is derived from the basic land-cover database. As mentioned before, the categories are grouped by using eco-physiognomic attributes. In Section 3 we change from the database concepts to the modeling part. The project aims to simulate impacts of environmental changes on the distribution and productivity of different categories of natural land cover. Therefore environmental attributes are added to re-organize and further sub-divide the basic classification. Thus, both eco-physiognomic and environmental attributes are used to distinguish the basic elements of the classification. We illustrate the approach by presenting the original and aggregated vegetation data for the Former Soviet Union (FSU). We used FSU data, because they became first available within the project. In Chapter 4 we describe some future activities of the LUC project, which are related to modeling natural vegetation. Again, the aim of this paper is only to present the basic outlines of the approach. In the near future linkages to the environmental variables (climate, soil, landform) will be established. Finally, Chapter 5 contains some conclusions regarding the ongoing activities.

2. THE LAND-COVER DATABASE OF THE IIASA LUC PROJECT

Many definitions of land cover exist around the world (e.g., summarized by De Leeuw & De Bie, 1995), but most of them only partly fit the tasks of the LUC project. We combined elements from previous definitions to develop a definition that reflects the special needs of the LUC project, namely to relate land use and land cover: *The biogeophysical state of the Earth's surface, shaped by and relevant to various kinds of land use and other human activities* (Fischer *et al.*, 1995a). For our purposes we grouped the activities into agriculture, forestry, settlement & industry, nature conservation/protection and not-used. The compilation of the LUC land-cover database uses several basic sources of data, including land categories and vegetation maps of China, Japan, and Russia and the Digital Chart of the World (DCW, ESRI, 1993). The DCW is used to define cities, industry, and infrastructures. These basic data sources define the building blocks of our database. The categories of the land-cover classification will be set up in accordance with the availability and suitability of the basic data.

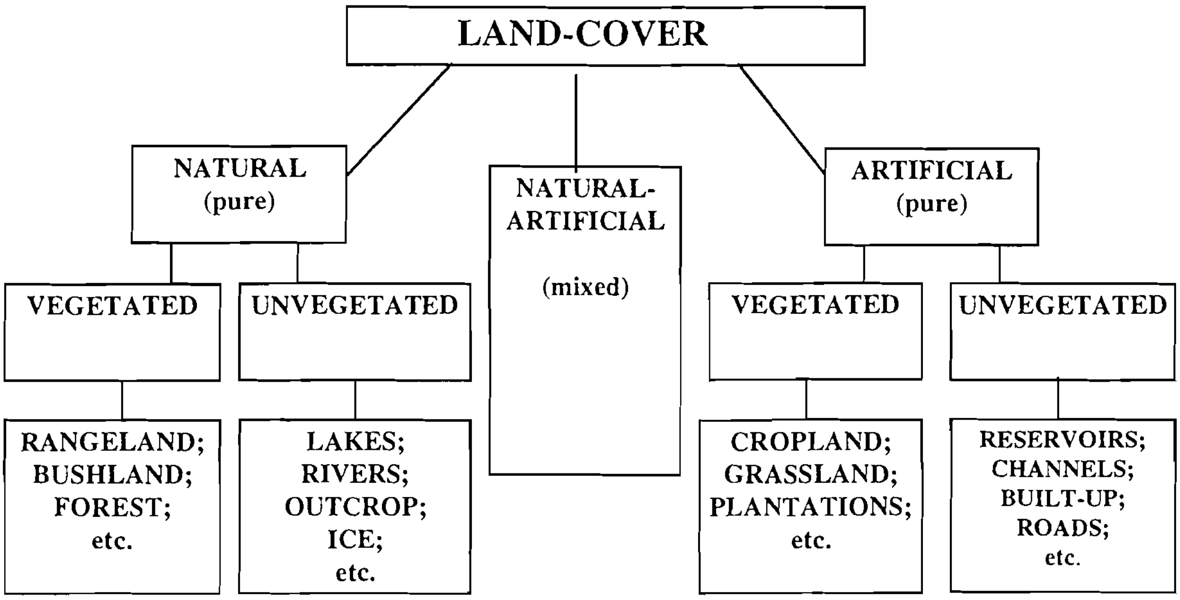


Figure 1: Conceptual scheme of the IIASA land cover database (Fischer *et al.*, 1995a)

Figure 1 illustrates the principle scheme of the IIASA land-cover database. It shows that land cover is determined by both natural and human processes. We define pure natural areas as areas without any direct human intervention, while pure artificial areas are compiled of fully man-made categories. The classification presented in this paper aims to compute the appearance and functioning of the actual land cover of the areas covered by natural and semi-natural vegetation.

For the purpose of this classification, the general database categories were aggregated, emphasizing (semi-)natural land cover. The classification uses eco-physiognomical plant attributes as a base. Although a classification based on floristic attributes might give a higher level of accuracy, eco-physiognomical attributes are more useful for setting up a classification on a regional scale. As stated by Küchler & Zonneveld (1988), *a uniform classification of vegetation for world-wide or regional mapping use must necessary be physiognomic in character and principle.* Floristic characteristics are less useful at these scales as dominant factors, because the flora composition is incompletely known in many areas (sometimes is might be useful to use it as secondary criteria for classifying, e.g. as done in Strong *et al.*, 1990). And even if the classification would only be based on dominant species, the number of species is often prohibitively large. Other advantages of using eco-physiognomical attributes are that they can easily be linked to the vegetation map of China, Japan, and Russia, that they create the possibility of an accurate comparison with other datasets, and that they can be related to environmental conditions (see Chapter 3). Scheme 1 shows the basic set-up of the classification, the eco-physiognomical attributes that are used to distinguish the different classes, and presents one or more potential land-use types for each category. In addition to pure land-cover categories described in Scheme 1, combinations of categories occur. Following the principles of Fischer *et al.* (1995a), these will be described as percentages of the dominant and associated classes within an area. Another important aspect is that Scheme 1 describes a static situation. Dynamics, for example changes in productivity due to environmental changes, will be taken into account by using the categories within a modeling framework (see Section 3 and 4). The first attribute is the level of modification, where (semi-) natural classes are separated from artificial categories. We define artificial/man-made areas as conditions, where land cover is determined and organized by human activities. Environmental aspects often play a less important role in such areas (mostly only to define extreme boundary conditions). For example, forest plantations/planted forests are defined as artificial, while other types of forests are categorized as (semi-) natural, although the latter type could be largely affected by humans. For both levels of modifications, different (sets of) models will be used. Structural typology (third level) is taken into account to distinguish woody (perennial) vegetation types from non-woody (mostly annual) categories. It distinguishes trees and shrubs from grasslands and forb/fern areas. Vegetation height (fourth level) is especially important within (semi-) natural, woody vegetation types. Height is used to separate forest stands from non-forest types. We assume that plants which are unable to reach a height of more than 6 meters (e.g due to environmental constraints) will be classified as (e.g.) shrubs. This threshold value of 6 meters is derived from principles used in the Russian vegetation map (Isachenko *et al.*, 1990), Chinese vegetation map (Zheng Du, pers. comm., 1996), and the UNEP/FAO vegetation classification harmonization program (UNEP/FAO, 1994; Wyatt *et al.*, 1995). The distinction between forest and non-forest is important because of their different suitability for potential land-use types. Forests, for example, can be used to extract timber, while shrub lands are less useful for this purpose. Also for the carbon budget such a distinction is important. Canopy coverage, leaf type and leaf phenology (levels 5-7) are only used in areas which are (partly) covered by trees. First, because the classes are relatively large in area. Secondly and even more important, these factors determine the potential land-uses of the different forest/woodland types. Although the Russian forest statistics mostly use basal area (Chvidenko, pers. com., 1996), Russian and international UNEP/FAO, 1994; Wyatt *et al.* data can be used to distinguish the different categories by using canopy coverage. We set, in accordance with the literature, the class boundaries for separating dense versus closed forests and closed forest versus woodland at 60% and 40%, respectively.

Degree of modification	Land cover	Structural typology	Vegetation height[1]	Vegetation canopy coverage[1]	Leaf type	Leaf phenology		Potential use[2]
(Semi-) natural	Vegetated areas	Woody plants	forests (>6 m)	dense (>60%)	needle leaved			2,3,7,8
						evergreen	Evergreen needle leaved dense forest	
						deciduous	Deciduous needle leaved dense forest	
					broad leaved	evergreen	Evergreen broad leaved dense forest	
							Evergreen small leaved dense forest	
						deciduous	Deciduous broad leaved dense forest	
							Deciduous small leaved dense forest	
				closed (40-60%)				2,3,7,8
					needle leaved	evergreen	Evergreen needle leaved closed forest	
						deciduous	Deciduous needle leaved closed forest	
					broadleaved	evergreen	Evergreen broad leaved closed forest	
							Evergreen small leaved closed forest	
						deciduous	Deciduous broad leaved closed forest	
							Deciduous small leaved closed forest	
				sparse/open (<40%)				2[3],3,8
					needle leaved	evergreen	Evergreen needle leaved woodland	
						deciduous	Deciduous needle leaved woodland	
					broad leaved	evergreen	Evergreen broad leaved woodland	
							Evergreen small leaved woodland	
						deciduous	Deciduous broad leaved woodland	
							Deciduous small leaved woodland	
			non-forest (< 6m)				Bush/shrub land	1b[4],3,7,8
							(Wooded) tundra	
							(Vegetated) deserts	
							Wetlands	
		Non-woody plants					Natural grassland/meadows	1b,3,8
							(Herbaceous) tundra	
							Forb and fern areas	
							Moss/lichen areas	
	Unvegetated							
		Bare ground					Bare soils, rocks, sand formations	8
							(unvegetated) deserts	
		Water bodies					Large water bodies	3,4,6,8
							Rivers	
		Permanent snow/ice					Snow/Ice	3,8
Artificial/man made	Vegetated areas							
		woody/perennial						
			forests (> 6m)				Planted forests	2,4,7[4]
		non-woody/mainly annual						1a+b,
			non-forest (<6m)				Cropland	
							Pasture land/rangeland	
	Unvegetated areas							
		Water bodies					Water channels	4,6
							Large water reservoirs	
		Build ups/Infrastructure					Cities/industry	5,6
							Roads,railways etc	

Scheme 1: The land-cover classification of the IIASA LUC project, based on eco-physiognomic attributes. Further subdivision is possible using climate and soil conditions (see Table 2). The proposed land-uses are based on the description in Fischer *et al.* (1995): 1 Agricultural use (1a crops; 1b: pasture); 2 Forestry; 3 Nature conservation & Environmental protection; 4 Water supply; 5 Settlement & industry; 6 Transportation; 7 C sequestration; 8 Not used. Emphasis within this scheme is on (semi)natural land-cover. For other purposes classes could again be sub-divided.

[1] According to values used in Chinese, Russian, and FAO classification

[2] According to Küchler & Zonneveld (1988), Classes defined in Fischer *et al.* (1995)

[3] Is temporary less useful for that particular use

[4] Is less useful for that particular use, compared to other possibilities

3. CLASSIFICATION FOR MODELING NATURAL LAND COVER

In this chapter we describe how the land-cover classification is set up, which will be used within the LUC project to simulate changes in distribution and functioning of natural vegetation. As briefly stated earlier, requirements of the classification are that:

* it is based on a number of relevant and understandable driving variables. Eco-physiognomic attributes (Chapter 2) are very useful for this purpose.
* it includes attributes which enable us to relate current and future distribution of land cover to environmental variables.
* it is applicable for the continental study region of China, Japan, and Russia.
* it is not too general in order to retain sufficient detail in our database.
* it includes certain attributes which makes the classification interpretable to other studies, dealing with the definition and classification of land cover (Running *et al.*, 1994; UNEP/FAO, 1994; De Bie *et al.*, 1995; IGBP-DIS, 1995; Wyatt *et al.*, 1995). This goal will be achieved by extending the general classification, which uses eco-physiognomic plant attributes.

Important environmental variables, especially at the spatial scale of the LUC project, are climate, soils, and landform. Several relationships between climate and vegetation distribution have been designed in the past (e.g. Holdridge, 1967; Emanuel, Shugart & Stevenson, 1985; Prentice *et al.*, 1992). Walter & Breckle (1985) and Walter (1985) even related vegetation distribution to soils and physiography, although only in a qualitative. Parts of their scheme are useful and will be taken into account within our approach.

Furthermore, we wanted to set up the classification in such a way that it could be related to the vegetation maps of the LUC regions. However, using the maps directly would create several problems. First, the vegetation maps of China (Scale 1:4 Million), Japan (1:2 Million), and Russia (1:4 Million) contain 103, 58 and 132 vegetation categories respectively. It is impractical and even inadvisable to use this fine-scale information for modeling future distribution and behavior. Secondly, many natural vegetation categories of the maps differ in definition between the countries, which makes it difficult to establish a uniform classification for the whole region. Finally, the actual situation provides less information on environmental limits and therefore on how the land-cover types will change under changing conditions.

To eliminate these problems, we established a new classification independent of the particular vegetation maps. The classification is based on the concepts of the so-called Plant Functional Types (PFT), which are combined into biomes (Walter, 1985). PFTs are defined as vegetation units, distinguishable by combinations of eco-physiognomic characteristics (Box, 1981). We defined 27 PFTs (Table 1) and related their distribution to different environmental conditions. Therefore, our categories are linked to both eco-physiognomic and environmental attributes. By making overlays for climate, for example, evergreen coniferous trees (a land-cover type, classified by using eco-physiognomy; Scheme 1) can be divided into tropical, warm/temperate, cool/temperate and boreal coniferous evergreen classes (Table 1 and 2). The original 77 PFTs (Appendix 1) of Box (1981) are aggregated into our classes (Table 1) to increase the capability for comparison with other classifications. Finally, we defined 40 biomes as our basic land-cover categories, using different combinations of PFTs, assuming certain hierarchy and competition potentials. A biome is a fundamental vegetation unit of which larger ecological systems are made up and which are characterized by a uniform environment (Walter, 1985). We believe that the selected set of biomes represents a classification which is useful for modeling the current and future distribution of natural vegetation at a continental scale. In principle, our approach is similar to the approach of Prentice *et al.* (1992). However, we defined a larger number of biomes to enable a more accurate comparison with observations (e.g. vegetation maps). Table 2 contains an overview of the forty biomes or land-cover classification. The table illustrates how PFTs are combined into the basic land-cover (biome) types taking into account certain climate variables. At a later stage we may include a differentiation of the land cover types on the basis of soil and landform attributes. A statistical analysis (see Chapter 4) will clarify whether an additional sub-division is warranted.

Table 1: Plant Functional Types, used as a basis for the natural land cover classification in IIASA-LUC project (numbers between brackets refer to Plant Functional Types, given by Box, 1981[3]).

Trees

1 Tropical broadleaved evergreen (1,2[1],14[1,2],44[1,2])
2 Tropical narrow/needle leaved evergreen (7[1],8[1])
3 Tropical broadleaved raingreen (3,5,14[2])
4 Warm-broadleaved evergreen (4a+b)
5 Warm-temperate needle leaved evergreen (9[1],10a, 10b)
6 Temperate broadleaved summergreen (6a)
7 Cool/temperate needle leaved evergreen (10c, 12[1])
8 Cool broadleaved summergreen (hard leaved) (6a)
9 Boreal broadleaved summergreen (small leaved) (6b)
10 Boreal needle leaved evergreen (11)
11 Boreal needle leaved summergreen (13)
12 Cold needle leaved summergreen (13)

Dwarf trees/arborescents

13 Tropical dwarf (15,18,22[1,2],23[1,2],26,28)
14 Warm temperate/xerophitic dwarf (25[1],27,29,45[1])
15 Temperate/cool dwarf (16,17,28)
16 Boreal dwarf (20,30)

Shrubs/forbs

17 Tropical shrubs (31[1],58[1,2])
18 Warm temperate/sclerophyll (32a,35,36b,38,43[1],48,56[1],62,63)
19 Temperate shrubs (32b,34,36a,39,59[2],61)
20 Cool/Boreal shrubs (32c,37,39,40,48)
21 Cold shrubs (37,41,42[1],63)

Grammonoids/Grasses

22 Tropical tall grass (especially C4 species) (50[1])
23 Tropical short grass (esp. C4) (53[1])
24 Warm temperate tall grass (esp. C4) (49)
25 Warm temperate arid short grass (53)
26 Temperate tall grass (esp. C3) (51)
27 Temperate short grass (esp. C3) (52)
28 Boreal/cold short grass (esp. C3) (54,55)

Desert plants

29 Hot/dry desert plants (33,46[1],47[1],57,64)
30 Halophytic/salinid desert plants (62)
31 Cold desert plants (65,66)

Miscellaneous

PFT's which are not dominant and/or not determining the land cover on the medium spatial scale (19,21,24,44,60,67-77)

[1] Does not exist in Northern-Eurasia region
[2] Understorey/floor vegetation
[3] Classes are described in appendix 1

Table 2: Classification, used for modeling natural land cover within the IIASA-LUC project

Land cover name	PFT combination	Russian map[1]	Chinese map[1]
Forests			
1) Tropical evergreen forest	1, 1+2		33
2) Tropical raingreen forest	1+3,2+3		28,31,32
3) Broadl. evergreen/sub-tropical forest	4+5		9,10,20,25-27,29
4) Warm/temperate coniferous forest	5		11-15
5) Temperate deciduous forest	6+7+8+9+11	54-56,60-63,65	17-19,23a+b,24
6) Temp. mixed forest	6+7+8+9+10+11	50-52,59,64	16,22
7) Cool-temperate coniferous forest	7+9+11		8
8) Cool deciduous forest	7+8+9+11	37,58	20,21,23a
9) Cool mixed forest	7+8+9+10+11	34,36,57	
10) Cool conif. forest/southern taiga	7+9+10+11	30-32,35,47,53	5,7,15
11) Middle sub-continental taiga	9+10+11	26-28,43-46	3,4
12) Middle continental taiga	11	29,33,48	1
13) Northern sub-continental taiga	9+11	22,24,49	
14) Northern continental taiga	12	23,25	2
Woodlands			
15) Tropical dry woodland/savanna (Broadleaved deciduous)	13+17+22+23, 3+13+17+22+23		44
16) Xerophitic woods	14	103,106-108	35,36,38,45
17) Temperate woodland (needle & broadleaved)	15+16+19+20+21+25 +26+28		6,34,37
18) Cool/boreal woodland (needle & broadleaved)	16+21+28	15,40-42	
Shrub lands			
19) Tropical shrubs	17+23		40-43,80
20) Xerophitic shrubs	18+27	71,72102,104,105,109	39,45,55-60,83
21) Cool-Temperate shrubs	19+20+21+25+26+28	118	46,47
22) Wooded tundra	16+19+20+21+25 +26+28	11,19-21	48
23) Southern tundra	16+20+21+25+26+28	7,8	81,82
24) Northern tundra	20+21+25+26+28	3-6	
25) Alpine tundra	21+28	9,10	49
Grassland areas/steppes			
26) Tropical steppes, tall	17+22+23		30
27) Tropical steppes, tall	23		
28) Warm/temperate dry steppes/meadow	27	67-70,80	65,71,72
29) Warm/temperate steppes	24+27		66-69,70
30) Forest steppe	16+21+25+26+28	38,39,66	73-75(?)
31) Cool grassland	21+25+26+28	13,14,16,17,73-79,81,82	76-79,83-86
Deserts			
32) Hot dry desert	25	85,88,90,93-95,97-101	50-53
33) Salt halophytic desert	26	83,84,86,87,89,91,92,96, 119,120,128	54,61-63
34) Cool desert	21	2,12,18	64
35) Polar desert	31	1	
Others			
36) Alluvial sequences		121-127,129,137	
37) Reed brakes		130-132	
38) Mires/swamps		110-117	87-89
39) Large water bodies		135,150	
40) Ice		136	

? not certain yet and require a more detailed geographical analysis

[1] classes are described in appendices 2 and 3

As stated earlier, environmental characteristics will be taken into account to distinguish the PFTs of Table 1 (and therefore also biomes). These characteristics include several climatic factors (temperature of coldest month to evaluate cold tolerance and chilling requirements, temperature of the warmest month; temperature sum above zero and above five degrees as a measure for heat provision; and precipitation), soil moisture availability, soil fertility/nutrient availability, and certain landform factors. First, climatic conditions and soil water availability are assessed using the BIOME model (Prentice *et al.*, 1992; Prentice, Sykes & Cramer, 1993), followed by additional steps accounting for the other attributes. These additional steps are necessary because BIOME, like most global land-cover distribution models, relates the distribution of PFTs only to climate variables and a measure of moisture stress. For a broad-scale distribution analysis such an approach may be sufficient, as discussed for instance by Prentice *et al.* (1992) and Cramer & Solomon (1993). However, at a more detailed-spatial scale local factors, such as topography and soil conditions, cannot be ignored, as indicated by Box (1981). Soil fertility, for example, could be used to distinguish closed forests versus woodlands versus herbaceous vegetation. In addition to the BIOME approach (Prentice *et al.*, 1992; Prentice *et al.*, 1993) we simulate soil moisture availability by considering different rooting depths and texture classes, using the approach described by Otto, Hunt & Kohlmaier (1995). Which specific soil fertility and landform factors will be taken into account in the model is still under investigation. No model for natural land cover we know incorporates soil fertility and/or landform to determine the vegetation distribution. As already mentioned, the critical variables and their thresholds will be identified by carrying out a statistical analysis (when the complete LUC land resources database becomes available). These variables will then be linked to the BIOME model. Finally, we intend to tackle the issue of species migration, competition, and succession, by relating changes in PFTs to the distribution in adjacent areas. One of the possible approaches is implemented in the terrestrial component of the IMAGE model and described by Van Minnen *et al.* (1995).

To compare the results of our approach, we aggregated the categories of the vegetation maps of China and Russia into our land-cover categories (see Table 2 for the aggregation. The original classes are described in Appendix 2 and 3). The aggregation is based on similar eco-physiognomic plant characteristics (e.g. vegetation height, coverage), as used to set up the general land-cover classification of the project (Scheme 1), followed by making an overlay for environmental conditions. The aggregation was analyzed in detail for Russia, using a recent digital vegetation map developed within the LUC project (Stolbovoy *et al.*, 1996). The result is shown in Figure 2.

To illustrate the usefulness of the aggregation, the distribution figures of the original and the aggregated categories of the Russian vegetation map (Isachenko *et al.*, 1990) are shown below (Table 3). Some categories of the original classification (Table 3a) are widely distributed (in area and/or frequency), while others occur only rarely. The aggregation (Table 3b) resulted in a more balanced ratio of the categories. Statistically (Table 4), the aggregation resulted in a more balanced distribution with less large extremes around the mean values (resulting in lower coefficient of variation, CV). CV is chosen because it describes a relative variance (Janssen, Heuherger & Sanders, 1992). A relative measure is in our analysis necessary because the original and aggregated vegetation include two different distributions. The more balanced distribution enables a more accurate statistical analysis (see Chapter 4) between the distribution of the categories and the environmental attributes.

Table 4: Statistics of the frequency and area distribution of the original and aggregated vegetation categories

	Original data		**Aggreg. data**	
	Frequency	Area (km^2)	Frequency	Area (km^2)
Minimum	1	2.6×10^{2}	29	2.9×10^{10}
Maximum	348	1.9×10^{12}	597	2.9×10^{12}
Mean	38.3	1.6×10^{11}	182.3	7.8×10^{11}
Median	21.5	7.0×10^{10}	120	6.4×10^{11}
Coefficient of Variation[1]	1.37	1.51	0.87	0.88

[1] CV is defined as the standard deviation/mean ratio (Janssen *et al.*, 1992). It describes the relative width with respect to the mean value. A relative measure is necessary because of the number of samples and the mean value largely differ.

Table 3: Frequency and area distribution of the original vegetation categories (3a) and aggregated biomes (3b) for the vegetation map of the Former Soviet Union.

3a: Original data (Isachenko *et al.*, 1990)[1]

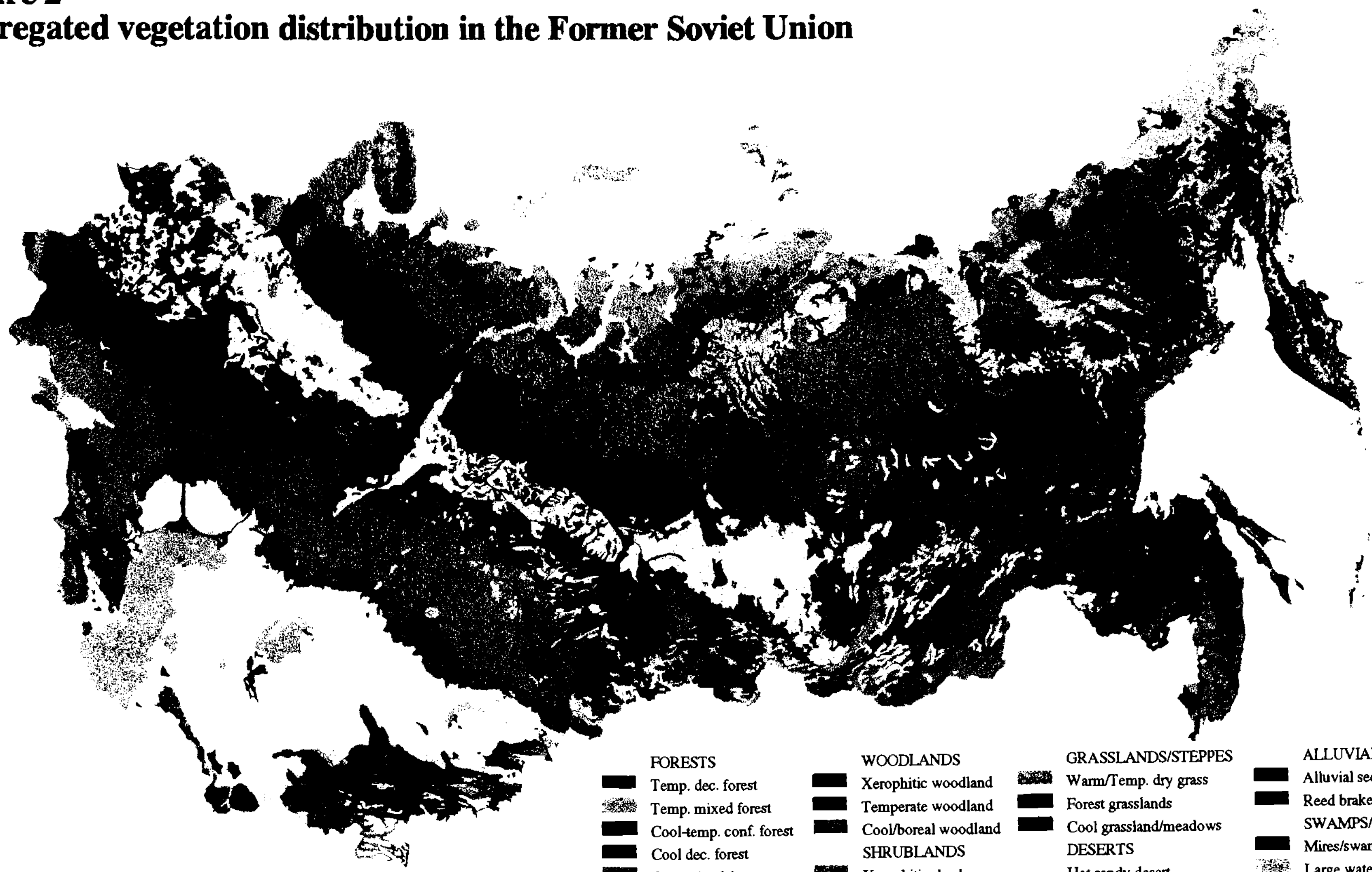
No.	Freq.	Area	No.	Freq.	Area	No.	Freq.	Area	No.	Freq.	Area
1	31	2.9E+10	36	17	2.4E+10	71	29	3.6E+11	106	8	4.4E+09
2	93	2.3E+11	37	13	1.3E+11	72	30	1.5E+11	107	6	1.7E+09
3	41	2.2E+11	38	58	8.0E+10	73	26	5.8E+10	108	7	1.7E+10
4	6	7.1E+10	39	52	4.3E+10	74	6	2.9E+10	109	23	4.9E+10
5	24	1.6E+11	40	37	3.5E+10	75	23	3.9E+10	110	68	6.0E+10
6	21	7.1E+10	41	120	9.5E+11	76	7	1.6E+10	111	83	1.8E+11
7	62	3.9E+11	42	348	6.4E+11	77	9	3.0E+10	112	98	1.7E+11
8	15	1.6E+11	43	106	2.5E+11	78	9	1.1E+10	113	49	2.9E+10
9	329	6.3E+11	44	21	2.2E+11	79	10	5.8E+10	114	45	1.4E+11
10	38	1.3E+11	45	56	2.1E+11	80	16	3.1E+10	115	194	2.7E+11
11	196	5.4E+11	46	47	1.9E+11	81	4	9.6E+09	116	32	4.5E+10
12	47	4.0E+10	47	48	1.8E+11	82	7	1.5E+10	117	28	1.8E+10
13	11	1.4E+10	48	105	1.9E+12	83	28	3.3E+11	118	59	7.5E+10
14	8	1.2E+10	49	37	9.3E+10	84	61	8.1E+10	119	74	5.0E+10
15	17	4.6E+10	50	1	1.6E+10	85	30	9.2E+10	120	192	1.7E+11
16	31	3.1E+10	51	8	1.1E+10	86	19	3.4E+11	121	53	2.5E+10
17	24	5.1E+10	52	13	1.1E+10	87	16	5.2E+10	122	2	2.1E+10
18	13	1.6E+10	53	9	1.9E+09	88	31	1.8E+11	123	18	8.9E+10
19	10	1.7E+10	54	3	3.4E+09	89	5	5.1E+10	124	6	4.0E+10
20	11	4.7E+10	55	15	7.2E+10	90	8	8.1E+10	125	3	2.9E+09
21	26	2.6E+11	56	47	1.2E+11	91	3	1.2E+10	126	41	9.1E+10
22	57	2.9E+11	57	26	1.1E+11	92	8	2.8E+11	127	3	2.4E+10
23	15	9.5E+10	58	80	2.5E+11	93	19	9.5E+10	128	18	6.3E+10
24	66	2.9E+11	59	11	1.0E+10	94	3	1.8E+10	129	9	1.8E+10
25	57	1.0E+12	60	27	3.8E+10	95	24	7.2E+10	130	13	4.5E+10
26	29	3.6E+11	61	14	7.3E+10	96	2	2.7E+10	131	25	3.6E+10
27	34	2.0E+11	62	10	4.8E+10	97	14	4.4E+10	132	10	1.5E+10
28	187	4.8E+11	63	2	2.1E+10	98	1	4.6E+09	133	15	1.5E+10
29	47	9.7E+11	64	7	7.6E+10	99	10	6.5E+10	134	19	6.9E+10
30	45	5.4E+11	65	2	3.6E+08	100	4	4.9E+09	135	1	1.5E+10
31	35	2.0E+11	66	83	6.8E+11	101	4	8.8E+09	136	61	5.1E+10
32	85	3.9E+11	67	37	4.4E+11	102	5	2.5E+10	137	4	2.6E+08
33	18	1.2E+11	68	61	4.9E+11	103	8	8.8E+10	150	58	5.9E+11
34	50	5.0E+11	69	62	5.8E+11	104	13	8.4E+10			
35	78	3.3E+11	70	22	2.2E+11	105	8	9.5E+10			

3b: Aggregated classes

no	freq.	area	no	freq.	area
5	120	3.8E+11	24	92	5.3E+11
6	40	1.2E+11	25	367	7.6E+11
8	93	3.8E+11	28	198	1.8E+12
9	93	6.4E+11	30	193	8.1E+11
10	300	1.6E+12	31	175	3.7E+11
11	480	1.9E+12	32	148	6.7E+11
12	170	2.9E+12	33	479	1.5E+12
13	160	6.6E+11	34	153	2.9E+11
14	72	1.1E+12	35	31	2.9E+10
16	29	1.1E+11	36	120	3.7E+11
18	522	1.7E+12	37	48	9.6E+10
20	108	7.6E+11	38	597	9.1E+11
21	59	7.5E+10	39	59	6.1E+11
22	243	8.6E+11	40	61	5.1E+10
23	77	5.5E+11			

[1] Description of the vegetation classes is given in Appendix 2

Figure 2
Aggregated vegetation distribution in the Former Soviet Union



VEGETATION of the USSR. Scale 1:4 M. GUGK, M., 1990.
Edition by: c.g.s.T.I.Isachenko,c.biol.s., et. al.

LUC IIASA

4. FUTURE ACTIVITIES

An important activity in the near future will be the validation of the proposed classification scheme. First, we will evaluate the applicability of our classification scheme for China and Japan with vegetation experts from outside the project (within and outside IIASA). The evaluation is necessary because it is intended to apply it to the entire study region of the project. For the FSU this evaluation has already been undertaken (Chapter 3). In addition, we will undertake additional GIS analyses to verify the distribution of our vegetation categories. Figure 2 shows the results for the FSU. The aggregation for China is only in the starting phase (because currently only have a paper version of the vegetation map is available), while the aggregation for vegetation types in Japan has still to be initiated. Finally, we have to clarify whether the classification is consistent with other parts of the project (e.g. the agricultural model). For example, we will investigate whether the level of aggregation is roughly equivalent with other parts in order to avoid differences in detail.

Another future activity will be the development of a new vegetation distribution model to specify natural vegetation in the LUC core model. This model will contain linkages to environmental databases, which are set up within the project. Existing model approaches will be used as much as possible, but adaptations and additional assumptions might be necessary to tailor these models to the objectives of the LUC project. For example, linking the current and future distribution of the vegetation classes to soil conditions and landform characteristics requires additional research in order to specify the most important determining factors, including a consistent list of constraints (e.g. organic matter content). Furthermore we intend to define for every category an 'internal' sensitivity rating to different environmental changes. By using such indicators we try to capture also relatively small changes, which may occur within biomes. These changes would not show up if only complete conversions between categories were taken into account.

Additional to the latter aspect, we will take into account dynamics within the land-cover categories. Simulating dynamics is for example necessary, because of changes in productivity due to changes in climatic and soil conditions. Furthermore, we have to implement spatial dependencies within the model to approximate the issues of migration, succession and competition. The spatial variability will be initialized by using the large database (Stolbovoy *et al.*, 1996), which will be one of the major outcomes of the LUC project. Temporal dynamics will be taken into account by using different carbon and nitrogen cycle models, which exist already at various other institutes we have contacted.

Finally, we have to link the vegetation distribution model, including its classification, to other activities of the LUC project. Important links will be the core model (Fischer *et al.*, 1995b), the agricultural specifications (Rosenzweig & Iglesias, 1995), the carbon-cycle model, and the forestry model. For the latter two activities, cooperation with the Siberian Forestry Project at IIASA has been initiated. Again, these require research, e.g. about the kind of information needed by the different models and scale considerations.

5. CONCLUSION

The natural land-cover classification, proposed in this paper, has been set up to link land-cover information at different spatial scales. Broad-scale climate changes can be related to more local conditions, like soil fertility. Changes in environmental conditions at different scales will be used to simulate the impacts on natural land cover. By using the classification within the LUC model we hope that the interactions between climate, soil, landform on one hand and minor and major natural land-cover changes on the other will be better understood.

The classification represents an approach which is based on clearly defined and relevant plant attributes. This enables model results for current situations to be compared with observations at a (sub-)continental scale, with national vegetation maps, and with databases from other projects, which present current land-cover data. The latter point is important because of the contribution to the UNEP/FAO project, which develops methods to harmonize different land-cover classifications (Wyatt *et al.*, 1995).

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SUMMARY

In this paper, a classification is introduced, which will be used for modeling current and future natural land-cover distribution within the IIASA project *Modeling land-use and land-cover changes in Europe and Northern-Asia* (LUC). Natural vegetation is important within the project because it is part of the continental land cover, it affects certain land-use types (especially forestry and agriculture), and it plays an important role within the cycles of most greenhouse gasses. The classification is set up after an evaluation of existing classifications and combines eco-physiognomic principles (of the general LUC land-cover classification; Chapter 2) with environmental (climate, soils, landform) attributes. The classification aims to be useful in such way, that 1) natural land cover (changes) can be simulated, taking into account broad-scale as well as more regional environmental conditions; 2) it can be applied in a similar way for the entire region of the project; and 3) it can be compared with other databases/classification within the project and from outside (e.g. remote sensing). Applications for the current available data (especially for the FSU) have shown the approach is useful. However, setting up the classification is just the beginning of modeling natural land-cover distribution and behavior within the project. More detailed analysis of the classification, the development of a regional applicable vegetation distribution model, and the coupling of this model to other parts of the project will start in the near future.

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Appendix 1:

Life forms of world terrestrial vegetation, described by Box (1981)

The life forms (numbered) are listed in the left column, grouped by general growth form or structural type (e.g. broad-leaved trees) and with sub-types in some cases (e.g. warm-temperate, mediterranean, and rainforest broad-evergreen trees). Some forms are divided further into ecoclimatic sub-types with less physiognomic difference (e.g. lowland and montane tropical rainforest trees). Examples of each life form (or sub-form) are provided in the right column. The 77 life forms (90 counting all sub-types) cover the full range of variation in terrestrial plant form, including both potential formation dominants and understorey forms, which are usually more generalized. The life forms were conceived primarily as ecologically significant combinations of certain physiognomic characters, including general structural type, size, leaf form and size, and seasonal habit. Some life forms thus include very few species while others involve many hundreds (even thousands) of species and still considerable variation in less obvious aspects of both form and function. Each life form is related to various annual and seasonal aspects of temperature and water balance regimes by means of estimated tolerance limits (Table 7). Predicted world distributions and importance of the life forms, based on their tolerance limits and hypothesized form-based dominance relationships, are shown in Table 12 and in Maps 10–22. Estimates of potential changes in distribution with changes in climate are presented in Tables 17–19.

Plant form	Examples
Trees (Broad-leaved)	
Evergreen	
1. Tropical Rainforest Trees (lowland, montane)	*Lauraceae, Rubiaceae*
2. Tropical Evergreen Microphyll Trees	*Leguminosae, Meliaceae, Simaroubaceae*
3. Tropical Evergreen Sclerophyll Trees	*Eucalyptus*
4. Temperate Broad-Evergreen Trees	
a. Warm-Temperate	*Quercus virginiana*
b. Mediterranean	*Quercus ilex, Arbutus, Olea europaea*
c. Temperate Rainforest	*Magnoliaceae, Lauraceae*
Deciduous	
5. Raingreen Broad-Leaved Trees	
a. Monsoon mesomorphic (lowland, montane)	*Tectona, Dipterocarpaceae*
b. Woodland xeromorphic	*Acacia, Adansonia, Caesalpinaceae*
6. Summergreen Broad-Leaved Trees	
a. typical-temperate mesophyllous	*Quercus, Acer, Fagus*
b. cool-summer microphyllous	*Betula, Populus, Nothofagus*
Trees (Narrow and needle-leaved)	
Evergreen	
7. Tropical Linear-Leaved Trees	*Podocarpus, Agathis*
8. Tropical Xeric Needle-Trees	*Juniperus procera, Widdringtonia*
9. Temperate Rainforest Needle-Trees	*Tsuga, Thuja, Sequoia*
10. Temperate Needle-Leaved Trees	
a. Heliophilic Large-Needled	*Pinus taeda, P. caribbea*
b. Mediterranean	*Cedrus, Cupressus, Pinus pinea*
c. Typical Temperate	*Pinus strobus, P. ponderosa*
11. Boreal/Montane Needle-Trees	*Picea, Abies*
Summergreen	
12. Hydrophilic Summergreen Needle-Trees	*Taxodium, Metasequoia*
13. Boreal Summergreen Needle-Trees	*Larix, Pseudolarix*

Appendix 1 (continued)

Plant form	Examples
Small and dwarf trees	
14. Tropical Broad-Evergreen Small Trees	rainforest understorey, *Leguminosae*
15. Tropical Broad-Evergreen Dwarf-Trees	'campo cerrado' treelets
16. Cloud-Forest Small Trees	*Podocarpus, Ericaceae*
17. Temperate Broad-Evergreen Small Trees (typical, cool-maritime)	*Ilex, Nothofagus, Berberis*
18. Broad-Raingreen Small Trees	*Leguminosae*
19. Broad-Summergreen Small Trees	*Prunus, Nothofagus, Betula tortuosa*
20. Needle-Leaved Small Trees	*Juniperus, Actinostrobus*
Rosette-trees	
21. Palmiform Tuft-Trees	palms, *Caricaceae*
Rosette-treelets	
22. Palmiform Tuft-Treelets	understorey palms, cycads
23. Tree Ferns	*Cyatheaceae, Dicksoniaceae*
24. Tropical Alpine Tuft-Treelets	*Senecio, Espeletia*
25. Xeric Tuft-Treelets	*Yucca, Dracaena, Xanthorrhoea*
Arborescents	
26. Evergreen Arborescents	mallee eucalypts
27. Raingreen Thorn-Scrub	*Acacia, Commiphora*
28. Summergreen Arborescents	*Prosopis, Salix*
29. Leafless Arborescents	*Haloxylon, Calligonum*
Krummholz	
30. Needle-Leaved Treeline Krummholz	*Picea, Abies, Juniperus*
Shrubs	
31. Tropical Broad-Evergreen Shrubs	*Coffea, Rubiaceae, Ericaceae*
32. Temperate Broad-Evergreen Shrubs	
a. Mediterranean	*Proteaceae, Quercus dumosa, Rhamnus*
b. Typical Temperate	*Ilex, Ligustrum*
c. Broad-Ericoid (perhumid)	*Rhododendron*
33. Hot-Desert Evergreen Shrubs	*Zygophyllaceae, Acacia aneura* (mulga)
34. Leaf-Succulent Evergreen Shrubs/Treelets	*Crassula argentea*
35. Cold-Winter Xeromorphic Shrubs	*Artemisia*
36. Summergreen Broad-Leaved Shrubs	
a. mesomorphic	*Rosa, Vaccinium*
b. xeromorphic	'deciduous chaparral', šibljak
37. Needle-Leaved Evergreen Shrubs	*Juniperus communis*
Dwarf-shrubs	
38. Mediterranean Dwarf-Shrubs	*Thymus, Salvia, Eriogonum*
39. Temperate Evergreen Dwarf-Shrubs (typical, maritime heath)	heath and arctic/alpine *Ericaceae*
40. Summergreen Tundra Dwarf-Shrubs	*Betula nana, Salix reptans*
41. Xeric Dwarf-Shrubs	*Ephedra, Anabasis, Retama*
Cushion-shrubs	
42. Perhumid Evergreen Cushion-Shrubs	*Azorella selago*
43. Xeric Cushion-Shrubs	puna/Patagonian hard cushions

Appendix 1 (continued)

Plant form	Examples
Rosette-shrubs	
44. Mesic Rosette-Shrubs	understorey and ground palms
45. Xeric Rosette-Shrubs	*Agave, Yucca, Aloë*
Stem-succulents	
46. Arborescent Stem-Succulents	*Carnegiea gigantea, Euphorbia candelabrum*
47. Typical Stem-Succulents	.unbranched barrel cacti, *Mammillaria*
48. Bush Stem-Succulents	branched *Opuntia* spp.
Graminoids	
49. Arborescent Grasses	bamboos
50. Tall Cane-Grasses	*Imperata, Arundinaria*
51. Typical Tall Grasses	*Andropogon, Festuca,* prairie grasses
52. Short Sward-Grasses	*Cynodon dactylon, Bouteloua gracilis*
53. Short Bunch-Grasses	*Festuca, Stipa, Agropyron*
54. Tall Tussock-Grasses	pampas and Patagonian grasses (e.g. *Stipa*)
55. Short Tussock-Grasses	puna grasses, *Festuca novae-selandiae*
56. Sclerophyllous Grasses	'spinifex' (*Triodia*), *Scleropoa*
57. Desert Grasses	*Aristida* (wire grass), *Stipa*
Forbs	
58. Tropical Evergreen Forbs	*Cannaceae, Begonia, Zingiberaceae*
59. Temperate Evergreen Forbs	*Gaultheria, Chimaphila, Hexastylis*
60. Raingreen Forbs	*Leguminosae, Compositae*
61. Summergreen Forbs	forest dicots, geophytes, *Compositae*
62. Succulent Forbs	*Portulacca, Sedum, Sempervivum*
Undifferentiated small herbs	
63. Xeric Cushion-Herbs	*Saxifraga, Dryas, Draba*
64. Ephemeral Dry-Desert Herbs	annuals, dwarf-geophytes, graminoids
65. Summergreen Cold-Desert Herbs	dwarf-geophytes, graminoids
66. Raingreen Cold-Desert Herbs	geophytes, graminoids
Vines and lianas	
67. Tropical Broad-Evergreen Lianas	*Ficus, Calamus,* stranglers
68. Broad-Evergreen Vines	*Philodendron, Lonicera, Smilax*
69. Broad-Raingreen Vines	*Leguminosae, Ipomoea*
70. Broad-Summergreen Vines	*Vitis, Parthenocissus, Rhus radicans*
Ferns	
71. Evergreen Ferns	rainforest ferns (e.g. *Polypodium*)
72. Summergreen Ferns	temperate ferns (e.g. *Aspidiaceae*)
Epiphytes	
73. Tropical Broad-Evergreen Epiphytes	bromeliads, orchids, aroids, cacti
74. Narrow-Leaved Epiphytes	ferns, mosses, *Tillandsia*
75. Broad-Wintergreen Epiphytes	'mistletoes' (*Loranthaceae*)
Thallophytes	
76. Mat-Forming Thallophytes	forest and tundra mosses, folious lichens
77. Xeric Thallophytes	crustose lichens

Appendix 2: **VEGETATION OF THE USSR**. (Isachenko *et al.*, 1990)

(Chinese classification is given in Appendix 3, while the final Japanese data set is still under investigation)

VEGETATION OF THE USSR.

Edited by M. Gugk. Scale 1:4 M., 1990.

Compiled by: c.g.s. A.V. Belov (Inst. geography SO AN SSSR), c.g.s. I.I. Buks (Inst. applied geophisics named by E.K. Fedorova Goskomgidromet USSR), c.biol.s. S.A. Gribova, c.g.s. T.I. Isachenko, et al. Edition by: c.g.s.T.I.Isachenko,c.biol.s. Z.V. Karamysheva, c.biol.s. G.M. Ladygina, c.biol.s. I.N. Safronova, et al.

POLAR DESERTS

1. Open (unclosed) primitive aggregations of lichen, moss and arctic species of flowering plants

TUNDRA

Plain tundra

Arctic tundra

2. Grass-moss and low bush-grass-moss

Northern tundra

3. Grass-moss and low bush-moss
4. Low bush-moss
5. Small willow stand
6. Small willow stand

Southern tundra

7. Shrubbery grass-low bush-moss
8. Low bush-cotton grass-moss

Alpine tundra

9 Open (unclosed) aggregations of crustaceous and foliose lichen, moss, arctic-alpine species of flowering plants
10. Low bush-moss, grass-low bush-moss and lichen
11. Low bush-lichebn and low bush-moss in combination with shrubs and sparse vegetation in placers

HIGH MOUNTAIN VEGETATION

(carpet-like meadows, umbelliferous plants, cushion plant formation, elfin and open woodlands)

12. Sparse communities of subnival plants, scree and rock vegetation
13. Herb (alpine) and carpet-like meadows in combination with communities of shrubs and sparse scree and rock vegetation
14. Herb (short grass) meadows in combination with communities of mountain cryoxerophytes
15. Elfin and open woodlands (subalpine)
16. Herb (middle grass) meadows and umbelliferous plants
17. Sedge, Cobresia apline, herb (short grass) meadows
18. Cushion plant formation of herbs, semi-shrubs and shrubs

DARK AND LIGHT CONIFEROUS, BROAD-LEAVED FORESTS, OPEN WOOD-LANDS

Plain forests

Boreal forests and open woodlands

Pretundra open woodlands

19. Birch forest with short grass-low bush cover
20. Spruce forest with mosaic low-shrub-grass cover
21. Larch forest with low-bush-lichen-grass cover

North-taiga forests

22. Spruce thin forest with Betula nana in low bush-lichen-grass undergrowth
23. Larch-spruce-cedar thin forest with low bush-lichen cover
24. Pine thin forest with low bush-grass-lichen cover
25. Larch thin forest with low bush-moss and low bush-lichen cover

Middle-taiga forests
26. Spruce and fir-spruce forest with low bushes and short grasses
27. Spruce-cedar and cedar-spruce forest with grass and low bush cover
28. Pine forest with low bushes, grasses and lichens
29. Larch forest

South-taiga forests
30. Spruce, fir-spruce and spruce-fir forest with mosaic grass-low bush and grass cover
31. Cedar-spruce-fir forest with mosaic short grass cover
32. Pine and larch-pine forest with grasses and low bush-lichens
33. Larch and pine-larch forest with shrubs and grasses

Subtaiga forests
34. Dark coniferous forest with admixture of broad-leaved one (undergrowth and cover of nemorose species), broad leaved-dark coniferous forest
35. Pine forest with grass cover, frequently forest with pine and meadow-steppe species (southern bor)
36. Larch forest with Quercut mongolica, Betula davurica and other grass species
37. Aspen-birch forest with grass cover, Tilia cordata,predominated in Pre-Ural region; birch-aspen forest with nemorose species in the region of Kuznetsk Alatau

Steppe forests
38. Pine forest with steppe grass cover
39. Aspen-birch and birch-aspen forest with steppe grass cover

Mountain forests

Boreal forests and open woodlands

Subgoltsy (tundra belt above the timberline) open woodlands
40. Dark coniferous forest with low bush-moss-lichen cover
41. Larch forest with low-bush-moss-lichen cover
42. Communities with Pinus putila in combination with larch open woodland and tundra

Mountain taiga forests
43. Cedar-spruce and fir-spruce forest
44. Spruce-fir and cedar-fir forest with grass-low bush cover
45. Cedar and fir-cedarr forest with low bush-short grass cover
46. Spruce-fir, cedar-fir, fir-spruce forest with nemorose species
47. Pine forest
48. Larch forest
49. Birch forest with high grass cover

Dark coniferous forests outside boreal belt
50. Spruce, fir and beech-fir forest
51. Spruce-fir forest often with Fagus orientalis
52. Spruce, fir-spruce, aspen-spruce forest in combination with meadows and steppes
53. Pine forest

Broad-leaved forests

Plain forests
54. Beech forest frequently with Quercus petraea, Carpinus betulus, Acer pseudoplatanus
55. Oak-hornbeam, hornmeam forest with Acer pseudoplatanus, Cerasus aviumm
56. Oak forest
57. Pine-broad-leaved forest with boreal types in the cover
58. Lime-tree and oak forest
59. Cedar and broad-leaved forest with ferns and high grasses

Piedmont and mountain forests
60. Beech forest
61. Oak and hornbeam-oak forest
62. Broad-leaved and oak forest
63. Polydominant moist broad-leaved forest
64. Cedar-broad leaved forest
65. Walnut and apple-tree forest

STEPPES AND SECONDARY COMMUNITIES

Plain steppes
Meadow steppes and steppe meadows
66. Herb-grass and grass-herb meadow steppe and steppe meadows in combination with forests (forest steppe)
67. Herb (xeromesophytic herbs) and bunchgrass steppe
68. Herb (mesoxerophytic herbs), bunchgrass and bunchgrass herbs
69. Northern dry bunchgrass and rootstock (rhizome) grasses
70. Southern dry xerophytic herbs and bunchgrasses

Desertificated steppes
71. Northern semishrub and bunchgrass steppe
72. Southern semishrub and bunchgrass steppe

Piedmont and mountain steppes
73. Meadow and herb-bunchgrass steppe
74. Shrub communities in combination with meadow steppes
75. Herb-bunchgrass and bunchgrasses in combination with shrubs
76. Shrubs and bunchgrasses in combination with petrophytes
77. Short bunchgrasses
78. Halfshrub-bunchgrass desert steppe
79. Ephemeroid-bunchgrasses

High mountain steppes
80. Mountain xerophytic-bunchgrasses
81. Cryophytic herbs and bunchgrasses, in some places with ad-mixture of dwarf-pine wood
82. Pillow-like brunchgrass steppe

DESERTS

Plain desert
Northern deserts
83. Sagebrush (Artemisia) among grasses in complex with sage-brush and saltwort (Salsola rhutenica)
84. Saltwort in complex with halophytic sagebrush
85. Meadow grass - sandy-sagebrush, meadow-psammophytic shrub

Central deserts
86. Saltwort in complex with sagebrush
87. Sagobrush with Haloxylon aphyllum
88. Sandy sagebrush-psammophytic shrub with Haloxylon

Southern deserts
89. Saltwort in complex with sand sagebrush
90. Sagebrush
91. Haloxylon aphyllum woodland
92. Sedge-psammophytic shrubs and Haloxylon
93. Sedge-sandy sagebrush and psammophytic shrubs

Piedmont and mountain deserts
94. Young and thalloid plants
95. Ephemeroid-sagebrush
96. Ephemeroid-saltwort
97. Ephemeroid-fether grass-sagebrush
98. Ephemeroid-psammophytic shrub and Haloxylon
99. Ephemeroid-psammophytic shrub
100. Dwarf halfshrubs in some places together with grasses

High mountain deserts
101. Dwarf halfshrub and grass-dwarf semishrub

COMMUNITIES WITH EPHEMERE-EPHEMEROIDAL COVER (SAVANNOIDES)

Piedmont and mountain
102. Mesophytic open woodlands and dwarf shrubs with tall-grass cover
103. Xeromesophytic open woodlands and dwarf shrubs with tall-grass cover

104. Xerophytic open woodlands, dwarf shrubs and dwarf semishrubs with short grass cover, in some places high grasses
105. Short grasses and dwarf semishrub-short grasses

OPEN WOODLANDS AND MOUNTAIN XEROPHYTIC STEPPE VEGETATION (PHRYGANOIDES)

Mountain

106. Jumper open woodland with meadow-steppe cover, admixture of mountain xerophytes in combination with steppes and shrub communities
107. Jumper open woodland with mountain xerophytic steppe cover
108. Jumper open woodland with ephemeroid-mountain xerophytic steppe cover
109. Mountain xerophytic steppe communities

Mires

110. Grass and hypnum grass bog
111. Grass-subshrub-lichen-moss complex polygonal bog
112. Grass-subshrub-lichen-moss palsa bog
113. Grass-hypnum-sphagnum aapa with ridges and pools
114. Hepatic-lichen-sphagnum high bog with ridges and pools
115. Sphagnum raised bog with ridges and pools
116. Grass-sphagnum and subshrub-grass-sphagnum transitional
117. Wooded swampy fen

Shrubbery vegetation

118. Shrub communities

Halophyticc vegetation

119. Herb and grass halophytic meadows
120. Ecological rows of perennial and annual saltworts, halo-phytic grasses, halophytic subshrubs, halophytic shrubs in combination with bare solonchaks

ECOLOGO-DYNAMIC SEQUENCES OF ALLUVIAL COMMUNITIES, SECONDARY (ANTHROPOGENIC) MEADOWS AND AGRICULTURAL AREAS

121. Meadow-bog-shrub sequence with an admixture of willow stand and yernik (dwarf shrub formation with Betula nana) tugai (bottomland complex with forests, bushes and meadows in river valleys)
122. Sor-meadow-small leaved-coniferous sequence
123. Shrub-coniferous sequence
124. Shrub-small leaved-coniferous sequence
125. Shrub-broad leaved-coniferous sequence
126. Shrub-broad leaved forest sequence
127. Shrub-broad leaved forest sequence
128. Halophytic meadow-tugai sequence
129. Shrub-small leaved-coniferous sequence
130. Meadow sequence
131. Reed brakes in plavni (long time flooded areas with Phragmites in river deltas and bottomlands) and lake kettle depressions
132. Reed brakes and halophytic grass meadows in combination with halophytic communities on solonetzes andf solonchaks

MISCELLENEOUS

133. Agricultural land in drained bogs
134. Agricultural land of old irrigation
135. Bare salt lakes
136. Ice plains
137. Contour (islands) without color on map. Lioral vegetation
150. Waterbodies

Appendix 3:Chinese vegetation classification

CONIFEROUS FORESTS

I Cold/temperate and boreal mountain coniferous forest

1. Larch forest
2. Siberian larch forest

II Temperate mountain evergreen coniferous forest

3. Temperate mountain pine forest
4. Spruce-fir forest
5. Spruce forest

III Temperate open coniferous forest on poor sandy soils

6. Open pine forest

IV Temperate evergreen coniferous forest

7. Temperate pine forest
8. Arborviate forest

V Sub-tropical/tropical evergreen coniferous forest

9. Subtropical/warm pine forest
10. Subtropical mixed forest
11. Subtropical pine forest mixed with shrubs
12. Subtropical/China fir forest
13. Subtropical open cypress forest

VI Sub-tropical/tropical mountain evergreen coniferous forest

14. Subtropical mountain pine forest
15. Subtropical mountain fir-spruce forest

BROADLEAVED

VII Temperate mixed deciduous and evergreen broadleaved forest

16. Temperate broadleaved deciduous, mixed with korean pine

VIII Temperate/sub-tropical deciduous broadleaved forest

17. Temperate deciduous oak forest
18. Broadleaved deciduous mixed forest (Maple-lime-ash)
19. Elm -pistache mixed forest

IX Temperate/sub-tropical mountain deciduous small leaved forest

20. Birch-poplar forest

X Temperate open deciduous small leaved forest

21. Temperate open Ulmus woodland, mixed with shrubs
22. Temperate open Poplar woodland, mixed with shrubs

XI Subtropical mixed deciduous and evergreen broadleaf forest on limestone soil

23. Subtropical Ulmus-Platycarya-Cyclobalanopsis mixed forest

XII Subtropical mixed mountain deciduous and evergreen broadleaf forest on acid soils

24. Subtropical Lithocarpus-Fagus-Cyclobalanopsis forest
25. Mixed Oak-Tsuga forest

XIII Subtropical evergreen broadleaf forest

26. Subtropical Castanopsis-Cyclobalaopsis-Lithocarpus forest
27. Subtropical Castanopsis-Cinnamomumacea-Schima forest

XIV Tropical seasonal evergreen broadleaved rainforests

28. Tropical Castanopsis-Cinnamomumacea-Camellia forest

XV Subtropical evergreen broadleaf (hardleaved) forests

29. Up-land oak forest

XVI Subtropical bamboo forest

30. Phyllostachys forest

XVII Tropical semi-evergreen broadleaved rain forest with secondary vegetation

31. Tropical rain forest on calcareous clay soil
32. Tropical rain forest on red soil

XVIII Tropical evergreen broadleaf rain forests mixed with secondary vegetation

33. Tropical rain forest

SHRUBLANDS AND SPARSE TREES

XIX Temperate/sub-tropical deciduous shrubs and dwarfs forest

34. Corylus-Lespedeza-Quercus shrubland
35. Ostryosis-Spiraea shrubland
36. Vitex shrubland
37. Forythia-Exochorda-Quercus shrubland
38. Caragana-Salix-Atremisia shrubland
39. Tamarix-grass shrubland

XX Sub-Tropical/tropical evergreen deciduous shrubs and dwarfs on acid soil

40. Rhododendron-Vaccinimum shrubland
41. Melastoma-Aporosa shrubland

XXI Sub-Tropical/tropical mix of evergreen deciduous shrubs and dwarfs on lime stone

42. Platycarya-Zanthoxylum-Rosa-Viburnun shrubland
43. Ficus-Alchornea-Boehmeria-Clausene shrubland and dwarfs

XXII Tropical, coastal, evergreen hardleaved shrubs and dwarfs

44. Rhizophora spp.

XXIII Tropical succulents and evergreen broadleaf shrubs and dwarfs on coral stone

45. Scaevola-Pisonia shrubland and dwarfs

XXIV Sub-tropical alpine evergreen leathery leaf shrubs and dwarfs

46. Rhododendron shrubland

XXV Temperate.sub-tropical alpine deciduous shrubs and dwarfs

47. Salix-Potentialla-Caragana shrubland

XXVI Temperate alpine dwarfs/shrub tundra

48. Salix-Vaccinium-moss tundra

XXVII Temperate/sub-tropical alpine polster semi shrubs and herbs

49. Arenaria-Androsacea tundra

DESERTS

XXVIII Temperate semi-dwarf desert

50. Low-land sympegma spp. desert
51. Anabasis spp. desert
52. Reamuria spp. desert

XXIX Temperate cactaceous semi shrub desert on saline soil

54. Kalidium spp. desert

XXX Temperate semi-shrub desert

55. Ephedra spp. desert
56. Ceratoides spp. desert
57. Potaninia-Ammopiptanthus-Tetraena desert
58. Artemissia desert
59. Calligonum spp. desert
60. Sparse Tamarix spp. desert

XXXI Temperate semi-tree desert

61. Haloxylon spp. desert
62. Haloxylon-Remuria desert
63. Haloxylon spp. desert (partly mixed)

XXXII Temperate alpine dwarf semi-shrub desert

64. Ceratoides-Ajania desert

GRASSLANDS

XXXIII Temperate mix of grasses and herbs

65. Folifolium spp. grassland
66. Aneurolepidium spp. steppe
67. Steppe of grasses and woods/shrubs
68. Aneurolepidium-Huandbeichao grassland

XXXIV Temperate grassland

69. Stipa steppe (S. grandis, S. krylovii)
70. Stipa-Cleisrogense grassland
71. Stipa steppe (S. krylovii, S. breviflora)

XXXV Temperate mountain grassland

72. Mixed Stipa and Festuca grassland

XXXVI Temperate mix of dwarf grass and semi-shrubs

73. Stipa grassland
74. Stipa grassland

XXXVII Temperate mix of mountain grasses and shrubs

75. Mixed Stipa and Festuca grassland

XXXVIII Temperate/sub-tropical grass land (temperature limited)

76. Mixed Stipa-Orinus grassland
77. Mixed Poa-Festuca grassland
78. Mixed Stipa and Festuca steppe
79. Stipa-Carex-Ceratoides grassland

XXXIX Sub-tropical shrub grassland and tropical savanna

80. Heteropogon-Cymbopogon grassland

MARSHES AND MEADOWS

XXXX Temperate meadow

81. Mix of grasses, herbs, and forbs
82. Grass-sedge forbs

XXXXI Temperate/sub-tropical mountain meadow

83. Grass-sedge forbs mixed with alpine shrubs
84. Grass-Artemisia-forbs
85. Artemisia spp.
86. Grass-Aretimisia forbs on salinid soil

XXXXII Temperate herbaceous swamps (low altitude)

87. Grass-Carex Swamps
88. Carex-moss-Betula Swamps

XXXXIII Temperate/cold herb swamps (high altitude)

89. Carex-Artemisia swamps

ARTIFICIAL VEGETATION

XXXXIV

Annual and cold resistant economic field crops

90-92. Spring wheat, soybean, maize, sorghum, sugar beet, millet, potatoes, barley, rape

XXXXV

Annual double cropping, bieannuakl three cropping, warm temperate deciduous fruit crops and economic forest

93-96. Winter wheat, cereal grain, soybean, maize, sweet potato, peanuts-cotton, apple, grapes, chestnuts, walnuts

XXXXVI

Annual wet-dry land double cropping, sub-tropical evergreen and deciduous economic forest and orchard

97-101. Summer rice, winter wheat, annual double cropping rice, cotton, tea, apple, pear, sweet potato, linen-orange, palm, orange

XXXVII

Double seasonal or double seasonal sequential cropping rice, tropical evergreen economic forest, orchard

102-103Double seasonal rice, winter peanut, hemp, coconut, rubber, coffee, cassava, banana, pineapple