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1. SITE CLASSIFICATION AND EVALUATION

1.1 Introduction

The principle of ecologically sustainable forest development and yield management is worldwide increasingly emphasized in the plantation context as well as in the broader ecosystem perspective. This is especially relevant to a region such as the Mpumalanga escarpment area, with its diverse forest site conditions and associated variability in forest productivity. The concept of "sustainability" in plantation productivity therefore requires a thorough understanding of the factors controlling tree growth and the limitations of the sites on which they are planted.

The intensive nature of the South African plantation forest industry relies heavily on scientifically based decision support systems. The strategic value of forest site classification and evaluation systems therefore has been realized by South African forest managers. Site-specific silviculture has long been part of forest management practices in the Mpumalanga forest region. With current changes in business management practices, land ownership and land use patterns in parts of the region, an analysis of the ecology of forest sites is required. The objectives of this part of the study are therefore as follows:

- to stratify the landscape into relatively homogenous units with respect to factors such as climate, topography, geology and soils, in order to promote precision forestry,
- to evaluate sites for the most important commercial tree species of the region, for accurate site-species matching to ensure the optimization of yield,
- to provide site-specific recommendations on site amelioration measures such as fertilizing and site preparation, and
- to provide information on nature conservation for the study area.

1.2 Environmental factors of the study area

1.2.1 Location

Injaka Plantation is located in the north-eastern part of the escarpment region of Mpumalanga. The plantation is located approximately 30km east of the town of Graskop, 5km south of Bushbuckridge and 20km north of Hazyview. The study area lies longitudinally from 31^{o}01' to 31^{o}07' E, and latitudinally from 24^{o}52' to 24^{o}58' S.

Injaka Plantation borders Mondi on the western and southern side, and the R40 main road crosses through the north-western part of the property. A plantation map and compartment register provided by the Department of Water Affairs and Forestry in electronic format was used as base map for the study. The total afforested area includes 1 960 ha in a fragmented pattern.

1.2.2 Physiography

The most conspicuous physiographic feature of the region is the Great Escarpment, which runs in a north-south direction, approximately 13km west of the western boundary of the plantation. The study area is therefore located in the lower foothills of the escarpment, which are characterised by a gentle to moderate undulating landscape. East of the plantation, the landscape drops to the lower lying flatter areas of the Lowveld.

The majority of the study area has gentle to moderate slopes of less than 35%, although some areas under indigenous vegetation in close association with drainage lines have steeper slopes approaching 50%. There is no specific orientation with respect to the aspect of the study area. The nature of the topography has an important influence on soil properties, especially depth criteria and drainage.

The study area is drained in a general easterly direction by tributaries of the Modderspruit and Maritsane Rivers, which flows into the Marite River, to form part of the greater Sabie River catchment. The altitude of the afforested area ranges from approximately 700 to 950m above sea level.

1.2.3 Climate

Within the confines of the study area, climatic gradients in terms of temperature and rainfall are not as marked as in the case of areas located closer to the escarpment. Due to distance from the escarpment edge, the east-west orographic effect in rainfall patterns is also not as pronounced. However, a weak east-west gradient is still encountered in mean annual rainfall, which ranges from approximately 1 150mm in the western extremes of the plantation, to 950mm on the eastern boundary. A similar gradient is encountered in mean annual temperature, which is mainly a function of altitude, with the highest temperature of 20^{o}C occurring in the lower lying eastern parts, decreasing to 18^{o}C in the higher lying western parts. Mistbelt conditions, which are generally found above 1 200m altitude, are not encountered in the study area. These climatic patterns forms an integral part of the site classification of Injaka Plantation, as described in Section 1.3.1.

Injaka Plantation falls within the summer rainfall region, and an average of 85% of the annual rainfall occurs during the months October to March. During this period, rain is precipitated mainly in the form of thundershowers and instability showers. According to Schutz (1990), rainfall is generally reliable in the escarpment area, with approximately 78% of the years falling within 20% of the average normal rainfall. The intensity and length of the dry season, with rainfall of the driest month (June or July) often dropping below 5mm, can be regarded as the most limiting site factor of the area. Hailstorms are more associated with the areas in close proximity to the escarpment edge, and the study area can be considered as low risk in terms of hail occurrence. The area can also be regarded as a frost-free area, increasing the range of options for forestry or agricultural crops (Louw, 1995). Figures 1 and 2 indicate seasonal variation for rainfall patterns and temperature respectively for the study area. Representative climatic data for the study area were obtained from modelled long term data generated by the Institute for Commercial Forestry Research (ICFR), using bioclimatic modelling techniques in a Geographic Information System (GIS) environment (ICFR, pers. comm.).

Local climatic conditions play an important role in especially site-species matching as well as forest nutrition. The prevailing climatic conditions in the study area, coupled to the relatively deep soils with a high moisture holding capacity, leads to moderate to optimal growing conditions for a wide range of the commercial forestry species as well as agricultural crops.

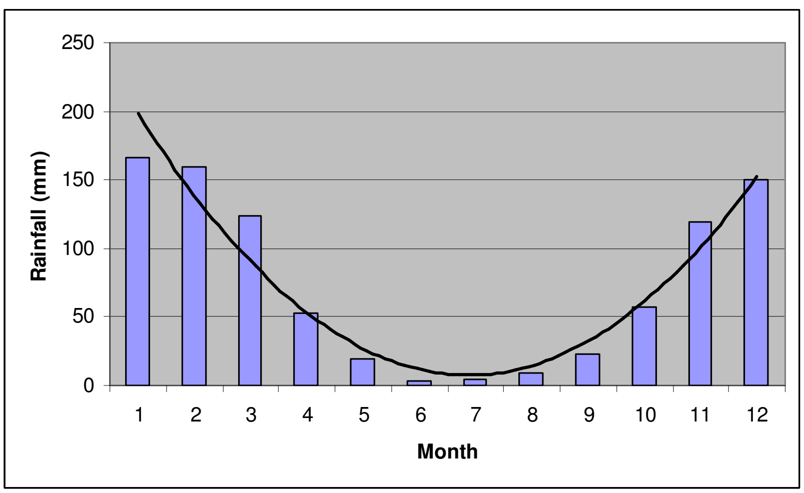


Figure 1: Monthly rainfall distribution for a representative site on Injaka Plantation.

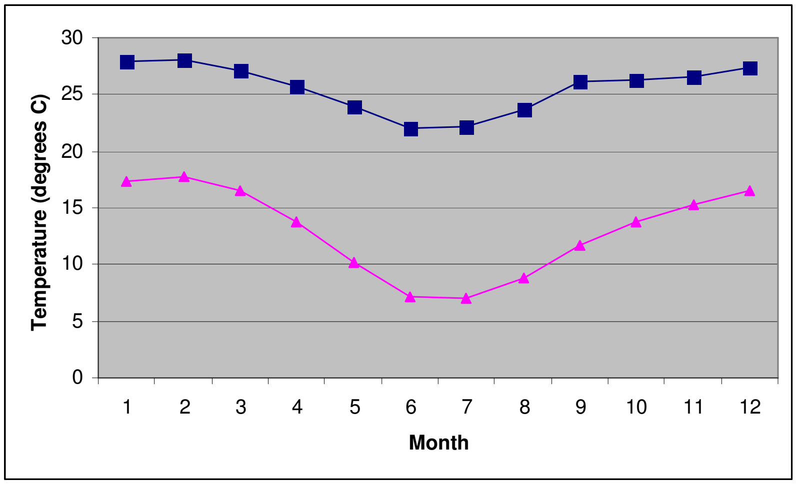


Figure 2: Mean minimum and maximum monthly temperature values for a representative site on Injaka Plantation.

1.2.4 Geology and soils

The entire study area is underlaid by Nelspruit Granites, with a limited occurrence of diabase intrusions in the form of dykes. The latter, however, plays a minor role in soil formation in the study area, and only one isolated area was considered for delineation as a separate site type based on parent material.

The soils of the high rainfall areas along the escarpment have relatively little variation in general morphology and are subjected to a limited spectrum of pedogenetic processes. The greatest variation that does occur, can be related to the nature of the underlying parent material, which often results in highly localised phenomena, as well as topography, drainage patterns and macro and meso climatic patterns. The process of ferrallisation, which takes place under intense weathering conditions of high rainfall and temperatures in areas with good internal drainage and leaching, has resulted in the formation of deep, red apedal soils (Louw, 1995, Louw & Scholes, 2002).

The general characteristics of the ferralitic soils of the study area, are as follows:

- With the exception of quartz, there are no primary aluminosilicate minerals left in the profile.
- The clay fraction consists entirely of 1:1 clays (kaolinite in this case), hematite and to a lesser extent goethite.
- The soils have a low cation exchange capacity; < 16cmol (-).kg^{-1} Clay, measured at pH 7 (KCl).

- Soils are mostly dystrophic (< 5 cmol(+) basic cations per kg clay).
- pH is generally low.
- The sand and silt particles are covered by oxides of free iron and aluminium, making the clay particles less susceptible to deflocculation and eluviation.
- Soils are generally apedal, porous to weakly, fine structured.

Generally there is little difficulty or misconceptions in classifying soils of the study area according to Soil Classification: A Taxonomic System for South Africa (Soil Classification Working Group, 1991). Tables 1 and 2 provide a summary of some selected soil physical and chemical properties.

Variable	Mean	Minimum	Maximum
pH (H_2O)	5.1	4.7	5.3
Organic C (%) (Walkley Black)	1.36	0.85	1.77
K (mg kg^{-1}) NH_4OAc	24.3	7	49
Ca (mg kg^{-1}) NH_4OAc	43.8	25	136
Mg (mg kg^{-1}) NH_4OAc	40.0	26	111
P (mg $kg^{-1)}$ Bray 2	2.9	2	5

Table 1: Soil chemical data for 16 A horizons from Injaka Plantation.

Variable	A horizon			B horizon		
	Mean	Min.	Max.	Mean	Min.	Max.
Sand (%)	50	32	60	42	23	51
Silt (%)	14	6	23	11	7	22
Clay (%)	34	20	39	46	25	61

Table 2: Soil textural data for 16 A and B horizons from Injaka Plantation.

The granite derived soils of the study area can be regarded is of the most productive forest sites along the escarpment. However, the analyses outlined in Table 1 indicate that the soils are relatively low in basic cations and plant available P. This low level in P is mainly due to fixation to clay particles as a result of low pH. Soils are also relatively low in organic carbon due to the low altitude and associated high temperatures and high mineralization rates. The organic carbon content of the soil is an accurate indication of mineralisable N, and is specifically important for the growing of *Eucalyptus* species (Louw & Scholes, 2002, Noble & Herbert, 1991). An inverse relationship has been observed between the organic carbon content of the soil and the relative response of *Eucalyptus grandis* to applied N on the granitic soils of the region (ICFR, 1995).

The granites have weathered to form the deepest soils in the escarpment area – effective soil depths exceeding 1.5m is common in the study area, and in exceptional cases, depths in excess of 5m have been recorded. Saprolite is usually well decomposed to great depths. A very gradual transition from the actual solum to saprolite is usually found. Only on sharp narrow ridge crests, or on steeper slopes subjected to erosion, shallower soils are found which can be classified as the Glenrosa 1111 and 2111 soil families. Intensive forms of soil preparation such as ripping or ploughing are therefore not regarded as an economical proposition for the study area, unless the soil is severely compacted after mechanised operations such as harvesting. Isolated localised areas with quartzitic stonelines are a common phenomenon in the area, which might impose some limitations on root development. However, it normally covers such small areas that it is difficult to delineate on the mapping scale required for this study.

Granite derived soils are usually well- to excessively drained. Surface horizons tend to have a relatively low water-holding capacity, mainly due to a high content of medium to course sand, as well as a strong aggregation of clay particles into water-stable micro-aggregates, with a resultant high frequency of macro pores. In combination with the non-expanding properties of the kaolinitic clay, this causes rapid drainage and low plasticity. Hydromorphic soils are found in bottomland positions with a more gentle slope. However, these soils in the study area are mostly confined to the areas covered by indigenous vegetation along riparian zones. It is therefore not necessary that any of the existing plantation areas be reverted back to indigenous vegetation due to establishment in wetland areas.

The subsoils of the study area are conspicuously red in colour, mostly with a hue of 2.5YR or 5YR (Munsell Colour Company, 1975). The subsoils are generally of an apedal nature, although isolated areas with neocutanic properties or red structured subsoils are found. The Hutton 1200/1100 soil families predominate. Topsoils are often light coloured, especially in the lower lying areas. The lower levels of organic material in the topsoils necessitate careful management of slash after harvesting. Silvicultural practices must aim at preserving and improving soil organic matter in order to minimize risk to erosion, compaction and nutrient depletion. The soils of the area must be regarded as sensitive to disturbance, and measures must be undertaken after clearfelling, wildfires or site preparation to prevent serious losses of topsoil.

1.3 Methodology and Products

1.3.1 Delineation of site boundaries

Orthophotos on a scale of 1:10 000, obtained from the Department of Land Affairs, were used as base maps for the study. The soil survey was carried out during February 2009, using a free survey, with an observation density of approximately 1 observation per 3.5 hectares. Orthophotos were interpreted beforehand, together with topographical (1:50 000 sheet 2431CC Bosbokrand), geological (1:250 000 sheet 2430 Pilgrims Rest) and climate overlays (See Section 1.2.3), to study variation in site conditions across the study area. Soil observations were located to cover maximum site variation, and to establish site boundaries as accurate as possible. Areas of "ecological equivalence" could therefore be identified and demarcated. Soil observations were made using hand augers and road cuttings, up to a maximum depth of 150cm. The following information was captured at each observation point as part of the soil survey:

- Soil form and family (Soil Classification Working Group, 1991)
- Total soil depth
- Effective soil depth
- Depth limiting material
- Wetness hazard
- Topsoil organic carbon (qualitative based on field observation)
- Lithology
- Terrain position

For each soil horizon:

- Accumulated depth
- Color
- Clay % (Field estimate)
- Sandgrade
- Consistency
- Structure
- Coarse fragment %

1.3.2 Site Classification

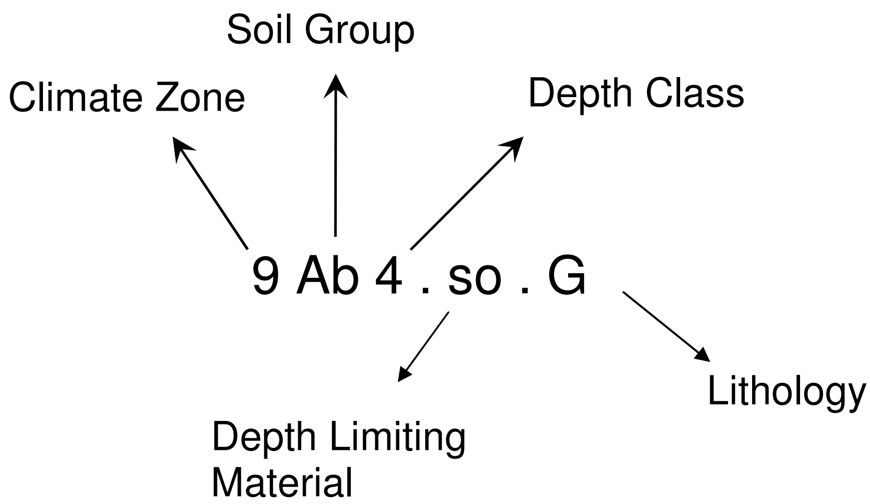
Forest site classification involves the delineation of areas of homogenous geology, topography, climate and soil conditions. This implies that a specific site will have similar growing conditions. In the forestry context, a site type can be regarded as an area of homogenous silvicultural implications in terms of selected species, expected growth and yield, nutrient management strategies, soil preparation, risk of induced stress and harvesting techniques (Louw, 1995).

Several studies on forest site classification, as well as the interaction between various commercially important species with its growing environment, have been undertaken in the Mpumalanga escarpment area. The most widely used site classification system is the one developed by Louw (1995). All forest land currently managed by Komatiland Forestry (KLF) was classified according to this system. The fact that Injaka Plantation includes similar growing conditions compared with some of the KLF land holdings, motivated for adopting the same site classification system. Through this regional site classification, the future management of Injaka can benefit from many technological developments and research findings that accumulated over many years of forest science and development.

The main variables used for differentiating between site types are as follows:

- Climate zone
- Soil Group
- Effective soil depth
- Depth limiting material
- Geology
- Slope

A comprehensive discussion on this selection of variables for site delineation in the escarpment area is provided by Louw (1995). The maps with spatial information label each site type according to a code. An example is as follows:



The *Climate Zone* classification used for the forestry areas of the Mpumalanga escarpment is indicated in Table 3. Combinations of arbitrarily delineated classes of mean annual precipitation and temperature are used to give an indication of the climate regime of a specific site. This classification not only provides an indication of the moisture regime of a specific site, but also the actual temperature regime as well as the influence of climate on soil forming and nutrient cycling patterns. The prevailing climatic conditions at Injaka Plantation only include zones 9 and 15, i.e. moderate rainfall and high temperatures relative to other parts of the escarpment area.

		Mean annual temperature (°C)				
		< 14	**14-16**	**16-18**	**18-19**	**> 19**
Mean annual precipitation (mm)	**> 1300**	1	2	3	4	5
	1050-1300	6	7	8	9	10
	850-1050	11	12	13	14	15
	< 850	16	17	18	19	20

Table 3: Climate Zone classification for the Mpumalanga escarpment area (Louw, 1995).

The abbreviations used for *Soil Groups* follow a system that is widely used in the South African forest industry (Forest Soils Database Cooperative, In: Louw, 1995). The Soil Group classification encompasses both the dominant soil forming process as well as many soil physical and chemical attributes. The homogenous nature of the soils of the study area resulted in only one dominant Soil Group being identified, i.e.:

Ab = Red dystrophic apedal soils

Soil Depth is dealt with by means of six classes, as indicated in Table 4. Within the context of the South African landscape, tree growth is most often related to available moisture, which is best expressed by effective soil depth. Effective soil depth is defined as depth to a restrictive layer such as weathering rock, stone layers, dense subsoil, wetness, etc.

Class	**Effective Soil Depth (cm)**
1	< 30
2	30-60
3	60-90
4	90-120
5	120-150
6	> 150

Table 4: Classes of Effective Soil Depth

The *Depth Limiting Material* variable uses codes according to the system developed by the Forest Soils Database Cooperative (Louw, 1995). Examples include the following:

w1 = wetness
so = weathering rock
sl = stone layer
st = loose rocks in profile
r = hard rock

The *Slope Class* uses the same categories as for the Terrain Classification (See Section 1.3.3)

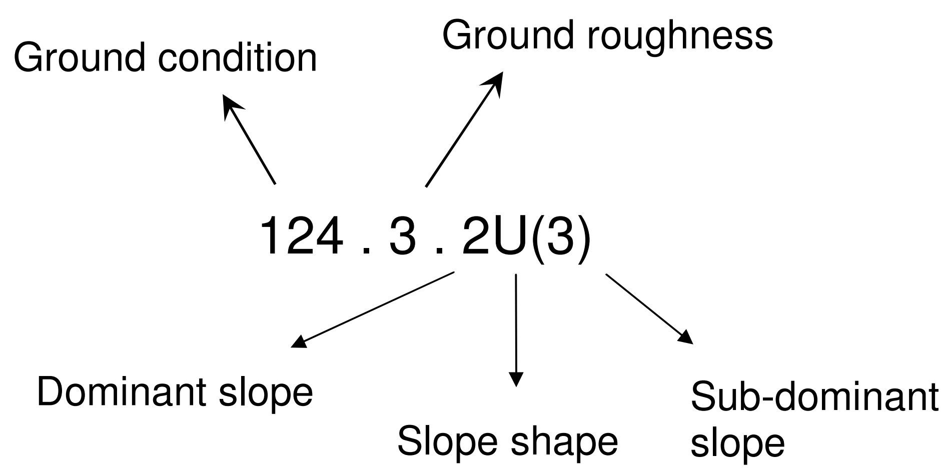
The codes used to indicate the nature of the underlying *Lithology* (rock), are as follows:

G = granite
D = Diabase

1.3.3 Terrain Classification

A National Terrain Classification System (NTCS) was developed to enable forest managers to assess the different types of terrain to be managed as well as for accurate budgeting and cost control purposes. This terrain classification facilitates the correct deployment of machinery on the sites best suited to their particular capabilities (Musto, 1993). It is recognized that the NTCS is more useful on a tactical rather than on an operational or functional level. A survey of terrain conditions was done in conjunction with the soil survey. Contours indicated on orthophotos were used as an additional source of information to complement the survey.

The terrain classification code used, with explanation, is as follows:



The *ground condition* expresses a ground strength rating for trafficability purposes under dry, moist and wet conditions. Ground condition under the various moisture conditions is a function of soil factors such as texture and soil organic matter content. Ground condition is dealt with by means of five classes, where:

1 = very good
2 = good
3 = moderate
4 = poor
5 = very poor

The *ground roughness* class of an area is assessed according to the size (height) and incidence of obstacles. Obstacles refer to depressions, boulders, and other permanent ground obstructions at least 0.1m high (Musto, 1993).

Ground roughness is dealt with by means of five classes, where:

1 = smooth
2 = slightly uneven
3 = uneven
4 = rough
5 = very rough

Slope is dealt within the context of both gradient and shape. The range of slope classes is based on norms for machinery limits. The dominant slope is indicated for each polygon, and in the case of complex slope conditions, the sub-dominant slope class is indicated in brackets (if the latter exceeds 5% of the area). The slope classes according to the NTCS are indicated in Table 5.

Slope class	Gradient	
	Percent	Designation
1	0 – 12	Level
2	13 – 20	Gentle
3	21 – 35	Moderate
4	36 – 50	Steep
5	50+	Very steep

Table 5: Slope classes according to the National Terrain Classification System.

The shape or type of slope is described using the following symbols:

R = Regular
U = Undulating
T = Terraced
V = Concave
X = Convex

The percentage breakdown, as calculated from the terrain spatial database, of dominant slope and ground roughness classes for Injaka Plantation, is indicated in Table 6.

Class	Slope (%)	Total area (ha)	Ground roughness (%)	Total area (ha)
1	29.88	683.4	100	2286.6
2	62.52	1429.5	0	0
3	7.60	173.6	0	0
4	0	0	0	0
5	0	0	0	0
Total:	**100**	**2286.6**	**100**	**2286.6**

Table 6: Percentage breakdown of dominant slope and ground roughness conditions for Injaka Plantation.

1.3.4 Site Evaluation

Species prescriptions: The predictions of growth for a range of commercial forestry species are based on existing information on site-species matching in the Mpumalanga escarpment area. Many studies have been undertaken to study the intricate interaction of various species with its growing environment, and efforts to quantify these relationships led to the formulation of a number of site quality prediction models (Strydom, 1991(a, b); Schutz, 1990; Louw, 1995, 1997, 2006).

For each of the site types identified in the study area, a range of commercial *Pinus* and *Eucalyptus* species that can be considered for afforestation, is evaluated in terms of suitability. A qualitative evaluation is done in terms of suitability classes, i.e. *Optimal*, *Suitable* or *Marginal*. Quantitative predictions of growth of species for which growth data and site quality prediction models are available, are also included. These predictions are in the form of mean annual increment at the age of 20 (MAI_{20}). It must be borne in mind that the predictions of growth are based on "ideal conditions", i.e. the possible negative influence of competition from weeds is not incorporated.

Silvicultural implications: The implementation of appropriate management strategies to both optimize nutrient availability and to reduce risks to the environment is generally accepted by forest growers in the escarpment area. Specifically in the case of *Eucalyptus*, fertilization is regarded as an economic proposition to increase growth rates (ICFR, 1995). Due to the homogeneity of soils in the area, a standard prescription is included for all the sites.

The most appropriate soil preparation technique for establishment purposes is also indicated. Due to the high sensitivity of the soils to disturbance, as well as the deep, apedal nature of the profiles, a conservative prescription of pitting is recommended for all sites.

Site sensitivity: Soil sensitivity is generally a function of factors such as texture, structure, depth, chemical characteristics, soil organic matter and temporal soil moisture variation. A site-sensitivity rating in terms of risk to erosion and soil compaction is therefore included for each site type.

1.3.5 Products

In terms of the site classification and evaluation of Injaka Plantation, the following products are included:

- A legend to the site types is included as Annexure 1. This legend includes information on areas (ha) involved, climate and soil descriptions as well as a site evaluation according to the aspects listed in Section 1.3.4.

- The spatial distribution of the site types of the study area is included as Map 1.
- The terrain classification of the study area is included as Map 2.
- For ease of practical implementation, a compartment list is included as Annexure 2, with the different site types listed for each compartment, areas in terms of hectares, the optimal species choice for Pines and Eucalypts for each site within the compartment, as well as a yield prediction.