The South African Land-cover Characteristics Database: a synopsis of the landscape

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Accurate, up-to-date information on land cover and land-use is essential for strategic planning, sustainable resource management and environmental research. A land-cover database for South Africa, Swaziland and Lesotho, designed for use in a variety of regional modelling, monitoring and analytical endeavours, has been created. Database development involved (1) a stratification of natural land cover and human land-use, (2) a contextual classification of hardcopy multispectral data derived from Landsat Thematic Mapper (TM) imagery collected from 1994 to 1996, and (3) a stratified post-classification accuracy assessment using a large sample of field data. The resultant database has yielded substantial information to characterize the landscapes of South Africa. The analysis uses data recorded by province, primary hydrological catchment and vegetation biome to explore the land-cover characteristics of South Africa, Swaziland and Lesotho. Aggregated results show that South Africa comprises the following general surface types: 5.8% forest and woodland; 0.3% forest; 17.6% thicket and bushland; 34.1% shrubland and low fynbos; 0.2% herbland; 21.3% grassland; 12.2% cultivated lands; 1.5% forest plantations; 0.4% waterbodies; 0.5% wetlands; 0.2% barren rock; 4.9% degraded lands; 1.1% urban/built-up lands; and 0.14 % mines and quarries. The accuracy of the database ranges from 51% to 93%, depending on geographical area, with corresponding kappa index values from 35 to 88.

Information regarding the characteristics and spatial distribution of South Africa's land cover is critical for sustainable land-use planning, strategic environmental assessments and global change research. Capabilities to record and map land-cover conditions and to monitor change are required for, among others, modelling hydrological cycles and global carbon, establishing rates of land transformation, and habitat destruction for biodiversity conservation planning.[1–4] Land process research and land planning in South Africa has relied in the past on simple interpretations of gross land-cover and surface properties, such as biomass (as in the national biomass initiative[5]). Acocks' veld types[6] and the National Botanical Institute's vegetation potential map[7] are the most common sources of land-cover and surface data available. These databases have a low spatial resolution (e.g. 1:1 000 000). Higher-resolution data with greater precision for classification purposes are clearly required.[1]

Before the implementation of the National Land-cover (NLC) Database project, no single standardized database of current land-cover information existed for the whole of South Africa. Most land-cover/land-use classifications (derived from satellite remote sensing data) in use had typically been developed around specific user objectives and had often been influenced by geographical location[8–10] and data capabilities.[8,11] Very few datasets were thus directly comparable in terms of class definitions, mapping standards, geographical coverage and satellite imagery, making the compilation of a national dataset difficult.

The primary objective of the NLC project was to produce a standardized digital land-cover database for all of South Africa, Swaziland and Lesotho (Fig. 1). The product is designed for 1:250 000 scale mapping applications, and is intended to provide national, baseline information on land cover. It contains broad-level thematic classes applicable to southern Africa, that can be adapted further to suit individual user requirements.

In previous works,[12–16] various quantitative estimates of human impacts on the natural resource base have been made. These historical results were primarily based on agricultural cropland and plantation statistics, which had been collected in the field. Agriculture, plantations and urban areas are the primary agencies affecting the landscape of southern Africa. The benefits from a remotely sensed approach to land-use areal assessments can be summed up in the added advantages of deriving spatial location, shape and neighbourhood context. This has never previously been achieved using cropland and plantation statistics, for which there is the high probability of undercounting.

This paper documents the procedures and results of the NLC project. These include statistics of areal coverage by country,[17] South African province,[17] primary hydrological catchment,[18] and potential vegetation biome.[7] The results are discussed with respect to past estimates of land-use cover when available, meaning for provincial planning, as well as an assessment of the natural resource base.

Methods

Discussions of land-cover mapping often lead to debate over classification schemes, assignment of class descriptors and

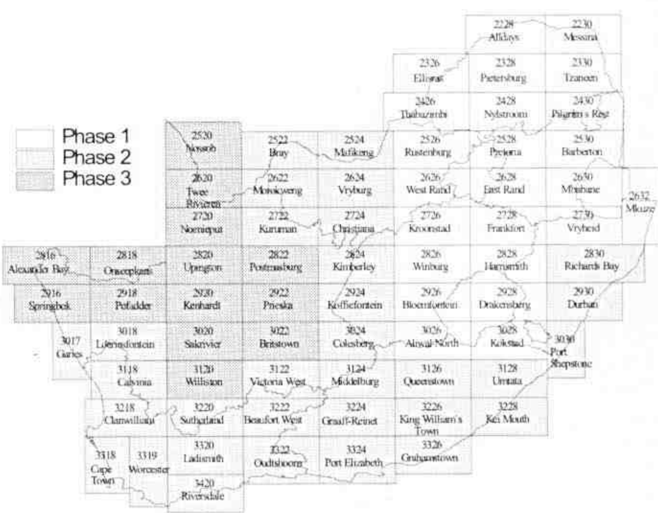

Fig. 1. Components of the three production phases.

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Table 1. Level I land-cover classes mapped for the database.

NLC code	Level I land-cover class	Aggregated land-cover class
1	Forest and woodland (savanna)	Forest and woodland
2	Indigenous forest	Forest and woodland
3	Thicket, bushland, bush clumps	Thicket and bushland
4	Low shrubland and Fynbos	Thicket and bushland
5	Herbland	Grassland
6	Unimproved grassland	Grassland
7	Improved grassland (pasture, recreational fields)	Cultivated lands
8	Forest plantations (exotic tree spp)	Forest plantations
9	Waterbodies	Waterbodies
10	Wetlands	Wetlands
11	Bare rock and soil (natural)	Degraded lands
12	Bare rock and soil (erosion surfaces)	Degraded lands
13–17	Degraded vegetation, by classes 1,3,4,5,6	Cultivated lands
18–23	Cultivated lands, variations of permanent/temporary crops,irrigated/dryland, and commercial/subsistence/sugarcane	Urban/built-up lands
24	Urban/built-up land (residential)	Urban/built-up lands
25–28	Urban/built-up land (residential small holdings by subdivided vegetation classes 1,3,4,5,6	Urban/built-up lands
29	Urban/built-up land (commercial)	Urban/built-up lands
30	Urban/built-up land (industrial/transport)	Urban/built-up lands
31	Mines and quarries	Mines and quarries

labels, and product specifications. Most classification schemes are designed to be useful for a rather narrow range of applications; conversely, no single classification scheme can satisfy all, or even most, applications.

Land cover and land-use are closely related criteria, and are often confused, but they are *not* the same. It is important clearly to distinguish between the two in any classification design. In its broadest sense, land cover can be defined as 'all the natural and human features that cover the earth's immediate surface',[19] including 'vegetation (natural or planted) and human constructions (buildings, roads), water, ice, bare rock or sand surfaces'.[20] Land-use typically refers to the human activity that is associated with a specific land-unit, in terms of utilization, impacts or management practices.[19] Land-use is therefore based upon function, where a specific use can be 'defined in terms of a series of activities undertaken to produce one or more goods or services'.[20] As such there can be only one land-cover type associated with a point on the earth's surface, but this may be associated with several land-uses (e.g. a 'grassland' may be used for communal grazing within a conservancy area).

The land-cover classes mapped within the NLC project are based exclusively on those defined by Thompson[19] for southern Africa. It is a hierarchical framework designed to suit the southern African environment, and incorporates known land-cover types that can be identified in a consistent and repetitive manner from high-resolution satellite imagery such as Landsat TM and SPOT. The classification scheme is based on clear, unambiguous terminology and class definitions, designed to ensure data standardization and to allow easy subdivision of the broad generic classes into more specific, user-defined subclasses.

The classification scheme has been designed to conform to internationally accepted standards and conventions, in order to ensure, as far as possible, cross-border compatibility and integration with existing national and international land-cover classification systems and datasets, such as those already in use in Zimbabwe's Vegetation Resource Information System[21] and proposed for the FAO's Africover project.[20]

The classification legend used for the NLC project is derived primarily from level-I classes and a few selected level-II classes (Table 1). Although primarily designed (and defined) as a land-cover classification system, it incorporates a land-use component in the lower hierarchical subclasses such as 'permanent commercial-irrigated crops'.

The broad, structurally based natural vegetation categories and their definitions and naming conventions were based primarily on those defined in Edwards,[22] initial FAO-Africover documentation[23] and the Zimbabwean National Woody Cover Mapping project.[21] Although the vegetation classes consist primarily of level-II categories, a 'degraded' subdivision has been included as an indication of land-use impact (two examples are overgrazing or fuelwood collection). This inclusion stems from the copious work and results on degraded land mapping conducted in Botswana.[24,25] Table 1 lists the land-cover classes used in the NLC project with their associated aggregated remapping classes (see Thompson[19] for full class definitions).

Land-cover mapping methodology

The NLC project incorporates four basic stages in the compilation of the digital land-cover database. Initial field orientation for image interpretation, image interpretation and annotation, digitization of annotated land-cover data, and both field and aerial photograph verification for map accuracy assessment.

Field orientation was used to familiarize interpreters with the local terrain, vegetation types and agricultural practices prior to annotation. This involved completing extensive road transects across each individual satellite image map area, when reference notes and photographs were taken. The land-cover information was then mapped directly from the 1:250 000 scale Landsat TM Spacemaps (described below), using manual photo-interpretation techniques. Rigorous quality reviews during and after annotation were used to ensure uniform contiguous mapping standards and accuracies *between* and *within* each sheet. Although the use of reference material (such as vegetation maps, land-type maps) was encouraged, final category boundaries were determined only from the imagery. In general a minimum mapping unit of 25 ha (i.e. 500 × 500 m or 2 × 2 mm at 1:250 000 scale) was used. However, smaller features such as irrigation dams, planted woodlots and wetlands have been included wherever feasible, owing to their relative importance in terms of water, fuelwood resources and conservation. The annotated land-cover data were then manually digitized according to pre-defined data capture standards.[26]

Field and airphotograph verification was used to validate the final land-cover data and to provide a statistical measure of overall classification accuracy for each Spacemap.[26] In a limited number of cases the original land-cover data were subsequently modified on the basis of field verification information to improve the overall mapping accuracies, but these changes were not re-assessed in the accuracy statistics. During field verification a limited amount of additional data was collected (in particular land-management information and fixed-point ground photographs).

Spacemap compilation

The land-cover information has been mapped directly from a new series of 1:250 000 scale, geo-referenced Landsat TM Spacemaps, produced by the CSIR's Satellite Application Centre (SAC). The Spacemaps are based on the same layout format as the standard 1:250 000 scale South African Surveyor General national map series. One difference is that, to facilitate edge matching and continuity of mapping across adjacent Spacemaps, the actual image area within each map is slightly larger than the standard map sheet by approximately 5 minutes.

The Spacemaps are based on seasonally and climatically standardized, single-date TM imagery captured primarily between 1994 and 1996. Decision rules were established for image selection in order to maximize information on vegetation and crop-cover types, while minimizing any temporal effects and land-cover variability between adjacent images captured on different dates. These were based on 'optimum season', distinguished by uniform vegetation growth (defined as April–June in summer rainfall areas, and September–December in winter rainfall areas) and 'seasonal rainfall' (that produced uniform vegetation response and condition). The latter condition was based on the analysis of rainfall data for a three-month period before the beginning of each optimum season, where suitability is defined on the basis of average or greater than average precipitation levels.

Additional rules were established for combining two or more TM images within a single Spacemap in terms of histogram spectral reflectance matching.

Quality control

Rigorous pre-classification error reduction procedures were followed during initial data capture phases, concentrating on interpreter training, class standardization, spatial error avoidance (related to map edgematching, polygon definition) and quality checking.[26] An initial pilot mapping exercise was completed by all teams before actual NLC mapping, based on the *same* Spacemap, in order to optimize consistency of interpretation among analysts. Stringent data quality checks were enforced during data capture to ensure digitization accuracy before transferring the land-cover data into the final database, based on the repetitive contact-scale comparisons between the original annotated acetates and the plotted vector data.

Photo-interpretation *vs* digital image processing

The decision to use manual, photo-interpretation methods of image analysis rather than digital, computer-based analysis was based on a number of factors relating to product accuracy and cost. Skilled photo-interpreters with extensive local knowledge are able to evaluate shape, location, texture, context as well as spectral characteristics when classifying land-cover features within complex landscapes, in comparison to standard digital classification routines, which are typically biased towards spectral analysis only.[27] This usually results in a far more accurate land-cover classification because interpretation problems resulting from, for example, temporal effects (such as burn scars), relief shadowing and spectral similarities can be avoided. The results of a test study comparing mapping accuracies achieved within the NLC project on the Pretoria (2528) sheet using manual photo-interpretation with those from a supervised classification of equivalent digital data confirmed this approach.[27]

Field verification and classification accuracy

Verification procedures were designed to balance scientific rigour and defensibility with practical limitations of cost and time (that is, to be economically feasible within budgetary limitations). The stated objectives of the verification exercise were to determine the mapping accuracy of level I land-cover types. The target accuracy for level I land-cover types was set at 85%, with an acceptable error of 10% at 90% confidence level, based on the original US Geological Survey's land-cover/use model, which was designed to meet an overall minimum mapping accuracy of 85% at level I.[26]

The actual procedure involved a combination of extensive field survey (based on road transects) and additional analysis of suitable (archival) aerial photography. Approximately 180 sample sites were assessed per Spacemap, via GPS-controlled field sites and archival aerial photography. The original assessment techniques[26] were slightly modified during the initial stages of the project after several trial runs, on the basis of improved feasibility. The revised methods were found to be more time and resource effective without any reduction in statistical accuracy, and also allowed the verification procedures to become independent of the actual land-cover mapping, allowing a greater flexibility in scheduling. The principal modifications were (1) road-transect sample sites were determined in a random, systematic manner in the field by the analyst, rather than as previously specified by pre-survey GIS modelling, and (2) agricultural cropland, plantations and urban area evaluation was limited to aerial photography assessment only.

Mapping accuracy

The NLC dataset is designed for 1:250 000 scale mapping applications (25 ha minimum mapping unit), and is intended to provide national, baseline data on land cover for the whole of South Africa, Swaziland and Lesotho. It is a representation of the mapped landscape, whose accuracy, level of generalization and information content are defined by the limitations and constraints imposed by the minimum mapping unit, the mapping scale, the satellite imagery and the land-cover class definitions. As such the dataset cannot be expected to be 100% accurate (nor is it intended to be), since it is a generalized representation of reality, where in many cases artificial map boundaries have been imposed upon natural gradients (especially in relation to 'natural' cover types). Land-cover classes are fairly broad in terms of their definitions, but have been designed to allow more detailed subdivision at a later stage by individual users if so desired.

Results

The South African land-cover maps are primarily compiled to answer the fundamental question: what is the current distribution and area of the nation's principal natural and human

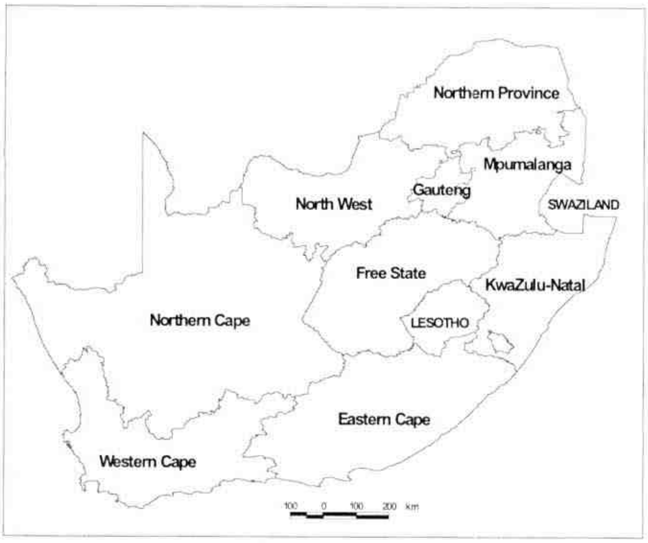


Fig. 2. South Africa, Swaziland, Lesotho and South African provincial boundaries.[17]

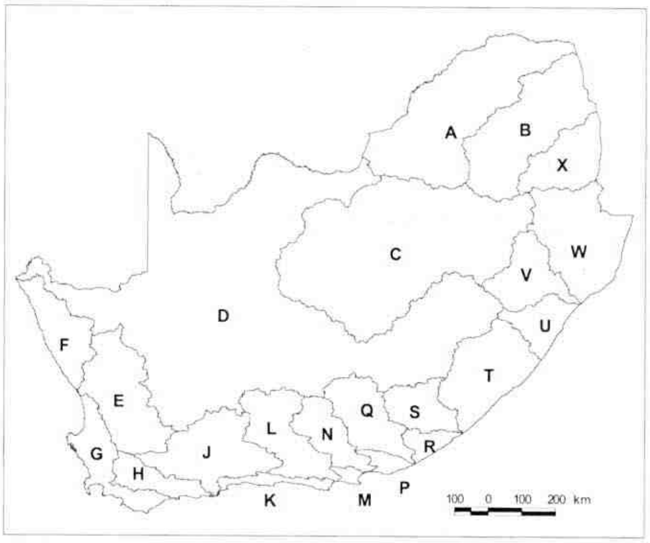


Fig. 3. Primary hydrological catchment boundaries.[18]

land-cover types? The overall results and analysis are arranged to convey the full impact of land characterization for various sectors of interest. We recognized three main sectoral uses for the NLC results and thus have arranged findings by political zone, primary hydrological catchment and vegetation biome (Figs 2–4). The political groupings are represented at country and South African provincial level and can be used to combine with the 1996 census figures.[28] These findings can be used by government and others for development planning. The analysis provided by hydrological catchment[18] emphasizes the importance of water demand and quality in a relatively dry region of the world. The catchment results have particular relevance to issues elucidated in the National Water Act[29] and with the setting up of catchment water boards. Providing results by vegetation biome[7] type emphasizes the biological heritage of southern Africa, and our continued need to conserve and protect representative remnants of the natural vegetation and their associated landscapes.[30] The NLC has particular relevance for issues pertinent to the White Paper on the Conservation of Biological Diversity[31] and the recently completed Kumleben commission of inquiry[32] regarding national parks and provincial nature reserves.

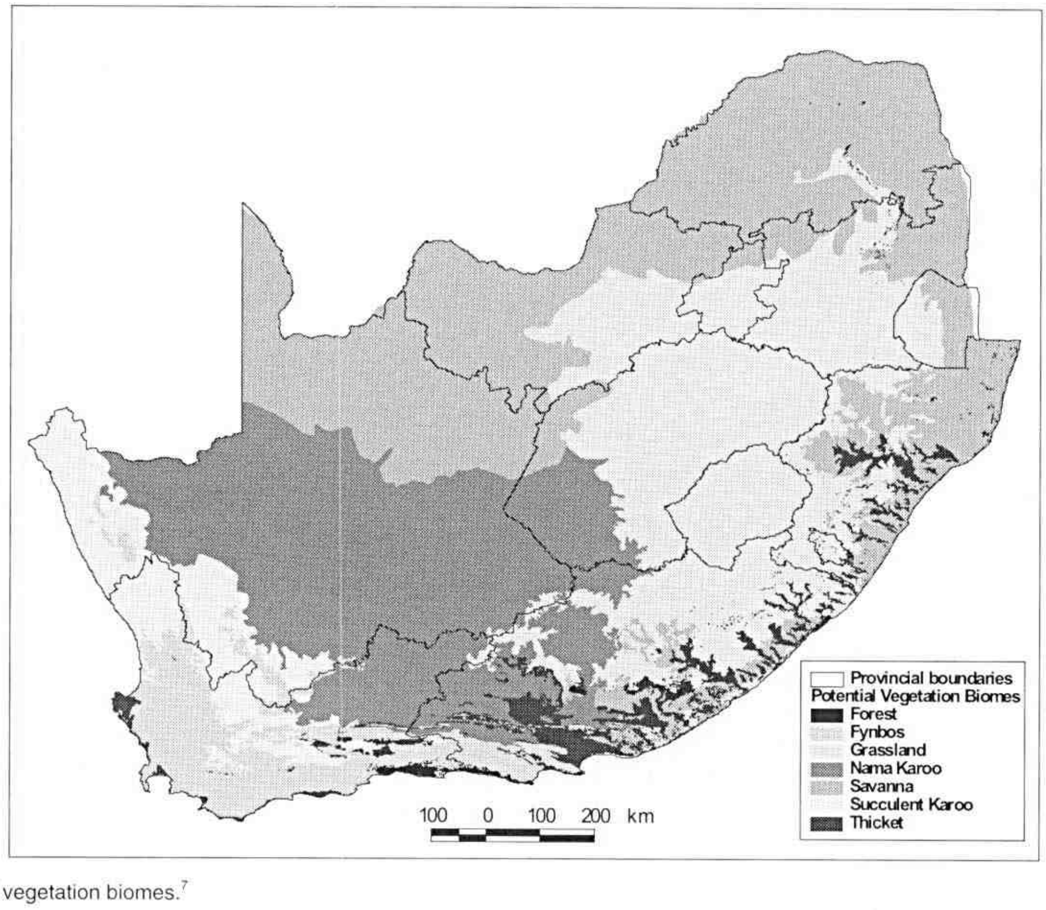
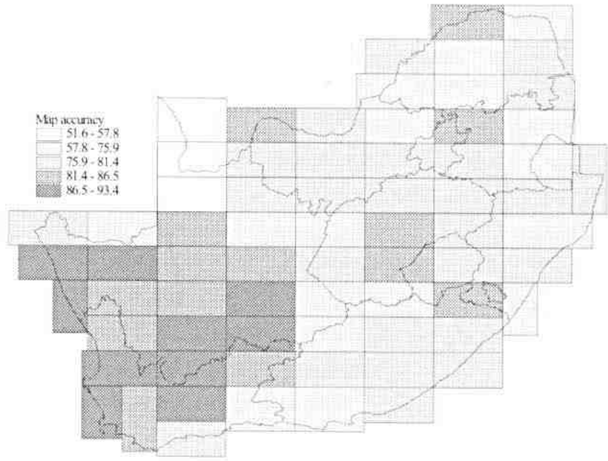


Fig. 4. Potential vegetation biomes.[7]

The final accuracies for each 1:250 000 map sheet summed for the entire study area, although slightly less than the 85% target,[26] were 52–93% with kappa statistics from 35–88, which are taken to be indicative of an accurate and useful digital map product (Fig. 5). Overall mapping accuracy for all of Phase I data taken as a single, contiguous dataset is 78% (77–79% at 90% confidence limits) with a kappa index of 74.1, based on an analysis of 4365 sample points. Mapping accuracy for Phase II is 80.7% (80–81.4% at 90% confidence limits) with a kappa index of 77.3, based on an analysis of 5423 sample points. The mapping accuracy for Phase III is 79.7% (78.5–80.9% at 90% confidence limits) with a kappa index of 73.0, based on an analysis of 1838 sample points. Overall, the results illustrate the real-world, practical limitations of land-cover mapping at a 1:250 000 scale in complex, often highly heterogeneous landscapes using single-date, hardcopy satellite imagery.

In general, regions with homogeneous land cover were well identified if they comprised relatively large, regular landscape patches. In spatially complex areas, such as along the Drakensberg escarpment and east coast, seasonally distinct land-cover regions were more often correlated with mosaics of cover having variable physiognomic and vegetative characteristics.

Table 2 presents the overall results for South Africa, Swaziland and Lesotho at the level-I classification. By areal coverage alone, 79% of South Africa is composed of 'natural' woody and grassland vegetation communities (such as forest and woodland; thicket, bushland and high fynbos; shrubland and low fynbos; herbland; and grassland). Wet landscape classes (for example,



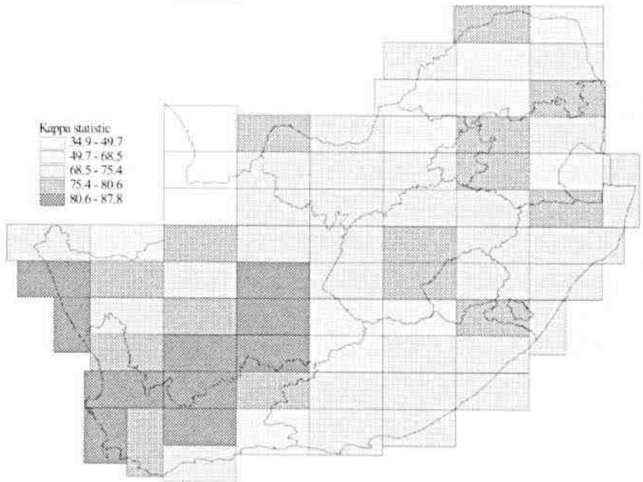


Fig. 5. Percent correctly classified and kappa index statistics per 1:250 000 scale Surveyor General mapsheet. →

Table 2. Land-cover areal totals for South Africa, Swaziland and Lesotho by level I land-cover category.

Land-cover description	National					
	South Africa		Lesotho		Swaziland	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Barren rock	260361.2	0.21	7569.14	0.25	533.09	0.03
Cultivated: permanent — commercial dryland	83086.8	0.07	0.00	0.00	2730.35	0.15
Cultivated: permanent — commercial irrigated	416753.4	0.34	0.00	0.00	3830.91	0.21
Cultivated: permanent — commercial sugarcane	459370.0	0.38	0.00	0.00	49874.72	2.75
Cultivated: temporary — commercial dryland	9 748 150.8	8.00	1949.14	0.06	13564.14	0.75
Cultivated: temporary — commercial irrigated	1 081 256.7	0.89	771.62	0.03	3259.46	0.18
Cultivated: temporary — semi-commercial/subsistence dryland	2 964 630.6	2.43	691038.60	22.61	279908.32	15.41
Degraded: herbland	138.6	0.00	0.00	0.00	0.00	0.00
Degraded: forest and woodland	965723.1	0.79	29.26	0.00	94353.99	5.19
Degraded: shrubland and low fynbos	563182.4	0.46	0.00	0.00	0.00	0.00
Degraded: thicket & bushland (etc)	2 256 031.7	1.85	570.71	0.02	42907.55	2.36
Degraded: unimproved grassland	1 862 583.9	1.53	819751.74	26.82	84388.82	4.64
Dongas and sheet erosion scars	186513.8	0.15	1033.99	0.03	293.70	0.02
Forest	401369.5	0.33	144.10	0.00	6933.54	0.38
Forest and Woodland	7 011 196.3	5.75	0.00	0.00	344004.00	18.93
Forest plantations	1 790 269.6	1.47	1842.42	0.06	120310.48	6.62
Herbland	242995.9	0.20	326.49	0.01	0.00	0.00
Improved grassland	128202.9	0.11	243.67	0.01	215.02	0.01
Mines and quarries	175420.7	0.14	292.32	0.01	254.48	0.01
Shrubland and low Fynbos	41 514 273.8	34.05	297705.35	9.74	0.00	0.00
Thicket and bushland (etc)	21 409 243.0	17.56	79502.96	2.60	408283.53	22.47
Unimproved grassland	25 945 426.7	21.28	1 136 281.12	37.17	350871.25	19.31
Urban/built-up land: commercial	34476.3	0.03	45.87	0.00	64.69	0.00
Urban/built-up land: industrial/transport	64652.0	0.05	560.73	0.02	499.86	0.03
Urban/built-up land: residential	1 084 164.1	0.89	10137.61	0.33	5779.28	0.32
Urban/built-up land: residential (small holdings: bushland)	27927.5	0.02	0.00	0.00	0.00	0.00
Urban/built-up land: residential (small holdings: grassland)	134927.3	0.11	0.00	0.00	0.00	0.00
Urban/built-up land: residential (small holdings: shrubland)	12301.6	0.01	0.00	0.00	0.00	0.00
Urban/built-up land: residential (small holdings: woodland)	40462.6	0.03	0.00	0.00	0.00	0.00
Waterbodies	460959.4	0.38	765.07	0.03	3908.07	0.22
Wetlands	581736.8	0.48	6416.40	0.21	19.82	0.00
Totals	121 907 789		3 056 978.31		1 816 789.07	

Table 3. Land-cover areal totals for South African provinces by level I land-cover category.

Land-cover description	Eastern Cape		Free State		Gauteng		KwaZulu-Natal		Mpumalanga	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Barren rock	49100.87	0.29	20259.05	0.16	0.00	0.00	4143.86	0.04	951.26	0.01
Cultivated: permanent — commercial dryland	17892.70	0.11	288.36	0.00	0.00	0.00	8099.97	0.09	11549.23	0.14
Cultivated: permanent — commercial irrigated	11069.82	0.07	46.07	0.00	18.13	0.00	2747.32	0.03	18498.40	0.23
Cultivated: permanent — commercial sugarcane	3354.76	0.02	0.00	0.00	15.54	0.00	411372.44	4.47	44642.75	0.56
Cultivated: temporary — commercial dryland	292285.45	1.72	3 665 422.50	28.21	327546.18	19.83	236464.18	2.57	1 102 283.76	13.79
Cultivated: temporary — commercial irrigated	179995.21	1.06	68763.84	0.53	16330.00	0.99	131974.19	1.43	116976.72	1.46
Cultivated: temporary — semi-commercial/subsistence dryland	887890.57	5.22	6465.15	0.05	2249.08	0.14	790723.67	8.58	94356.14	1.18
Degraded: herbland	17.28	0.00	0.00	0.00	0.00	0.00	57.84	0.00	0.00	0.00
Degraded: forest and woodland	1121.04	0.01	35.37	0.00	480.72	0.03	95483.96	1.04	105427.58	1.32
Degraded: shrubland and low fynbos	185780.66	1.09	626.49	0.00	20.59	0.00	0.00	0.00	0.00	0.00
Degraded: thicket & bushland (etc)	86855.48	0.51	9217.21	0.07	0.00	0.00	277814.39	3.02	11531.32	0.14
Degraded: unimproved grassland	1 302 191.09	7.66	65849.00	0.51	0.00	0.00	326281.58	3.54	16472.69	0.21
Dongas and sheet erosion scars	19814.08	0.12	12112.79	0.09	122.08	0.01	27997.06	0.30	2052.21	0.03
Forest	153000.23	0.90	498.07	0.00	0.00	0.00	120354.31	1.31	26562.25	0.33
Forest and Woodland	55882.79	0.33	20671.40	0.16	162942.71	9.86	605182.60	6.57	1 441 250.03	18.03
Forest plantations	190955.33	1.12	20964.31	0.16	22567.39	1.37	617686.85	6.71	708065.79	8.86
Herbland	73.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.17	0.00
Improved grassland	23927.22	0.14	1748.74	0.01	10119.72	0.61	23681.65	0.26	3101.88	0.04
Mines and quarries	1322.94	0.01	17878.33	0.14	34922.38	2.11	7427.39	0.08	47850.74	0.60
Shrubland and low Fynbos	5 625 718.84	33.08	1 453 169.06	11.18	0.00	0.00	7436.46	0.08	829843.50	10.38
Thicket and bushland (etc)	2 684 931.02	15.79	763461.28	5.88	55413.91	3.35	1 619 529.73	17.58	3 262 712.83	40.81
Unimproved grassland	4 876 532.41	28.67	6 579 414.29	50.64	684681.19	41.45	3 588 875.09	38.96	823843.50	10.38
Urban/built-up land: commercial	2530.69	0.01	5172.09	0.04	13863.50	0.84	4018.61	0.04	3262712.83	40.81
Urban/built-up land: industrial/transport	5049.33	0.03	10560.80	0.08	14642.86	0.89	9118.99	0.10	1077.42	0.01
Urban/built-up land: residential	260458.99	1.53	53466.14	0.41	160197.11	9.70	105682.14	1.15	8467.95	0.11
Urban/built-up land: residential (small holdings: bushland)	2326.81	0.01	216.72	0.00	0.00	0.00	13561.94	0.15	86748.84	1.03
Urban/built-up land: residential (small holdings: grassland)	0.00	0.00	16678.25	0.13	101696.75	6.16	2747.28	0.03	0.00	0.00
Urban/built-up land: residential (small holdings: shrubland)	127.97	0.00	74.77	0.00	0.00	0.00	243.53	0.00	3990.53	0.05
Urban/built-up land: residential (small holdings: woodland)	26.23	0.00	103.06	0.00	28342.01	1.72	17.15	0.00	0.00	0.00
Waterbodies	69249.46	0.41	85238.53	0.66	8281.78	0.50	97285.17	1.06	0.00	0.00
Wetlands	17503.49	0.10	115170.19	0.89	7461.31	0.45	75840.64	0.82	420122.63	0.50
Totals	17 006 986.07		1 299 3571.9		1 651 914.94		9 211 849.99		7 994 845.8	

Land-cover description	North West		Northern Cape		Northern		Western Cape	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Barren rock	166.04	0.00	157465.70	0.43	6595.91	0.05	21678.55	0.17
Cultivated: permanent — commercial dryland	84.28	0.00	638.89	0.00	41136.61	0.34	3396.79	0.03
Cultivated: permanent — commercial irrigated	706.10	0.01	34759.46	0.10	58704.24	0.48	290203.82	2.24
Cultivated: permanent — commercial sugarcane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cultivated: temporary — commercial dryland	1 623 368.14	13.98	100548.39	0.28	659966.93	5.39	1 740 258.14	13.44
Cultivated: temporary — commercial irrigated	114094.46	0.98	130180.56	0.36	160616.59	1.31	162325.13	1.25
Cultivated: temporary — semi-commercial/subsistence dryland	383004.85	3.30	0.00	0.00	799927.42	6.53	13.76	0.00
Degraded: herbland	0.00	0.00	0.00	0.00	0.00	0.00	63.51	0.00
Degraded: forest and woodland	115485.58	0.99	0.00	0.00	647688.87	5.29	0.00	0.00
Degraded: shrubland and low fynbos	15.60	0.00	75558.83	0.21	0.00	0.00	301180.24	2.33
Degraded: thicket & bushland (etc)	1 270 785.85	10.95	43379.36	0.12	551535.40	4.51	4912.65	0.04
Degraded: unimproved grassland	633.49	0.01	136018.43	0.38	15043.13	0.12	94.52	0.00
Dongas and sheet erosion scars	1325.47	0.01	63811.28	0.18	7777.28	0.06	51501.50	0.40
Forest	717.31	0.01	139.89	0.00	37650.01	0.31	62447.45	0.48
Forest and Woodland	608793.64	5.24	99936.68	0.28	4 016 534.87	32.81	1.59	0.00
Forest plantations	20594.98	0.18	2474.27	0.01	99236.21	0.81	107708.93	0.83
Herbland	0.00	0.00	242866.56	0.67	0.00	0.00	56.04	0.00
Improved grassland	3990.86	0.03	2372.75	0.01	389.44	0.00	58870.66	0.45
Mines and quarries	20934.11	0.18	28733.01	0.08	14513.23	0.12	1838.55	0.01
Shrubland and low Fynbos	533.78	0.00	25 252 910.26	69.68	2942.62	0.02	9 171 562.79	70.81
Thicket and bushland (etc)	4 867 206.33	41.92	5 153 788.66	14.22	4 779 212.69	39.04	655855.83	5.06
Unimproved grassland	2 359 842.97	20.33	4 335 698.03	11.96	135951.40	1.11	121718.45	0.94
Urban/built-up land: commercial	1924.91	0.02	1107.98	0.00	1460.28	0.01	3320.80	0.03
Urban/built-up land: industrial/transport	3446.45	0.03	3936.31	0.01	2775.12	0.02	6654.20	0.05
Urban/built-up land: residential	138683.44	1.19	21706.00	0.06	172705.01	1.41	84516.44	0.65
Urban/built-up land: residential (small holdings: bushland)	4490.95	0.04	1118.87	0.00	6002.23	0.05	209.99	0.00
Urban/built-up land: residential (small holdings: grassland)	9785.23	0.08	0.00	0.00	0.00	0.00	29.23	0.00
Urban/built-up land: residential (small holdings: shrubland)	0.00	0.00	568.00	0.00	4.91	0.00	11282.41	0.09
Urban/built-up land: residential (small holdings: woodland)	3540.24	0.03	0.00	0.00	8433.93	0.07	0.00	0.00
Waterbodies	20578.80	0.18	58948.89	0.16	12816.05	0.10	68438.08	0.53
Wetlands	35803.51	0.31	294926.42	0.81	1759.77	0.01	22969.27	0.18
Totals	11 610 537.37		36 243 593.48		12 241 380.		12 953 109.3	

Table 4. Land-cover areal totals for South African potential vegetation biomes by level I land-cover category.

Land-cover description	Fynbos		Grassland		Nama Karoo		Savanna		Succulent Karoo		Thicket	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Barren rock	3881.3	0.05	55124.5	0.17	128131.9	0.43	43176.1	0.10	7534.3	0.09	18691.7	0.45
Cultivated: permanent — commercial dryland	4453.6	0.06	7539.3	0.02	566.7	0.00	67773.2	0.16	0.0	0.00	4196.2	0.10
Cultivated: permanent — commercial irrigated	248206.1	3.22	1698.2	0.01	34479.7	0.12	82861.7	0.19	47832.2	0.58	5451.0	0.13
Cultivated: permanent — commercial sugarcane	0.0	0.00	65494.5	0.20	0.0	0.00	387919.6	0.91	0.0	0.00	50496.7	1.22
Cultivated: temporary — commercial dryland	1 643 874.1	21.32	5 887 078.6	17.63	204151.8	0.69	1 680 791.3	3.94	208599.5	2.53	110067.7	2.65
Cultivated: temporary — commercial irrigated	120643.4	1.56	201296.9	0.60	181812.9	0.61	486803.4	1.14	37735.9	0.46	52542.6	1.26
Cultivated: temporary — semi-commercial/subsistence dryland	6.4	0.00	1 678 276.8	5.02	288.3	0.00	2 040 967.7	4.79	154.6	0.00	201239.3	4.84
Degraded: herbland	0.0	0.00	75.1	0.00	0.0	0.00	0.0	0.00	0.0	0.00	63.5	0.00
Degraded: forest and woodland	0.0	0.00	37454.0	0.11	0.0	0.00	1 017 127.8	2.38	0.0	0.00	4413.8	0.11
Degraded: shrubland and low fynbos	107584.8	1.40	2830.9	0.01	380203.1	1.28	10044.4	0.02	26329.3	0.32	35428.2	0.85
Degraded: thicket & bushland (etc)	4207.5	0.05	75850.8	0.23	353.9	0.00	2 114 570.6	4.96	0.0	0.00	107204.9	2.58
Degraded: unimproved grassland	94.5	0.00	2 014 669.3	6.03	6600.0	0.02	537641.8	1.26	37.8	0.00	196805.4	4.74
Dongas and sheet erosion scars	2848.1	0.04	32300.7	0.10	3337.8	0.01	34593.0	0.08	110606.9	1.34	4146.3	0.10
Forest	10586.1	0.14	84519.9	0.25	1329.7	0.00	105021.2	0.25	154.1	0.00	36350.5	0.87
Forest and Woodland	0.0	0.00	269967.4	0.81	22179.1	0.07	6 984 340.9	16.38	284.3	0.00	10228.2	0.25
Forest plantations	92033.3	1.19	1 117 737.9	3.35	3852.3	0.01	571810.9	1.34	605.1	0.01	33537.4	0.81
Herbland	16.7	0.00	389.8	0.00	61171.1	0.21	17.2	0.00	178207.9	2.16	39.4	0.00
Improved grassland	25139.8	0.33	41769.6	0.13	7726.2	0.03	14321.4	0.03	5905.1	0.07	7878.4	0.19
Mines and quarries	1146.8	0.01	106668.9	0.32	2025.6	0.01	49313.6	0.12	14651.4	0.18	1496.3	0.04
Shrubland and low Fynbos	4 473 780.2	58.01	1 006 780.4	3.01	2 5385 932.9	85.23	2 377 417.0	5.57	7 503 054.5	90.91	1 018 930.2	24.52
Thicket and bushland (etc)	720810.6	9.35	1 957 586.9	5.86	1 243 304.9	4.17	16 240 061.3	38.08	53912.5	0.65	1 574 548.6	37.90
Unimproved grassland	113551.1	1.47	17 842 402.9	53.42	1 761 893.7	5.92	6 919 499.9	16.22	26861.8	0.33	576079.4	13.87
Urban/built-up land: commercial	2683.0	0.03	20633.4	0.06	692.0	0.00	7523.3	0.02	83.4	0.00	2474.2	0.06
Urban/built-up land: industrial/transport	5526.5	0.07	35443.9	0.11	2141.6	0.01	17444.3	0.04	329.0	0.00	4396.3	0.11
Urban/built-up land: residential	67270.1	0.87	442713.9	1.33	15217.8	0.05	489277.5	1.15	8318.7	0.10	71165.9	1.71
Urban/built-up land: residential (small holdings: bushland)	251.9	0.00	2077.5	0.01	165.4	0.00	23394.3	0.05	0.0	0.00	2396.2	0.06
Urban/built-up land: residential (small holdings: grassland)	29.2	0.00	131930.8	0.40	0.0	0.00	1466.8	0.00	0.0	0.00	1254.4	0.03
Urban/built-up land: residential (small holdings: shrubland)	9651.0	0.13	212.6	0.00	534.2	0.00	266.4	0.00	0.0	0.00	1682.5	0.04
Urban/built-up land: residential (small holdings: woodland)	0.0	0.00	2757.9	0.01	0.0	0.00	37678.4	0.09	0.0	0.00	26.2	0.00
Waterbodies	40468.8	0.52	127829.0	0.38	108485.3	0.36	126679.6	0.30	13086.9	0.16	15879.2	0.38
Wetlands	13317.4	0.17	148994.5	0.45	227057.3	0.76	179355.1	0.42	9169.8	0.11	5606.9	0.13
Totals	7 712 062.02		33 400 106.8		2 978 3635		42 649 159.64		8 253 454.72		4 154 717.3	

waterbodies and wetlands) covered a little less than 1%. Human transformed classes (for instance, cultivation, exotic plantations, degraded lands, urban/built-up lands, and mines and quarries) covered the other 20% of the land surface.

Lesotho is 49% covered by 'natural' woody and grassland vegetation communities. Wet landscape classes covered only 0.2% (before the filling of the Katse dam). Human-transformed classes represented the other 50.8% of the land surface.

Swaziland is 61% covered by 'natural' woody and grassland vegetation communities. Wet landscape classes covered only 0.2%. Human-transformed classes made up the other 38.8% of the land surface.

Tables 3–5 also describes the land-cover area by province,[17] primary hydrological catchment[18] and vegetation biome[7] category. These results should be used with the maps in Figs 2–4 to understand the implications of the areal totals. The areal extent of land-cover/land-use classes by province is only significant if one acknowledges the currently defined political boundaries. For example, the total urban/built-up lands cover 18% of Gauteng, and are rapidly growing in extent,[33] yet this is only significant in relation to the current political boundaries, which could change in the future. As the provinces are used for demographic, budgeting and planning purposes by national government, however, these results are important when combined with the 1996 census figures.[28]

The primary hydrological catchments[18] are well-defined units that can be physically located on the ground. One example, catchment 'U', which comprises the KwaZulu-Natal midlands and the Durban metropolitan area, is 28% covered by exotic plantations and sugarcane alone. These crops have a large impact on the water resources provided by this catchment, therefore their areal extent is important for catchment management authorities, when combined with streamflow characteristics, as well as the spatial pattern of the land-use classes and rainfall.[34]

The vegetation biomes are fairly well defined on the ground, but because the map is based on potential rather than actual boundaries, there is some disagreement between our mapped classes and the potential

Table 5. Land-cover areal totals for South African primary hydrological catchments by level I land-cover category.

Land-cover description	A (Limpopo) Area (ha)	%	B (Olifants) Area (ha)	%	C (Vaal) Area (ha)	%	D (Orange #1) Area (ha)	%	E (W. Cape #1) Area (ha)	%	F (Orange #2) Area (ha)	%	G (W. Cape #2) Area (ha)	%	H (W. Cape #3) Area (ha)	%
Barren rock	3914.43	0.04	3881.23	0.05	9638.02	0.05	183116.37	0.45	1071.48	0.02	4850.69	0.17	13000.05	0.51	2234.01	0.14
Cultivated: permanent — commercial dryland	17672.95	0.16	23547.96	0.32	283.46	0.00	643.79	0.00	40316.02	0.82	0.00	0.00	3227.81	0.13	168.98	0.01
Cultivated: permanent — commercial irrigated	3166.75	0.03	57345.76	0.78	125.16	0.00	34803.84	0.09	0.00	0.00	0.00	0.00	131502.30	5.20	108659.96	7.00
Cultivated: permanent — commercial sugarcane	0.00	0.00	0.00	0.00	15.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cultivated: temporary — commercial dryland	585238.28	5.34	828792.58	11.27	5 237 970.46	26.68	659470.32	1.61	141139.88	2.88	92747.10	3.25	1 030 131.06	40.70	391001.41	25.18
Cultivated: temporary — commercial irrigated	196522.63	1.79	136478.68	1.86	149610.45	0.76	98556.84	0.24	40367.06	0.82	19.71	0.00	43763.77	1.73	12349.63	0.80
Cultivated: temporary — semi-commercial/subsistence dryland	521797.13	4.76	464381.99	6.32	47927.48	0.24	914066.77	2.23	0.00	0.00	0.00	0.00	13.76	0.00	0.00	0.00
Degraded: herbland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	63.52	0.00	0.00	0.00
Degraded: forest and woodland	354498.64	3.24	416665.70	5.67	0.00	0.00	395.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Degraded: shrubland and low fynbos	15.60	0.00	20.59	0.00	76.94	0.00	81316.93	0.20	1918.11	0.04	0.00	0.00	72721.22	2.87	19822.20	1.28
Degraded: thicket & bushland (etc)	574818.83	5.25	80351.12	1.09	148229.41	0.76	1 056 266.70	2.58	40.21	0.00	0.00	0.00	4835.43	0.19	65.76	0.00
Degraded: unimproved grassland	90.04	0.00	15786.43	0.21	63802.67	0.33	1 063 740.87	2.60	0.00	0.00	0.00	0.00	94.52	0.00	0.00	0.00
Dongas and sheet erosion scars	4909.85	0.04	5579.80	0.08	11461.15	0.06	12854.62	0.03	105679.63	2.15	0.00	0.00	510.13	0.02	38.58	0.00
Forest	15932.99	0.15	28195.60	0.38	581.26	0.00	210.61	0.00	167.26	0.00	0.00	0.00	0.00	0.00	105.95	0.01
Forest and Woodland	2 864 689.44	26.15	2 271 664.79	30.90	61957.13	0.32	219848.78	0.54	0.00	0.00	0.00	0.00	1.59	0.00	0.00	0.00
Forest plantations	42161.43	0.38	138359.01	1.88	53059.72	0.27	9386.63	0.02	974.58	0.02	0.00	0.00	40156.81	1.59	11157.12	0.72
Herbland	6253.00	0.06	7.17	0.00	0.00	0.00	239380.94	0.58	0.00	0.00	0.00	0.00	56.04	0.00	4949.95	0.32
Improved grassland	23019.25	0.21	2382.35	0.03	7370.90	0.04	9998.51	0.02	690.45	0.01	0.00	0.00	7118.15	0.28	43.32	0.00
Mines and quarries	2985.13	0.03	47769.58	0.65	64897.94	0.33	13637.83	0.03	55.56	0.00	14107.65	0.49	1620.59	0.06	911236.37	58.67
Shrubland and low Fynbos	4 996 264.46	45.61	0.00	0.00	596578.74	3.04	22 141 205.64	54.08	4 122 711.34	84.03	2 702 480.83	94.64	849354.42	33.56	39940.46	2.57
Thicket and bushland (etc)	386763.69	3.53	1 438 427.96	19.57	3 552 399.14	18.10	6 073 036.23	14.83	288721.16	5.88	6585.93	0.23	157520.16	6.22	25295.10	1.63
Unimproved grassland	8014.00	0.07	1 218 235.69	16.57	9 095 250.05	46.33	7 636 356.03	18.65	148392.53	3.02	28792.87	1.01	56348.87	2.23	65.23	0.00
Urban/built-up land: commercial	7977.49	0.07	532.46	0.01	14208.36	0.07	1462.33	0.00	0.00	0.00	0.00	0.00	2700.13	0.11	677.59	0.04
Urban/built-up land: industrial/transport	213251.90	1.95	4639.66	0.06	27007.87	0.14	3279.13	0.01	0.00	0.00	0.00	0.00	5474.16	0.22	6757.47	0.44
Urban/built-up land: residential	7118.39	0.06	141032.18	1.92	169848.18	0.87	81160.40	0.20	2403.06	0.05	1573.18	0.06	63830.99	2.52	0.00	0.00
Urban/built-up land: residential (small holdings: bushland)	57658.27	0.53	0.00	0.00	873.22	0.00	3890.89	0.01	0.00	0.00	0.00	0.00	0.00	0.00	9.32	0.00
Urban/built-up land: residential (small holdings: grassland)	4.90	0.00	4240.33	0.06	69917.35	0.36	215.08	0.00	19.92	0.00	0.00	0.00	0.00	0.00	23.15	0.00
Urban/built-up land: residential (small holdings: shrubland)	40161.92	0.37	0.00	0.00	33.79	0.00	683.80	0.00	0.00	0.00	0.00	0.00	10898.20	0.43	0.00	0.00
Urban/built-up land: residential (small holdings: woodland)	14725.70	0.13	59.18	0.00	103.07	0.00	95.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16154.05	1.04
Waterbodies	5359.20	0.05	19697.64	0.27	86396.64	0.44	103406.96	0.25	8326.07	0.17	2872.69	0.10	21142.26	0.84	2274.04	0.15
Wetlands	0.00	0.00	3212.04	0.04	159780.69	0.81	298341.43	0.73	3416.72	0.07	1451.22	0.05	14940.13	0.59	0.00	0.00
Totals	10 954 986.3		7 351 287.48		1 962 9405		40 940 828.6		4 906 411.04		2 855 481.87		2 531 026.1		1 553 029.65	

biome classes. For these results we have omitted the forest biome and instead provide the areal coverage of indigenous forest within each major biome category. Two examples of these results include the grassland biome, which includes within its potential boundary 9% coverage of woody vegetation and 53% remaining grassland coverage. The 'savanna' biome, however, according to its definition, contains 16% grassland coverage and a 60% remaining woodland. These results should be used within the context of the potential biome definitions, which are not definitive, but they do provide some measure of landscape change over the last 325 years since European colonization.

As an indication of change, Table 6 provides an assessment of national plantation forestry and agricultural cropland development and historical agriculture development by province where known (these estimates include former self-governing territories).

Discussion

Changes in natural ecosystems in which the structure and species composition are completely or almost completely altered, are termed transformations.[35] The principal land transformers in South Africa are cultivation, afforestation and urbanization.

Currently 12.2% (of a total country size of 1 219 077 km^2) is estimated by the NLC to be under cultivation (Table 6). Though not directly comparable, 12.26% was estimated be under cultivation throughout the 'white' controlled portion of South Africa in 1987.[13] The areas most continuously and extensively cultivated include the Swartland/winelands (7366 km^2), Bredasdorp/Swellendam/Caledon region (5039 km^2), and the Springbok flats (3457 km^2). By comparison, global trends from 1950 to the mid-1990s showed the area of cropland per person fell by half, from 0.23 ha to 0.12 ha, less than a quarter the size of a soccer field.[36,37] According to the NLC results against the 1996 census totals, South Africa currently maintains 0.364 ha of cropland per person, but with highly varying amounts per province (Table 7).

South Africa is not well endowed with indigenous forests. As a result, large areas have been planted to fast-growing, exotic trees, mainly *Pinus* and *Eucalyptus* species, to meet

Table 5 (continued).

Land-cover description	J (W. Cape #4) Area (ha)	%	K (W Cape #5) Area (ha)	%	L (W. Cape #6) Area (ha)	%	M (E. Cape #1) Area (ha)	%	N (E.Cape #2) Area (ha)	%	P (E. Cape #3) Area (ha)	%	Q (E. Cape #4) Area (ha)	%	R (E. Cape #5) Area (ha)	%
Barren rock	4379.68	0.10	4378.11	0.61	4569.42	0.13	3255.94	1.24	473.23	0.02	11284.15	2.12	49.52	0.00	2983.83	0.38
Cultivated: permanent — commercial dryland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6746.00	1.27	882.80	0.03	6718.04	0.85
Cultivated: permanent — commercial irrigated	8137.26	0.18	93.02	0.01	9723.49	0.28	0.00	0.00	0.00	0.00	0.00	0.00	2631.04	0.09	210.11	0.03
Cultivated: permanent — commercial sugarcane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cultivated: temporary — commercial dryland	142078.52	3.15	119408.13	16.54	16391.56	0.47	28719.89	10.93	13121.43	0.62	28846.34	5.42	2476.83	0.08	8242.20	1.04
Cultivated: temporary — commercial irrigated	55384.76	1.23	9338.22	1.29	26130.06	0.75	3174.33	1.21	45784.41	2.16	2708.50	0.51	66174.64	2.19	3844.24	0.48
Cultivated: temporary — semi-commercial/subsistence dryland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	470.24	0.09	5257.16	0.17	48853.51	6.16
Degraded: herbland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Degraded: forest and woodland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Degraded: shrubland and low fynbos	67222.50	1.49	8147.39	1.13	209001.14	6.02	0.00	0.00	48096.92	2.27	0.00	0.00	54587.17	1.81	0.00	0.00
Degraded: thicket & bushland (etc)	12.86	0.00	32.42	0.00	0.00	0.00	125.40	0.05	13446.71	0.63	11140.36	2.09	23961.58	0.79	21039.95	2.65
Degraded: unimproved grassland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.02	0.01	12359.84	0.41	102048.41	12.86
Dongas and sheet erosion scars	0.00	0.00	0.00	0.00	1000.77	0.03	0.00	0.00	0.00	0.00	0.00	0.00	667.83	0.02	32.77	0.00
Forest	428.32	0.01	76559.26	10.60	87.72	0.00	53.51	0.02	1105.94	0.05	12792.97	2.40	17009.67	0.56	25471.74	3.21
Forest and Woodland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2544.82	0.12	0.00	0.00	49441.56	1.64	5.94	0.00
Forest plantations	1372.29	0.03	73842.58	10.23	6563.59	0.19	5682.39	2.16	827.81	0.04	1673.43	0.31	5157.63	0.17	16076.88	2.03
Herbland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Improved grassland	10291.66	0.23	36273.33	5.02	222.99	0.01	161.01	0.06	3426.95	0.16	3074.22	0.58	7348.66	0.24	1870.31	0.24
Mines and quarries	58.27	0.00	53.39	0.01	41.25	0.00	549.30	0.21	0.00	0.00	95485.21	17.95	129.89	0.00	207.41	0.03
Shrubland and low Fynbos	4 102 499.10	90.90	215758.02	29.88	2 904 211.12	83.62	84221.81	32.06	1 332 439.21	62.78	227843.26	42.83	1 677 453.73	55.49	10466.45	1.32
Thicket and bushland (etc)	99710.20	2.21	152264.34	21.09	270760.92	7.80	109767.04	41.78	521453.92	24.57	125771.80	23.64	527391.55	17.45	324518.56	40.90
Unimproved grassland	11702.91	0.26	3822.15	0.53	17913.74	0.52	0.00	0.00	132425.94	6.24	69.75	0.01	556099.02	18.40	179867.23	22.67
Urban/built-up land: commercial	48.22	0.00	595.63	0.08	0.00	0.00	1344.35	0.51	0.00	0.00	89.78	0.02	0.00	0.00	708.71	0.09
Urban/built-up land: industrial/transport	0.00	0.00	498.57	0.07	19.80	0.00	2445.40	0.93	39.34	0.00	2937.24	0.55	0.00	0.00	1745.94	0.22
Urban/built-up land: residential	4494.21	0.10	9841.66	1.36	1496.03	0.04	19604.15	7.46	1952.44	0.09	85.43	0.02	7535.76	0.25	33360.47	4.20
Urban/built-up land: residential (small holdings: bushland)	0.00	0.00	354.83	0.05	0.00	0.00	579.48	0.22	0.00	0.00	0.00	0.00	0.00	0.00	606.29	0.08
Urban/built-up land: residential (small holdings: grassland)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban/built-up land: residential (small holdings: shrubland)	349.90	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban/built-up land: residential (small holdings: woodland)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	935.57	0.18	0.00	0.00	26.23	0.00
Waterbodies	4551.87	0.10	9309.33	1.29	4703.30	0.14	2253.67	0.86	5411.59	0.25	30.81	0.01	3993.45	0.13	4456.54	0.56
Wetlands	711.32	0.02	1457.11	0.20	288.05	0.01	764.29	0.29	0.00	0.00	0.00	0.00	2217.17	0.07	129.32	0.02
Totals	4 513 433.85		722027.49		3 473 124.95		262701.96		2 122 550.7		532029.08		3 022 826.5		793491.08	

the nation's timber needs. Currently, 3.3% of land area is afforested (Table 6) with these introduced species in South Africa alone. On a regional scale, these plantations account for only a small percentage of the total area, but for certain regions of the eastern seaboard (8794 km^2) and along the eastern escarpment (19 370 km^2 in the Sabie/Graskop area and 11 082 km^2 in the Amersfoort/Oshoek area) the percentages become substantial (see Table 5 Catchments).

Since the advent of European colonization, the impact of towns and cities has become regionally significant. In the only analyses of the extent of urbanization, MacDonald[12] synthesizes two independent estimates from the mid-1970s for South Africa: Edwards[38] gives the area as being 21 270 km^2 (1.7%) of a total of 1 221 110 km^2, whereas Serfontein[39] cites 16 260 km^2 (1.3%) of a total area of 1 114 830 km^2. The estimate from the NLC, though not directly comparable, gives the area as 11 832 km^2 (1.2%) of a total of 1 219 077 km^2. The most extensive urban areas are: Johannesburg 1464 km^2, Cape Town 50 km^2, Durban 46 km^2, Pretoria 25 km^2, and Bloemfontein 19 km^2.

Although it was difficult to draw a distinction between smallholdings and agricultural land, they were estimated to cover 32 028 km^2 (3.0%) of 'white' South Africa in 1982,[40] but were estimated by the NLC to comprise 2156 km^2 (0.17%). Interpretation of satellite imagery could have provided this large undercount, but the method used by the Department of Water Affairs and Forestry[40] for the 1982 estimate is unknown.

The database highlights possible errors in several commonly held beliefs in regard to the grasslands of South Africa[41] and the fynbos biome.[7,8] Grasslands in total cover an estimated 259 452 km^2 (21.3%) at an identification accuracy of 73%. In 1988 the original extent of grassland was estimated to be 351 314 km^2 (28.8%), therefore 91 862 km^2 (26%) has been transformed through direct removal and alien shrub and bush encroachment. The exotic plantation industry, which occupies only 3.3% of the land, was not shown by the NLC results to be the driving force in the overall transformation of grassland. Rather the agriculture sector, which represents 23.3% coverage, has played the main role in historical times. As indicated in

Table 5 (continued).

Land-cover description	S (E. Cape #6) Area (ha)	%	T (E. Cape #7) Area (ha)	%	U (E. Escarpment #1) Area (ha)	%	V (E. Escarpment #2) Area (ha)	%	W (E. Escarpment #3) Area (ha)	%	X (E. Escarpment #4) Area (ha)	%
Barren rock	5670.26	0.28	6589.55	0.14	192.41	0.01	848.90	0.03	3968.84	0.07	1088.01	0.03
Cultivated: permanent — commercial dryland	29.03	0.00	5389.95	0.12	0.00	0.00	20.28	0.00	8936.94	0.15	11549.25	0.37
Cultivated: permanent — commercial irrigated	0.00	0.00	0.00	0.00	327.38	0.02	0.00	0.00	5007.65	0.08	18543.37	0.60
Cultivated: permanent — commercial sugarcane	0.00	0.00	30317.46	0.65	260991.20	14.26	9609.79	0.33	162060.56	2.74	46273.42	1.49
Cultivated: temporary — commercial dryland	20888.86	1.02	73816.25	1.58	36417.94	1.99	111212.68	3.83	113926.62	1.92	83314.79	2.67
Cultivated: temporary — commercial irrigated	17941.44	0.88	37567.78	0.81	21329.49	1.17	70133.29	2.42	11983.46	0.20	37206.32	1.19
Cultivated: temporary — semi-commercial/subsistence dryland	695339.83	14.91	142873.32	6.98	136883.51	7.48	206399.14	7.11	680701.40	11.50	57943.97	1.86
Degraded: herbland	17.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	57.84	0.00	0.00	0.00
Degraded: forest and woodland	362.61	0.02	676.30	0.01	0.00	0.00	7329.90	0.25	149874.18	2.53	130415.47	4.19
Degraded: shrubland and low fynbos	81.99	0.00	79.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Degraded: thicket & bushland (etc)	14095.03	0.69	10270.07	0.22	94664.18	5.17	76092.24	2.62	135387.44	2.29	40060.99	1.29
Degraded: unimproved grassland	247350.36	12.08	866766.98	18.59	44199.21	2.42	136467.51	4.70	185011.79	3.13	28866.58	0.93
Dongas and sheet erosion scars	15795.13	0.77	961.53	0.02	0.00	0.00	19148.93	0.66	9137.27	0.15	54.76	0.00
Forest	6116.40	0.30	88182.20	1.89	20289.82	1.11	16630.60	0.57	77009.75	1.30	22050.39	0.71
Forest and Woodland	1678.48	0.08	2189.45	0.05	24.20	0.00	21666.98	0.75	829960.38	14.02	933583.57	29.97
Forest plantations	27671.85	1.35	170388.78	3.65	255884.89	13.98	54178.90	1.87	589829.12	9.96	407970.93	13.10
Herbland	17.16	0.00	56.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Improved grassland	2919.69	0.14	4306.57	0.09	11567.96	0.63	7937.57	0.27	585.40	0.01	37.30	0.00
Mines and quarries	50.87	0.00	388.74	0.01	213.46	0.01	4044.42	0.14	3988.41	0.07	874.26	0.03
Shrubland and low Fynbos	46663.98	2.28	1918.86	0.04	1731.82	0.09	5427.93	0.19	206.18	0.00	0.00	0.00
Thicket and bushland (etc)	368656.26	18.00	385602.32	8.27	344908.10	18.85	569780.97	19.62	920065.76	15.54	556294.18	17.86
Unimproved grassland	1 069 725.85	52.22	2 110 571.81	45.26	500436.39	27.34	1 540 653.70	53.06	1 856 693.44	31.37	691214.09	22.19
Urban/built-up land: commercial	176.75	0.01	255.86	0.01	2838.40	0.16	539.06	0.02	657.44	0.01	436.58	0.01
Urban/built-up land: industrial/transport	440.73	0.02	299.65	0.01	5441.00	0.30	1990.51	0.07	2590.05	0.04	1014.75	0.03
Urban/built-up land: residential	51618.71	2.52	134758.50	2.89	67118.01	3.67	24075.65	0.83	22847.03	0.39	38693.73	1.24
Urban/built-up land: residential (small holdings: bushland)	878.50	0.04	3940.16	0.08	9922.15	0.54	0.00	0.00	318.89	0.01	0.00	0.00
Urban/built-up land: residential (small holdings: grassland)	0.00	0.00	0.00	0.00	2731.99	0.15	15.29	0.00	119.75	0.00	0.00	0.00
Urban/built-up land: residential (small holdings: shrubland)	45.79	0.00	7.36	0.00	0.00	0.00	243.51	0.01	0.00	0.00	0.00	0.00
Urban/built-up land: residential (small holdings: woodland)	0.00	0.00	17.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waterbodies	6320.91	0.31	10572.90	0.23	10552.99	0.58	15380.45	0.53	84339.80	1.42	6844.61	0.22
Wetlands	224.40	0.01	22344.88	0.48	1486.16	0.08	3978.54	0.14	63985.40	1.08	609.35	0.02
Totals	2 048 311.6		4 663 576.22		1 830 152.66		2 903 806.74		5 919 250.79		3 114 940.67	

Table 6, however, agriculture is not a rapidly growing industry; instead, the exotic plantation industry has been the main transformer of grasslands in the last 10 years.

In a previous study by Moll and Bossi,[8] the fynbos biome was delineated and assessed to determine its extent and transformation. Their definition of the fynbos biome was also used by Low and Rebelo[7] for the same purpose, and thus Moll and Bossi's[8] transformation statistics are comparable to ours. We calculate that 30.28% of the natural vegetation has been removed from this biome by farming and urbanization activities. By contrast, Moll and Bossi[8] calculated that 34% had been lost. Their delineation and calculation procedures using a planimeter may be subject to greater error than our product. Nevertheless, it is the individual vegetation types (such as coastal renosterveld) that should be assessed for transformation to give a clearer picture of the urgency to protect this globally important floral kingdom.

Surrounded by rangeland, exotic plantations, cultivation, villages or urban areas, fragments of the natural landscape that are available for conservation or development have important considerations.[42–46] Two major problems are isolation and human impacts from the landscape matrix. Isolation primarily affects the interior species. Therefore 'natural' habitat patch size, shape, number and configuration are critical as are corridor width and connectivity.[43,46] Patches must be able to support the interior species. Both corridors and patches provide for a networked configuration that permits rapid recolonization when an interior species becomes locally extinct (source/sink models).[42,44]

A few caveats should be raised with regard to coverage totals for any of the analysis results presented in this paper. First, the sum totals for each of the zonal units for all of South Africa, Swaziland and Lesotho are marginally different, depending on the recording unit. This is due to the various cadastral boundaries employed on the northern and interior eastern South African and eastern Swaziland international borders. The current national borders were used to delineate the countries and provincial boundaries (Fig. 2), but both the primary hydrological catchment and vegetation biome maps (Figs 3, 4) have a slightly larger overlap along the Limpopo River valley and North-West Province boundary and a slightly contracted boundary along the Kruger National Park's international border and Swaziland's eastern international border. Second, the amount of natural vegetation remaining untransformed in South Africa may not seem as negative as might previously been perceived by both government departments, conservation organizations, and the public.[12–14] This can be misleading, as the coverage totals do not take into account habitat fragmentation, which can be seen as perforations of land-use in the 'natural' vegetation matrix within the accompanying map printed on the journal's cover. Results are also only provided by major biome type[7] rather than individual vegetation type, which would provide a more definitive picture. In a subsequent analysis, results for individual vegetation type[7] transformations will be provided. The coverage totals represent

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Table 6. The estimated extents of past afforestation (1985) and cultivation (1987) and NLC estimates (1994) with percentage change for some national states and provincial regions.

National and provincial	Historic hectares	NLC hectares (1994)	Change in coverage (% increase)
Afforestation in South Africa	1 189 000 (1985)[13]	1 790 269	50.5
Afforestation in Swaziland	107 000 (1985)[13]	120 310	12.4
Cultivation in South Africa	13 838 100 (1987)[11,12]	1 4881 4551	7.5
Cultivation in KwaZulu-Natal	1 316 500 (1987)[11,12]	1 581 381	20.0
Cultivation in Free State	1 683 600 (1987)[11,12]	3 740 985	122.0
Cultivation in Western Cape	1 800 000 (1987)[11,12]	2 196 197	22.0

Table 7. Population density by South African province.

Region	1996 Census	NLC area (ha)	Ha/person
South Africa	40 583 573	14 753 248.3	0.364
Eastern Cape	6 302 525	1 392 488.5	0.221
Free State	2 633 504	3 741 320.4	1.421
Gauteng	7 348 423	346 158.9	0.047
KwaZulu-Natal	8 417 021	1 581 381.8	0.188
Mpumalanga	2 800 711	1 388 307.0	0.496
Northern Cape	840 321	266 127.3	0.317
Northern Province	4 929 368	1 720 351.8	0.349
North West	3 354 825	2 121 257.8	0.632
Western Cape	3 956 875	2 196 197.6	0.555

summations of all bits of each land-cover type mapped within the project, though some of the 'natural' pieces of land may be degraded in their ability to harbour biodiversity or perform valuable ecosystem functions. Mounting evidence that habitat fragmentation is detrimental to many species and may contribute substantially to the loss of regional and global biodiversity[42,43] has provided empirical justification for the need to manage entire landscapes not just the components.

Database development issues

This preliminary evaluation indicates that the procedures used and the results obtained are, for the most part, acceptable. The research into and the development of this land-cover database illuminated many issues that remain to be addressed or noted in future updates and revisions such as landscape complexity, verification procedures, image acquisition dates in relation to feature identification, land-use variability within a single land-cover type, verification procedures and change detection.

One of the key issues related to mapping accuracy is landscape complexity, especially in terms of the mapping scale used. The results indicate that it is the actual landscape components that have a greater influence on overall mapping accuracy than simply landscape complexity if measured in terms of the number and frequency of small polygon units making up a specific region. For example, sheets containing complex patterns and gradients of natural and degraded vegetation types (e.g. 2830 Richards Bay) were significantly harder to map than those containing significantly more (and often smaller) polygons that were based on *uniform cover types with clearly definable boundaries*, such as occurs with dryland maize cultivation (e.g. 2628 East Rand).

The accuracy of boundary delineations is also closely linked to the achievable minimum mapping unit. As indicated previously, the target minimum mapping unit for the land-cover project was 25 ha. This was generally achieved with those land-cover (or use) types that have distinct, clearly definable boundaries, such as plantations, cultivated fields or waterbodies. Where boundaries are more difficult to define, such as the natural gradients between different natural vegetation covers, such as 'Forest and Woodland' and 'Thicket, Bushland', then the minimum mapping unit has tended to be larger, since it is difficult to define such small areas accurately within transition zones.

Boundary delineations of natural vegetation types are always problematical, since in effect an artificial boundary is being imposed on what is really a natural gradient or progression from one cover type to another. The boundaries that caused most problems within both image-interpretation and field-evaluation were the transition zones between 'Forest and Woodland' and 'Thicket, Bushland', especially in the lowveld/bushveld regions, and the 'Grassland' and 'Shrubland & Low Fynbos' classes along the grassland and karoo biome boundary.

Where landscape complexity is low, and a uniform, homogeneous cover is predominant, such as in the Northern Cape Province, it appears that the field validation method used may have resulted in some erroneous indications of lower than actual map accuracies. In such large homogeneous regions, the *random* selection of field sample points along the road transects is likely to have resulted in an over-sampling of the predominant cover-class (e.g. 'Shrubland and Low Fynbos'), and a significant under-sampling of other, sparsely distributed cover types (such as small, irrigated cultivated areas around homesteads). Because of the way in which the statistical models calculate the mapping accuracies, in these single cover-type biased map sheets, although the dominant cover type has been mapped accurately, inaccurate mapping (and under-sampling) of small area, sparsely distributed cover types may have resulted in lower classification accuracies and kappa values being reported.

As a result of the (unavoidable) generalizations that can result from mapping complex, often highly fragmented landscapes, several instances were found where, due to imposed scale limitations, only the 'dominant' cover type could be mapped from within a mosaic of cover types. This was an unfortunate, but unavoidable constraint that has to be accounted for when interpreting the mapped data in relation to the stated land-cover class and associated definition. For example, in many rural districts, where settlement infrastructure is often widely distributed within a larger framework of subsistence-level cultivation, it is often not possible to identify the individual settlement units or clusters, so they would by default have been included within the larger (subsistence) cultivation class.

The decision whether or not to map subsistence-level cultivation as a separate cover type depends on the relative density of the actual field structures. Where small field units are widely scattered throughout a particular area (as opposed to being farmed in a 'concentrated-block' approach as apparent, for example, in many regions of the former Bophuthatswana), they will have often been incorporated within the 'background' cover type, which in most cases is (unfortunately) a 'degraded' vegetation class. The problem of identifying scattered subsistence-level cultivation is compounded further when the surrounding vegetation is degraded, since, in terms of the project, 'degraded' is defined as having a higher albedo as a result of lower overall vegetation cover and increased soil exposure. Thus small fields with high soil exposures exhibit similar spectral characteristics to the surrounding degraded vegetation, making identification and subsequent delineation difficult.

Although stringent guidelines were developed to ensure that, as far as possible, the most recently acquired satellite images were used throughout the project, it is important to note that in some cases there is still an inherent time-delay factor associated with actual acquisition dates and optimum feature identification. This problem is most pronounced in commercial (mono-species) plantation forestry, where the accuracy with which this cover type can be mapped (from satellite imagery) is greatly influenced by characteristics such as age profile, stand structure, species type and crop management practices. Previous experience suggests that high-resolution imagery (such as Landsat TM) may be used to identify new plantation areas as a single forest category (with 95–100% areal accuracy) only when the canopy cover exceeds 50–60% (although there are exceptions to this rule). Since closure varies significantly by site and species, no single age threshold can be given at which a particular stand is guaranteed to be visible. However, under 'normal' or optimum site conditions all stands should be visible between 24 and 36 months after planting, with eucalypts typically being visible even earlier due to their faster growth rates.[47] This means that any plantations established after 1992/93 may not be included within the land-cover database, which, over the main afforestation regions, is based primarily on 1994/95 imagery.

A further problem is that exotic wattle (e.g. *Acacia mearnsii*) exhibits similar spectral reflectance characteristics (on Landsat TM imagery) to some indigenous bush communities, making identification difficult if the two cover types are in close proximity, unless contextual differences are apparent (such as non-natural linear fence-line effects). In general, unmanaged wattle 'jungle' has been coded as 'Thicket, Bushland', although most of the self-seeding wattle 'plantations' developed as major fuelwood sources in Swaziland have been coded as 'Plantations'. This problem is not likely to be overcome in the short term, until significant improvements or modifications in spectral resolution are made on commercial earth observation satellites.

Similar problems of spectral confusion were found for physically similar cover types such as irrigated lucerne and irrigated-improved grasslands, and cultivated maize fields and cut hay-grass fields (with hay fields being misinterpreted as dryland maize as a result of clear fence-line effects and similar spectral reflectance characteristics). These problems may have resulted in some limited area-specific misclassification of 'temporary-commercial-irrigated crops' and 'improved grasslands', and a slight over-estimation of the extent of 'temporary-commercial-dryland cultivation', respectively.

It is possible for several land-uses to be associated with a single cover-type, especially in terms of non-physical land-management processes. In some cases, this has led to some confusion when mapping at level 2, because of possible land-use variability within a single land-cover type. For example, cultivated areas have been classified as irrigated on the basis of field observation and/or close proximity to dams, irrigation schemes (including centre-pivot schemes) and perennial river sources (as used for locally piped in-field irrigation). Although generally accurate for large, commercial irrigation schemes, some small-scale irrigation (for instance, based on mobile pipe-based sprinkler systems) may have been underestimated, where the timing and location of irrigation activities differed from either the preparatory field visits and/or the date of satellite image acquisition.

Although in general the definitions applied to each land-cover (and use) class are based on clear and unambiguous criteria, which are both exhaustive and mutually exclusive, some area-specific variability has been introduced where subclass qualifiers (such as 'degraded') have been used. The degradation classes (as defined within the land-cover database) are inferred from relative lower vegetation cover and an associated higher albedo from the imagery. In most cases there is a relationship between low vegetation cover and degradation. However, this relationship is not true for all cases and a low cover may reflect local grazing differences with no negative species composition change, bush encroachment or soil erosion. Indeed, bush-encroached areas will not be mapped as degraded owing to the relatively high crown cover. Large areas of degraded grassland (in terms of species composition) with a good cover were also not mapped as degraded. This means that the severity of degradation varies across the database, since each area is defined in terms of the vegetation condition immediately adjacent to it. Thus, for example, the severity of grassland degradation in the higher parts of Lesotho may be greater than that found in the Eastern Cape grasslands.

Both the collection and interpretation of the verification data collected in the field and from archival aerial photographs suffered from small inherent problems that necessitated subsequent data manipulation. These included modification of the field and aerial data as well as (limited) post-validation adjustment of the actual land-cover data. Although such an approach may be questionable, in all cases the aim of the modifications was to improve the overall accuracy of the final dataset. In all cases, such modifications have been fully documented[48] to inform users and ensure that an auditable record exists. Practical examples of these are many, which may seem to be criticism of the final map product, but is rather viewed as a positive indication of the thoroughness of the review process, both during and on completion of the project.

Some degree of interpreter bias exists in the final data with regard to transitional land-cover zones and/or physically similar cover-types, but as far as possible all these have been specifically documented in the Data User's Guide.[48] Some variation in the classification of sparsely vegetated areas associated with ostrich camps in the Karoo is known to have occurred, with the larger, more extensive 'camp' areas often being coded as 'Degraded Shrubland', whereas smaller ones, and those with more clearly definable boundaries, may have sometimes been mis-coded as 'Dryland Temporary Commercial Cultivation'. This would have had an effect on reported accuracies, although wherever possible, coding discrepancies between field and/or aerial photograph validation data and classified data were corrected if found to be consistent across the entire map sheet. Likewise, there was some confusion in the coding of sparsely vegetated areas in some central and southern Karoo regions, which are a combination of both dry washout zones and/or areas suffering from locally intensive grazing pressures. Both 'Erosion Surfaces (Bare Rock and Soil)' and 'Degraded Shrubland' categories have been used to code these areas, although the allocation has varied between map sheets based on the preference shown by individual analysts. No attempt was made to standardize this coding — rather, the original code allocated by the individual image analyst based on direct in-field observation has been retained.

Scale-dependent biases were the result of possible confusion when comparing the land cover as determined by visual assessment in the field from a ground-level perspective with that deduced from a 1:250 000 scale satellite print. For sites where possible discrepancies existed, the modification procedure involved comparing the *field reported* land-cover code to the *field-recorded* fixed point photograph (and in the case of natural vegetation, also to the additional attribute data). The original field code was only then modified if the argument for this was supported by the fixed-point field photograph. Such an approach allowed the generic land cover to be confirmed and reduced the risk of mis-coding on the basis of *visually (not spatially) dominant* features smaller than the prescribed 25 ha minimum mapping unit.

The use of non-differentially corrected field GPS readings was also found to be a source of some local boundary error when combined with the geopositional accuracy of the land-cover database, despite recommendations not to sample in the field within approximately 500 m of a perceived land-cover boundary. Such problems were corrected by plotting the actual GPS readings as a point-transect map at 1:250 000 scale to allow direct overlay on the original annotation acetate sheet. Each GPS point was ringed with a 200-m-diameter boundary. If any point within this sample area straddled a mapped land-cover boundary, and *both* cover codes equated to that mapped and reported, then the field data point was modified in favour of the mapped code.

Additional data edits were also allowed in cases of obvious time-induced change, such as where a wetland mapped on the satellite imagery is recorded as a water body in the field due to recent high rainfall, or where obvious land-cover change had occurred when comparing aerial photographs that were significantly older than the date of image acquisition. All time-dependent differences were corrected on the assumption that the NLC dataset was supposed to be representative of the land-cover and resource status *at the time of satellite image acquisition.*

These are seen as examples of practical problems that arose, and will no doubt continue to arise despite rigorous pre-assessment training of field staff, since they are often unavoidable because field conditions cannot all be anticipated during training and pre-planning.

Conclusion

The research results reported here are definitive. Although these findings represent milestones in mapping South African resources, problems that limited the current attempts to characterize South African land cover using hardcopy multispectral Landsat TM at 1:250 000 scale and ancillary data require further effort. Some of the respects in which further investigation is needed include:

- Assessment of the effects of seasonal and annual variations on identification and characterization of land-cover regions; cyclical effects of weather and climate on the development of seasonally distinct land-cover regions.
- Identification of influence of landscape-sensor interaction on the definition and characterization of 'natural' land-cover regions, especially in defining vegetation continuums.
- Refinement of data interpretation methods, including integration of ancillary GIS data (e.g. potential vegetation type) as vector overlays on the hardcopy product, integration of data from other sensors and pre-processing of imagery by sharpening as well as brightness adjustments before final production of hardcopy.

The Earth's surface is not divided into homogeneous regions of greater than some minimum area, by infinitely narrow lines. Areas are heterogeneous to varying degrees, and lines are actually zones of transition of varying width. A cynic describes the process of mapping as drawing 'lines that do not exist around places that have nothing in common'. However, as long as a map is assumed to be the desired end product, there is scope for improving the process.

The results of the NLC project suggest that 1:250 000 scale hardcopy imagery, rigorous pre-classification error reduction procedures, and a critical post-classification field and aerial accuracy assessment can be used to develop a baseline land-cover characterization over very large areas in southern Africa.

The NLC database has been designed and produced as a joint venture between the CSIR's Division of Water, Environment and Forestry Technology, the Satellite Applications Centre (CSIR), the Agricultural Research Council's Institute for Soil, Climate and Water, with additional support and funding from the departments of Agriculture, Environmental Affairs and Tourism, and Water Affairs and Forestry, and Johan van der Waals of the South African National Defence Force. We also thank Professor Mike Clark of the University of Southampton and as director of GeoData UK for conducting the external audit on the project. A detailed technical report of the entire project with accuracy information is available at www.sac.co.za ~ publications subdirectory.

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South African National Land-Cover Database

The 1:250 000 scale South African National Land-Cover database is available as a digital GIS map product, in both ArcInfo and ArcView data formats. The data set is available from the CSIR's Satellite Application Centre [(012) 334 5051], and can be purchased as either 1:250 000 map sheet tiles, provincial or national map sets. The entire dataset is divided into both public domain and commercial data packages, depending on the geographical region of interest, although all data become public domain in October 2000. More information on the actual data, satellite imagery, classification details, mapping accuracies and purchase costs, etc. can be obtained from the Internet-based 'Data Users Manual', located at: http://www.sac.co.za (under 'geo-information—standard products —national landcover' sub-directories).

Future Updates of the Land-Cover Database

The recent completion of the South African National Land-Cover database has provided, for the first time, a standardized baseline inventory of current land-cover (and land-use) for the whole of South Africa, Swaziland and Lesotho. The database is based primarily on Landsat TM imagery captured during 1994/95, and provides a unique window on national resource status and land-use at that time. However, in order for this type of information to remain valid, to have continued use within all aspects of environmental management, and to be able to detect trends, it is imperative that a longer-term national *change detection and monitoring framework* is established that will ensure future updates of NLC equivalent or comparable data.

The primary objective of such an initiative is to monitor any changes in the spatial extent of South Africa's resource base, based on changes in dominant land-cover (and associated land-use) types. The CSIR and Agricultural Research Council (as co-producers of the original South African National Land-Cover Database) have been jointly contracted by the Department of Water Affairs and Forestry, and the National Department of Agriculture (Directorate of Land Resource Management) to complete a scoping project that will provide key information on the next steps required to implement such a long-term operational monitoring and updating mapping programme. The objectives of this scoping project are to (i) identify the long-term land-cover change monitoring information requirements of key data-users, (ii) determine the most appropriate remote-sensing data processing techniques to achieve these requirements, and (iii) develop a strategic plan to assist with the long-term continuity of such a monitoring programme. This review process is expected to be completed by the end of 2000, after which it is hoped that a programme for land-cover updating and change monitoring can be implemented.