Erosion phenomena on Round Island, Mauritius

by

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Submitted in partial fulfilment of the requirements for the degree

MASTER OF SCIENCE (Environmental Management)

in the

Faculty of Natural and Agricultural Sciences

Centre for Environmental Studies

University of Pretoria

February 2015

"All things bright and beautiful,

All creatures great and small.

All things wise and wonderful,

The Lord God made them all."

To my late father, Selwyn Roy Bean.

DECLARATION

I, Tamsyn Anne Bean, declare that the dissertation entitled **Erosion phenomena on Round Island, Mauritius**, which I hereby submit for the degree **Master of Science (Environmental Management)** at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

17/02/2015

SIGNATURE **DATE**

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Abstract

Round Island is a 219 hectares islet north of the Mauritian mainland and has been classified as a Nature Reserve since 1957. The island has been subjected to human influence in the form of land degradation through introduced grazing animals (goats and rabbits) which has detrimentally affected the floral and faunal ecology of the island. Since the removal of the grazers, intensive conservation management has been undertaken to restore Round Island's unique ecological status.

The aim of this research project was to investigate erosion phenomena at specific study sites on Round Island through field-based classification and mapping procedures and describe physical soil characteristics. A modified version of the SARCCUS (1981) Erosion Classification system was used to classify linear erosion forms in the field, based on morphometric parameters. The effect of rock hardness was also assessed to determine lithological controls on bedrock-incised erosion features.

Given the size of Round Island and the extensive nature of erosion, five study sites were chosen for the soil and erosion assessment. An additional two gully networks, 'camp' and 'big' gully were chosen to allow the investigation of an entire erosion system. Soils are thin and discontinuous, with a sandy texture and are poorly sorted. The Helipad habitat has the coarsest soils indicative of wind erosion where the deflation of fines leaves a coarser gravel pavement. No significant differences are found between sites for soil physical properties, with the exception of pH where the Summit has a significantly lower pH than the Helipad (Mann- Whitney U test, $z= -2.21$, $p= 0.03$) and Rock Slab (Mann- Whitney U test, $z= -2.93$, $p< 0.01$) habitat regions.

No linear erosion forms are found on the soils of Round Island, however bedrock incised rills and gullies extensively occur. The Summit, Rock Slab and Palm Savannah habitats represent erosion processes along a profile gradient on the steep, convex western slope. The Summit habitat is subject predominantly to sheetwash and wind erosion, with the presence of two bedrock-incised rills of moderate severity. The Rock Slab region is predominated by parallel, shallow bedrock rills and gullies running downslope with moderate and slight severity, respectively. Soil and vegetation cover is highly variable within the region. Downslope, the Palm Savannah region is subject to moderate gully erosion with an irregular morphology. Soil is transported during rainfall within the gully channels where it is ultimately lost to sea.

The two large gully systems, ‘camp’ and ‘big’ gully represent erosion of the highest severity on Round Island. The gullies have their starting points on the mid- upslope regions as rills, which increase in width and depth downslope, as indicated by decreasing width: depth ratios. The gullies have their end point at sea, both with a severity of very severe bedrock-gully erosion. During periods of intense rainfall the bedrock-incised gullies act as transport channels for sediment which is ultimately lost to sea. Little sediment is able to remain and this is exemplified by a lack of vegetation. This is a natural cycle where conservation efforts will remain ineffective.

In addition to morphology, rock hardness was assessed using a Schmidt Hammer for the bedrock incised forms. The rate of erosion of the bedrock dominated channels depends on various factors such as rock strength, sediment supply and grain size. The predominant rock type on Round Island is tuff which is a relatively weak volcanic rock, as indicated by low mean Schmidt Hammer R-values, implicating higher expected bedrock erosion rates.

Acknowledgments

This study was carried under financial assistance of the Department of Research and Innovation Support through the Post-graduate Study Abroad Bursary, for which I am thankful. The Mauritian National Parks and Conservation Services are acknowledged for granting me permission to undertake research on Round Island, Mauritius.

The author is extremely thankful to her supervisors Prof. Paul Sumner, Department of Geography Geoinformatics and Meteorology, University of Pretoria (UP), and Prof. R. Boojhawon, Faculty of Science, University of Mauritius for their professional guidance, support and enthusiasm throughout the research project. I would like to thank Prof. Sumner for initiating the research relations between UP, University of Mauritius and the Mauritian Wildlife Foundation (MWF).

Special thanks to my volunteer field assistants Hashrada Ramburn and Lilly Kessler who were always there with me in the field. Their valuable input, company and friendship will be always remembered. I would also like to thank the Faculty of Agriculture, University of Mauritius for allowing me to undertake my soil analysis in their Soil Science laboratory. Special thanks to Jenny for their technical assistance in the research efforts, friendship and expanding my knowledge on local Mauritian culture. Thanks to Prof. S. D. D. V. Rughooputh for his valuable and objective comments toward my dissertation.

I am extremely grateful to numerous staff within the Department of Geography, Geoinformatics and Meteorology. In particular, I would like to acknowledge Barend van der Merwe for providing me with his valuable suggestions regarding data analysis. Thanks also to Michael Loubser, Ryan Anderson and Yvette Bevis for their full encouragement, assistance and guidance in my research.

The author is thankful to the MWF for their assistance and support in the research project. I am especially grateful to Dr Vikash Tatayah, conservation director, MWF, for his logistical assistance and provision of valuable data. It was a true honour to undertake research on Round Island.

Lastly, I would like to thank my family for their support in my career. Thank you to my late father, Selwyn Roy Bean and mother, Jeanette Rose Bean for always believing in me and for your generous financial and moral support. Thanks also to my brothers, Mark Bean and Michael Georgiadis, and friends for your encouragement.

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Chapter 1 : Introduction

Round Island is a 219 hectare volcanic islet north of the Mauritian mainland and has been a Nature Reserve since 1957. The island was subjected to human influence through introduced grazing animals (goats and rabbits) which has detrimentally affected the floral and faunal ecology of the island. Since the removal of the grazers, intensive rehabilitation management has been undertaken to restore Round Island's unique ecological status. This is important for a number of reasons (Merton et al., 1989). Round Island is one of very few elevated tropical islands without introduced rodents and hosts the largest area of native vegetation in Mauritius. It supports at least 10 threatened native plant species, including six endemic to Mauritius, and supports eight species of native reptiles, three of which are endangered (one gecko and two snakes). Seven are endemic to the Mascarene Islands and four only occur on Round Island. Round Island is also the only known breeding ground in the Indian Ocean for the Round Island Petrel and is an important breeding ground for many other seabird species.

1.1. General aims and objective

The monitoring and management of Round Island has been a success story and the rehabilitation process of this degraded island is internationally praised (MWF, 2008). Despite such conservation efforts, many parts of the island remain barren and soil erosion hinders habitat restoration (MWF, 2008). In order to select appropriate conservation measures, the identification and classification of erosion is first necessary (Zachar, 1982). The purpose of this research project was thus to undertake an investigation of erosion phenomena on Round Island. This included identifying, classifying and mapping the spatial distribution of erosion features present on the island. A comparison of the erosion phenomena in relation to the physical template of Round Island enabled a description of erosion processes and highlighted intensive areas of erosion. Based on the findings and an improved understanding of erosion processes on the island, recommendations for management were explored.

1.2. Erosion phenomena

Erosion has long been recognised as an environmental concern. A part of this concern was the realisation that soils perform several important functions, including food production, storage of water, provision of nutrients and providing a habitat medium for organisms (Morgan, 2005). Drivers of erosion include overgrazing, intensive cultivation, deforestation and poor soil and water management. Soil erosion results in a decline of soil fertility, loss of organic matter and changes to the chemical and physical properties of soil (Haynes, 1997). Erosion is traditionally associated with agriculture in tropical and semi-arid areas and is important for its long-term effects on soil productivity and sustainability of agricultural lands (Lal, 1988). However, erosion is a wider problem in other land use types including natural and recreational areas (Morgan, 2005). Soil erosion in such areas presents challenges in terms of managerial, social and environmental aspects.

The term erosion is used to describe the process of disruption of the pedosphere or underlying rock material by the action of an external agent (Zachar, 1982). This is a two way process of the detachment of individual particles from the soil mass and the subsequent transport of it by erosive agents. A third phase may be added when energy is lost and deposition of sediment occurs (Morgan, 2005). Soil erosion can be distinguished between normal and accelerated erosion with the latter further sub-divided into naturally accelerated and human-accelerated erosion. Naturally accelerated erosion is caused by, for example, abnormal droughts, fire and floods. Human-accelerated erosion, such as through poor agricultural practices, is the focus of many soil conservation studies to reduce erosion rates to normal (Zachar, 1982).

The extent and intensity of erosion is determined by complex and interactive factors. Erosion is determined, first, by the nature of processes operating, and second, by the response of an area to environmental conditions, including climate, geology, topography, soil properties and vegetation cover (Beckedahl et al., 1988). In terms of topography, erosion rates on sloping lands are significantly higher than on flat lands (Pimentel & Kuonang, 1998). For example, in the Philippines, where more than half of the land has slopes greater than 11%, soil erosion rates are as high as 400t/ha/yr (Lal & Stewart, 1990). Vegetation cover plays an important protective role in preventing soil erosion, as raindrop and wind energy is dissipated by the vegetation (Pimentel & Kuonang, 1998). Organic matter produced by plant cover binds soil particles, building aggregate stability, thus reducing erosion rates.

Erosive agents include water, ice, snow, air (wind), weathered debris, gravity, organisms (plants and animals) and humans (Zachar, 1982). Water erosion is in the form of rainfall, surface flow and subsurface flow, and sea water in coastal areas (SARCCUS, 1981). Generally speaking, three types of erosion (sheetwash, rill and gully erosion) occur by water and these are discussed in further detail below. Wind erosion is the process of wind-forced movement of particles (Zachar, 1982). This occurs by deflation where the topsoil is removed and transported causing surface lowering (Beckedahl et al., 1988). Wind erosion generally occurs in open landscapes that offer little wind resistance to the prevailing wind and may be enhanced in the absence of vegetation.

Erosion initiated and exacerbated by grazing animals is well documented (Evans, 1998). When animals are introduced by humans, grazing pressures which were previously not present result in erosion. For example, 30-40% of Iceland suffered erosion as a result of sheep (Evans, 1998) and irreversible soil erosion occurred on Macquarie Island as a result of introduced rabbits that damaged peat soils (Costin & Moore, 1960). Animals impact directly on soil erosion by creating and expanding areas of bare soils, upon which weather elements act, and indirectly by facilitating rapid runoff of rainfall. The impacts of erosion, accelerated by grazing animals are dependent on grazing intensity and frequency, grazing area size and the physical environment (Evans, 1998). For example, it is expected that erosion will be more severe when animals are confined to small spaces or by rough terrain such as areas too rocky or steep. Trampling removes vegetation cover and creates depressions in the soil surface. This increases bulk density allowing runoff to be channelled along tracks. Thus, a higher traffic of animals along paths will increase erosion by trampling. The effects have been seen particularly with cattle where gullies are formed along paths (Mulholland & Fullen, 1991). Climate also plays an important role in determining erosional impacts by grazers. In humid climates bryophytes protect soil by forming crusts but these are easily broken down by animals' hooves.

1.2.1. Erosion processes: Sheetwash

Erosion of hillslopes occurs by a combination of rainsplash impact, overland flow/ sheetwash, movement of water through subsurface pipes and mass movements (Morgan, 2005). As raindrops strike and break the soil surface, erosion is initiated as soil particles are displaced. Splash erosion is driven by rainfall kinetic energy, which depends on rainfall characteristics. Rainsplash is an important erosive agent in splash and rainfall erosion as it modifies soil surface properties and flow hydraulics (Bryan, 2000). When continuous and uniform, the removal of soil particles through raindrop action and subsequent transport by runoff water occurs as overland flow. Overland flow depends on the infiltration capacity of hillslope material. When infiltration of water is minimal, water flows over the surface rather than into the material. Two types of overland flow exist. Horton overland flow (infiltration excess overland flow) arises when rainfall intensity exceeds the infiltration capacity (Horton, 1945). Horton overland flow generally occurs on frozen soil and where large areas of bare rock are exposed. Saturation excess flow happens when a rising water table prevents further infiltration (Bergsma et al., 1996). Overland flow occurs in sheets or small rills over land surfaces. For erosion to take place the rate of rainfall must be sufficient to produce runoff and the shear stress provided by water must exceed soil surface resistance (Bull & Kirkby, 1997). Overland flow can be erosive without forming channels.

The initiation of channel incision is a function of the erodibility and hydraulic properties of hillslope material. Factors affecting these properties include texture, porosity, permeability, infiltration capacity, water content, shear strength and vegetation cover. The primary cause of channel incision forming rills and gullies is the concentration of overland flow. Additional processes include piping and mass movement such as landslides or rotational slips (Bull & Kirkby, 1997).

1.2.2. Rill erosion

Rills arise when the removal of soil through the concentration of overland flow creates shallow channels (Bergsma et al., 1996). Rill development occurs in four stages: unconcentrated overland flow, overland flow with concentrated flow paths, microchannels without headcuts and microchannels with headcuts (Merritt, 1984). In laboratory experiments, Reynolds number and sediment yield increase with each stage and rill incision follows when flow becomes turbulent instead of laminar. Rills extend upslope through headcut erosion and become deeper and wider downslope due to channel erosion (Selby, 1994).

The presence of rills depends on the forces exerted by concentrated sheetwash exceeding the resistance of the soil, which together influence the morphological characteristics and permanence of rills. Generally, rills are temporary erosion features but permanent rills are common, particularly where they develop into emerging drainage lines or bedrock material (Beckedahl et al., 1988). Interrill erosion entails the erosion on the interfluve of rills occurring as sheet erosion (Morgan, 2005).

1.2.3. Gully erosion

Gully erosion is the removal of sediment whereby excessive concentration of runoff or subsurface flow water causes the formation of surface or subsurface channels (Bergsma et al., 1996; Poesen et al., 2002). Gullies are considered as permanent channels having cross-sectional forms which are recognisable without flowing water and have identifiable banks and headcuts (Bull & Kirkby, 1997). Poesen (1993) distinguishes rills from gullies by a critical cross-sectional area of 929cm^2. Other criteria also exists such as a minimum width of 0.3m and a minimum depth of 0.6m (Brice, 1966); or a minimum depth of 0.5m (Imeson & Kwaad, 1980) or 1.0m (Menéndez-Duarte et al., 2007).

To understand the processes of gully erosion, classifying gully morphology is important (Heede, 1970). There are many classifications of gullies based on various criteria (Poesen et al., 2002). Examples of criteria include plan form (Ireland et al., 1939; De Ploey, 1974), position in landscape (Brice, 1966; Poesen et al., 1996) and the shape of gully cross-section and soil material in which a gully developed (Imeson & Kwaad, 1980). Ireland et al. (1939) suggest six characteristic gully forms: linear, bulbous, dendritic, trellis, parallel and compound. Imeson and Kwaad (1980) further show that V-shaped gullies form due to surface runoff and U-shaped gullies form by surface or sub-surface runoff.

Once a gully is formed several processes, alone and in combination, related to water erosion and mass movements lead to channel expansion (Poesen et al., 2002). These processes include piping, headcut migration, undercutting by plunge-pool erosion, tension cracking, mass failure, fluting and channel bifurcation. Although most of the processes apply to gullies in soil, many of the same processes may be applied to bedrock-incised gullies. For example headcut retreat studies have been undertaken on bedrock channels in rivers (Wohl, 1993) and badlands (Howard, 1998).

The formation of gullies is controlled by a wide variety of factors: topographical, lithological, geomorphic, climatic, hydrologic, organic and anthropogenic (Schumm et al., 1984). Slope is a fundamental morphometric threshold controlling channel incision (Montgomery & Dietrich, 1988). Gullies are common features in mountainous or hilly regions (Valentin et al., 2005) since steep slopes increase runoff velocity favouring rill and gully formation. Deeper rill and gully forms may thus be expected on steeper slopes (Menéndez-Duarte et al., 2007) but the effect of slope can be counteracted by soil crusting where soils have lower crusting rates than on gentle slopes. Rill and gully initiation on crusted soils can then lower the slope threshold (Valentin et al., 2005). Furthermore, gully formation in non-riverine environments is common on erosive breaks of slope, or on hillsides showing characteristics of steep banks and eroding side walls.

Lithological factors play an important role in gully initiation. Tectonically induced compressions or tension forces can form fracture joints in rocks (Valentin et al., 2005). This in turn weakens the nature of rocks which act as starting points for weathering processes (Dickson et al., 2004). Sub-surface cavities formed by weathering enhance throughflow thus accelerating soil eluviation and lowering the soil surface. A lowered soil surface concentrates surface flows thereby initiating rill and gully erosion. Soil crusting also influences erosion. Headcuts are created where cracks from soil crusting initiate erosion and thus soils susceptible to crusting are commonly subject to sheet and gully erosion (Valentin et al., 2005). This is especially pronounced in arid and semi-arid regions where soils are prone to crusting due to sparse vegetation cover as seen in South Africa (Kakembo & Rowntree, 2003; Valentin et al., 2005).

Anthropogenic influences on gully erosion are well documented (Kirkby & Bull, 2000) and various studies have shown how gully erosion relates to historical events of deforestation and land use changes, in particular farming practices (Menéndez-Duarte et al., 2007). Gully erosion analyses generally utilise aerial photography and historic maps showing clear correlations between land use changes and gully development (Williams & Morgan, 1976; Kakembo & Rowntree, 2003; Menéndez-Duarte et al., 2007).

Based on the above, it is evident that various factors play a role in gully erosion. Furthermore, the combination of these factors makes gully erosion difficult to assess in varying spatial and temporal scales (Boardman, 2006). Despite this, gullies are important sources of sediment and create links in landscapes for the transfer of sediment from upslope areas to valley floors or water courses (Poesen et al., 2003). Erosion control measures can be effectively applied only when the nature of erosion phenomena and effectiveness of measures under specific conditions have been understood. It is important to add to the current knowledge of the dynamics of soil erosion to determine best methods of improving the properties of soil (Zachar, 1982).

1.3. Erosion processes in volcanic environments

Volcanic eruptions are natural disruptors or creators of geomorphic systems which significantly affect landscape development in volcanic regions (Kawasaki & Colomiers, 1990). An important type of volcanic eruption is hyrdovolcanic explosion (phreatomagmatism) which results from the interaction of magma with water (Wohletz & Sheridan, 1983). Water sources include groundwater and surface water in marine, lacustrine, lagoon and subglacial environments. Hydrovolcanic explosions commonly result in the formation of small monogenetic cones and also stratovolcanoes and caldera volcanoes. Tuff rings or tuff cones are products of single eruptions. The major difference between tuff rings and cones lies in the type of explosive hydromagmatic volcanism (Wohletz & Sheridan, 1983). Tuff rings have characteristically low topographic profiles and slopes, whereas tuff cones have high profiles with steep slopes. Tuff rings produce first explosion breccia which is overlaid with thinly bedded deposits. Tuff cones follow this pattern but continue into a third stage characterised by pyroclastic emplacement by poorly inflated surges and pyroclastic falls. This produces massive, crudely bedded tuff constituting the majority of the volcanic surface structure. Further differences between tuff rings and cones are documented yet are not necessary for comparison here (see Wolhetz & Sheridan, 1983 for detailed descriptions).

The erosion of volcanic cones is a natural process that begins during (Karátson et al., 1999; Németh & Cronin, 2007) and immediately after (Dóniz et al., 2011) eruption. Whilst the short-term erosion processes are important for denudation of volcanic environments, long-term erosion processes also play an important role in denudation. Regarding long-term erosion, the effects of water erosion are the most evident. Erosion rates on volcanoes are controlled by various factors including morphology, type and distribution of material, age of volcanic cone, eruption sequence, volcano size, topography, morphoclimatic environment and local runoff depth and intensity (Karátson et al., 1999; Dóniz et al., 2011). Studies have shown that erosion rates on volcanoes are highly variable indicating the role of different degradation factors (Dóniz et al., 2011).

Although various processes erode volcanoes, colluvial (mass movements) and gully processes are the most dominant. Pyroclastic flows, for example, are known to cause erosion as materials move downslope. Erosion by pyroclastic flows occurs largely in the body of the flow as a consequence of shearing and also in the head region of the flow as a consequence of fluidization. Erosion is controlled by topography, flow energy, flow composition, flow thickness, availability of debris and hardness of the bedrock (Sparks et al., 1997). Sparks et al. (1997) observed erosion features as a result of pyroclastic flows on Lascar Volcano, Chile, which erupted in 1993. Erosion features included large striations and abrasion marks into bedrock as a result of loose colluvium and talus movement downslope (a function of rock hardness), furrows (channels) formed parallel to flow direction with distinctive fan outlets, and plunge pool features caused by flow accelerating over the lava flow front then impacting the ground surface.

Gully networks are common erosion features on the flanks and craters of tuff volcanoes. Gully formation begins with mud and debris flow and gully length and depth increases with time and intense rainfall. The effects of rainfall are amplified in tropical environments with high rainfall intensities (Németh & Cronin, 2007). For example, Németh and Cronin (2007) identified gully formations on a tephra ring on west Ambrym Island, Vanuata, as a result of a pyroclastic surge and rainfall during an eruption in 1913. Gullies averaging 3m deep and one 6m deep formed within a short duration after eruption. These gullies are now well vegetated and are no longer actively eroding, indicating gully stabilisation. The study indicated how post-eruption erosion is an important phenomenon in shaping volcano morphology. Similarly, within 10 years of the 1977-1987 eruption, Mount Usu, Japan, formed severe rill and gully (10m wide, 5m deep) erosion features (Kawasaki & Colomiers, 1990). Rill channels were initiated upslope and coalesced to form gully channels on the midslope. Sediment was deposited on footslopes within colluvial cones and fans. Maximum erosion rates were found on slopes between 15º and 30º. Fault conditioned gullies were also common erosion features. Monitoring of gully evolution indicated that inactive gullies offered favourable microhabitats by providing shade, wind protection and moisture retention.

Cinder cones in Tenerife, Spain, also exhibit gully networks (Dóniz et al., 2011). Gullies occur on steeper slopes of volcanic cinders and in a parallel asymmetric network, but do not follow the normal radial distribution as described for other volcanic cones (e.g. Karátson et al., 1999). Dóniz et al. (2011) related the age of volcanic cones to gully formation and found that age plays a key role in gully formation processes on monogenetic cones. It was also found that craters, due to their own topographic configuration and morphology, are more prone to gully formation. Climatic factors also play a role in that gully density is greater in higher rainfall regions.

In addition to short-term erosion processes being important in volcanic environments, long-term erosion processes, over millennia, also play an important role, particularly with water as an erosive agent. Long-term erosion on tropical volcanic islands is well documented. Mauritius, for example, is known to have a high susceptibility to erosion due to its elevated interior, rugged topography, climate and changing land use patterns (Nigel & Rughooputh, 2010). The island of Tahiti-Nui has also experienced long-term erosion as a result of climate and geology (Hildenbrand et al., 2008).

1.4. Bedrock erosional processes

The morphology of many bedrock-incised channels is controlled by various erosional processes (Wohl, 1993). Corrosion involves the chemical weathering and solution that directly erodes a rock surface or weakens a surface, thus increasing erodibility. Corrasion is the abrasive weathering of bedrock by clasts moving along a surface as bedload or suspended load. Cavitation occurs when velocity fluctuations in a flow induce pressure fluctuations that cause the formation and implosion of vapour bubbles weakening the substrate.

These erosive processes operate at relatively small spatial scales as a function of chemical and physical mechanisms. The controls that influence how erosive processes interact with channel substrate vary spatially. At the micro-scale (mm to cm) heterogeneities in the form of intergranular boundaries, bedding, small fractures and mineral composition affect channel morphology. Plucking and abrasion are then the dominant erosive processes. At the meso-scale (cm to m) substrate discontinuities in the form of bedding contacts, joints and lithological contacts play a greater role in erosion. Selective erosion occurs at portions of channels along a cross-section or along the slope. Erosional features typically formed include potholes, longitudinal grooves, knick points, undulating walls, inner channels and step pool sequences. Differences in flow energy across and along a channel influence erosion forms. An initial weakness in substrate may create localised channel erosion such as a pothole. At the macro-scale regional joint patterns, lithological controls, structural folding and faulting, tectonic regime and patterns of stream power dominate channel morphology produced by erosion. On steep slopes, gully erosion may be evident to an extent where channels incise into bedrock. This is more obvious toward upstream reaches of drainage basins as shown by Menédez-Duarte et al. (2007) in the northern Iberian Peninsula.

1.5. Evaluation of erosion: field-based erosion assessment and mapping

In evaluating soil erosion, there are two important aspects to consider: 1) rate of erosion and 2) distribution and extent of erosion within a landscape (Evans & Brazier, 2005). Evaluating erosion may be undertaken with the use of models to determine rates or through physical mapping to examine distribution. Most erosion research is done through modelling and field test plot measurements (Ledermann et al., 2008) with the aim to understand the mechanisms and predict erosion rates and ultimately to assist decision-makers (Evans & Brazier, 2005).

Models are of necessity simplifications of reality aimed at predicting or explaining systems to aid managers, planners and policy-makers in decision-making of complex systems (Morgan, 2005). Models describe how a system functions to guide the understanding of systems' mechanisms and responses to change (Morgan, 2005). There are many erosion models, developed for specific conditions and used for a variety of purposes in different parts of the world. The choice of model must therefore be based upon its intended purpose and geographic region. According to Nearing et al. (1994) three types exist: empirical, conceptual and physical models. Modelling fails to answer questions relating to the temporal and spatial contexts of erosion as well as sources and causes (Boardman, 2006). The erosion mapping approach may be used as a tool to answer questions such as: where does erosion occurs? Why and when? How severe? Who is affected? How to control erosion (Ledermann et al., 2008)? Erosion models are not used in this research and are therefore beyond the scope of further detailed discussion.

An erosion map is the representation of the areal distribution of erosion indicating information about the types, frequency and intensity of erosion with the application focused on conservation planning (see Bergsma et al., 1996). Three types of soil erosion maps exist: static, sequential and dynamic. Static surveys involve mapping erosion features occurring in an area (Jones & Keech, 1966). Sequential surveys evaluate change by comparing the results of static surveys done over two or more time periods while dynamic maps involve mapping erosion features and the factors influencing them to find a relationship between the two (Morgan, 2005).

Erosion mapping is an event- and field-based approach (Herweg, 1996) by allowing the representation of spatial response of an area to an event such as erosive precipitation (Van Dijk et al., 2005). Spatial variations in erosion intensity can be related to topography, soil and land use factors to aid an understanding of the mechanisms involved that affect erosion and provide key solutions. For example, Ledermann et al. (2008) surveyed changes in erosion forms after every erosive precipitation or snow melting event over a ten year period in Switzerland. Van Dijk et al. (2005) devised a method for the rapid assessment of erosion after heavy rainfall events in cultivated fields of France. In the field, this can be done by traversing landscapes to locate eroded areas (Boardman, 1990) or by interpreting aerial photography which can be validated by fieldwork (Evans, 2002; Kakembo & Rowntree, 2003). Kakembo and Rowntree (2003) used aerial photography to assess changes in the extent of erosion as a response to changes in land use in South Africa.

No universally accepted method for mapping erosion exists, but rather independent site-specific methodologies are used to describe erosion. A geomorphological mapping system for dynamic erosion surveying has been described by Williams and Morgan (1976) and involves assessing information on the distribution and type of erosion, erosivity, runoff, slope length, slope steepness, slope curvature, relief, soil type and land use (Morgan, 2005). Herweg (1996) proposed a field-based technique for the Assessment of Current Erosion Damage (ACED) based in Ethiopia. ACED is a method designed for monitoring and assessing soil erosion damage as a result of recent erosive events. It is a “rough field method that can be used to establish soil loss from current rill and gully erosion to identify causes of erosion and identify initial steps in soil and water conservation” (Herweg, 1996, pp.9).

Geomorphological mapping involves the illustration of landforms and processes to understand geomorphic phenomena and guide planning. In modern analytical geomorphology, five fundamental landform concepts describe the Earth’s surface and are present in a detailed geomorphological map (Pavlopoulos et al., 2009). Morphology identifies and describes the shape of the landscape based on descriptive elements of landforms. Morphometry involves measurements, dimensions and slope values of landforms quantitatively. Morphogenesis describes the origin of each landform and morphochronology depicts the relative age of landforms. Morphodynamics are the land forming processes which are currently active or have the potential to occur in the future. The data, which are collected at different scales in relation to the purpose of investigation, are used on topographic sheets or enlarged remotely sensed images to highlight spatial distribution and mutual relationships between components (Dramis et al., 2011).

Field work is the primary basis for geomorphological mapping, but with technological advances the use of satellite imagery and GIS software is becoming increasingly popular (Gustavsson, 2006). Different methodologies and legends are used which are generally nation or region specific (Pavlopoulos et al., 2009). In different countries, geomorphological mapping has developed on different paths due to diverse interests and opinions by researchers of landforms found in various regional settings. The International Geographic Union (IGU) has developed a manual for a uniform mapping system aimed at producing a standardised approach to geomorphological mapping (Gustavsson, 2006; Pavlopoulos et al., 2009). Despite attempts for a uniform mapping system, much diversity and disagreement on the nature of geomorphological maps is evident.

The principles of geomorphological mapping have been used in the mapping of erosion phenomena (Williams & Morgan, 1976; Herweg, 1996). This is based on the important influence of topographical and related geomorphic processes on erosion. With the advances in GIS, event-based geomorphic-erosion maps may greatly enhance the understanding of erosion and the prediction thereof. However, the complexity involved in geomorphological mapping may cause difficulties based on the multi-disciplinary approach and vast baseline data required for comprehensive geomorphic maps.

1.5.1. Erosion mapping procedure

Erosion mapping comprises of four phases (adapted from Williams & Morgan, 1976; Van Dijk et al., 2005):

1) Mapping preparation and erosion intensity inventory

Prior to field work, the study area is defined and base maps collected. A literature review guides the identification of research problems, aims and objectives. Available maps are studied in detail and a printed map with field limits is produced, which is overlayed with a topographic background to facilitate localisation and orientation (Van Dijk et al., 2005). In addition, erosion types and intensity classes are defined. Various methods used to identify and classify erosion forms exist and are discussed in further detail below.

2) Detailed stereo-interpretation

This stage involves preliminary detailed erosion mapping on aerial photographs. The type and location of erosion features are identified. Subsequently, badly located or ill-designed conservation structures, areas of contributing high runoff and areas of sedimentation are identified and located. If available, supporting information may be mapped on the main map or overlays expressing information, for example, of erosivity, soil types, slope steepness, land-use and vegetation.

3) Field surveys

Stage three confirms the reliability of photo interpretation and allows for the collection of additional information (Williams & Morgan, 1976). This involves soil sampling for analysis and incision measurements of linear erosion features (rills and gullies). Incision measurements aim to guide classification of erosion forms in the field and thus aid identification of processes (Dardis et al., 1988, Herweg, 1996). In addition, the incision measurements can be used to quantify erosion damage by calculating soil loss (Herweg, 1996). Contradictory ideas exist as to whether sheet wash should be included in soil erosion assessments as sheet wash erosion may not significantly contribute to soil loss and there are often uncertainties in detecting sheetwash in the field (Cerdan et al., 2006; Ledermann et al., 2008). However, Ledermann et al. (2008) included sheet wash erosion as an estimate of soil erosion and found that inclusion was feasible.

Field forms are used to document incision measurements (Herweg, 1996) and additional physical environmental parameters which influence erosion and will help understand causes and processes as well as off-site impacts (Van Dijk et al., 2005). Such environmental parameters include topographic factors, soil surface conditions, vegetation cover, land use, erosion and depositional features and management practices (Van Dijk et al., 2005). Simplified sketches can be made of observed incisions, runoff pathways and the location of deposition areas (Van Dijk et al., 2005).

4) Database construction, data presentation and analysis

This stage is the second detailed stereo-interpretation involving the revision of, and additions to, the first stereo-interpretation following field work (Williams & Morgan, 1976). All collected field data are entered as attribute data of the numbered sampling site polygon in a GIS. The database allows the preparation of maps of the different physical environmental variables and of the erosion intensity, with the sampling area as the basic spatial unit. Erosion classes can be converted to soil loss using the results of incision measurements and surface area as described above. In addition, it is possible to compare the physical template and soil analyses in relation to the types of erosion features present and their respective intensity classes (Morgan, 2005; Van Dijk et al., 2005). A final map of erosion phenomena may be presented on an aerial photograph or as a vector map. The final stage of the mapping procedure is the use of the erosion map to assess erosion and plan conservation work (Williams & Morgan, 1976).

1.5.2. The issue of scale

The spatial scale is an important consideration in terms of assessing erosion (Boardman, 2005) and the choice of scale depends on the purpose of the survey and size of study area (Williams & Morgan, 1976). Erosion mapping is most viable at a local, and less preferable at a regional scale (Boardman, 2006). At the local scale, the assessment of erosion can be undertaken in relation to the impact of an extreme event, exceptionally high erosion rates, impacts of new or changed land use or the efficacy of conservation measures.

When using aerial photography to assess erosion phenomena, Jones and Keech (1966) recommend aerial photographs of 1:25 000 as appropriate scale. At the regional scale, mapping erosion is generally integrated with erosion models. For example, in England, Evans and Brazier (2005) compared results of field measurements and the Water Erosion Prediction Project model results. Generally, at the national scale, the modelling approach is preferred to provide a generalised picture of erosion and erosion prone areas.

1.5.3. Advantages and disadvantages of field-based erosion assessments and mapping

The methods utilised in field-based erosion assessments have various advantages and disadvantages; including:

- The method is quick, inexpensive and relatively easy (Ledermann et al., 2008; Van Dijk et al., 2005).
- Questions about the extent, frequency and severity of erosion can be answered.
- Field surveys yield information that reflects functioning of local area systems under local conditions. Thus there is reduced risk of drawing wrong conclusions due to inadequate, non-local data (Van Dijk et al., 2005).
- Field surveys can complement existing erosion empirical modelling studies by validating predicted measurements to actual field measurements (Van Dijk et al., 2005).
- Mapping is suited to long term monitoring of erosion and changes in erosion patterns under changing conditions (e.g. land-use or precipitation regimes).
- A disadvantage is that erosion mapping has an accuracy between 15-30% (Herweg & Stillhardt, 1999).
- In the absence of reliable rainfall data, spatial variations in observed erosion intensity may be due to spatial differences in rainfall (Van Dijk et al., 2005).
- As erosion mapping generally involves identifying linear erosion forms ane sheet erosion can only be estimated (Ledermann et al., 2008).

In general, field-based erosion assessment allows a quick and easy method for quantifying and mapping erosion phenomena at a local scale. However, the true value to field-based erosion assessment lies in the classification of erosion forms to enable an understanding in erosion processes, as discussed in the following section.

1.6. Classification of erosion processes and features

Methodologies used in identifying erosion features in the field are not uniform and difficulties tend to arise when differentiating between forms and degrees of erosion grouped under one term and between stages of development (Dardis et al., 1988). In addition, there are different systems of classifying erosional forms based upon morphology, climate, lithology, the erosive agent and type of water flow. The definition of erosion severity classes is an important step in the procedure that influences the final accuracy of the erosion assessment (Van Dijk et al., 2005).

An example of a classification system which defines erosion types is the Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS, 1981) soil erosion classification system (Table 1.1, see Appendix 1 for original classification table). The SARCCUS classification scheme is a descriptive tool developed to allow for a standardised approach to the identification and assessment of erosion forms in southern Africa. The SARCCUS Classification defines four types of erosion features (sheetwash, rills, gullies and wind forms) which are further subdivided into varying erosion intensity classes based on set measurements. Although more commonly used in assessing erosion through aerial photography, the method is also applicable for field-based research and has been used in several studies of soil erosion in Southern Africa. In particular, it has been used to study changes in erosion over time often associated with changes in land use (see, for example, Boardman et al., 2003, Kakembo & Rowntree, 2003).

Field-based assessments of erosion entail field surveys where mapping and classification of erosion forms is undertaken. Mapping the spatial distribution of erosion forms and indicating the type and severity of such forms, allows for an increased understanding of erosion processes within an area. These assessments are relatively quick and easy, and allow long term monitoring of erosion patterns under changing conditions. To reach the objectives of this research project, field surveys to map and classify erosion forms using the principles of erosion mapping and classification criteria were used, based on the already existing knowledge of erosion.

Table 1.1: Abbreviated version of SARCCUS (1981) classification system indicating the types and classes of erosion caused by water and wind (see Appendix 1 for full table).

Type of erosion	Class	Symbol
Sheet	None	S1
	Slight	S2
	Moderate	S3
	Severe	S4
	Very severe	S5
Rill	None	R1
	Slight	R2
	Moderate	R3
	Severe	R4
	Very severe	R5
Gully	None	G1
	Slight	G2
	Moderate	G3
	Severe	G4
	Very severe	G5
Wind	None	W1
	Slight	W2
	Moderate	W3
	Severe	W4
	Very severe	W5

1.7. Aims and objectives

The aim of this research project is to investigate erosion phenomena on Round Island, Mauritius. After identifying specific study sites on Round Island, this aim will be met through the following objectives:

- Describe soil physical characteristics at selected study sites,
- Map and classify all erosion features based on a modified version of the SARCCUS (1981) Soil Erosion Classification System at these study sites,
- Describe the erosion processes occurring, based on observations and morphological characteristics of erosion features.

1.8. Project outline

This research project is divided into six chapters. The above Chapter presented an introduction and literature review on the concept of erosion, erosion processes in soil, volcanic and bedrock based environments, and the classification and mapping of erosion processes within geomorphology. Chapter 2 provides information regarding the study area and a background of Round Island including information on its physical environment and documented erosion and management history. Chapter 3 outlines the methodology followed during field work to meet the above objectives based on the existing literature. Chapter 4 presents the results produced following the described methodology which is followed by a discussion and interpretation of these results in Chapter 5. Research limitations and recommendations for future research are also provided. Finally, Chapter 6 highlights the main conclusions drawn and implications of this research.

Chapter 2 : Site description

This chapter provides background on the setting and physical environment of Round Island. Thereafter, a review is given on documented erosion on Round Island and the management thereof.

2.1. Location

Round Island (19º 54' 03'' S; 57º 47' 03'' E) is a volcanic islet situated off the north coast of Mauritius (Figure 2.1). It is situated 22.5km northeast of Cap Malheureux, the closest point on Mauritius, covering an area of 219ha and has a maximum altitude of 280m (MWF, 2008).

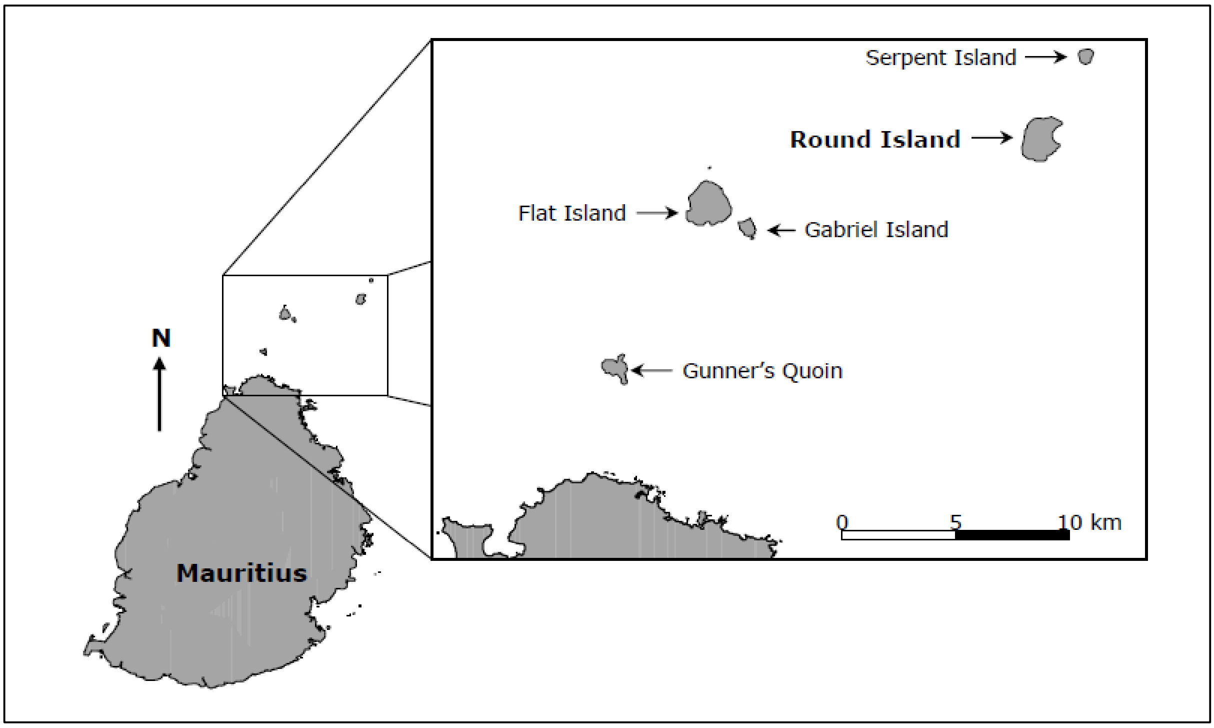


Figure 2.1: Map of Mauritius and northern islands, Round Island is highlighted.

2.2. Climate

Round Island has a sub-tropical climate. Weather monitoring on Round Island has only been undertaken since 2003 and the average annual rainfall measured was 866mm with an average daily temperature of 24.7˚C (MWF, 2011). The dry period occurs from September to November, where droughts are frequent. Climate is dominated by the South East Trade winds and frontal systems. The wetter period is between December and March which coincides with the tropical cyclone season. During cyclones wind speeds can exceed 250km/h and are accompanied by terrestrial rains. Summer thunderstorms are classified as erosive rainfall events on Mauritius (Nigel & Rughooputh, 2010) and thus probably also for Round Island. The western side of Round Island (the leeward side) is hotter and drier, whilst the east, summit, south and south eastern parts are cooler and wetter as they are influenced by the South East Trade winds.

Rates of erosion generally follow a seasonal pattern especially when rainfall follows a wet and dry regime (Morgan, 2005). The most vulnerable time for erosion is the early part of a wet season when rainfall is high but vegetation has not yet fully grown to protect soil; thus the erosion peak precedes the rainfall peak. On Mauritius the lowest vegetation cover is in December which marks the start of the high rainfall summer and thus the greatest rainfall erosivity period occurs in this time. It can be expected that Round Island follows such a pattern.

2.3. Topography

Throughout the island, steep convex slopes occur with an average of 10-15º over the lower two thirds of the island and an average of 20-25º in the upper third (Figures 2.2 and 2.3). The slopes in the west are continuous and generally 22º where they are dissected by gullies running west-north-west. The northern end of the island has narrow ledges and steep slopes (Johnston, 1993) and is characterised by 50-100m high sheer cliffs. A crater exists on the east to south east part of Round Island (Figure 2.2.a), where slopes are as steep as 33º. In comparison, the south west side contains two notable flats, nicknamed the ‘helipads’.

2.4. Geology

Mauritius and its surrounding islands form part of the Mascarene Island group which are summits of volcanic cones that rose from the ocean floor and are part of the Reunion mantle plume track that stretches northward from Mauritius to the Mascarene plateau, the Chagos-Laccadive Ridge and Deccan Traps of western India (Morgan, 1981; Duncan & Richards, 1991). The volcanic evolution of Mauritius is complex (Paul et al., 2007) and occurred in three phases (McDougall & Chamalaun, 1969). The Older Series eruptions (7.8-5.5Ma) may be subdivided into the early Shield building stage which gave rise to transitional basalts visible in erosional remains of a single shield volcano and the late Shield building stage (Paul et al., 2007). The intermediate Series eruptions (3.5- 1.9Ma) occurred after a period of calm volcanic activity and erosion processes to give rise to more alkaline basalts found on Mauritius. The Younger Series eruptions (0.7- 0.03Ma) produced less alkaline olivine basalts with smaller volumes of basanite from various small craters (Paul et al., 2007).

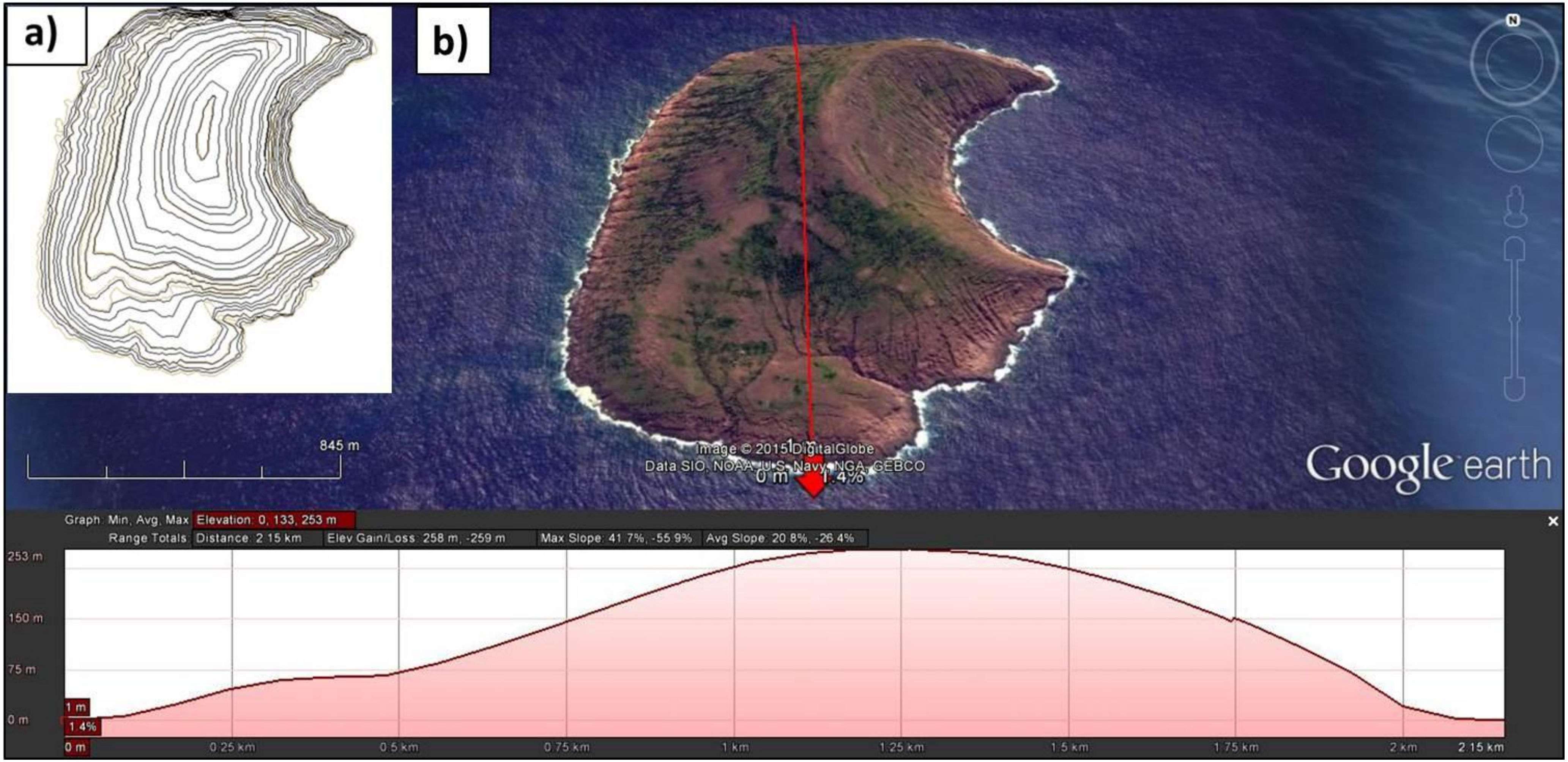
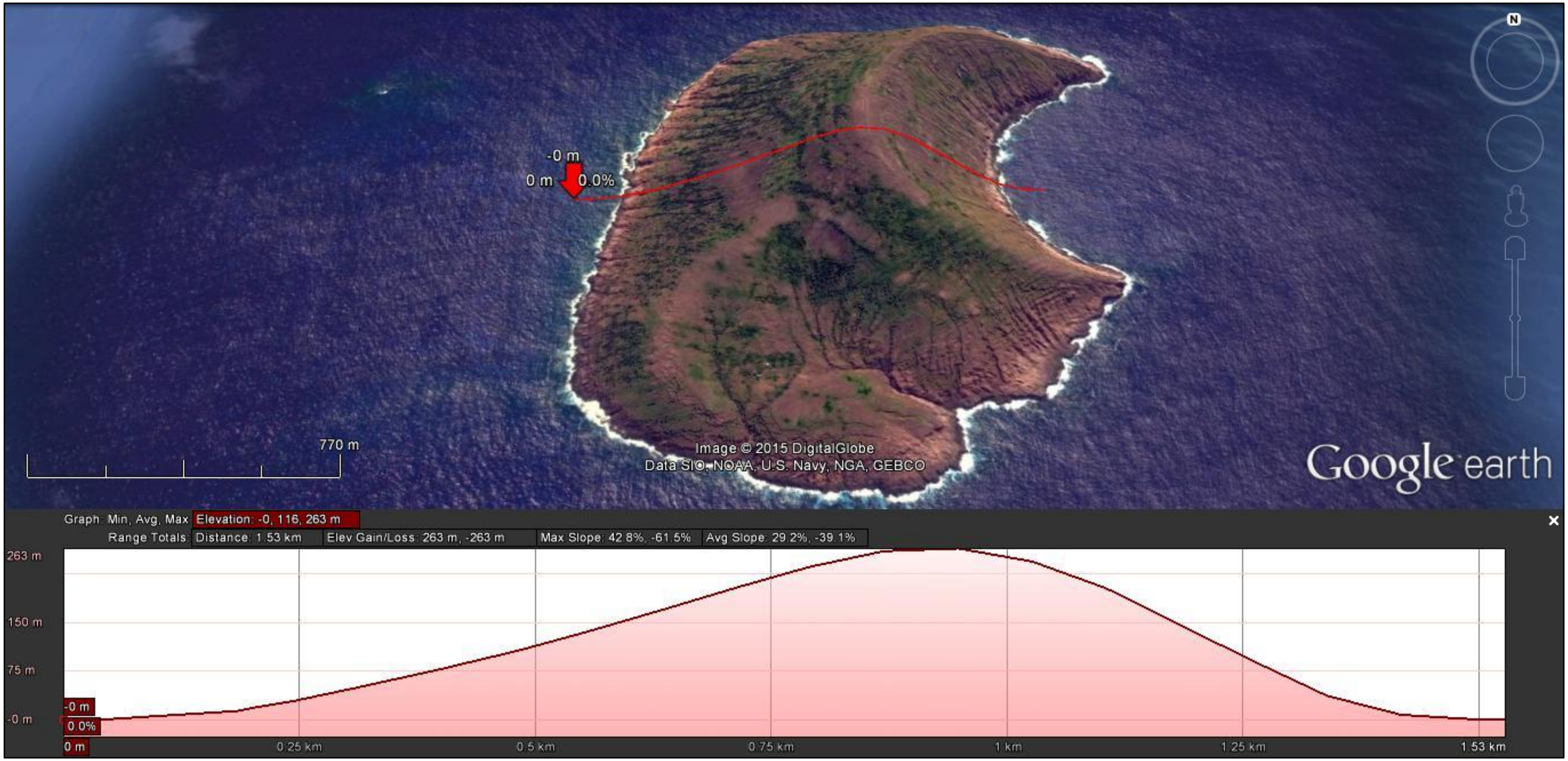


Figure 2.2: a) Contour map of Round Island (scale not shown) and b) satellite image from Google Earth of Round Island, showing the north to south profile.



Graph: Min, Avg, Max Elevation: -0, 116, 263 m

Range Totals: Distance: 1.53 km Elev Gain/Loss: 263 m, -263 m Max Slope: 42.8%, -61.5% Avg Slope: 29.2%, -39.1%

Figure 2.3: Satellite image from Google Earth of Round Island, showing the west to east profile.

Round Island's volcanic core has been dated around 25 000 to 100 000 years old which is younger than mainland Mauritius. Round Island is defined as a tuff cone which is a "volcano composed of indurated ash with slopes between 20-30º" (Wohletz & Heiken, 1992:384). The parent material is composed of successive beds of tuff, formed from deposits of volcanic ash with coarse ejecta, mostly scoriaceous. Large boulders of solid basalt occur throughout the island, with some calceourous boulders at the summit and quartz along fissures in the rock. Found within the calcarinite are fossils incorporated within the tuff which was possibly lifted up and included at the time of formation of the island (Johnston, 1993). The tuff beds dip steeply toward the sea on all slopes of Round Island.

2.5. Pedology

A comprehensive soil survey has been undertaken by the Mauritius Sugar Industry Research Institute (MSIRI) in 1961 for the Mauritian mainland yet did not incorporate the smaller islands. The first soil survey on Round Island was undertaken by Johnston (1993) who identified two types of soils based on the FAO-UNESCO mapping units: first, lithic leptosols on the western facing slopes, where the A-horizon is poorly developed with bedrock less than 10cm from the soil surface, and second, dystric leptosols with dystric regosol components common to the southern spur areas with depths occasionally more than 50cm. These soils are poorly developed with an ochric A-horizon under which lies homogenised, stable old soil material above welded tuff. The soils of Round Island have very little resemblance to those found on the Mauritian mainland (Johnston, 1993) and are therefore not suitable for comparison.

Merton et al. (1989) speculate that Round Island soils were probably originally continuous. The current distribution is poor due to the introduction of herbivores and it is not possible to determine the original nature of soil on the island (Johnston, 1993). The majority of soils on Round Island are primarily sandy loams with a relatively uniform texture, little structure and poor profile development. The limited profile development is indicative of previous soil loss and recent regeneration since conservation activities began and may be considered as a secondary parent material overlying the original welded tuff parent material (Johnston, 1993). Soil depth is also highly variable and ranges between 11- 30cm. However, on the south western side of the island, known as 'old-camp' gully, the deepest soils recorded were 60cm (Johnston, 1993).

As Round Island is a geologically young volcanic cone, shallow, stony and relatively infertile soils can be expected (Dóniz et al., 2011). Generally, the input of guano from nesting seabirds is responsible for the soil fertility properties on Round Island, affecting plant species distribution and thus rehabilitation (Johnston, 1993). The soils are acidic, with an exceptionally high phosphorous content, but low nitrogen. The percentage organic matter is highly variable but averages 5.4% (Johnston, 1993). Soils formed in volcanic ejecta have distinctive morphological, physical and chemical properties. This is due to the formation of non-crystalline materials and the accumulation of organic carbon which are the two dominant pedogenic processes of volcanic soils (Ugolini & Dahlgren, 2002). Many of the properties of Round Island soils follow the distinctive nature of soils developed from volcanic ash in humid tropical environments; such as high phosphorous retention, high degree of variable charge, low bulk density and pH between five and six.

2.6. Geomorphology

Weathering and erosion occurs throughout the island with wind and water as two major agents. Overlapping ash beds have been weathered into numerous peculiar cave-like overhangs, steps and pedestals. Large deep-sided gullies occur throughout the island (Figure 2.4.a). Gullies extend to below sea level in the north western region indicative that they were formed when sea level was much lower (Cheke, 2004). Erosion of the coastline caused by wave action is evident by steep cliffs (Figure 2.4.b).

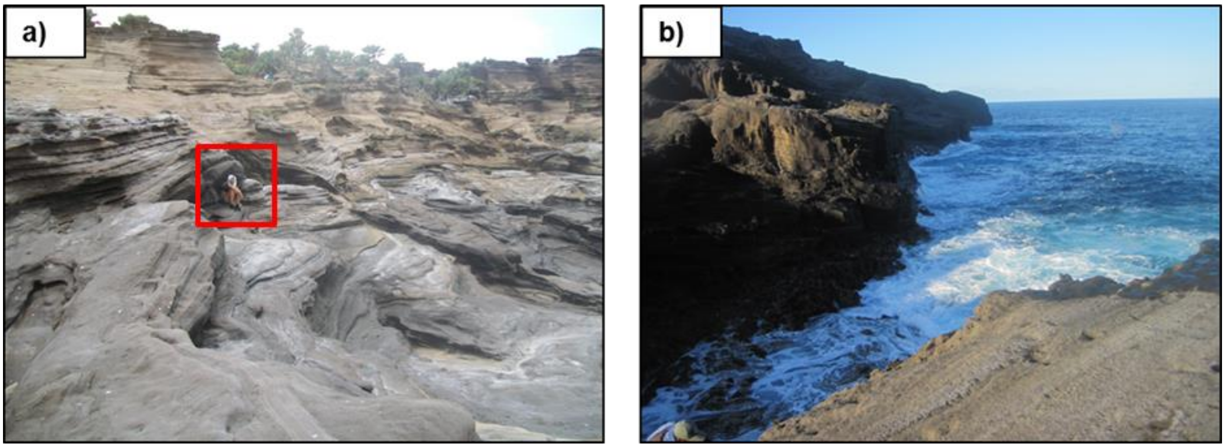


Figure 2.4: Geomorphology of Round Island coastline which a) dips steeply toward the sea (with the red box indicating a person for scale) and b) is subject to coastal erosion by wave action.

2.7. Hydrology

Large swells affect Round Island by producing salt sprays (Cheke, 2004). Due to the porous nature of the rocks, steep slopes and gullies there is little accumulation of water; except in small ephermal pools (MWF, 2008). Flash floods occur during the high rainfalls in summer. Most water is channelled through gullies into the sea (Figure 2.4.a) thus hindering plant regeneration ability within channels and increasing the risk of erosion (Johnston, 1993).

2.8. Vegetation

The vegetation on Round Island has significant conservational value (Merton et al., 1989). The island supports the largest area of native vegetation in Mauritius and is the only relatively large island in the Mascarene group free of major woody species. It also supports the last remnant of a palm savannah once characteristic of the northern plains of Mauritius. Seven distinct habitat types have been described according to vegetation and substrate and include the open and closed Palm Savannah, Mixed Weed, Herb-rich, Rock Slab, the "Helipads" and the Summit communities (Johansson, 2003). Each community contains Critically Endangered species with the Palm Savannah being the most notable (MWF, 2008). Round Island supports at least ten threatened native plant species, including six endemic to Mauritius.

The introduction of goats and rabbits to Round Island in the 19th century greatly degraded the soil and vegetation. Major reductions and even extinctions in vegetation communities have been recorded as a result of the grazers and large areas of bare ground exposed due to a reduction in vegetation cover (Figure 2.5.a, North & Bullock, 1986, cited in North et al., 1994). After the removal of the grazers by 1986 vegetation monitoring shows a gradual but significant increase in vegetation cover and regeneration of communities (MWF, 2008). In particular, *Latania* tree species have shown a marked increase in the number of individuals on the south west slope (Figure 2.5.b) which is favoured for the recovery of the palm savannah on Round Island. The number of recorded species on the island has increased since monitoring and 114 known species have been documented (Johansson, 2003). The increase in species numbers reflects increasing numbers of weed species, native introductions and reintroductions (MWF, 2008). Ile Aux Aigrettes has served as a nursery for many of the plants introduced to Round Island (Khadun et al., 2008) and this forms a part of the management plan for the island with many reintroductions being successful.

2.9. Documented erosion phenomena on Round Island

Soil erosion is an important land denudation process on tropical islands (Cooley & Williams, 1985). The soils on Round Island are subject to water and wind erosion with water erosion being the dominant process (Johnston, 1993). The state of erosion on Round Island is severe although recovering since the removal of herbivores and increased management efforts. As many parts of the island are un-vegetated with bare rock exposed, infiltration is reduced and runoff increased causing erosion. Erodability is increased further due to the steep slopes of the island. Common erosion features present on Round Island include gullies, rills, sheet erosion and eroded rock surfaces such as mushroom rocks (Johnston, 1993; Cheke, 2004). Little is known about the genesis of the gullies found on Round Island.

According to Cheke (2004) there is a misconception that the gullies formed as a result of overgrazing by the goats and rabbits.

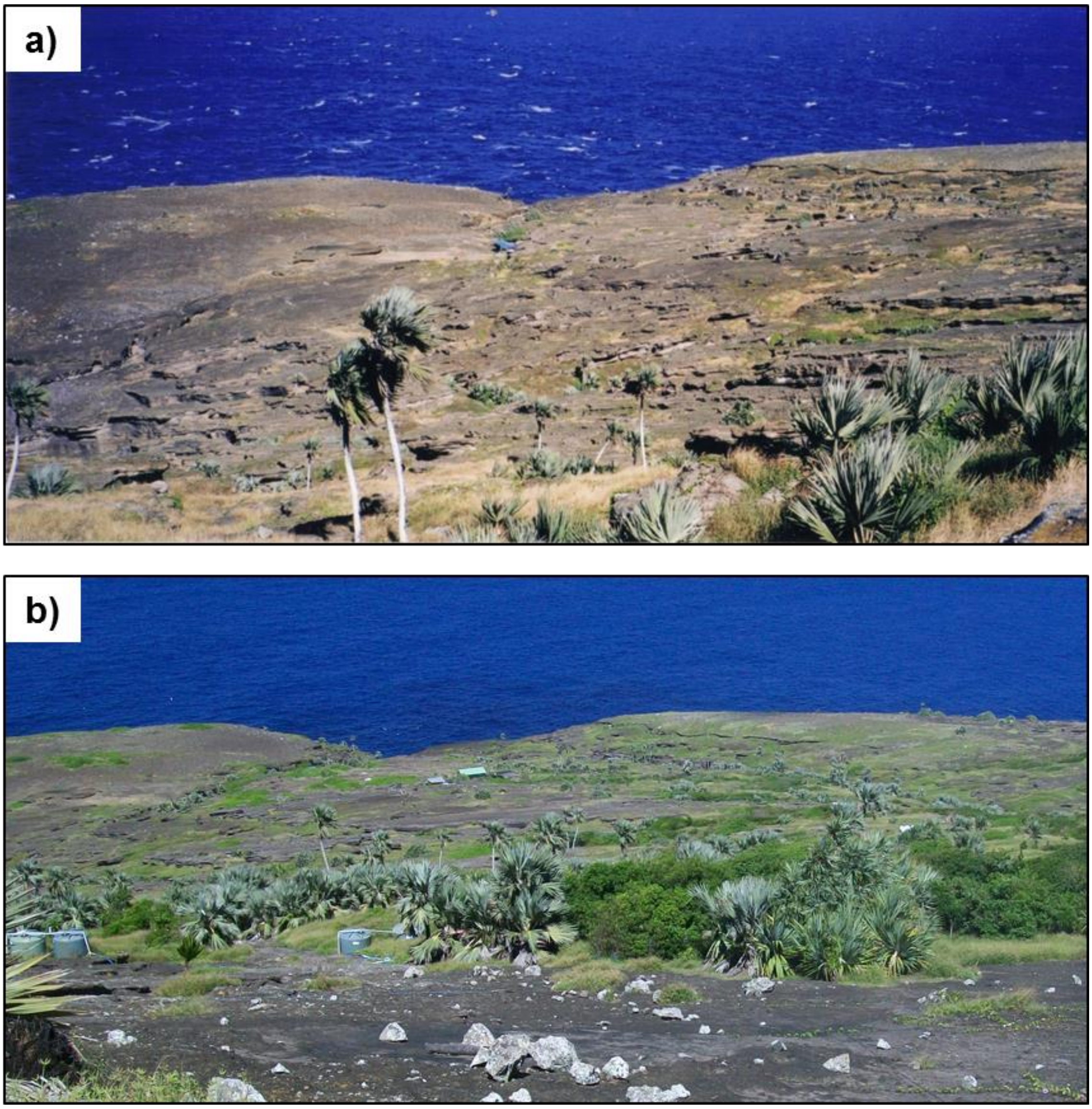


Figure 2.5: Vegetation recovery on Round Island where a) is a photograph taken in the late 1990's where vegetation degradation was evident through the introduction of exotic grazers (photo provided by MWF) and b) shows vegetation cover in 2013 which is more dense through intensive management especially through the regeneration of the *Latania* palm species.

While the grazing of animals is known to cause widespread erosion and typical erosion features (Evans, 1998), the gullies on Round Island extend into the sea which is indicative that they formed when the sea level was much lower than it currently is, possibly during the late Quaternary glacial low-stand (Cheke, 2004). The type of erosion features expected to be present on Round Island caused by grazers would possibly be sheet erosion from the removal of vegetation resulting in overland flow, leading to rill erosion.

2.9.1. Western slope

Soil erosion is most severe on the steep, continuous western slopes of Round Island. Here the sandy soil texture, low organic matter content and poor profile development indicate that soil was subject to degradation (Johnston, 1993). Water erosion is the dominant process as the western slope is protected from the south east trade winds. In addition, honeycomb weathering and mushroom pillars are present on the western slopes indicative of wind erosion in the past (Cheke, 2004). The western slopes have raised areas which are well vegetated. Bare areas that feed into gullies have little or no vegetation present, but slow recolonisation of *Ipomea pes-caprae* is helping to reduce soil loss (Johnston, 1993). *Ipomea pes-caprae* is a creeping herbaceous coastal plant commonly known for its salt tolerance and dune stabilising characteristics (Morton, 1957). This regeneration binds soil particles improving aggregate stability and thus resistance to erosion processes such as rainsplash, and favours soil formation processes.

2.9.2. South western spur and southern slopes

Johnston (1993) notes that there are two distinct landforms on the southern slopes that require different management. First, the south western slope north of the ‘big’ gully which is subject to the same erosional processes as the western slopes. Second, the gentle slopes (11º) of the south western facing spur which contain most of the deep soils found on Round Island and are relatively stable. This area is also a collecting point for wind-blown sediment from eastern areas (Johnston, 1993; Cheke, 2004). These slopes are subdivided into crevices and hollows, partially stabilised gullies and bare steps of welded tuff (Figure 2.6.a, Johnston, 1993). Soil is translocated to hollows during intense rainfall or crevices as a result of winds, thus having deeper soil with vegetation (Merton et al, 1989). There is also a relatively high density of shearwater burrows in this area (Figure 2.6.b). Johnston (1993) observed the presence of rill erosion (one noted at 20cm long) below burrows. Burrowing seabirds are known to impact on soil properties and increase erosion risks due to loss of vegetation, compaction of soil and reduced infiltration (Bancroft et al., 2005). The soils in the gullies of the south western facing slopes are similar to those found in crevices indicative of a soil accumulation area. These gullies channel the majority of water flow on the island which is then lost to sea. Despite the gullies’ subjection to water flow, natural dams of sediment have collected behind rocks that have fallen through undercutting. The bare steps of welded tuff are located between the old and new ‘camp’ gullies. Here the soil is shallow and lacks adequate vegetation cover and is thus susceptible to sheet erosion.

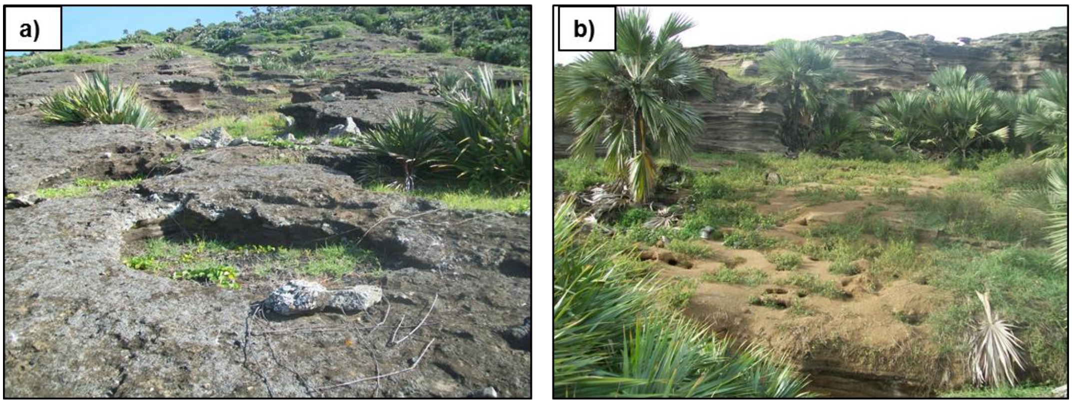


Figure 2.6: a) Bare steps of tuff with a natural hollow found in the Mixed Weed habitat which traps sediment thus promoting vegetation growth; and b) shearwater burrows occur in areas of deeper soils in the Mixed Weed habitat.

2.10. History of Round Island and its management

The tortoise trade and introduction of rabbits and goats have drastically changed the landscape of Round Island. Introduction of goats (*Capra hircus*) and rabbits (*Oryctolagus cuniculus*) occurred in the 19th century (about 1844, Cheke, 1987), where they had a significant impact by removing native vegetation, disrupting reptile communities and were thought to be responsible for large scale erosion (Johnston, 1993). Conservation interests began on Round Island since the late 19th and early 20th centuries, however actions were only undertaken in the 1970s. Round Island was classified as a Nature Reserve in 1957 under the Forests and Reserves Act No. 41 of 1983. Goats were eradicated in 1979 and rabbits in 1986 (North et al., 1994). In addition, vegetation monitoring, rehabilitation and weed eradication have been performed since 1975. The first management plan of Round Island was published in 1988 (Merton et al., 1989) and the second developed in 2008 (MWF, 2008).

Management visits occurred during the period of 1990-1998 with the aim of eradicating various alien invasive plant species. The 1993 Raleigh International Round Island Expedition focused on surveying small islands around Mauritius, including Round Island and in turn gave practical effect to the aims of Merton et al.'s (1989) management plan (Daszak, 1994). During this period, the soil survey was undertaken and experimental erosion control measures put in place (Johnston, 1993; Daszak, 1994).

One of the objectives of the current management plan is to intensify the restoration process in areas with suitable soils (MWF, 2008). This includes the recovery of degraded soils or the protection of areas with deep soils to favour regeneration of plant communities. Specific activities include establishment of pioneers and hardwood species (Figure 2.7.a) to increase vegetation which favours soil formation and protecting planted areas from wedge-tailed shearwater (*Puffinus pacificus*) burrowing. In terms of soil erosion the management plan aims to gain a greater understanding of soil erosion phenomena on Round Island and implement soil conservation measures where appropriate. Methods of soil conservation have previously been applied although in an *ad hoc* manner (Johnston, 1993; MWF, 2008) and soil traps have proven to be effective, although they only locally trap soil (e.g. Figure 2.7.b). The regeneration of *Latania loddigessii* and *Ipomea pes-caprae* has also shown positive results in reducing soil loss in gullies (Johnston, 1993).

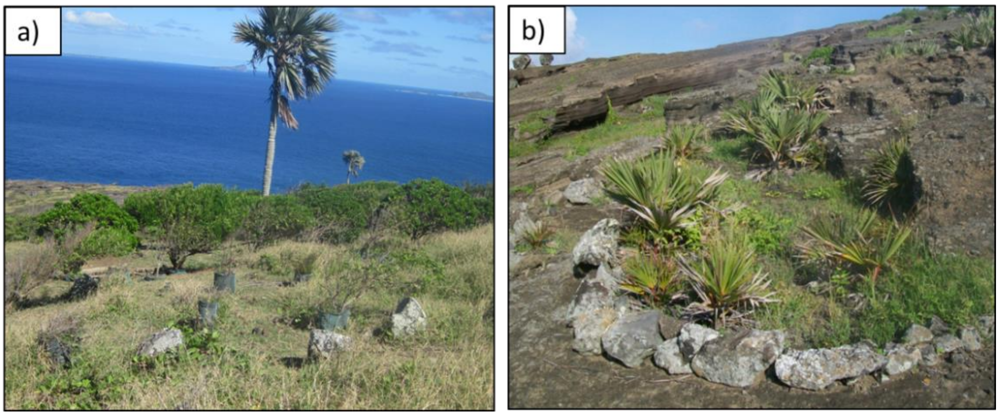


Figure 2.7: a) Increase in vegetation cover due to planting of hardwood species and b) soil trap used as a soil conservation method to trap sediment moving downslope.

Two species of tortoise (*Aldabrachelys gigantea* and *Astrochelys radiata*) were introduced to Round Island in 2007 as a restoration tool to replace extinct ecosystem engineers (Griffiths et al., 2009). Tortoises are grazers and a primary objective of their introduction was to influence plant communities in a beneficial manner by grazing on the faster growing exotic species. The tortoises eat and disperse large seeds of the endemic *Latania loddigesii* palm species. There is, however, question on the impact that the tortoises are having on soils by consuming vegetation and leaving soils bare and susceptible to erosion. Tortoises will have an impact on their environment as ecosystem engineers and thus it is suggested that it is important to weigh up the costs and benefits of using tortoises (Griffiths et al., 2009) to give effect to conservation plans.

This chapter has provided background information necessary for the assessment of erosion on Round Island, including details on the known climate, topography, geology and pedology of the island to provide context in which the next chapter will continue. A detailed description was provided on previous erosion studies and the documented history of managing erosion. The following chapter provides the methodology followed to assess and classify erosion phenomena on Round Island.

Chapter 3 : Methodology

This chapter deals with the methods and materials used in the undertaking of this dissertation. It describes the scope of research design, equipment and analyses situated amongst existing research strategies that were used to reach the objectives of the project. Since the whole island is subject to erosion by wind and water it was deemed practical to choose specific locations to assess erosion phenomena. Seven habitat types have been identified on Round Island according to vegetation type and substrate (Johansson, 2003). Five habitat types were chosen for the erosion assessment. Within these habitat types, permanent one hectare quadrants were established where research and environmental monitoring projects are carried out (Figure 3.1). The Summit, Rock Slab and Palm Savannah habitat type provide an overview of erosion along a profile from the summit toward the coastline on the west. The Mixed Weed habitat occurs in areas of deeper soils and where active planting activities take place and the Helipad habitat in the south which acts as an important sediment source to its western areas.

As the existing gully systems are not confined within the quadrant study sites, the erosion assessment was also extended to outside of these quadrants. Two gully systems (nicknamed ‘camp’ gully and ‘big’ gully) are located on the south and south eastern slopes of Round Island (Figure 3.1) and were examined due to ease of access. This enabled the mapping and analysis of two entire erosion systems on Round Island. Tortoises and seabirds naturally populate the Mixed Weed and Summit Habitat sites and visual observations of these animals and their impact on soil were also made.

3.1. Soil analyses

Soil samples were taken to determine the physical properties of Round Island soils. Six samples (± 500g each) were taken from randomly selected points within each of the five chosen habitat quadrant sites (Figure 3.1). At the Rock Slab study site, soil cover was discontinuous, thus samples were confined to these areas. Soil physical properties were determined from a total of 31 samples. Samples were collected with the location of each sample being recorded using a Garmin G62 Geographic Positioning System (GPS). Additional parameters in the field were recorded such as soil depth, proximal vegetation cover, elevation, aspect and recent weather conditions. Samples were taken to the mainland and analysed in the soil science laboratory at the University of Mauritius. The results of the soil analyses were used to study erosion processes on Round Island in relation to soil properties. Only topsoil samples were needed as soil erodibility generally refers to topsoil. Laboratory analysis procedures followed standard methods described in Briggs (1977), Goudie et al. (1990) and those used by Le Roux (2005) on Mauritius.

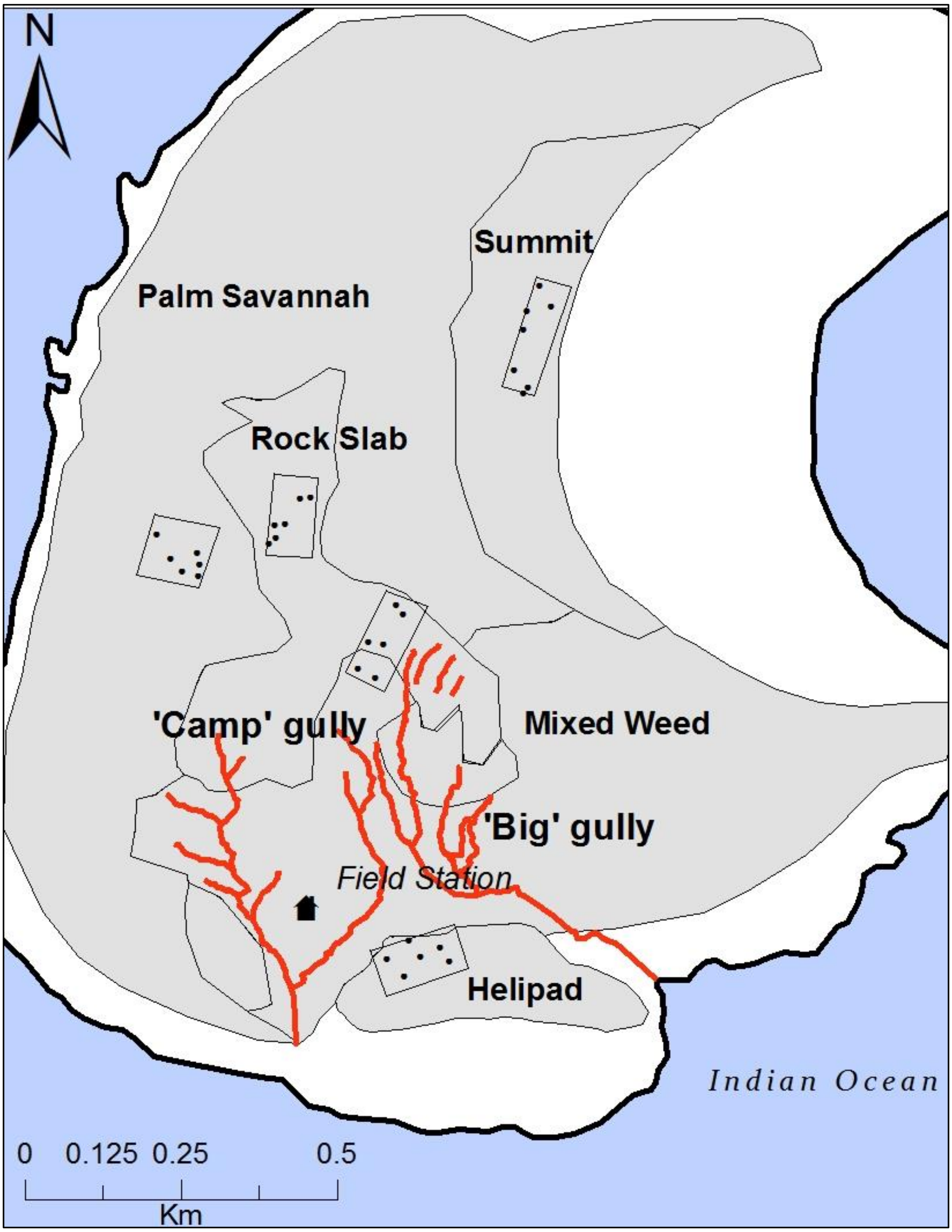


Figure 3.1: Round Island indicating location of sampling sites within selected habitat regions and location of the 'camp' and 'big' gully networks.

The samples were used for the following soil analyses:

3.1.1. Soil pH

A slurry of the soil sample was made by mixing 20g of soil with 50ml of water in a mechanical shaker at 125 rotations per minute for 30minutes. Soil pH was subsequently measured with a glass electrode in the soil solution suspensions with a buffer of 1:50 1 M NaF (Goudie et al., 1990).

3.1.2. Moisture content

Moisture conditions in the soil affect infiltration rate and erosion. The water content is the ratio, expressed as a percentage, of the mass of free water in a given mass of soil to the mass of the dry soil solids. To determine moisture content, soil samples were weighed and dried in an oven (at 110ºC) for 24 hours then reweighed (Goudie et al., 1990).

3.1.3. Organic matter content

Organic matter content (expressed as a percentage of weight) was measured by weighing a sample of soil then placing it into a furnace (at 600ºC) for 24 hours then reweighing the sample (Le Roux, 2005).

3.1.4. Bulk density

At soil sample sites, bulk density samples were taken in addition to the other samples. Bulk density was determined by hammering a metal cube with a known volume into the soil (Briggs, 1977). Samples were oven dried (at 110ºC) for 24 hours and weighed. The bulk density of the soil is the ratio of its mass to its volume:

$$\text{Bulk density} = \text{Weight (g)} / \text{Volume (cm}^3\text{)}$$

3.1.5. Particle size analysis

Particle size analysis was carried out by sieve analysis for 15 minutes using a mechanical shaker and sieve stack with different size classes (<0.063-4mm) on the Wentworth Scale. The percentage of total sample weight remaining on each sieve was determined. Data were transformed to a normal distribution. The mass of fines is underrepresented, thus requiring a logarithmic phi scale to be used: $\phi = -\log_2 d$; where d= diameter (mm) of each sieve. Subsequently the cumulative percentage frequency of the different sediment size ranges using the phi scale (x-axis) was plotted. Descriptive statistics as given by Briggs (1977) were used to describe the particle size distribution of the samples and includes mean, skewness and sorting. Quantitative statistics by means of the Kolmogov-Smirnov test were subsequently done to determine if there were differences between sample populations.

3.2. Classification of erosion forms

The assessment of erosion included identifying and classifying the types of erosion processes and resultant features present on Round Island and comparing these features to the environmental setting. The assessment entailed field observations describing erosion by water or wind using descriptors of each erosion feature, such as the type and severity of erosion. Classifying erosion processes and features is an important step that strongly influences the final accuracy of the erosion assessment (Van Dijk et al., 2005). However the identification of such features in the field is not uniform and difficulties tend to arise when differentiating between forms and degrees of erosion grouped under one term and between stages of development (Dardis et al., 1988; Herweg, 1996). In addition, there are different views of classifying erosional forms based upon morphology, climate, lithology, the erosive agent and type of water flow.

In the field, erosion forms with respective descriptors were identified and classified according to a modified version of the Southern African Regional Commission for the Conservation and Utilisation of the Soil (SARCCUS, 1981) soil erosion classification system; and was renamed here the Modified SARCCUS classification (MSC, Table 3.1). The SARCCUS classification scheme is a simple and descriptive tool developed to allow for the existence of a standardised approach to the identification and assessment of erosion. SARCCUS defines four types of erosion (sheetwash, rills, gullies and wind forms) which are further subdivided into various severity classes based on set measurements (Table 3.1). Although more commonly used in assessing erosion through aerial photography, this method is applicable to field-based research. This classification has frequently been used in numerous studies of soil erosion in Southern Africa. In particular, it has been used to study changes in erosion over time often associated with changes in land use (see for example Boardman et al., 2003, Kakembo & Rowntree, 2003). The choice of using the SARRCUS classification scheme is that it is applicable to any area where water is the dominant erosive agent (SARCCUS, 1981) as is the case on Round Island.

The SARCCUS classification needed to be modified as it was only applicable to erosion forms developed within soil profile, whereas, the erosion forms on Round Island extend predominantly into the bedrock. The severity of erosion features on Round Island also outweighed those found in the SARCCUS classification (see Appendix 1) and thus the descriptors and process remarks for each severity class needed to be increased or adapted to match the size classes of erosion forms found on the island.

Table 3.1: Modified SARCCUS Classification (MSC) System, adapted from SARCCUS, (1981); where the subscript b denotes incision into bedrock.

Type of erosion	**Class of erosion**	**Symbol**	**Description and remarks**
Sheet	None apparent	S1	No visible signs of erosion.
	Slight	S2	Erosion deduced from poor cover, sediment deposits and plant pedestals.
	Moderate	S3	Small rills present. Poor plant cover and extensive sediment deposits.
	Severe	S4	Rills and gullies present. No soil layer present.
	Very severe	S5	Very severe gully erosion.
Rill	None apparent	R_b1	No visible signs of erosion, bare bedrock.
	Slight	R_b2	Small, shallow (<0.1m) rills present into bedrock.
	Moderate	R_b3	Rills with considerable depth in bedrockl (0.1-0.3m).
	Severe	R_b4	Abundance of deep rills (<0.5m). Incision into bedrock.
	Very severe	R_b5	Large well-defined rills. Associated with gully erosion.
Gully	None apparent	G_b1	No visible signs of erosion.
	Slight	G_b2	Incision into bedrock, 1m in depth.
	Moderate	G_b3	Intricate pattern of gullies (1-5m in depth).
	Severe	G_b4	Landscape dissected and truncated by large gullies (5-10m); 25-50% of area unproductive.
	Very severe	G_b5	Large and deep gullies (>10m); over 50% of area denuded.
Wind	None apparent	W1	No visible signs of erosion.
	Slight	W2	Not readily observed. Field checks may show evidence of removal and deposition.
	Moderate	W3	Easily observed. Sand deposited against obstructions and small dunes are formed.
	Severe	W4	Sparse vegetation and soils very sandy. Or well defined mushroom rocks.
	Very severe	W5	Over 50% of area rendered unproductive.

To quantify erosion, physical measurements of linear erosion forms were taken at various points along the vertical profile of erosion features from the starting to end points where possible. Casali et al. (2006) recommend that the distance between cross-sections be 1m for gullies and 2m for rills. However, due to the extensive length of gully and rill forms on Round Island such frequent intervals were impractical. The method of Bou Kheir et al. (2008) was adopted where cross-section examinations occurred at intervals of approximately 10% of the total length of rills and gullies. Due to inaccessibility of various points along gullies this was not always possible and thus the closest point to a 10% interval was used. Cross-sectional profiles of erosion features can be characterised based on the physical measurements, including the width, depth and length of linear erosion forms (Casali et al., 2006). Even though this method of cross-section analysis has an error of 10.3%, it is most suited to measurements of large gullies (Casali et al., 2006) such as found on Round Island. The width: depth ratio of the physical morphological measurements was then calculated using the maximum width and maximum depth at each cross-section and subsequently the mean maximum width and depth for each gully. Cross-sectional profiles along the length of erosion features were compared from these morphometric parameters to assess changes in morphology of the erosional form (Dardis et al., 1988). Mean slope angle (expressed in degrees) was taken adjacent to each erosion form. The channel floor of erosion forms varied greatly in slope angle between forms and between cross-sections, and thus was not used in the erosion assessment.

3.3. Mapping erosion phenomena

An erosion map is the representation of the areal distribution of erosion features, indicating information about the types, frequency and intensity of erosion with the application focused on conservation planning (modified from Bergsma et al., 1996). Locating, mapping and measuring of channel erosion in the field is not difficult (Evans, 2002). However, no universally accepted method for mapping erosion exists, but rather independent site-specific methodologies are present to describe erosion. Thus for the purpose of this study a number of methodologies were integrated (Williams & Morgan, 1976; Ledermann et al., 2008) using the principles of geomorphological mapping to map the spatial distribution of erosion features on the island.

It is rare that actual processes are mapped, rather, a process map records an interpretation of forms and materials associated with a defined process (Cooke & Doornkamp, 1990). The process of erosion gives rise to distinctive land features which may be mapped to indicate process. For example, active gullies are indicative of water erosion and the presence of mushroom rocks indicative of wind erosion. Mapping the location and extent of these features allows for the estimation of remedial costs and aids landscape managers in selecting the most effective control measures (Cooke & Doornkamp, 1990).

A GPS was used to determine the geographic location of all erosion features and to aid in erosion mapping. In the case of the ‘camp’ and ‘big’ gully systems, where it was not possible to physically measure the complete profile due to the steep terrain, extrapolations were used and spot heights presented. Further, inaccuracies in the GPS elevations were noted, possibly affecting accuracies of the vertical profiles. Once field mapping was completed the maps were scanned and digitised into a Geographic Information System (GIS) software (ArcMap Version 10.1) to produce the final map with the associated GPS coordinates.

Using basic GIS analyses, a comparison of the erosion phenomena was made in relation to the physical template of Round Island. Physical template features include geology, topography, soil physical properties and vegetation. The aim of comparing these physical environmental variables was to establish at which study sites on Round Island erosion is most severe and what the controlling or limiting factors are.

3.4. Rock strength control on erosion processes

The Schmidt Hammer was originally produced for carrying out *in situ* tests on concrete hardness (Day & Goudie, 1977). Currently, the Schmidt Hammer is used in geomorphological studies such as weathering and relative dating (Goudie, 2006) and the device gives an accurate and rapid measure in the field of surface hardness (Day, 1980). A steel rod is triggered which impacts the surface of the material being tested. A given mass is projected a fixed distance to give a known kinetic energy to the surface (depending on type of hammer used). The steel rod rebounds a distance (*R*) according to the hardness of the body. For a hammer of known characteristics, the value of *R* gives a means of comparing rock hardness. Three types of Schmidt Hammers are used (Goudie, 2006). The ‘N’ type is applicable to a range of rock types from weak to very strong rocks. A digital version of the ‘N’ and ‘L’ type Schmidt Hammers, termed the ‘Digi-Schmidt’ are also available. These are based on the same principle but give a digital reading. The ‘L’ type has an impact three times lower than the ‘N’ type and is thus used on considerably weak rocks. The ‘P’ type is a pendulums hammer which tests materials of very low hardness although this device is rarely used.

Rock hardness of the bedrock erosion features on Round Island was used to evaluate lithological controls of erosion forms on Round Island. Estimation of the compressive strength of the *in situ* rock was obtained, in R-values, using an ‘L-type’ ‘Digi-Schmidt’ with a 0.5 unit precision. The guidelines provided by Day and Goudie (1977) were followed for the use of the Schmidt Hammer in the field. Twenty impact readings were taken on each test surface. The mean and standard deviation was then calculated to three significant digits as given by the instrument precision.

Chapter 4 : Results

In this Chapter results are presented. First, the soil analyses are shown for each of the five habitat study sites. Second, the results of the erosion assessment are presented for each habitat site and the two gully systems with maps, diagrams and supporting photographs for each site where applicable.

4.1. Soil analyses

4.1.1. Physical soil properties

Soil properties examined include depth, pH, soil moisture, organic matter, bulk density and particle size distribution (results shown in Table 4.1). At least six samples were obtained from each habitat quadrant and subsequently analysed (Figure 3.1, page 29).

Table 4.1: Results of Round Island soil analyses (mean ± SD).

Habitat site	**Mixed Weed**	**Helipad**	**Summit**	**Rock Slab**	**Palm Savannah**
Number of samples (n)	6	6	7	6	6
Soil depth (cm)	10.3 ± 4.3	6.1 ± 2.8	12.4 ± 10.1	11.3 ± 10.0	11.1 ± 6.5
pH	6.97 ± 0.17	7.25 ± 0.22	6.81 ± 0.29	7.31 ± 0.10	6.91 ± 0.72
Moisture content (%)	21.16 ± 4.43	13.19 ± 3.16	18.17 ± 9.09	17.90 ± 3.78	17.73 ± 3.29
Organic matter (%)	7.84 ± 2.17	2.81 ± 2.23	8.11 ± 4.30	7.31 ± 3.87	9.61 ± 5.23
Bulk density (g.cm^{-3})	0.68 ± 0.15	N/A	0.88 ± 0.15	N/A	0.67 ± 0.06

Soil pH values are approximately neutral with values ranging from 6.81 to 7.31. The Summit region has the lowest average pH (6.81 ± 0.29), whilst the Rock Slab habitat has the highest average pH (7.31 ± 0.10). A significant difference in pH occurs between habitat sites in general (Kruskal- Wallis ANOVA, H (4, n=31) =13.06, p=0.011, Figure 4.1) with the Summit region having a significantly lower pH than the Helipad (Mann- Whitney U test, z= -2.21, p= 0.03) and Rock Slab (Mann- Whitney U test, z= -2.93, p< 0.01) habitat regions. In terms of moisture content, the Mixed Weed habitat has soils with the highest average moisture content (21.16% ± 4.43) followed by the Summit habitat (18.17 ± 9.09), Rock Slab habitat (17.90% ± 3.78), Palm Savannah habitat (17.73% ± 3.29) and Helipad habitat (13.19 ± 3.16), although none of these sites are statistically different from each other (Kruskal-Wallis ANOVA, H (4, n=31) =8.60, p=0.07; results not shown). The Palm Savannah has the highest average organic matter content (9.61% ± 5.23, Table 4.1) with the Helipad having the lowest (2.81% ± 2.23). No significant difference is found between habitat regions when considering organic matter (Kruskal- Wallis ANOVA, H (4, n=31) =9.09, p=0.06; results not shown).

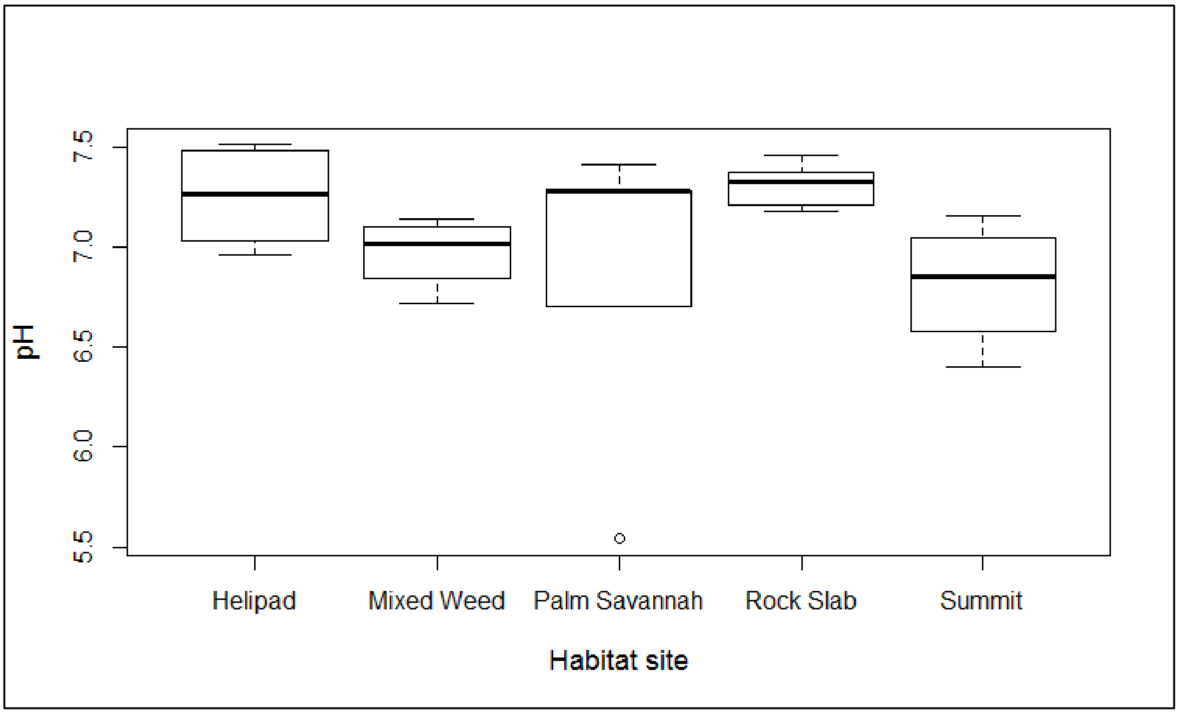


Figure 4.1: Comparison of soil pH between Round Island habitat regions.

As soil depth varies considerably (Table 4.1), it was not possible to take bulk density samples at all sites. Thus only the Mixed Weed, Summit and Palm Savannah regions were considered for bulk density analysis. Results indicate that the Summit region has a higher average bulk density (0.88g.cm^{-3} ± 0.15) than the Mixed Weed and Palm Savannah regions respectively (Table 4.1). No statistical tests were considered for bulk density as sample sizes were too small, due to the variable soil depth.

4.1.2. Particle size

Particle size distributions for each habitat on Round Island are illustrated in Figure 4.2, while particle size distributions for individual soil samples are given in Appendix 2. Results of the particle size distribution analyses are presented as cumulative curves on a logarithmic scale (phi) in order to normalise the distribution. The graph depicts the percentage coarser than a given grain size on a cumulative scale. Descriptive statistical analyses of the Round Island soils (Table 4.2) indicate that mean particle size varies between 0.349 and 0.986, with the Helipad habitat having the largest mean particle size. According to the Wentworth Grade, all sites fall within the sediment size of sand with the

Mixed Weed and Helipad being coarse sand and all other sites as medium sand. All sites are very poorly sorted with a sorting value in the range of 2.24 to 2.38. All sites are negatively skewed suggesting a predominance of coarser sediments with the exception of the Helipad site, which has a symmetrical distribution (-0.04).

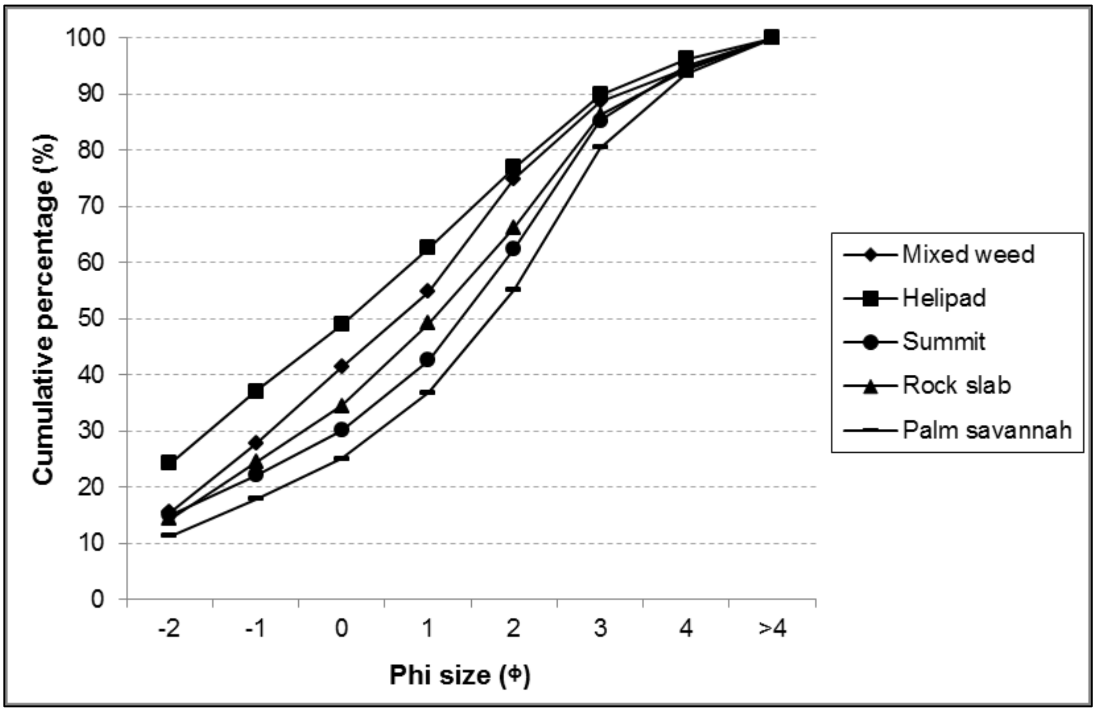


Figure 4.2: Cumulative percentage curves of particle size distribution for Round Island habitat sites.

Table 4.2: Descriptive statistics describing particle size distribution of Round Island soils (following Briggs, 1977).

Φ Analysis	**Mixed Weed**	**Helipad**	**Summit**	**Rock Slab**	**Palm Savannah**
Median (mm)	0.629	0.933	0.387	0.467	0.308
Mean (mm)	0.707	0.986	0.467	0.547	0.349
Wentworth Grade	Coarse sand	Coarse sand	Medium sand	Medium sand	Medium Sand
Skewness	-0.12	-0.04	-0.34	-0.20	-0.29
Grading	Negatively skewed	Symmetrical	Very negatively skewed	Negatively skewed	Negatively skewed
Sorting	2.29	2.27	2.38	2.35	2.24
Grading	Very poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted	Very poorly sorted
Kurtosis	0.89	0.97	1.05	0.91	1.13
Grading	Platykurtic	Mesokurtic	Mesokurtic	Mesokurtic	Leptokurtic

4.2. Assessment of erosion phenomena

The following section presents the results of the erosion classification and mapping assessment for each study site. Morphometric parameters of the linear erosion features are presented in tabular format, with supporting maps, cross-sectional diagrams and photographs to allow for a description of the erosion processes that occurs within each site. Sampling represents what is happening along a gradient and the most severe erosion areas on Round Island.

4.2.1. Summit

The Summit quadrant is located at the highest elevations on Round Island, is relatively flat (4 to 10˚) and feeds into the steep convex slopes of the island. The site is mainly a bare rock surface with numerous scattered volcanic blocks and bombs. Soil depth is variable and averages 12.4cm ± 10.1 (Table 4.1). Vegetation cover is patchy containing mainly herbaceous plant species and a few planted hardwood species. No palm species currently populate the Summit. Sheetwash is the dominant erosive process identified on the soils of the area. No linear erosion forms with considerable depth occur, but two short shallow bedrock rill-like forms were identified and mapped within the study site (Figure 4.3). Morphometric analyses were conducted on these rills as shown in Table 4.3.

Table 4.3: Summit quadrant erosion features morphometric parameters and Modified SARCCUS Classification (MSC) (see Figure 4.3 for locations).

Rill name	Slope (˚)	Total length (m)	Mean max width (m)	Mean max depth (m)	Width: depth ratio	MSC
Rill 1	9	31.4	6.38	0.73	9.38	S3, R_b3
Rill 2	6	20.0	2.92	0.46	7.82	S3, R_b3

Rill 1 is a bedrock dominated rill located on the western side of the Summit quadrant (Figure 4.4). The rill has a high width: depth ratio (9.38) as it is wide and shallow. Moderate sheetwash is the main erosive processes as water moves down its gentle slope (9˚). The general cross-sectional morphology is asymmetrical where the left sidewall is higher than the right wall as the rill curves following its course downslope concentrating water causing greater incision on the left hand side (Figure 4.4). Rill 2 is located on the eastern side of the quadrant study site and is formed due to concentrated flow over stepped terrace-like tuff (Figure 4.5). The rill is wide and shallow as indicated by its high width: depth ratio (7.82). On the Modified SARCCUS Classification (MSC), both rills fall in the category of moderate bedrock rill erosion (R_b3) and moderate sheet erosion (S3) in that both processes were observed. Sheet erosion occurs within the wide channels of the rills and bedrock rill erosion concentrated toward the sidewalls. Adjacent to the rills, moderate sheetwash occurs where the bedrock surface is sloped feeding into the rills.

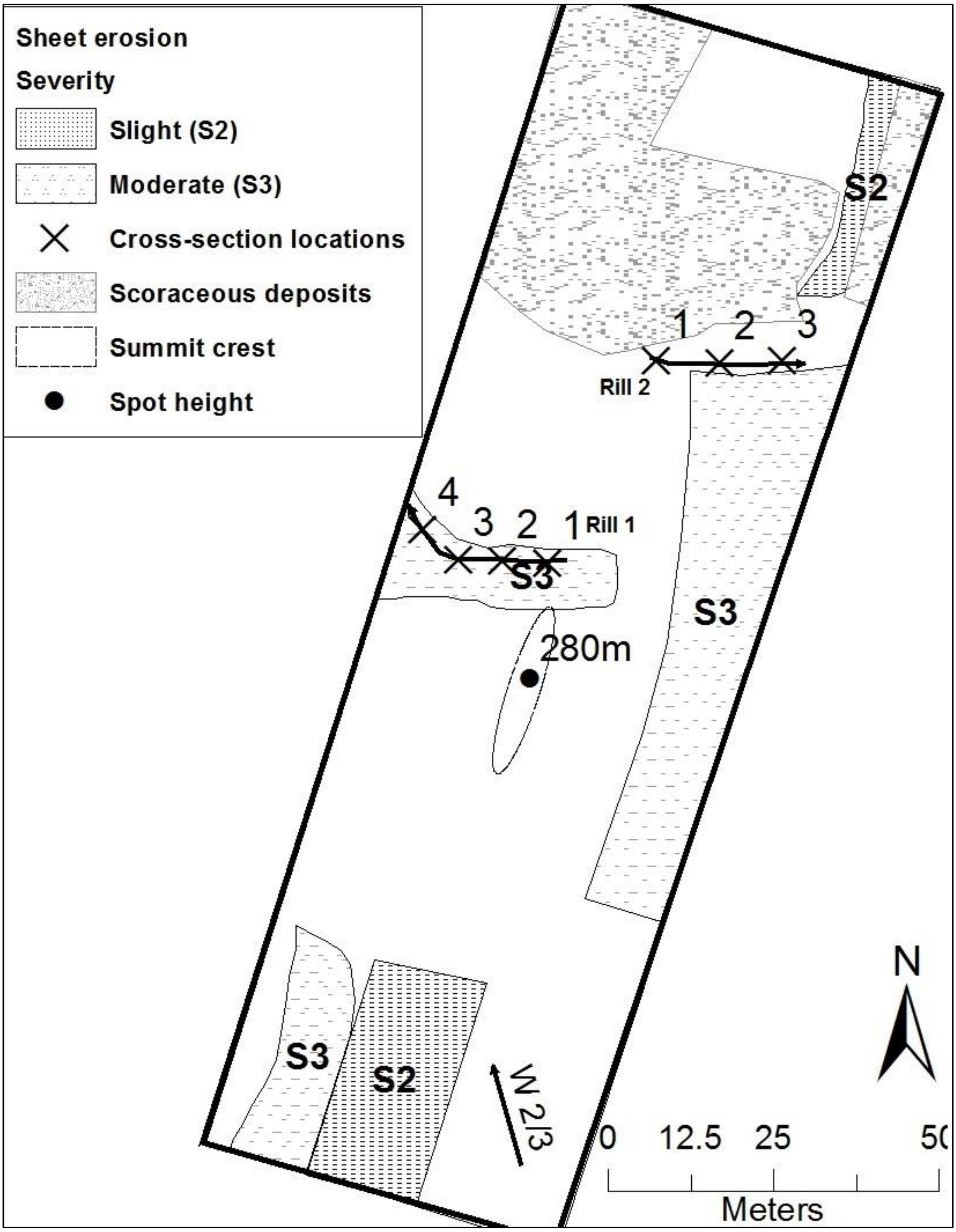


Figure 4.3: Location of linear (including cross-section locations in superscript) and non-linear erosion forms in the Summit quadrant study site.

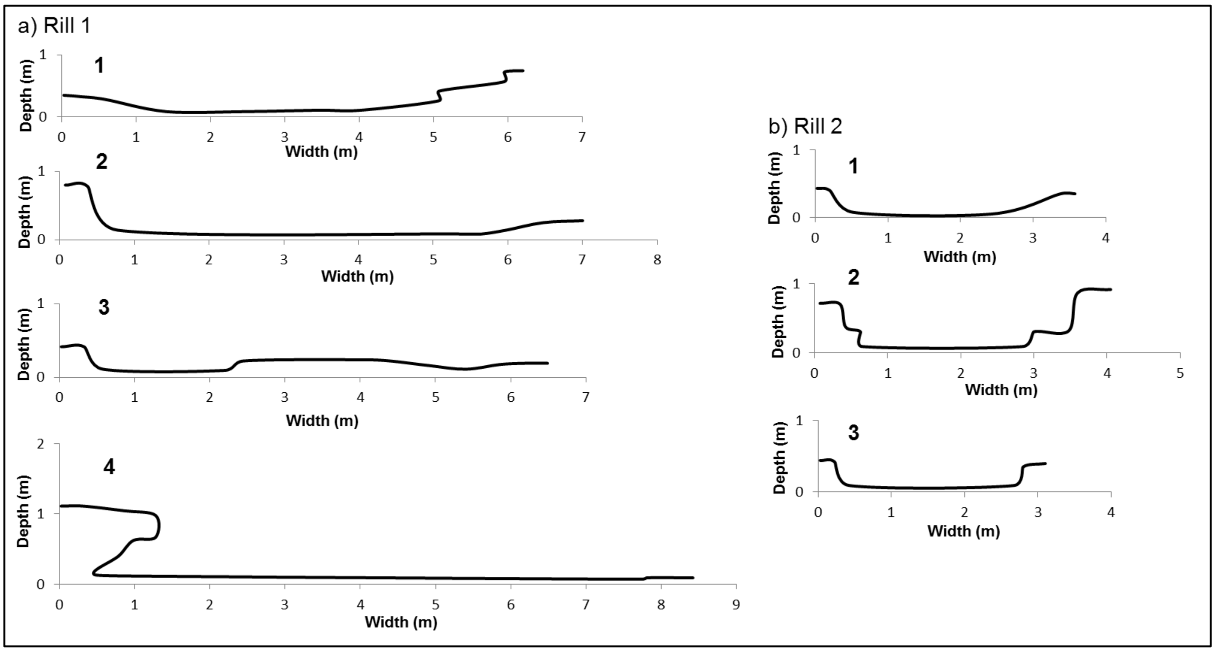


Figure 4.4: Cross-sections of a) Rill 1 and b) Rill 2, Summit habitat quadrant study site (see Figure 4.3 for locations); all cross-sections and subsequent diagrams are viewed upstream.

Figure 4.5: View upslope of cross-section 2, Rill 2 at the Summit study site.

The prevailing South East Trade Wind exposes the south-eastern region of the Summit to wind erosion which acts as a sediment source for the western areas of the Summit. Sediment suspended by wind is transported to the western side of the summit where it either collects in small bedrock depressions or behind overhangs. The sediment is then susceptible to sheetwash during rain events which would be transported down the western slopes of Round Island. Field observations indicate that the north-western section of the quadrant has a distinctly higher vegetation cover in terms of grasses in comparison to the southern area. Soil depth was also noted to be higher in this region, for example, the maximum soil depth recorded at the summit was 22cm in the north-west area. In addition, soil deposits appeared to have a more sandy texture giving rise to an MSC of W2/3 (Figure 4.3).

Tortoises naturally populate the Summit habitat (Figure 4.6.a) in particular at the north-western region possibly because of the higher vegetation cover and soil depth. The tortoises form wallows for resting and by doing this remove vegetation, exposing the underlying soil. Wallows are shallow (Figure 4.6.b) and relatively small. No linear erosion features are created as a result of the wallows although sheetwash may occur on exposed soils during rainfall. Furthermore, there is an exclusion plot near the study site, placed by MWF personnel to monitor the effects of tortoise on vegetation consumption. Vegetation cover is higher inside the exclusion plot (Figure 4.6.c) indicating that tortoises do have an effect on vegetation biomass although there appears to be no negative impact in the form of soil loss (Figure 4.6.d).

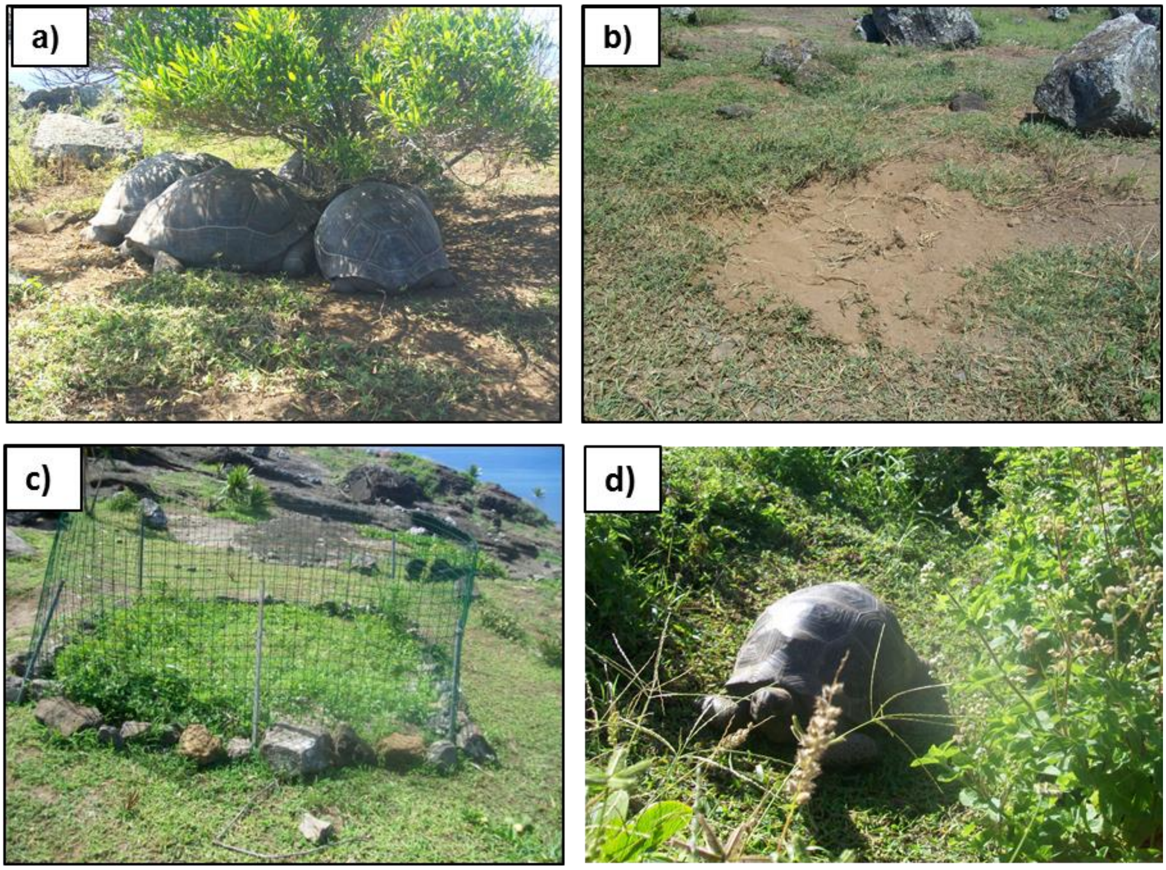


Figure 4.6: a) Tortoises grouped together under shade at the north-western region of the Summit study site; b) soil exposure from wallow formed by tortoises; c) tortoise exclusion plot showing higher vegetation as a result of no grazing, in comparison to d) where tortoises do eat vegetation although with no significant soil loss.

4.2.2. Rock Slab

The Rock Slab habitat is located on the steep (21 to 23°) convex west-facing slopes of Round Island and is situated below the Summit Habitat and between two (upper and lower) Palm Savannah habitat regions. The Rock Slab has a mainly bare rock surface with sparse vegetation confined mainly to depressions within rock surface and rills where sediment has accumulated. Soil cover is sparse but reaches an average depth of 11.3cm ± 10.0 where it occurs. Due to the steep nature of the slopes and low vegetation cover, sheetwash is an important erosion process occurring on the soils throughout the habitat region. Soil creep due to gravitational mass movement is also evident in the Rock Slab (Figure 4.7.a). Linear erosion features occur in the form of bedrock rills and gullies, with sheetwash occurring within and between the channels. These rills and gullies have distinctive headcut features (Figure 4.7.b) and run downslope into the lower Palm Savannah habitat. The headcuts appear to be actively retreating as a result of the stripping off of partial weathered bedrock by runoff. The heights of the headcuts vary, ranging from ± 10cm to ± 1m. Seven rills and two gullies were identified and mapped in the Rock Slab quadrant study site (Figure 4.8). Morphometric analyses were conducted on three of the rills and two gullies. Only these forms were assessed as to not cause any disturbance to bird nesting sites. Table 4.4 provides the morphometric parameters of the measured erosion features.

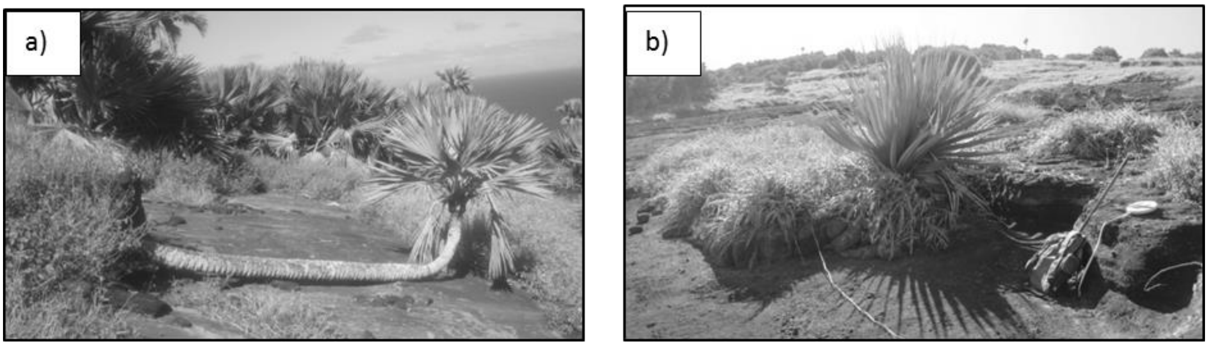


Figure 4.7: a) Fallen *Latania* palm species as a result of soil movement downslope; and b) headcut of Rill 1 in upslope area of Rock Slab study site.

Table 4.4: Rock Slab habitat quadrant erosion features morphometric parameters (see Figure 4.8 for locations).

Rill/ gully name	Slope (°)	Total length (m)	Mean max width (m)	Mean max depth (m)	Width: depth ratio	MSC
Rill 3	23	29	3.52	0.39	10.48	R_b3
Rill 4	23	26	6.09	0.34	17.93	R_b3
Rill 7	23	65	1.61	0.38	3.89	R_b2
Gully 1	23	58	8.64	0.82	10.95	G_b2
Gully 2	21	52	5.35	1.18	4.52	G_b2

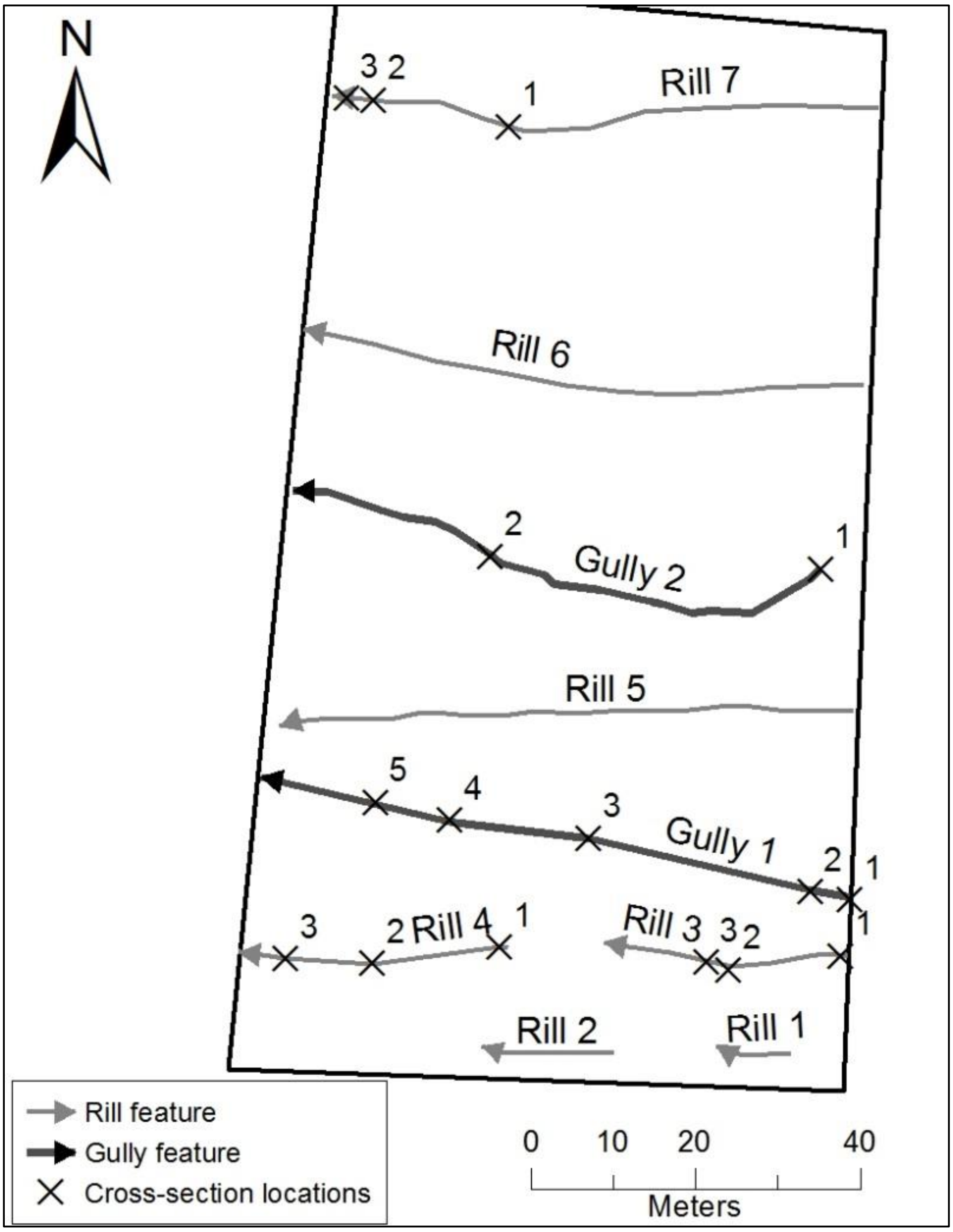


Figure 4.8: Location of rills and gullies classified and mapped (with superscript showing cross-section number) in the Rock Slab habitat quadrant study site.

In general, the rills are shallow with a mean depth ranging from 0.34 to 0.39m and do not show a pattern of increasing depth downslope. Average width of the measured rills is variable within the quadrant ranging from 1.61 to 8.64m. According to the MSC, the rills fall in the category of moderate bedrock rill erosion (R_b3) and moderate to severe sheet erosion (S3 to S4) on exposed bedrock and soils. Evidence is based on minimal vegetation cover, little to no sediment accumulation and steep slopes. Due to a lack of vegetation there is an inability to retain soil so that during rainfall sediment is washed downslope. Within the rills, shallow depressions (Figure 4.9.a) occur which allow for the accumulation of sediment and vegetation.

Rill 3 (Figure 4.10) and Rill 4 are relatively similar in terms of morphology in that both are wide and shallow and thus have large width-depth ratio values (10.48 and 17.93 respectively). Both rills are wide at their starting points and become narrower downslope. It was sometimes difficult to distinguish if Rill 4 was one or possibly two rills with a vague sidewall or partition. Rill 7 has a lower mean maximum width (1.61m) in comparison to Rill 3 and Rill 4 (3.52m and 6.09m respectively) and thus has the lowest width-depth ratio (3.89) of the measured rills within the study site. In addition, Rill 7 has a more conspicuous V-shaped morphology downslope in comparison to the other rills, as the channel is well defined (Figure 4.10) indicative of active downcutting.

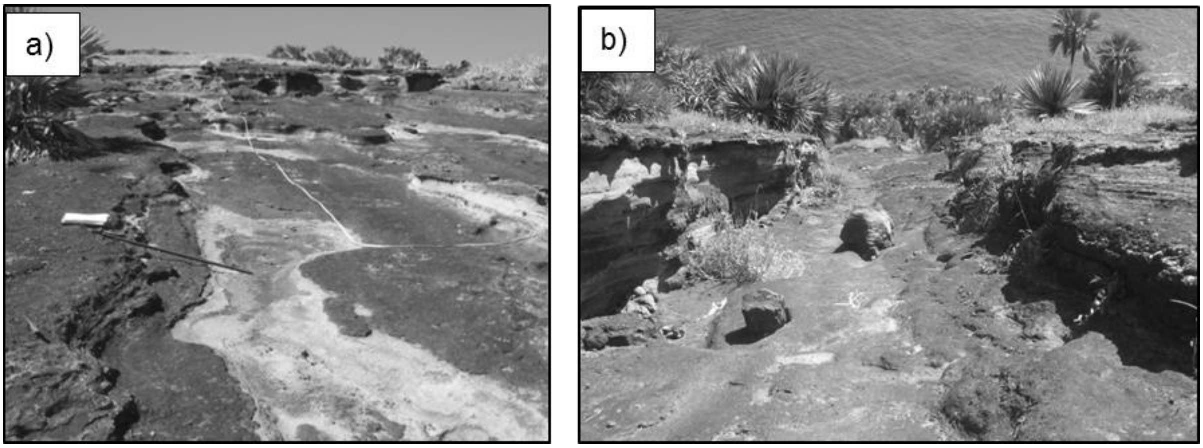


Figure 4.9: a) View upslope of Rill 3, note wide and shallow morphology and depressions with sediment accumulations; and b) view downslope of Gully 2.

Mean Schmidt Hammer R-values for Rill 3 and Rill 4 are relatively similar and in the range of 30.0 to 46.5, with the exception of the reading at cross-section 2 of Rill 3 (18.5, Figure 4.10). The Schmidt Hammer values for Rill 7 are on average higher than the other two rills (ranging 38.5 to 49.0), indicating resistance of the rill sidewall to bedrock rill erosion preventing widening.

Similarly to the rills in the study site, the gullies are shallow and wide. Gully 1 is particularly wide (8.64m) and shallow (0.82m) and thus has a high width: depth ratio (10.95). Sheetwash is evident throughout the gully, especially in its upper reaches as evident by a lack of vegetation cover and sediment deposits in bedrock depressions. At the second cross-section of Gully 1 an overhang on the right wall occurs as wash concentrates and undercuts the right hand side as the gully takes a slight turn (Figure 4.11). Mean Schmidt hammer values are lower at this point (35.5) in comparison to the other mean values of cross-section 2. Despite the average gully depths being below the requirement of the MSC (in particular for Gully 1), these forms are classified as slight bedrock gully erosion (G_b2), as portions of the upper region are below 1m in depth. At cross-section 2 the maximum depth is greater than 1m and exhibits a distinctively more V-shaped morphology at cross-section 3 which was conspicuous in contrast to the rills of the study site. Gully 1 mean Schmidt Hammer values are lower downslope in comparison to its upslope cross-sections (in particular cross-sections 2 and 3, Figure 4.11).

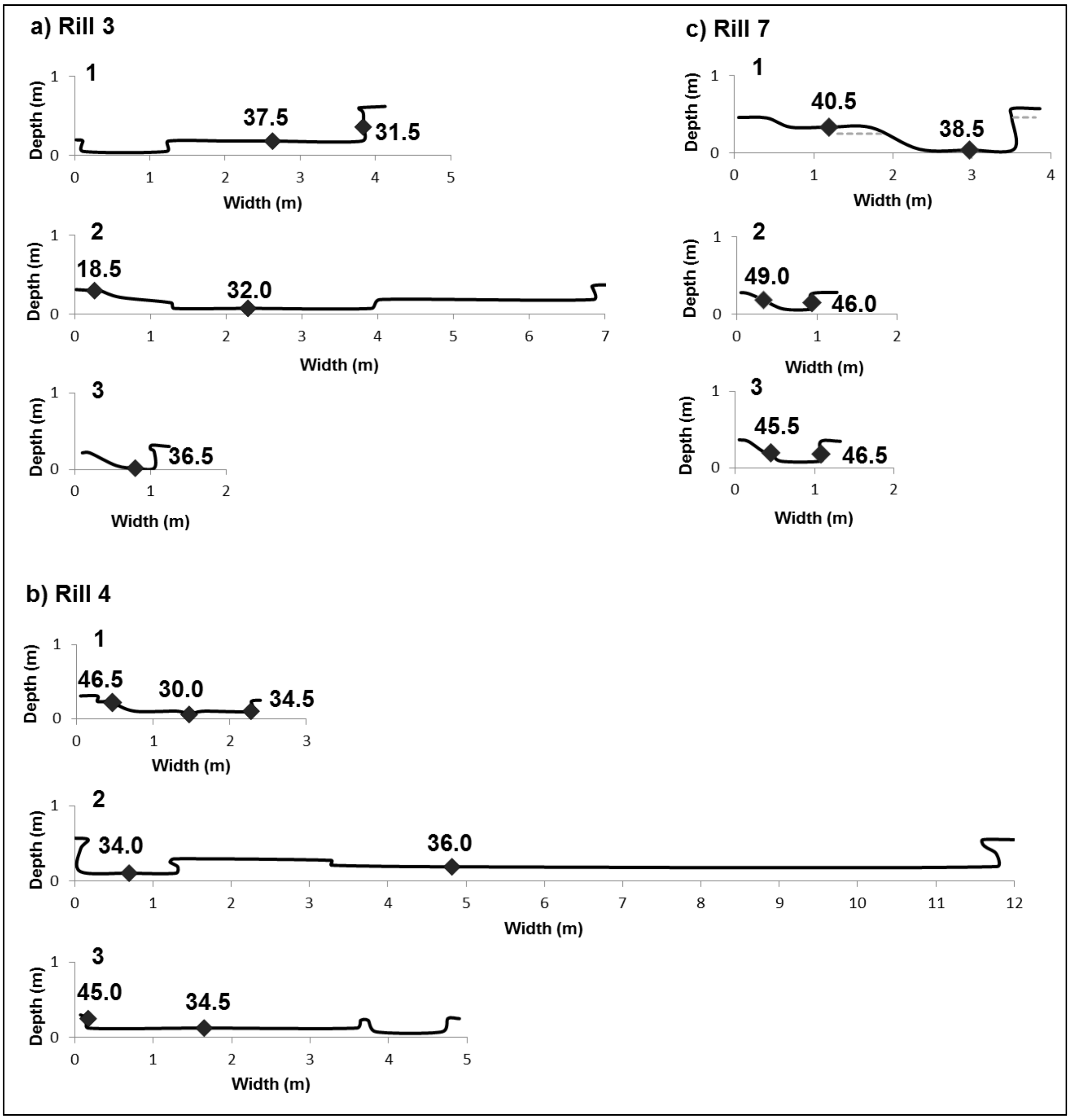


Figure 4.10: Cross-sections of a) Rill 3 (see also Figure 4.9), b) Rill 4; and c) Rill 7 of the Rock Slab habitat quadrant, including mean Schmidt Hammer R- values (see Figure 4.8 for locations).

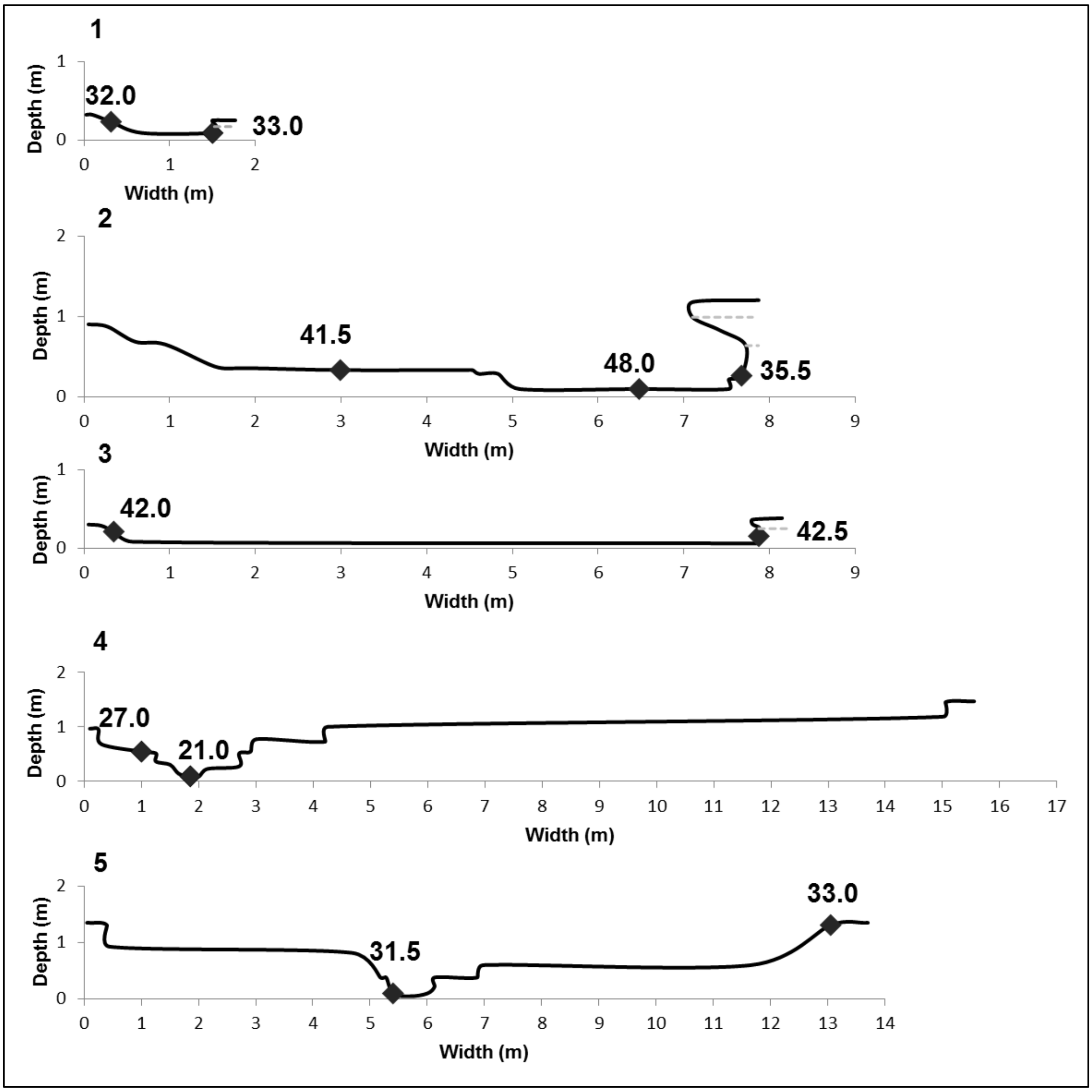


Figure 4.11: Cross-sections of Gully 1 of the Rock Slab Habitat quadrant study site, including mean Schmidt Hammer R-values (see Figure 4.8. for locations).

Gully 2 is wider and deeper than Gully 1 and thus has a lower mean width: depth ratio of 4.52 as shown by its more U-shaped morphology (Figure 4.10.b). Vertical incision is again evident in the channel. Sidewall overhangs showed evidence of undercutting, highlighting the nature of the tuff with layers of varying resistance to erosion. Mean Schmidt Hammer values for Gully 2 appear to be lower in general than Gully 1 and the rills of the Rock Slab, ranging from 23.5 to 37.0 (Figure 4.12).

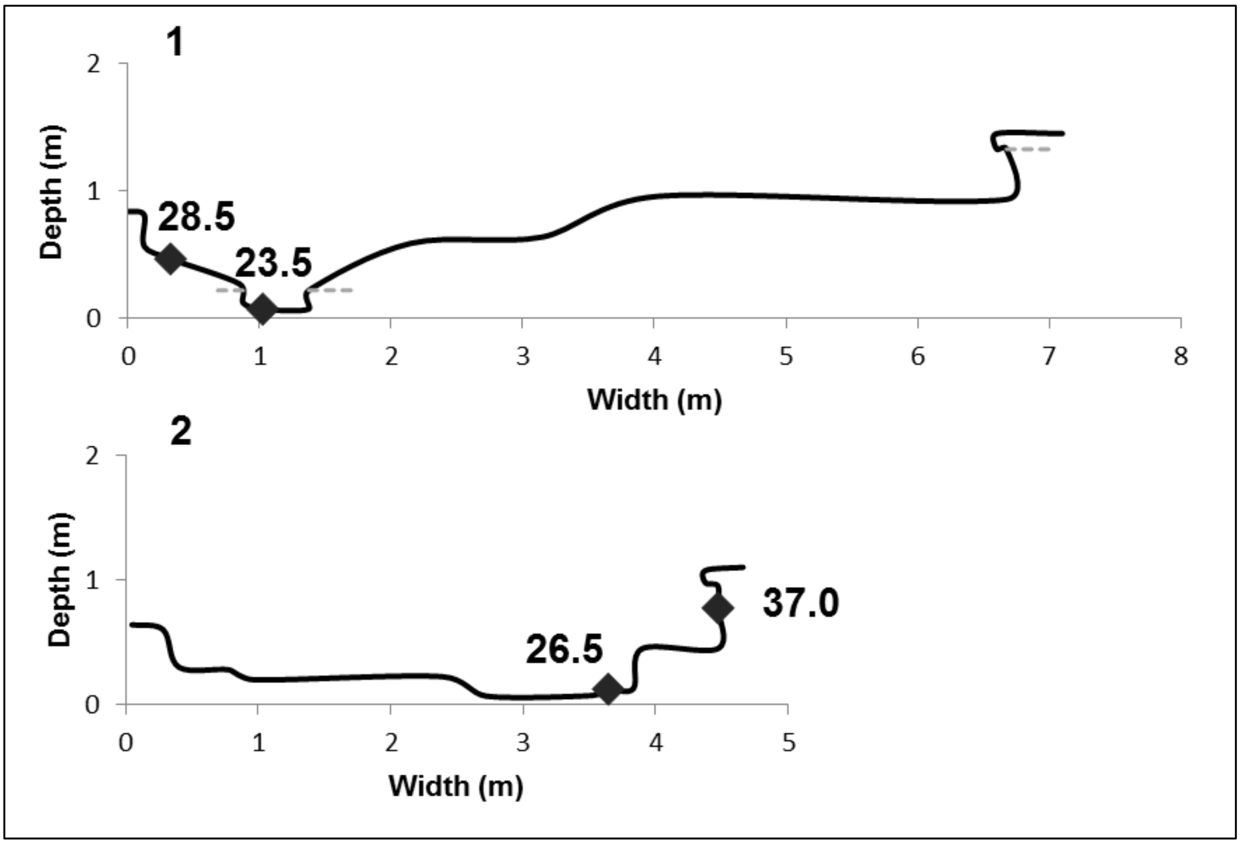


Figure 4.12: Cross-sections of Gully 2 of the Rock Slab Habitat quadrant study site, including mean Schmidt Hammer R-values (see Figure 4.8. for locations).

4.2.3. Palm Savannah

The Palm Savannah quadrant is located on the steep (19-23˚) western-facing slopes of Round Island. The habitat is well vegetated with grasses and palm species, but unvegetated bare rock areas are exposed. On a visual basis, soil cover was greater and deeper in certain areas, than in the upper Rock Slab study site. Recorded soil depth for the Palm Savannah (11.1cm ± 6.5) is, however, not greater than the Rock Slab (11.3cm ± 10.0). The dominant erosion processes on the soils and bedrock within the quadrant are sheetwash and bedrock gully erosion. Sheetwash occurs on exposed bedrock areas and within the gully formations. The gullies run downslope toward the sharp coastline where sediment is transported out to sea. In the quadrant study site, four gullies and one rill were identified and mapped running partly parallel downslope with cross-sectional analyses being carried out on three gullies (Figure 4.13). Table 4.5 provides the parameters of the gullies measured.

Table 4.5: Palm Savannah habitat quadrant linear erosion features morphometric parameters (see Figure 4.13 for locations).

Gully name	Slope (˚)	Total length (m)	Mean max width (m)	Mean max depth (m)	Width: depth ratio	MSC
Gully 2	21	80	7.63	1.67	4.74	G_b3
Gully 3	19	103	9.10	2.33	4.38	G_b3
Gully 4	20	80	7.40	1.87	3.96	G_b3

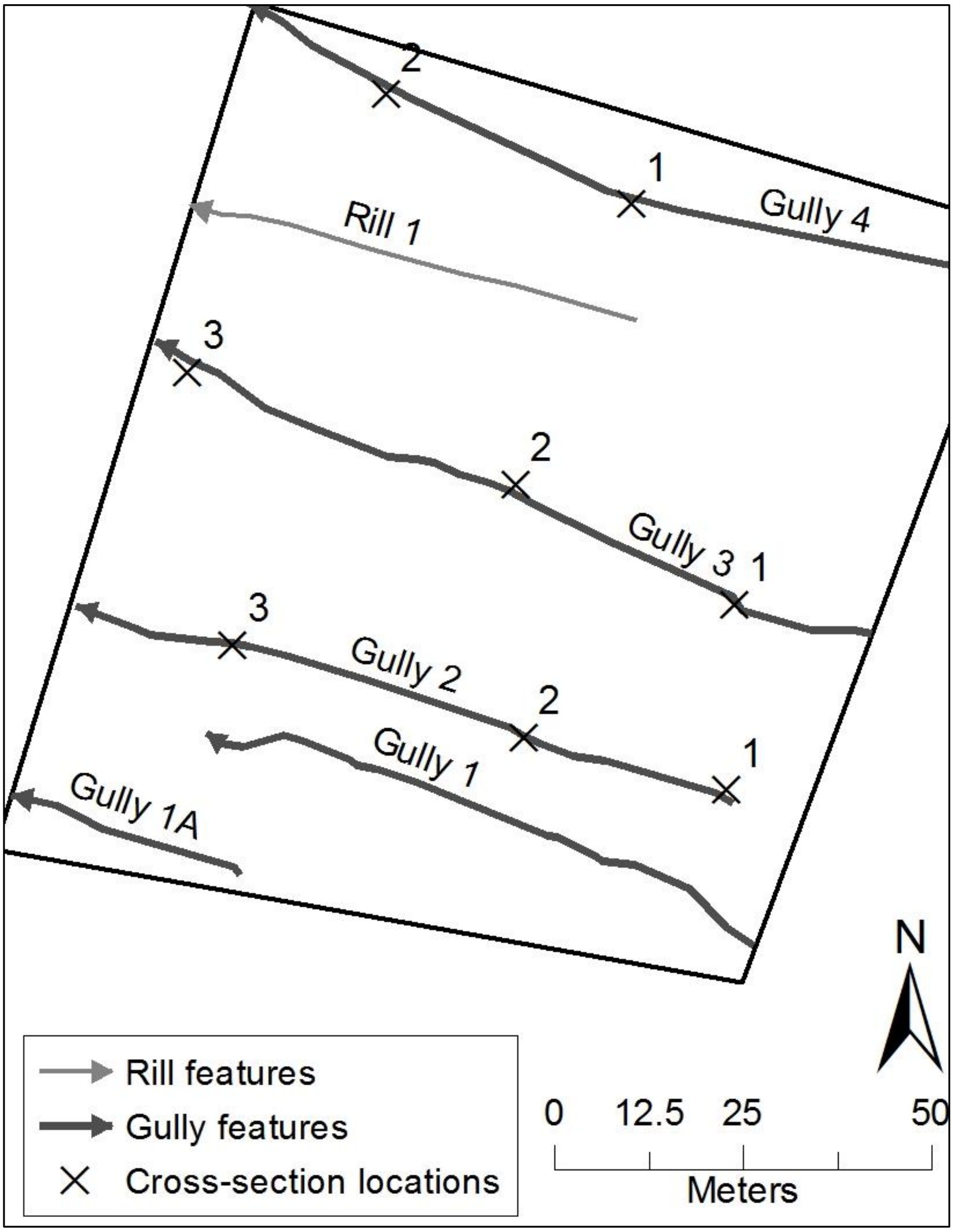


Figure 4.13: Location of rills and gullies classified and mapped in the Palm Savannah habitat study site (where the superscript denotes cross-section number).

Some of the gullies are linked to the gullies from the upper Rock Slab region (e.g. Gully 3 and Gully 4), although some distinctly have headcuts within the quadrant (e.g. Gully 1 and Gully 2). The headcut at Gully 2 is greater than 1m in depth. All gullies appear to have similar morphometric parameters with little variation in mean width and depth between gullies, resulting in similar width-depth ratios (3.96 to 4.74; Table 4.5). The gullies also show a similar pattern in terms of possessing a small width at base in relation to lip width. Morphology within each gully channel, however, is irregular throughout their course, indicating localised areas of erosion. Gully sidewalls appear to be surrounded by ash flows which increased depth. This was observed in, for example, Gully 2 and Gully 4 where the left side wall is higher than the right side wall (Figure 4.14 and Figure 4.15). The sidewalls have a blocky nature due to tension cracks. Subsequent sidewall collapse is evident throughout the study site. Mean Schmidt Hammer R- values are lowest on these upper left walls of the channel cross-sections (Figure 4.15).

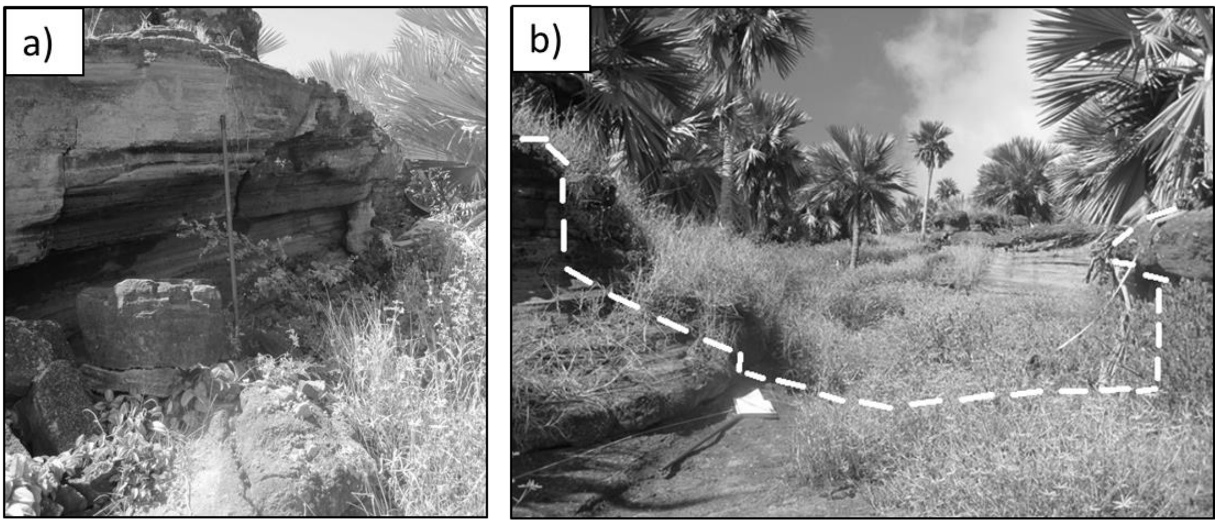


Figure 4.14: a) Left hand sidewall at cross-section 3 of Gully 1 and b) view upslope of morphology of cross-section 3 of Gully 2.

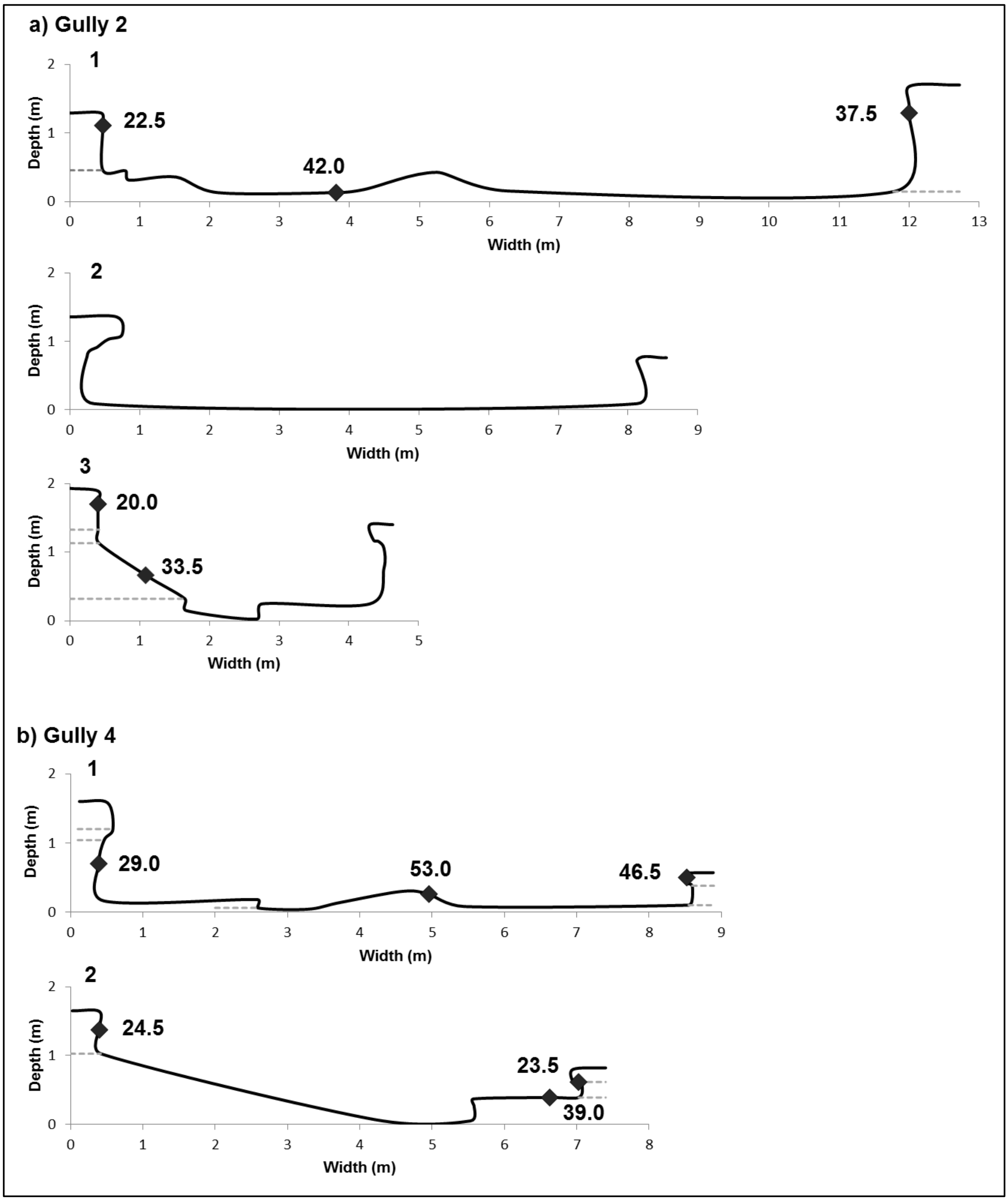


Figure 4.15: Cross-sectional profiles of a) Gully 2 and b) Gully 4 of the Palm Savannah habitat quadrant study site, including mean Schmidt Hammer R-values (see Figure 4.13. for locations).

The cross-sections of Gully 3 have a distinctive V-shaped morphology indicating gully deepening downslope (Figure 4.16). Numerous joints were observed on the channel floor in a downslope direction creating opportunity for increased incision, which can be seen by the higher mean maximum depth of 2.33m for Gully 3 (Figure 4.16, Table 4.5). In addition, mean Schmidt Hammer values are lower where jointing is near; for example, at cross-section 2 of Gully 3, Schmidt Hammer R-values are 25.0 at its base.

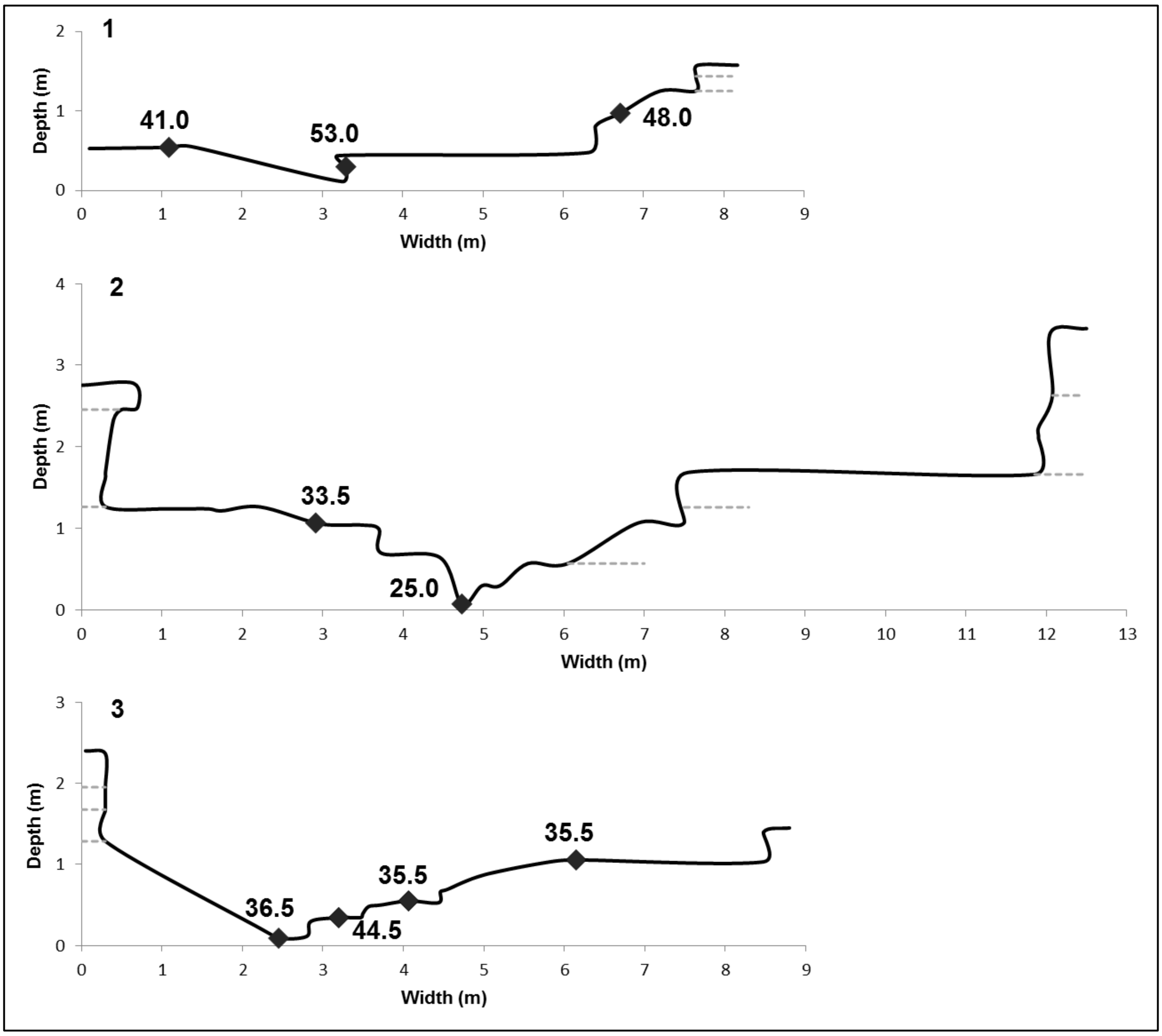


Figure 4.16: Cross-sections 1 to 3 of Gully 3 of the Palm Savannah habitat quadrant study site, including mean Schmidt Hammer R-values (see Figure 4.13. for locations).

The main erosive processes are bedrock gully erosion by vertical incision on channel floors and gully widening on sidewalls. Moderate sheetwash occurs through the deposition of sediment, especially on bare rock surfaces. The Palm Savannah study site gullies thus have a MSC erosion severity as moderate bedrock gullies (G_b3) with associated sheetwash within channels. Between gullies, the soils and bedrock are exposed to moderate sheetwash where vegetation is sparse. Overall, Schmidt Hammer values are relatively high at the Palm Savannah study site, with the exception of sample points where the rock surface has joints in the immediate vicinity.

4.3. Southern slope assessment of erosion phenomena

4.3.1. Helipad

The Helipad quadrant is on the relatively flat land surface of Round Island (Figure 4.17.a). The 'big' gully system lies to the east of the quadrant and the 'new-camp' gully to the west. Vegetation cover within the Helipad area is scarce, which may also be associated with a thin and sparse soil cover (6.1cm ± 2.8). The site is directly exposed to the prevailing South East Trade Winds and thus wind is the dominant eroding and transporting mechanism. Fine sediment is picked up by winds and transported toward the 'new-camp' gully and Mixed Weed habitat. Therefore, wind may be an important sediment source for these areas. Left behind are coarse gravel lags which are too heavy to be transported by wind. According to the MSC system, erosion present at the site may be categorised as widespread moderate wind erosion (W3, not represented). Evidence is based on observations of sparse vegetation cover (only wind and salt tolerant plant species present) and sediment deposited behind obstructions (e.g. behind rocks and vegetation). In addition, the Helipad has a very gravel-like ground cover and sandy soils (as supported by the results of the particle size distribution). In the Helipad region, just beyond the quadrant borders behind a rock overhang, fine sediment deposits accumulate as a result of protection from the prevailing South East Trade Winds (Figure 4.17.b). As mentioned above, the 'new-camp' gully lies west of the Helipad region and fine sediments from the Helipad are deposited on the gully channel floor of the 'new-camp' gully at cross-sections.

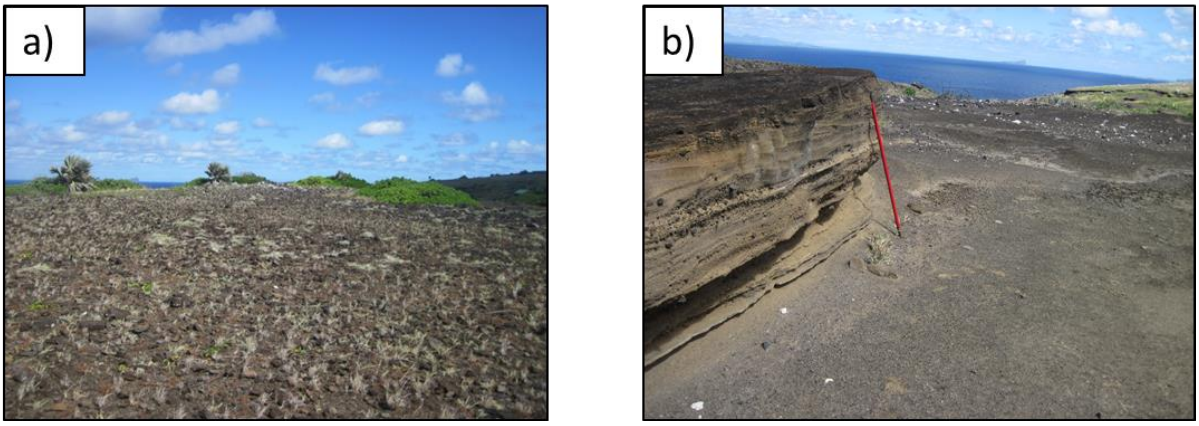


Figure 4.17: a) General view of the Helipad habitat study site showing bare vegetation cover; and b) fine sediment accumulation on leeward side of bedrock outcrop.

In terms of erosion by water, sheetwash is the dominant erosive process in the Helipad region, but with a low intensity due to the flat topography of the site. This results in no linear erosion forms occurring at the study site as water is unable to be concentrated to cause incision. Sheetwash erosion at the Helipad quadrant was categorised as slight to moderate (S2 to S3) and is a result of poor vegetation cover, sediment deposits and pedestals. No Schmidt Hammer measurements were taken at the Helipad quadrant study site since there was no surface bedrock exposure.

4.3.2. Mixed Weed habitat

The Mixed Weed habitat is located on the mid to lower southern slopes of Round Island. Soil depth is 10.3cm ± 4.3 and continuous throughout the majority of the site. In addition, the study site has a thick vegetation cover, especially grasses, hardwood species and other herbaceous species. The main erosion process in the area is sheetwash on exposed soils and bedrock, especially in the upper reaches of the study site. Footpath erosion occurs on tracks from animal (tortoise) and human traffic. Furthermore, no classified linear bedrock or soil erosion features were identified and thus mapped. The habitat has a high density of tortoises and numerous unoccupied wedgetailed shearwater (*Puffinuc pacificus*) burrows. The impact of tortoises is evident at a water provision point in the study site where the grass layer is clearly reduced, but with no significant soil loss (Figure 4.18). Due to the timing of field work in late summer (wet season), vegetation growth is prominent. Declines in vegetation during the drier winter season may leave the soils bare and thus susceptible to erosion. In addition, no impacts of shearwaters were observed in the field, since at the time of field work, the shearwaters had migrated for the winter season. Shearwaters do appear to have an impact on the structure of soils at the study site, particularly at the areas of deeper soils.

Figure 4.18: Water provision point for tortoises at the Mixed Weed habitat where grazing and movement have resulted in a localised decrease in grass cover and increase in soil exposure. Native plants (e.g. *Dodonea viscosa* and *Psiadia arguta*) have been reintroduced to Round Island as can be seen in the immediate background and regenerating *Latania loddigesii* in distance.

4.3.3. 'Camp' gully network

'Camp' gully is a third order gully located on the southern slopes of Round Island and is formed by the joining of two second order tributaries ('old-camp' and 'new-camp' gullies). The starting points of the gullies are at a concave break of slope from the steep upper slopes of Round Island where the more gentle slopes (10 to 13°) begin (Figure 4.19). Two main gully tributaries begin at a contributing 'drainage area' upslope described as bedrock dominated depressions and rills within the immediate upper reaches of the gully system (Figure 4.20). Active head walls exist which are void of vegetation cover. Sheetwash processes are observed by the presence of wash lines where water transports sediment into the gully areas. The concentration of flow from the depressions and rill-like forms lead into the main gully system which increases in size to form landscape dissecting gullies. 'Old-' and 'new- camp' gully join downslope at an elevation of approximately 30m above sea level and 100m from their end point at sea.

Figure 4.19: View of 'old-camp' gully where drainage downslope and concave change in slope marks the start of the gully system (MWF, 2008).

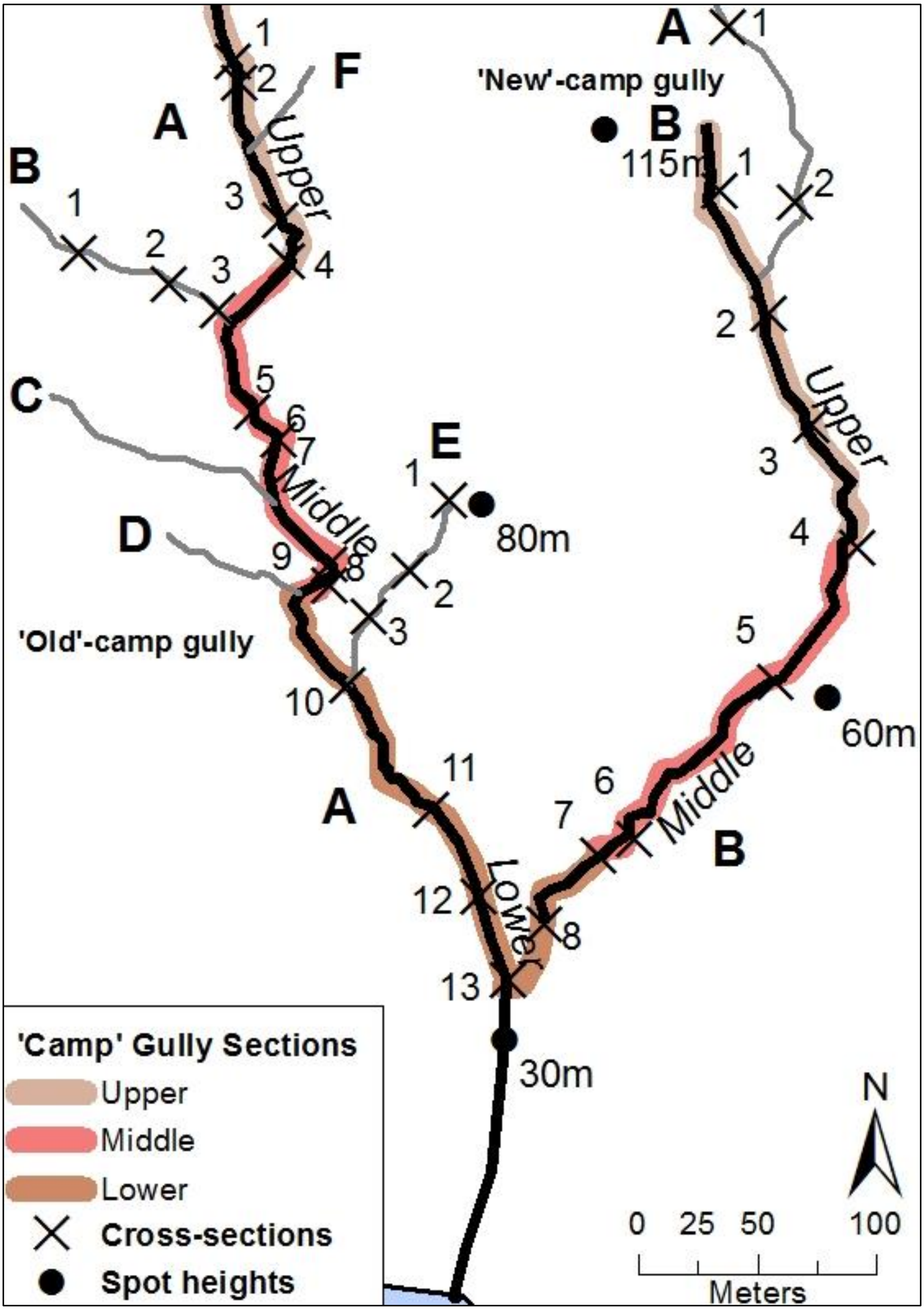


Figure 4.20: Location of cross-sections (in superscript) assessed for the 'camp' gully network with two main second order tributaries, the 'old-camp' and 'new-camp', labelled A and B respectively (see Figure 3.1, page 29 for reference).

Old-camp' gully

'Old-camp' gully has a length of approximately 550m from its starting point to end point at the sea (Figure 4.20). The starting point of 'old-camp' gully falls within the Helipad habitat (western side) and portions of the Mixed Weed habitat. The main drainage area of this gully is located on the south-west ridge within the Helipad habitat which is mainly void of vegetation and any substantial soil cover (Figure 4.19). At the base of bedrock hollows, soil traps have been built as an erosion control mechanism (Figure 4.21.a). Within the gully channels various grasses, *Ipomea pescapraea*, *Latania loddigesii* and *Pandanus vandermeeschii* are abundant. The *Latania* and *Pandanus* plants are efficient at trapping sediment within the gully channel and stimulate vegetation growth of other herbaceous and grass species. Vegetation cover and soil depth decreases as 'old-camp' gully proceeds downslope. Toward the lower region there is no soil or vegetation cover, with the exception of a few potholes in which fine sediment collects.

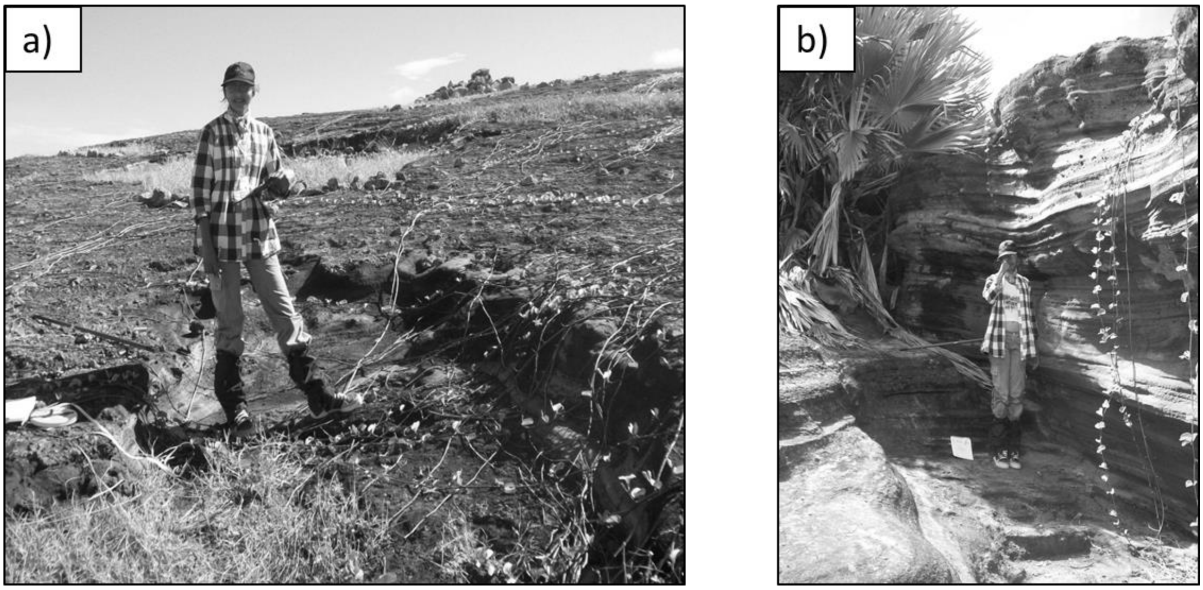


Figure 4.21: a) Upslope area of Tributary A with soil trap in background; and b) view upslope of cross-section 7 of Tributary A of 'old-camp' gully.

The second order 'old-camp' gully consists of five first order tributaries, which join into it at upslope locations of the main 'camp' gully. Cross-sectional gully morphology profiles were taken at 13 points along the second order 'old-camp' gully (labelled Tributary A). A tributary to the upper west (labelled Tributary B) and lower east (labelled Tributary E) were chosen and three profiles were taken to represent first order tributaries of the 'old-camp' gully (Figure 4.20). Due to inaccessibility, the last 100m of the gully was not included in the study. Table 4.6 provides the morphometric parameters of the tributary gullies measured. Tributary

A is divided into three sections (upper, mid and lower sections) based on similarities in gully form (Table 4.6).

Table 4.6: 'Old-camp' gully network morphometric parameters (see Figure 4.19 for locations).

Tributary	Slope (˚)	Total length (m)	Mean max width (m)	Mean max depth (m)	Width: depth ratio	MSC
A Upper	8	70	1.55	0.48	3.26	R_b4
A Middle	9	219	3.84	2.71	1.40	G_b3
A Lower	10	200	10.35	6.23	1.88	G_b4-G_b5
B	13	170	6.22	1.07	10.37	R_b3- G_b3
E	9	85	6.73	1.82	3.90	G_b3

In the upper reach of Tributary A, a series of shallow rill-like erosion features form by the collection of surface flow from depressions within the bare rock surface. The width: depth ratio for the upper region is 3.26, which is higher than the rest of the gully indicating a relatively wide and shallow channel (Table 4.6). Channel morphology is U-shaped with irregular stepped sidewalls. Within this upper region of Tributary A, erosion is classified as severe bedrock rill erosion (R_b4) with contributing moderate sheetwash (S3). As the channel precedes downslope the rill becomes wider and deeper. Mean Schmidt Hammer R- values for the upper region are low in general ranging from 13.0 to 24.5 (Figure 4.22).

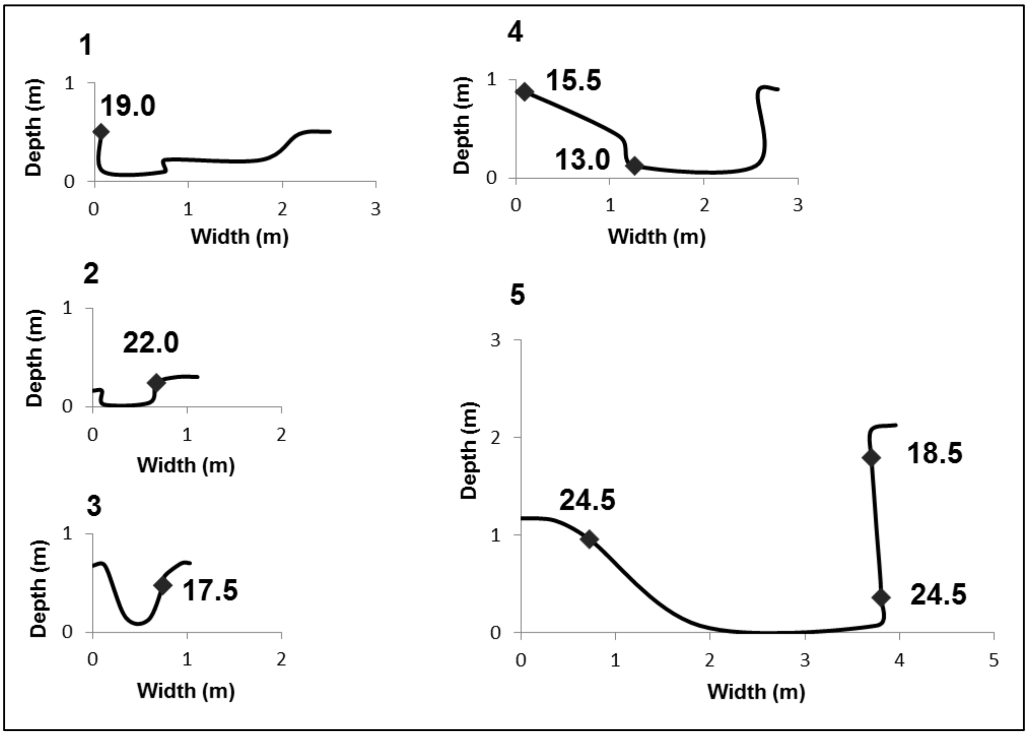


Figure 4.22: Cross-sections 1 to 5 of the upper region of Tributary A, 'old-camp' gully, including mean Schmidt Hammer R-values (see Figure 4.19. for locations).

Tributary A becomes a gully form at around 80m downslope with an increase in slope angle (mid-section of Tributary A). Incision is evident as mean channel depth becomes considerable (2.71m) and channel widening to a mean maximum of 3.84m occurs (Table 4.6). Channel form maintains the general U-shaped morphology, although there is a decrease in width: depth ratio to 1.40 for the mid-region. The channel floors for these cross-sections are flat. Sidewalls have an irregular morphology created by undercutting of more erodible tuff-layers within the geological profile of the gully (e.g. cross-section 7, Figure 4.21.b and Figure 4.23). Erosion at the mid-region of the main gully channel is classified as moderate bedrock dominated gully erosion (G_b3). Mean Schmidt Hammer values are slightly higher for the mid-region (ranging from 19.0 to 30.0) in comparison to the upper section of Tributary A.

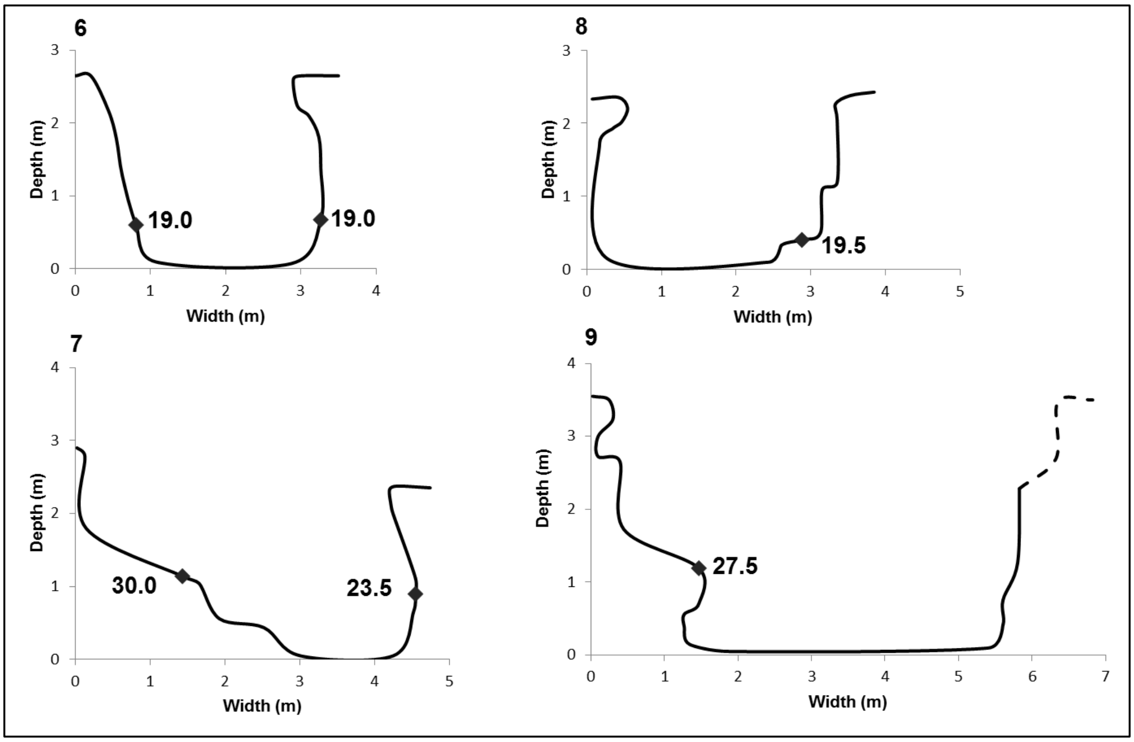


Figure 4.23: Cross-sections 6 to 9 of the mid-region of Tributary A, 'old-camp' gully, including mean Schmidt Hammer R-values and where dashed lines are extrapolations at inaccessible locations (see Figure 4.19 for locations).

A transition of gully severity occurs at around 300m downslope of Tributary A once all 'old-camp' gully tributaries join the main channel (Tributary A). The gully widens to a mean maximum width of 10.35m. In the lower section of Tributary A, the MSC erosion classification is severe to very severe bedrock gully erosion (G_b4 to G_b5) with a mean maximum channel depth of 9.20m at cross-section 13. The lower region maintains a mean low width: depth ratio of 1.88 with a U-shaped morphology (Figure 4.24.a, c) and Figure 4.25). Sheetwash along the bare rock gully channel floor is dominant due to an absence of vegetation and soil cover. Active vertical incision by concentrated flow occurs at cross-sections 12 and 13 (Figure 4.25), indicating channel deepening at certain areas of the channel floor. Schmidt Hammer readings in general increase for the lower section of Tributary A. This is highly variable within and between cross-sections, for example, cross-section 10 has mean Schmidt Hammer R-values ranging from 18.0 to 48.0 (Figure 4.25).

Along the longitudinal profile of the gully, vertical overfalls or knickpoints occur. The heights of these overfalls vary, although a few in the lower region of Tributary A are greater than 8m. At the base of the overfalls, potholes along the gully channel floor are present (Figure 4.24.b). Fine sediment accumulates in these potholes, although do not promote vegetation growth.

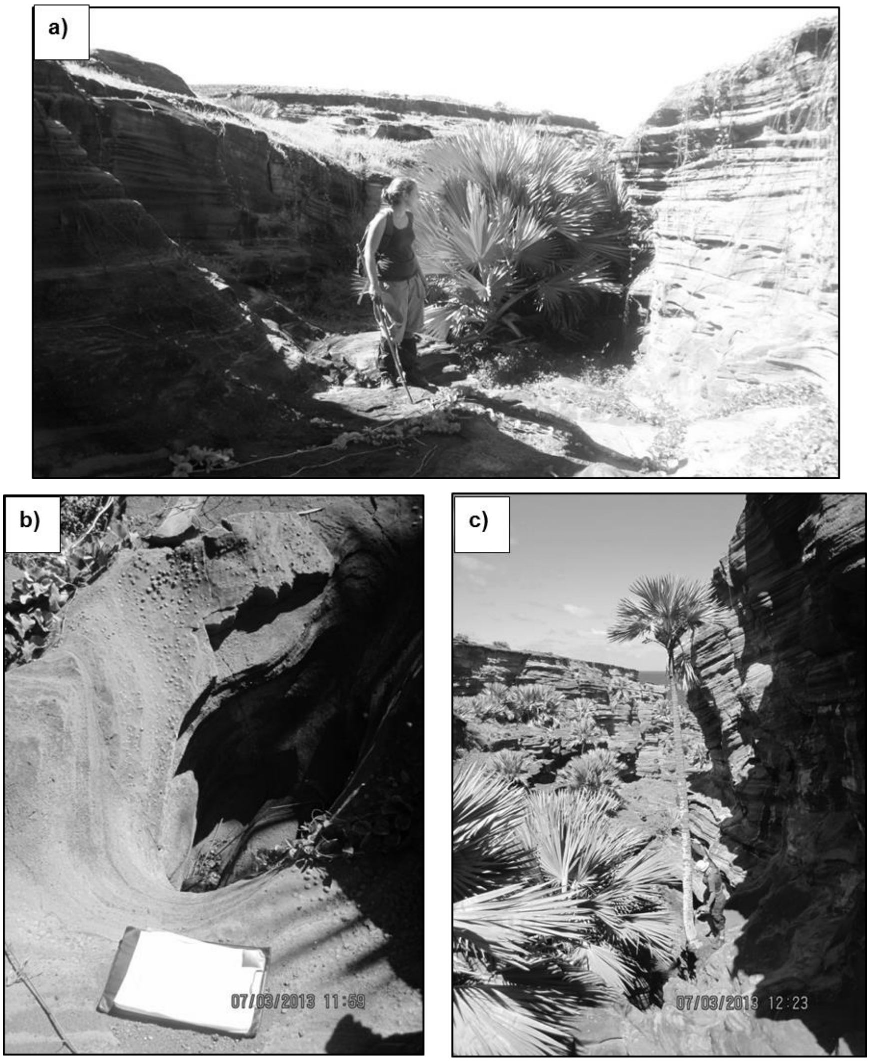


Figure 4.24: a) View downslope of cross-section 10 of Tributary A; b) pothole at base of vertical overfall; and c) view downslope out to sea of the lower section of Tributary B.

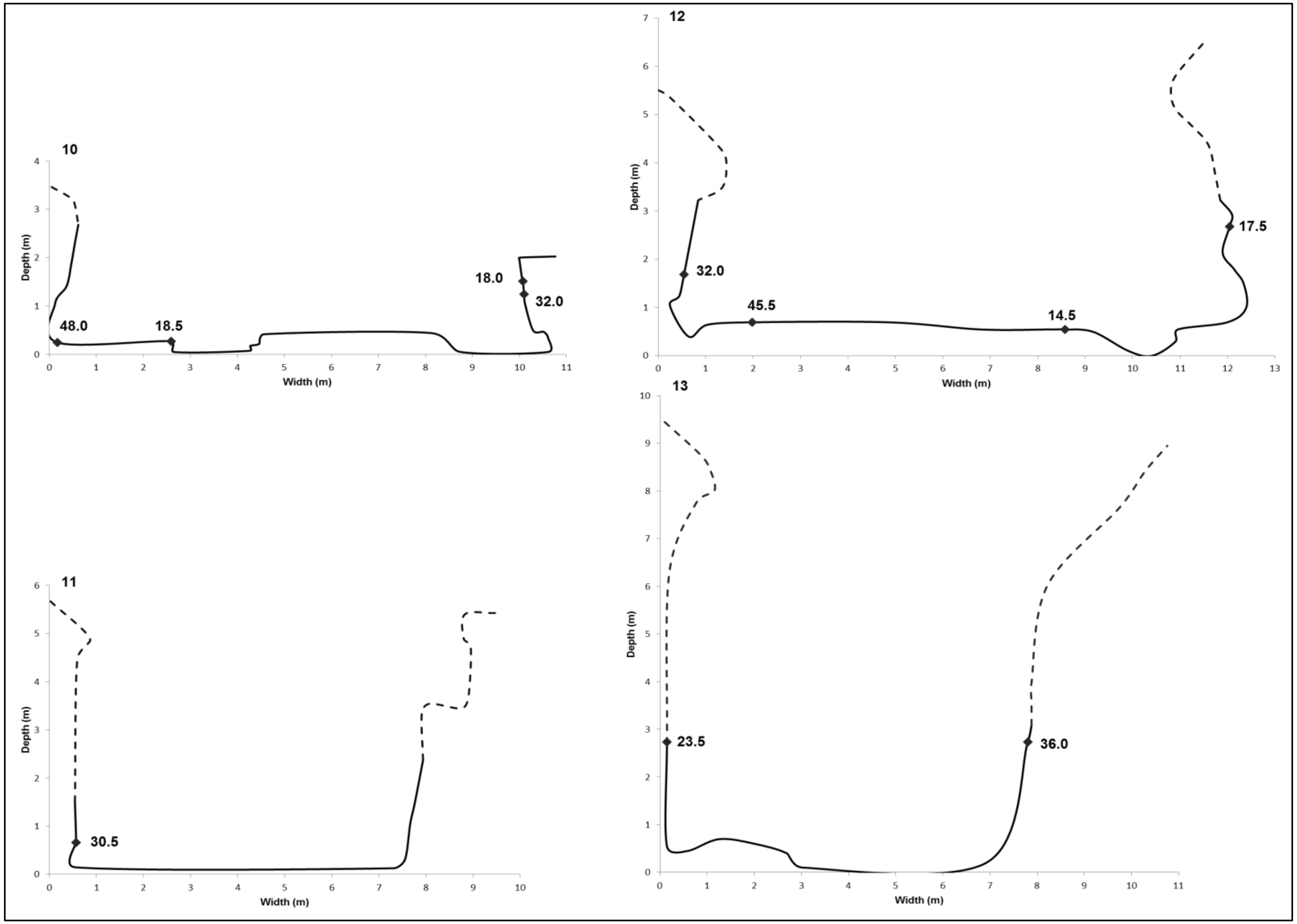


Figure 4.25: Cross-sections 10 to 13 of the lower region of Tributary A, ‘old-camp’ gully, including mean Schmidt Hammer R-values and where dashed lines are extrapolations at inaccessible locations (see Figure 4.19 for locations).

Tributary B of the ‘old-camp’ gully represents a first order tributary and forms from a drainage area from the south-west ridge region of Round Island and falls within the Helipad and Mixed Weed habitats. The channel begins at around 105m above sea level and spans a total length of 170m before joining the main gully channel (Tributary A) at approximately 60m above sea level. As with the other tributaries within the ‘old-camp’ gully system, Tributary B forms due to a contributing drainage area of bedrock depressions within the land surface. As water is channelled downslope a linear channel form is created.

The general morphology of Tributary B relates to a wide channel (mean maximum width of 10.35m) which is shallow in mean maximum depth (1.07m, Figure 4.26). This is the highest width: depth ratio for all tributaries of the ‘old-camp’ gully of 10.37 (Table 4.6). In its upper region the channel is well vegetated with grasses and planted hardwood species (Figure 4. 27.a). Tributary B starts very wide and shallow (cross-section 1, Figure 4.26). Along this portion of the channel erosion may be classified as moderate bedrock rill erosion (R_b3) with sheetwash (S3/4). As Tributary B progresses downslope, the channel increases in depth and decreases in width. Toward its end point channel morphology becomes more U-shaped with a flat bottom and steep sidewalls (cross-sections 2 and 3, Figure 4.26). Vegetation cover and soil cover also decreases within the channel. Erosion toward the end point is classified as slight bedrock dominated gully erosion (G_b2) since mean maximum depth only just exceeds one meter. Schmidt hammer readings were only taken at cross-section 3, where a bare rock surface was exposed. R- Values are relatively low with a mean of 16.0 on the upper right wall and a higher 26.0 on the lower right wall. These low mean Schmidt Hammer readings are similar to those of the upper region of Tributary A.

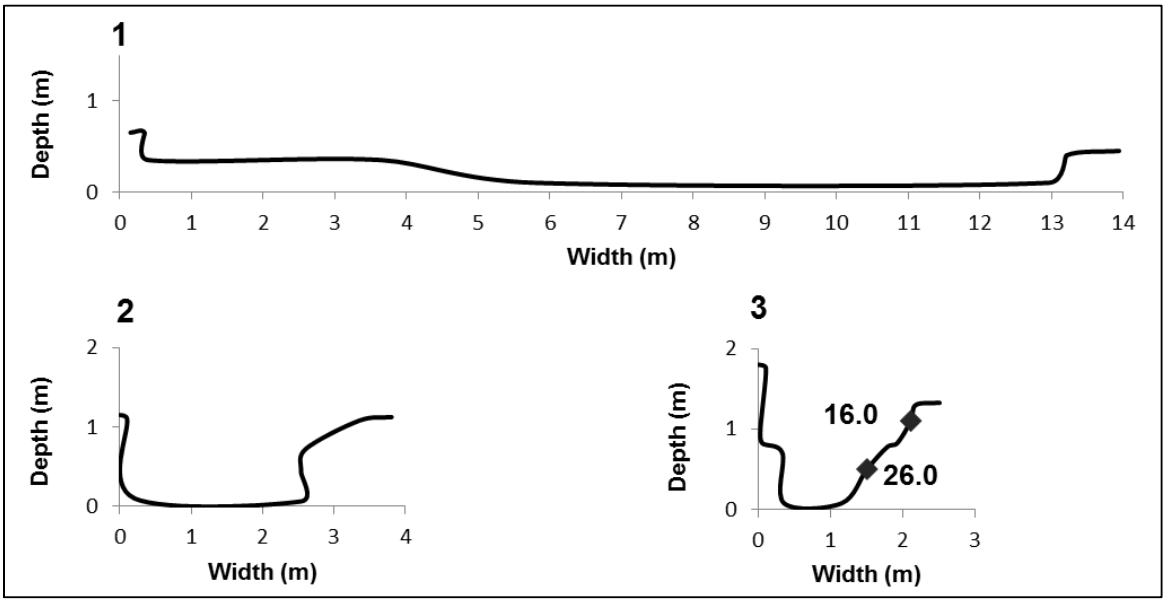


Figure 4.26: Cross-sections 1 to 3 of Tributary B, ‘old-camp’ gully, including mean Schmidt Hammer R-values (see Figure 4.19 for locations).

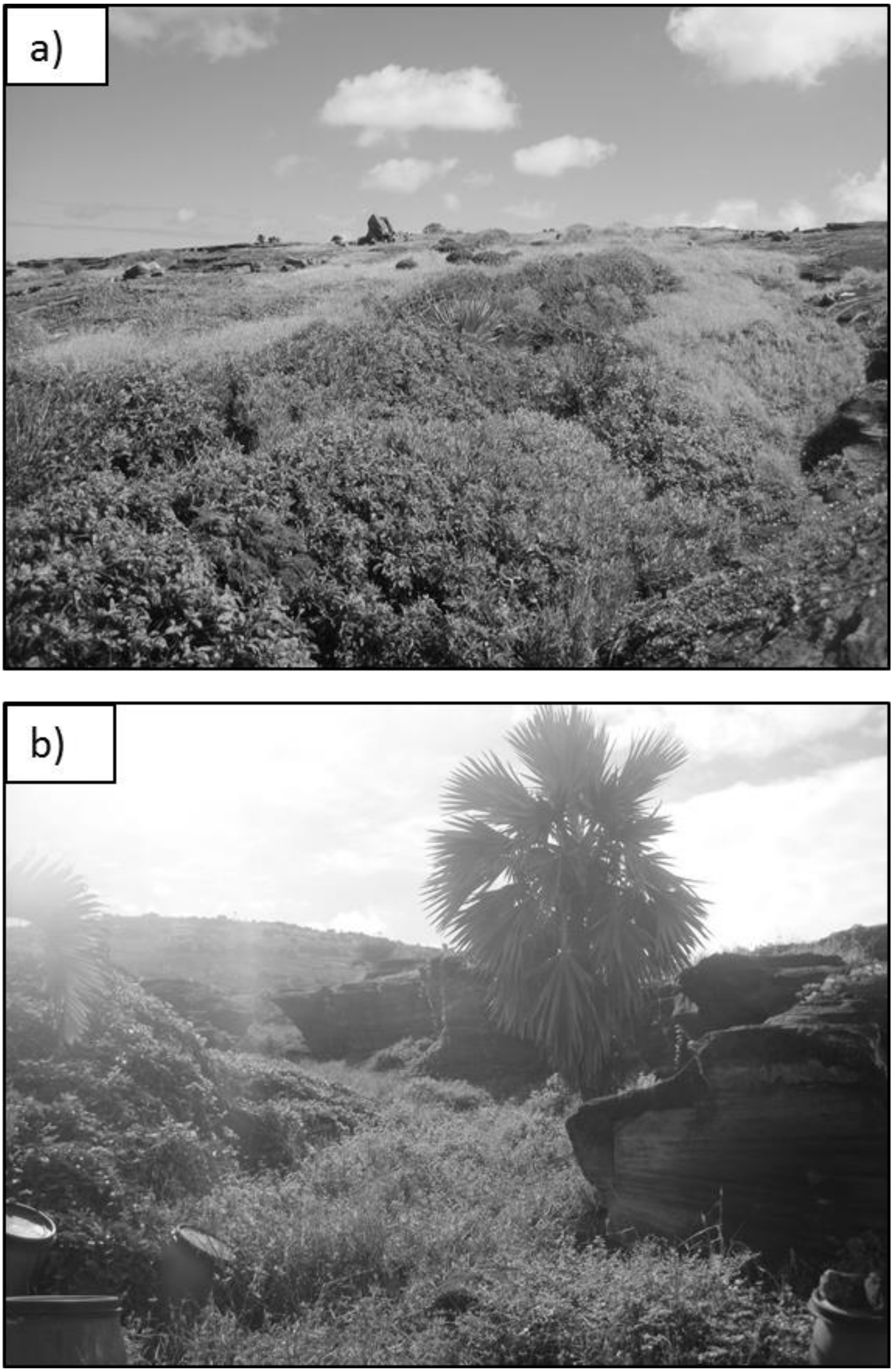


Figure 4.27: a) View upslope of Tributary B of ‘old-camp’ gully showing stabilisation from active planting within the gully channel; and b) view upslope of Tributary E of ‘old-camp’ gully also with dense vegetation cover, composed of *Ipomea pes-caprae* on right hand side slope and dense *Cenchrus echinatus* on the floor.

Tributary E, the final measured first order tributary of 'old-camp' gully, forms from a contributing drainage area of well vegetated depressions within the Mixed Weed habitat type, 55m above sea level. The gully runs a length of 85m before joining the main gully channel of 'old-camp' (Tributary A) at its middle section at 40m above sea level. Tributary E is well vegetated with grasses and other herbaceous vegetation types throughout its entirety (Figure 4.27.b). Soil cover is continuous and relatively deep (observations of 10cm soil depth at cross-section 1, with shearwater burrows occurring throughout. The width: depth ratio of 3.90 indicates a relatively wide channel (mean maximum width of 6.73m) with a moderate mean maximum depth of 1.82m (Table 4.6). Channel morphology tends toward U-shaped throughout its course with a relatively flat base and steep erosional terrace-like sidewalls (Figure 4.28). Erosion is classified as moderate bedrock gully erosion (G_b3) and appears to be confined to the tuff sidewalls through undercutting. Due to the extensive vegetation cover and higher soil depth, erosion appears to be stabilised as there is evidence of the soil remaining. Mean Schmidt Hammer R-values for Tributary E range between 20.5 and 34.0. These readings are higher in value to those taken at the mid-section of Tributary A.

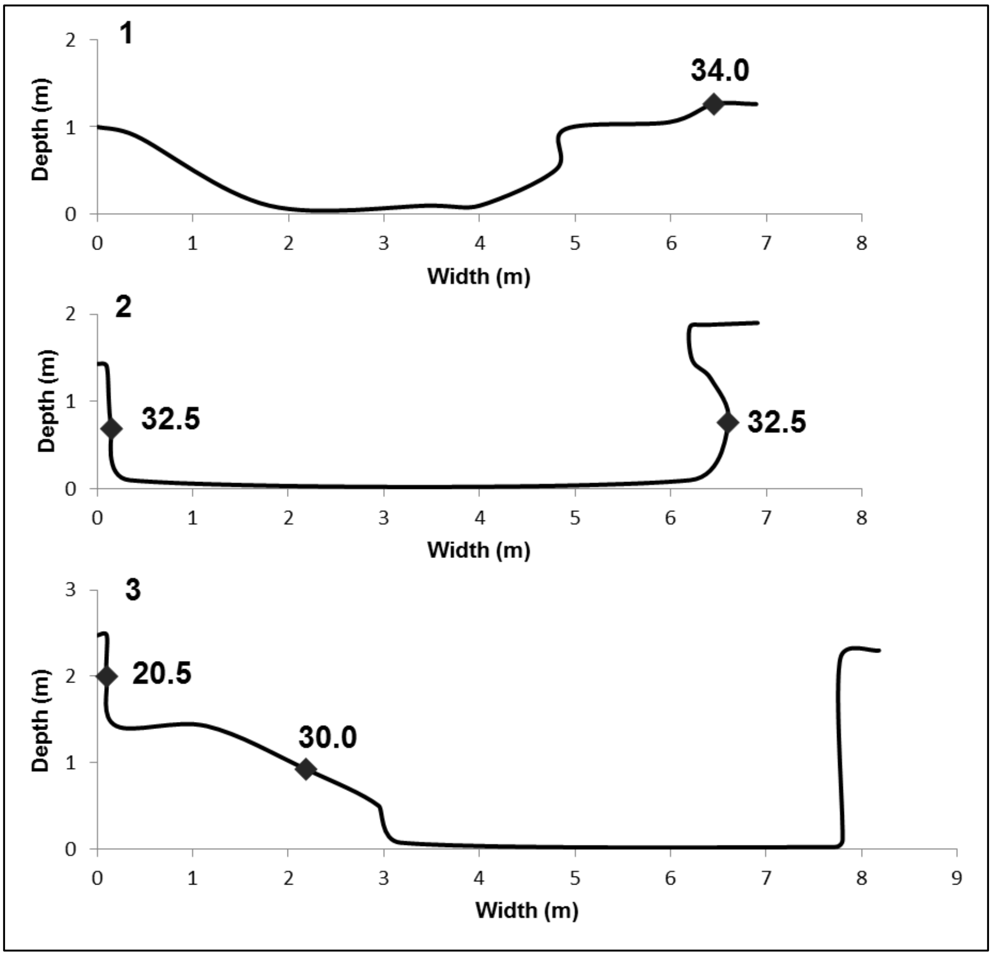


Figure 4.28: Cross-sections 1 to 3 of Tributary E, 'old-camp' gully, including mean Schmidt Hammer R-values (see Figure 4.19 for locations).

‘New-camp’ gully

‘New-camp’ gully located on the southern slopes of Round Island begins within the Mixed Weed habitat region approximately 130m above sea level and runs a length of approximately 450m to its joining point with ‘old-camp’ gully. The starting region of ‘new-camp’ gully forms a series of bedrock depressions creating rill-like features that become the main gully. The area is well vegetated with grass species and a few hard wood species which have been manually planted as part of the restoration programme. In comparison with the vegetation cover of the upper reaches of ‘old-camp’ gully; ‘new-camp’ gully has remarkably higher vegetation cover and deeper soils as it starts within the Mixed Weed habitat.

Two first order tributaries join in the upper region of ‘new-camp’ gully and become one main channel, ‘new-camp’ gully. Eight cross-sectional profiles were examined along the total length of the main, second order ‘new-camp’ channel (labelled Tributary B) to upslope of its joining point with ‘old-camp’ gully and two cross-sections along a shorter tributary (Tributary A, Figure 4.19). As previously mentioned, no cross-sections were taken after the joining point of the two gully systems. Table 4.7 provides the morphometric parameters of the tributary gullies measures. Tributary B is divided into three sections (upper, mid and lower sections) based on similarities in gully form between cross-sections (Table 4.7).

Table 4.7: ‘New-camp’ gully network morphometric parameters (see Figure 4.19 for locations).

Tributary	**Slope (˚)**	**Total length (m)**	**Mean max width (m)**	**Mean max depth (m)**	**Width: depth ratio**	**MSC**
A	10	155	8.53	1.35	7.15	G_b2
B Upper	14	212	13.85	2.97	5.49	G_b3
B Middle	10	190	6.93	4.67	1.59	G_b3
B Lower	12	64	21.50	13.50	1.59	G_b5

Tributary A begins at 135m above sea level and runs a length of 155m on the approximately 10˚ slope before joining the main gully channel of ‘new-camp’ gully at 104m above sea level. Tributary A is well vegetated throughout its entirety with a continuous but shallow soil cover. In general, the morphology is U-shaped with a flat bottom and steep stepped sidewalls (Figure 4.29). The gully has a high width: depth ratio (7.15) due to its large mean width (8.53m) compared to lower mean depth (1.35m; Table 4.7). Erosion processes occurring are slight bedrock gully erosion (G_b2), especially on the sidewalls, with sheetwash on the channel floor where vegetation cover is minimal or absent. Mean Schmidt Hammer R-values are, in general, relatively low ranging from 17.0 to 29.5 (Figure 4.29). There is no pattern of increase or decrease in Schmidt Hammer values between the two cross-sections. There is also no distinction in rock hardness within cross-sections, as neither the left nor the right hand side is higher in both cross-sections.

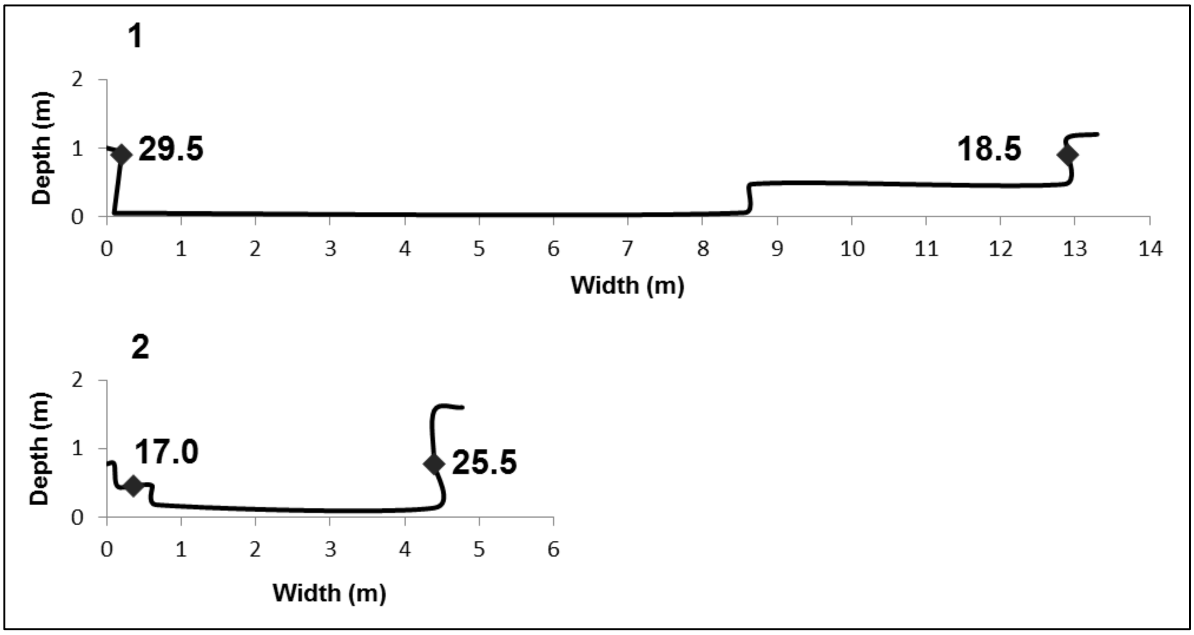


Figure 4.29: Cross-sections 1 to 2 of Tributary A, 'new-camp' gully, including mean Schmidt Hammer R-values (see Figure 4.19 for locations).

The second order main gully channel of 'new-camp' gully (Tributary B) starts at 117m above sea level and spans a total length of approximately 500m to its joining point with 'old-camp' gully. The upper section of Tributary B is well vegetated with grasses and hardwood species. The gully is wide and shallow, thus the upper section has a width: depth ratio of 5.49 (Table 4.7). Depth increases and width decreases as the gully progresses downslope. Sidewalls are steep and stepped (Figure 4.30). Erosion is classified as moderate bedrock gully erosion (G_b3). Mean Schmidt Hammer values are low for the upper section of Tributary B. Cross-sections 1 and 2 are particularly low, with mean R-units at three points being below 20.0 (Figure 4.30). However, mean R-values do appear to increase at cross-sections 3 and 4 ranging from 22.0 to 39.0.

The gully becomes deeper at its mid-section at around 200m downslope (Figure 4.31) as evident by a decrease in width: depth ratio (1.59, Table 4.7). Sheetwash and vertical incision increase in this region, associated with a decrease in vegetation and soil cover. Flow becomes concentrated along the channel floor leading to increased deepening (mean maximum depth of 4.67m). This can be seen in all the cross-sections for the middle section of Tributary B where there are localised flow paths (Figure 4.31 and Figure 4.32.a). Although not a true V-shaped morphology, the width at the base is narrower than the width at the gully wall lip. Sidewall undercutting with subsequent collapse are common within the mid-section. Erosion in the middle section of Tributary B is dominated by moderate bedrock gullying (G_b3), with sheetwash along the bare channel floor and lower sidewalls. Mean Schmidt Hammer R-values range from 30.0 to 39.5, which is on average higher in comparison to the upper and lower sections of Tributary B. In addition to erosion by water, the volcanic tuff of the upper region of 'new-camp' gully is directly exposed to the South East Trade Winds. Wind erosion is evident by mushroom rock formations in the immediate surrounding area of the 'new-camp' gully (Figure 4.32.b).

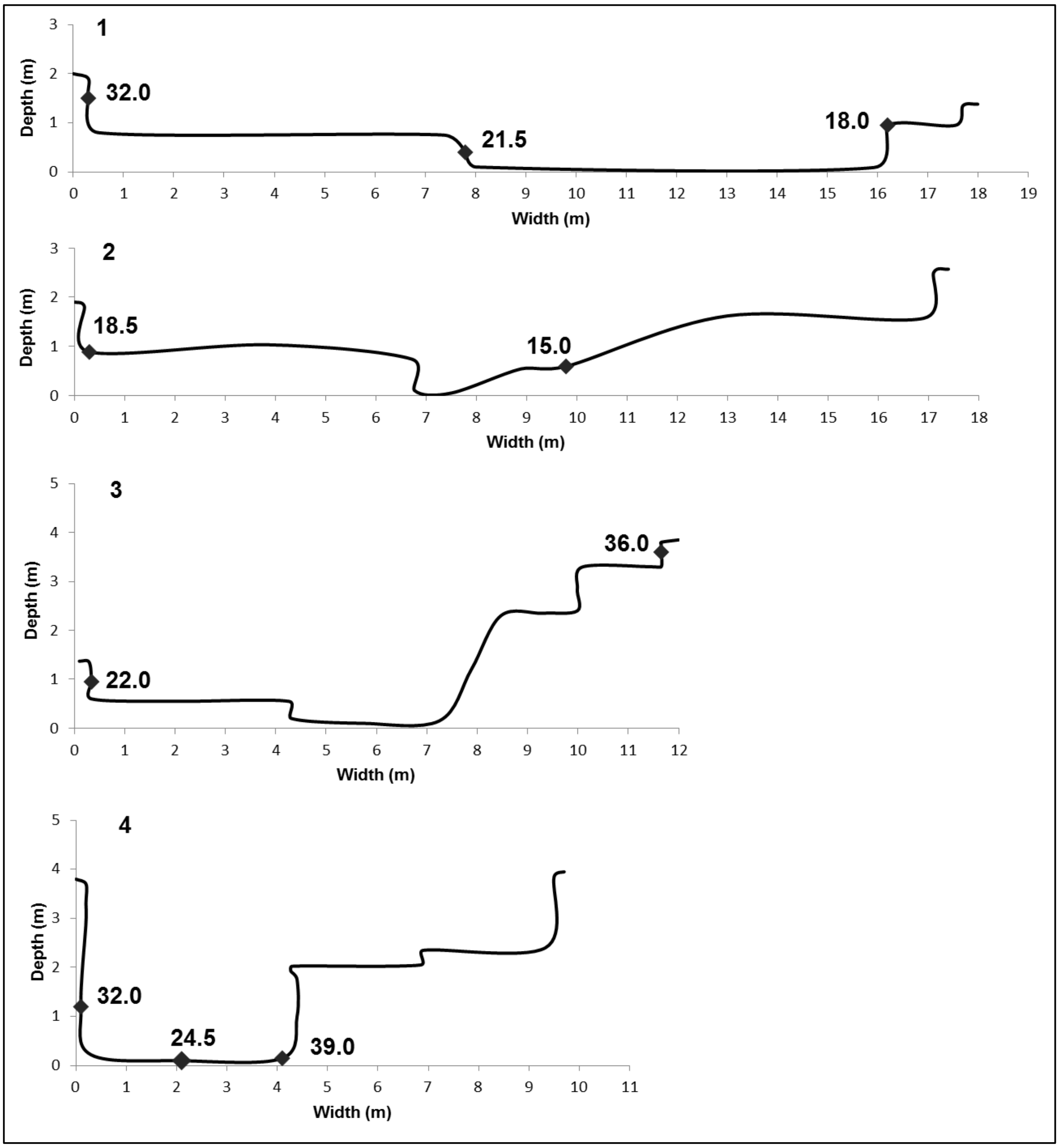


Figure 4.30: Cross-sections 1 to 4 of the upper region of Tributary B, 'new-camp' gully, including mean Schmidt Hammer R-values (see Figure 4.19 for locations).

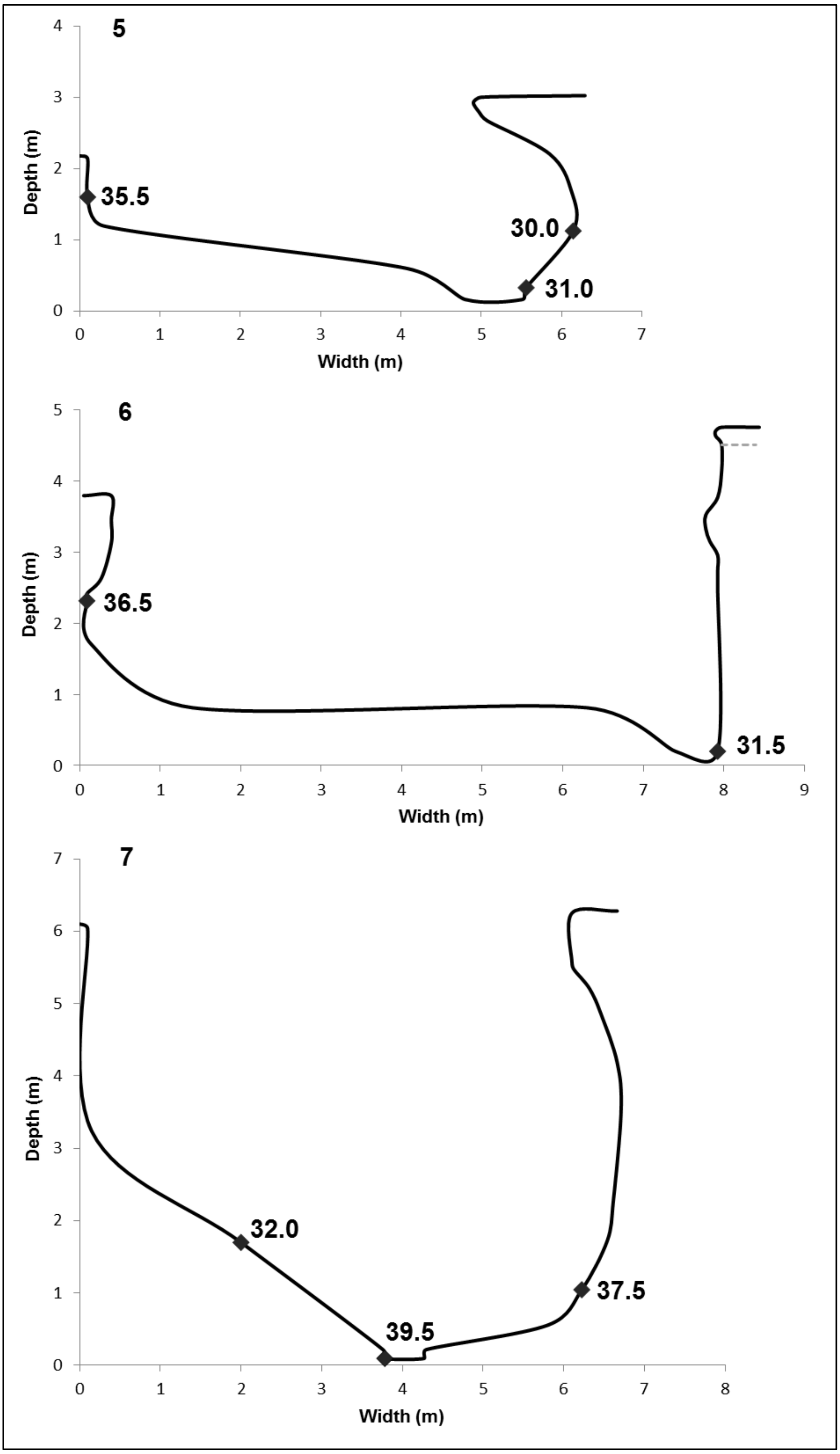


Figure 4.31: Cross-sections 5 to 7 of the mid- region of Tributary B, 'new-camp' gully, including mean Schmidt Hammer R-values (see Figure 4.19 for locations).

Figure 4.32: **a**) View upslope of cross-section 5 of Tributary B, 'new-camp' gully showing localised flow path at base of right hand sidewall; and b) mushroom rock formations as a result of wind erosion on exposed tuff.

A change in gully form occurs in the lower section, as the gully opens into a wide (greater than 20m) valley-like area (see cross-section 8, Figure 4.33 and Figure 4.34; Table 4.7). This area is well vegetated with deeper soils with observations of shearwater burrows. Incision in the downslope regions of 'new-camp' gully appears to have reduced as supported by the increased vegetation cover, U-shaped channel and flat channel floor. The gully progresses further to meet with the 'old-camp' main gully channel maintaining a U-shaped morphology. Once 'new-camp' gully joins 'old-camp' gully, vegetation disappears leaving a large bare rock gully form with a MSC of G_b5. Despite the apparent stabilisation in erosion, there is a decrease in mean Schmidt Hammer R-values for cross-section 8, from the middle section, with the two points measured being 17.5 and 27.0 respectively (Figure 4.34).

Figure 4.33: View upslope of lower section of Tributary B (cross-section 8), 'new-camp' gully, with increased vegetation cover.

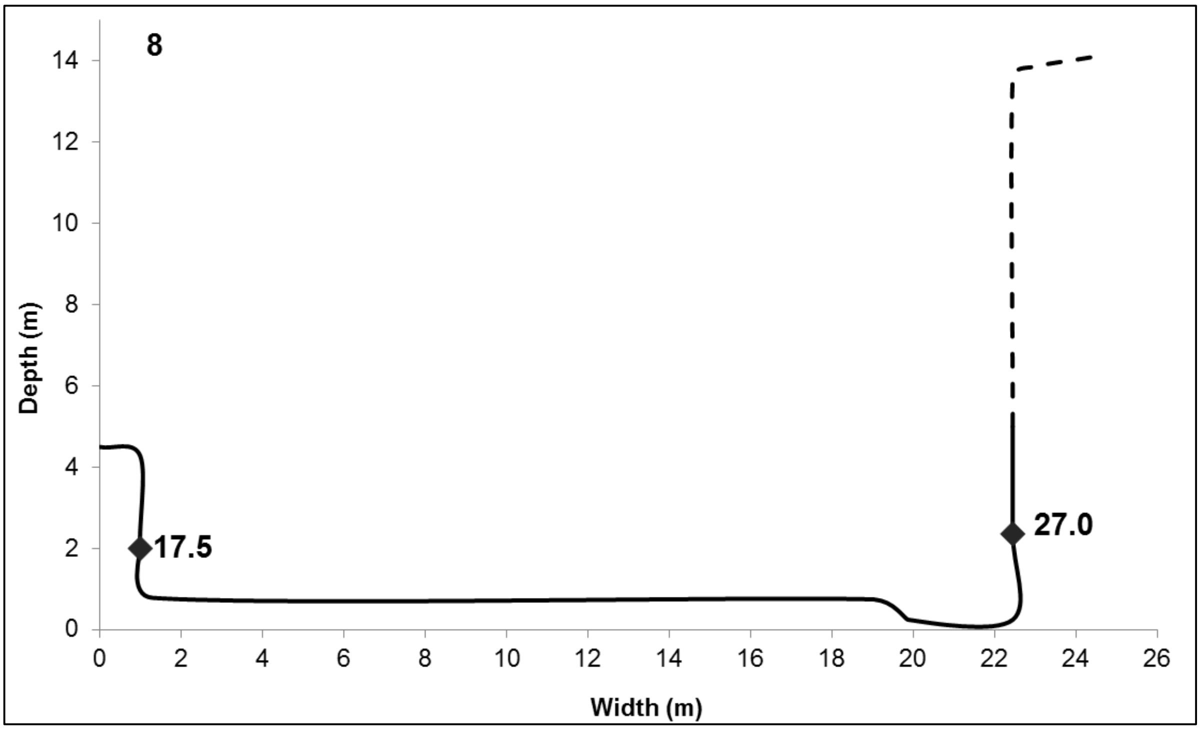


Figure 4.34: Cross-section 8 of the lower region of Tributary B, 'new-camp' gully, including mean Schmidt Hammer R-values, where dashed lines represent extrapolations at inaccessible locations (see Figure 4.19 for locations).

4.3.4. 'Big' gully network

The 'big' gully network located on the south-eastern slopes is the largest gully system found on the island and deeply dissects the landscape (Figure 4.35.a). The gully has its starting point on the steep convex slopes (23˚) of the bedrock dominated Rock Slab habitat at 180m above sea level with a total length of approximately 700m. In the upslope area of the Rock Slab region, a network of bedrock dominated shallow and narrow rills run downslope. Flow is concentrated along the rill forms and is channelled into gully tributaries which become wider and deeper downslope. Numerous tributaries join the 'big' gully main channel at various points along its profile (Figure 4.35 and Figure 4.36). In total, 10 cross-sectional profiles were taken from the fourth order main channel (labelled Tributary B) from its starting point to end at sea. Due to inaccessibility, gully morphology was assessed along only two tributaries. Five and four cross-sections were taken along two tributaries, Tributary E (second order) and Tributary G (third order) respectively (Figure 4.35). Two cross-sections were also analysed along two rills joining the 'big' gully system. Table 4.8 shows the morphometric parameters of the examined tributary rills and gullies within the 'big' gully network. Tributary B is divided into three sections (upper, mid and lower sections) as it progresses downslope based on similarities in gully form (Table 4.8).

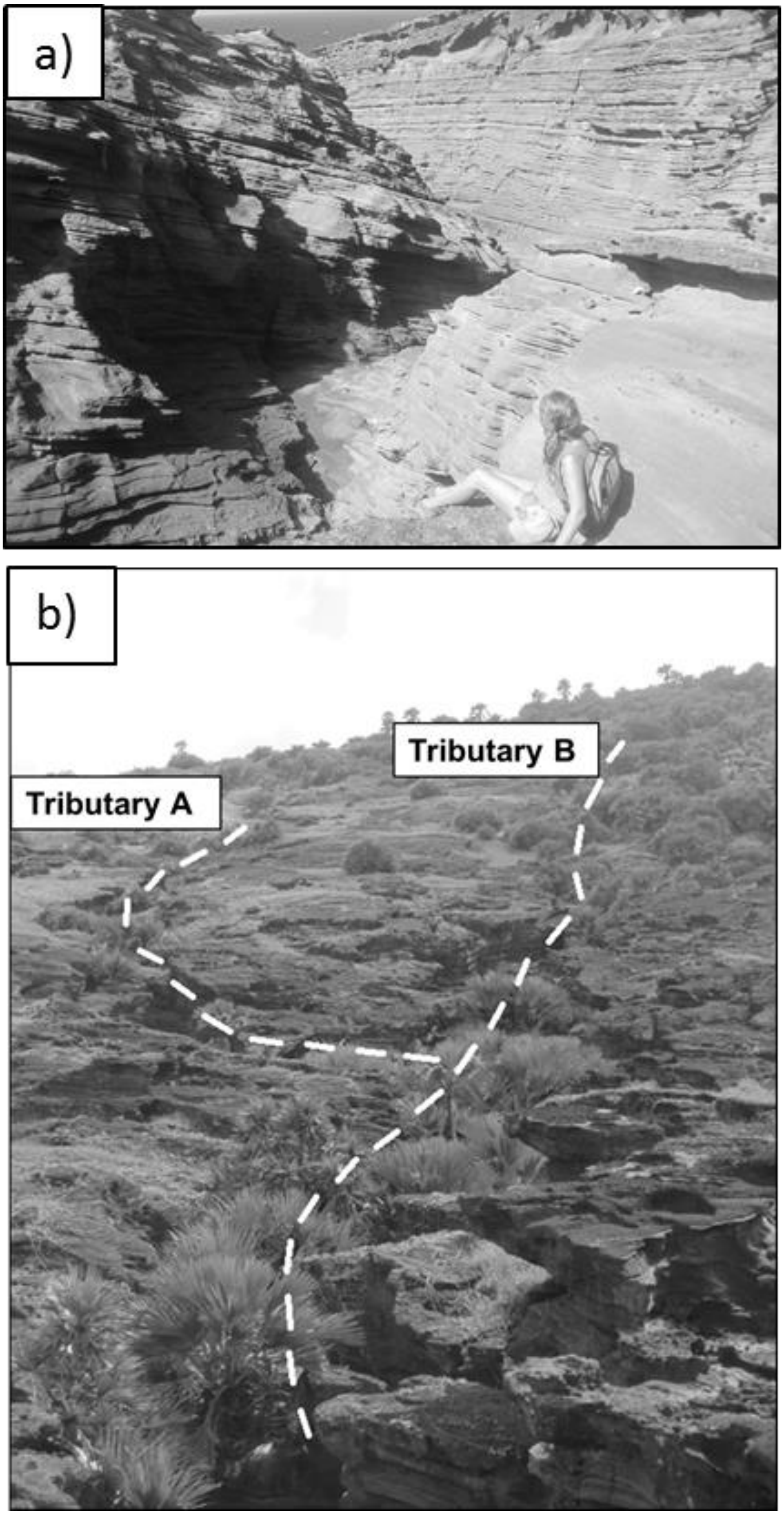


Figure 4.35: a) View downslope of the 'big' gully toward the coastline which deeply dissects the landscape and represents erosion of the highest severity on Round Island; and b) view upslope of Tributary A and Tributary B of the 'big' gully network.

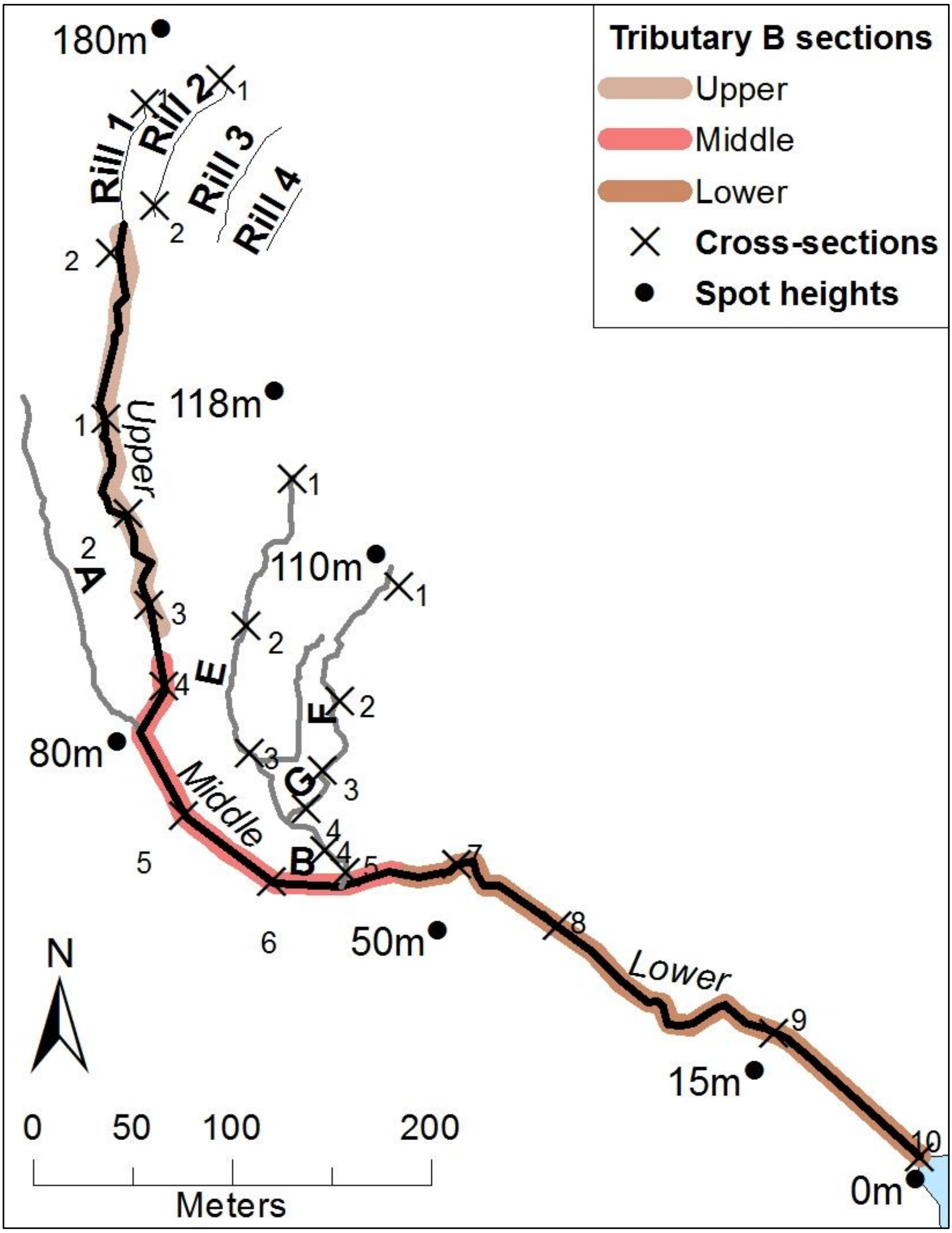


Figure 4.36: ‘Big’ gully network on Round Island indicating location of cross-sections (in superscript) assessed on Tributaries B, E and G respectively (see Figure 3.1, page 29 for reference).

In the upslope region of the ‘big‘ gully network, a network of bedrock rills begin at approximately 180m above sea level. The rills run downslope eventually joining and becoming wider and deeper to form the tributary gullies. Vegetation cover is absent around the upper reaches of the rills as their location falls within the Rock Slab habitat. The rills begin with a defined U-shaped morphology and through vertical incision by concentrating flow downslope tend toward a V-shaped morphology (Figure 4.37). The rills are shallow throughout their course (Figure 4.38.a). Rill 1 and Rill 2 have high width: depth ratios (5.10 and 2.96, respectively, Table 4.8). Moderate to severe bedrock rill erosion (R_b3 to R_b4) is the dominant erosion process with severe sheetwash occurring on the channel sidewalls, as well as on the surrounding bare rock surface of the Rock Slab. Sediment creep also occurs down the steep slope. Mean Schmidt Hammer values for the rills are similar. Rill 1 has R-values ranging from 34.0 to 35.5 (Figure 4.37). Rill 2 has lower R-values compared to Rill 1, ranging from 29.0 to 33.0.

Table 4.8: ‘Big’ gully network morphometric parameters (see Figure 4.36 for locations).

Tributary	Slope (˚)	Total length (m)	Mean max width (m)	Mean max depth (m)	Width: depth ratio	MSC
Rill 1	23	80	2.38	0.47	5.10	R_b4
Rill 2	23	65	0.72	0.22	2.96	R_b3
B Upper	22	130	6.47	2.70	2.38	G_b3
B Middle	20	160	6.88	5.32	1.29	G_b4
B Lower	20	280	16.13	13.88	1.16	G_b5
E	22	250	8.80	3.67	2.66	G_b3
G	22	120	6.40	3.61	2.42	G_b3

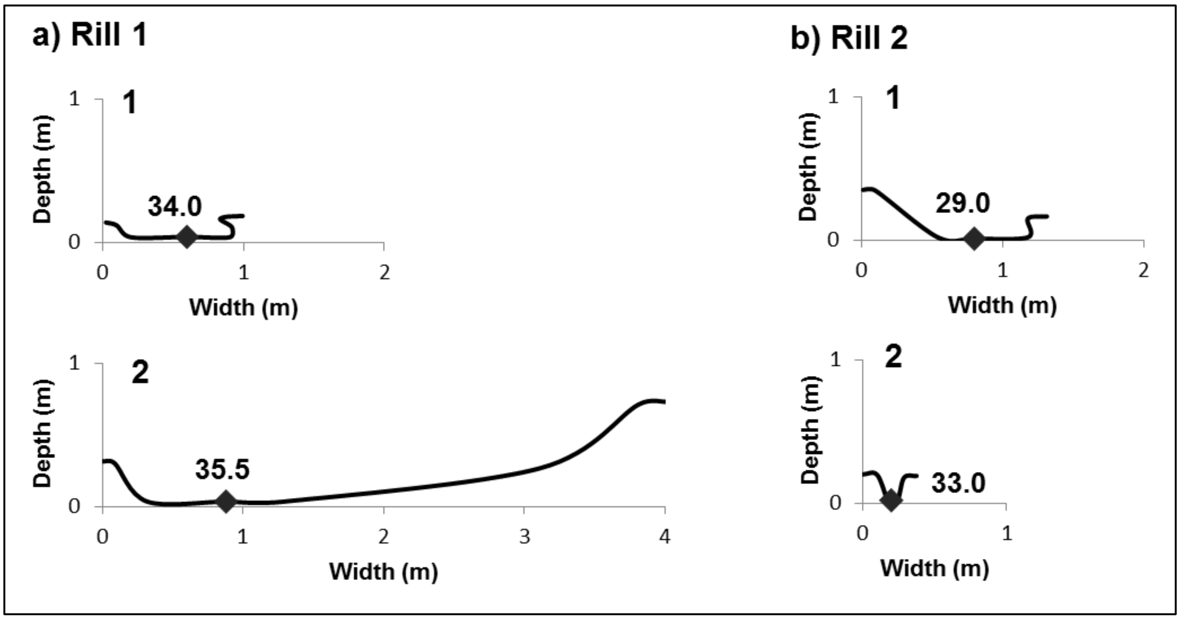


Figure 4.37: Cross-sections 1 to 2 of a) Rill 1 and b) Rill 2 of the ‘big’ gully, including mean Schmidt Hammer R-values (see Figure 4.35 for locations).

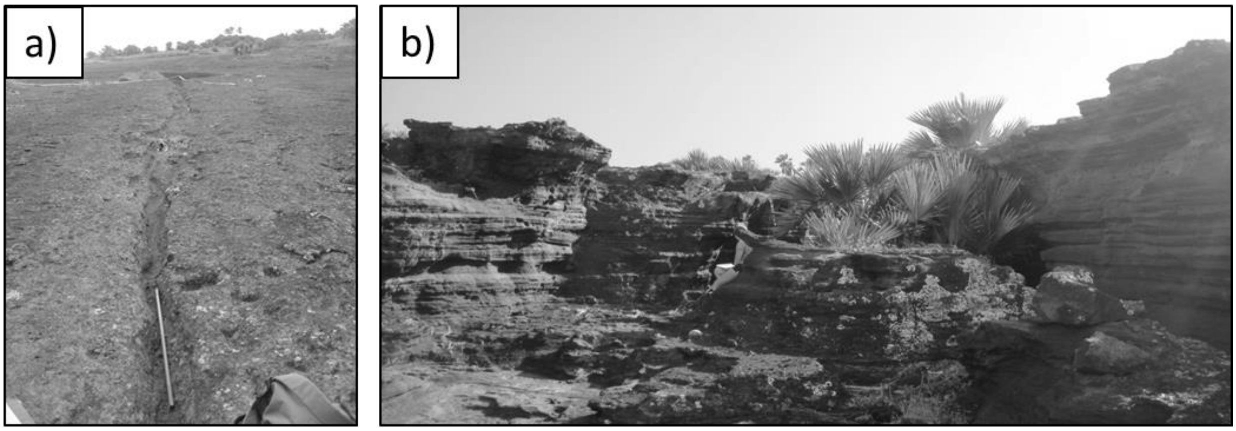


Figure 4.38: a) View upslope of cross-section 2, Rill 2 of the upslope area of the 'big' gully network (stick for scale); and b) View upslope of cross-section 3 of Tributary A of the 'big' gully.

The fourth order, main gully channel within the 'big' gully network, labelled 'Tributary B', begins at approximately 120m above sea level and runs a course of approximately 700m to its end point at the sea. Rill 1 becomes Tributary B at a transition area noted by an increase in vegetation of grasses and palm species. Vegetation cover is highest in the upper reaches of Tributary B. Despite the increase in vegetation, the gully channel generally remains devoid of vegetation further downslope, except for a few *Latania* palm species. Morphometric parameters indicate a wide channel (6.47m) which is relatively shallow (2.70m). The upper section thus has a width: depth ratio of 2.38 (Table 4.8). As the gully proceeds downslope, vertical incision occurs. Cross-section 3, in particular, shows an incision area on the right hand side whereas stabilisation appears to have occurred on the left hand side (Figure 4.39). The upper section has a general flat base with steep stepped sidewalls. Sidewall overhangs are present in this upper section of cross-sections 1 and 3 (Figure 4.38.b), indicative of undercutting. Mean Schmidt Hammer R-values for the lower section are variable ranging from 18.0 to 39.5. No readings were taken at cross-section 1. The readings taken at cross-section 3 are in general higher than those taken at cross-section 2 (Figure 4.39).

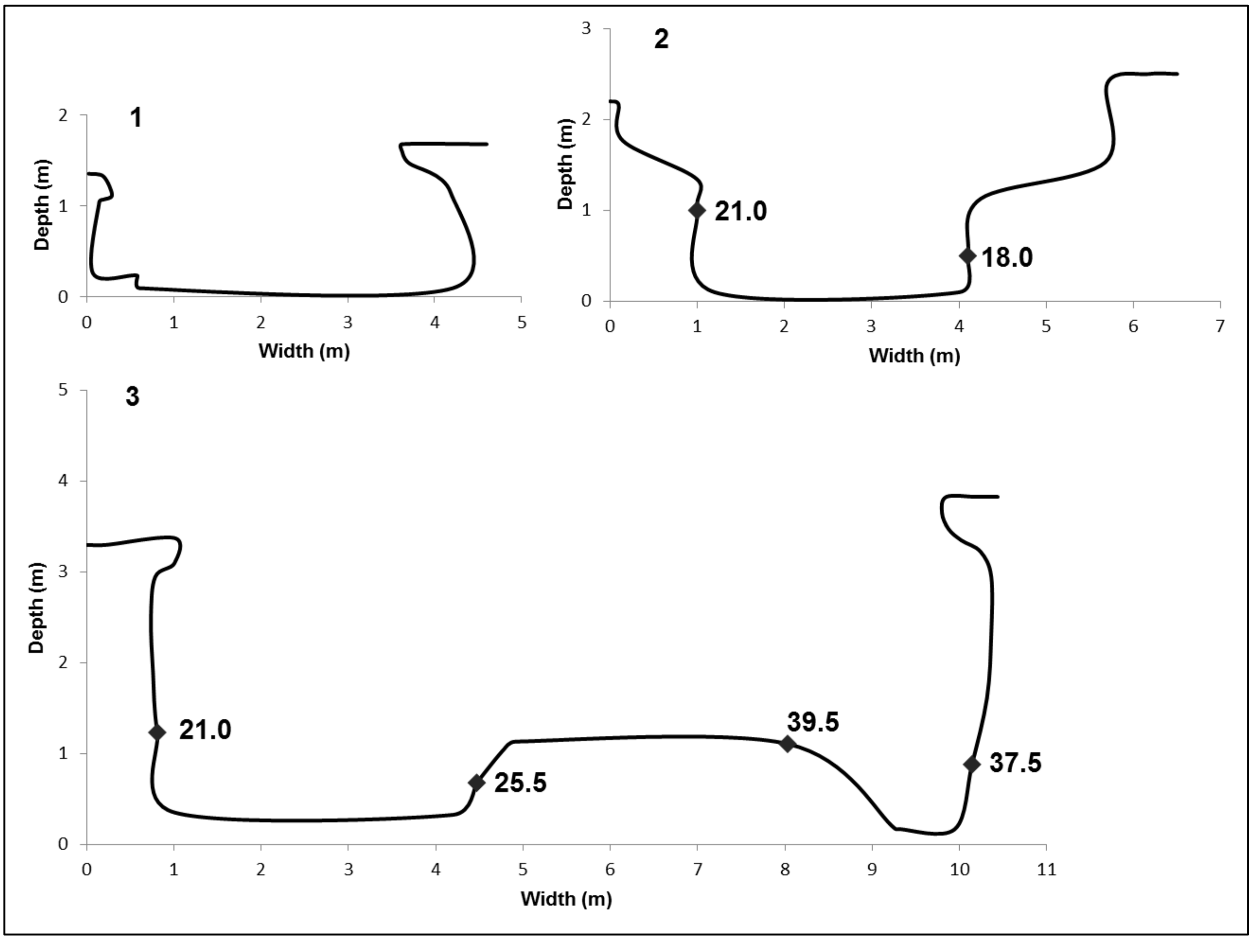


Figure 4.39: Cross-sections 1 to 3 of the upper-section of Tributary B, 'big' gully, including mean Schmidt Hammer R-values (see Figure 4.35 for locations).

The mid-section of Tributary B is densely vegetated with grasses and palm species. High vegetation cover exists with an increase in soil depth where, for example, at cross-sections 5 and 6 a soil depth of 10cm and 23cm, respectively, is present. This is also observed in the presence of unoccupied shearwater burrows. The mean maximum width (6.88m) of the mid-section remains constant in relation to the upper section of Tributary B. However, there is a marked increase in mean maximum depth to 5.32m through vertical incision (Table 4.8). Downslope, a U-shaped morphology is formed where the gully floor is flat (e.g. cross-sections 5 and 6, Figure 4.40). The width: depth ratio of the middle region of Tributary B is 1.29. Sidewalls show evidence of severe undercutting and subsequent mass failure. Mean Schmidt Hammer R-values for the mid-section range from 19.00 to 32.0. At cross-section 4, the values are relatively similar throughout the cross-section ranging from 20.5 to 25.0 (Figure 4.40). Mean R-values at cross-section 6 are higher (31.5 to 32.0).

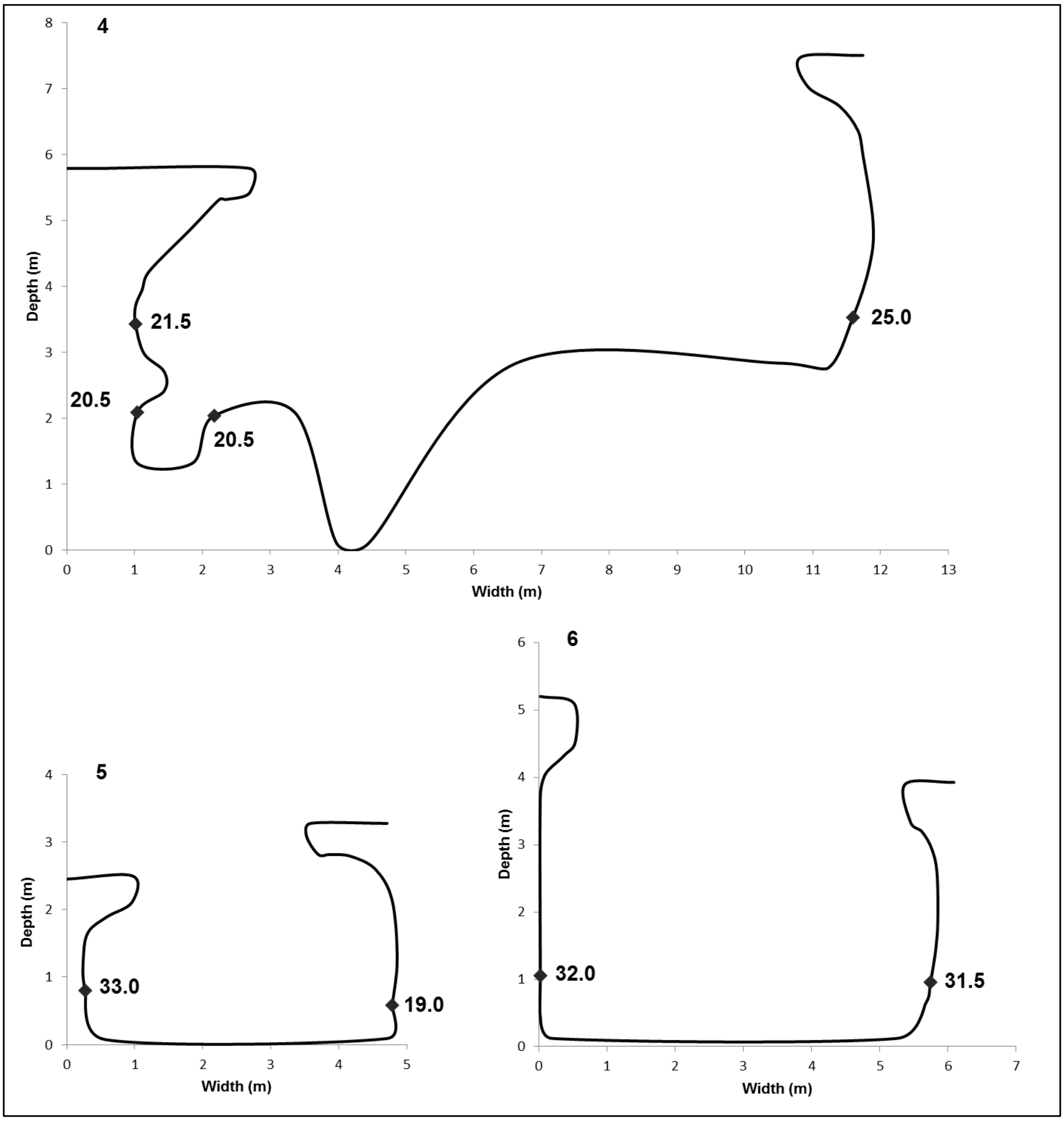


Figure 4.40: Cross-sections 4 to 6 of the mid-section of Tributary B, 'big' gully, including mean Schmidt Hammer R-values (see Figure 4.35 for locations).

In the lower section of Tributary B (from cross-section 7 and onward), gully morphology becomes distinctly more V-shaped for the rest of its length ending at the sea (Figure 4.41a). Vegetation cover disappears completely and so does soil cover. The gully becomes proportionately very wide (16.13m) and deep (13.88m), resulting in a low mean width: depth ratio of 1.16 (Table 4.8). The MSC classification in this region is very severe bedrock gully erosion (G_b5) as depth increases to more than 10m. Several vertical overfalls are found similar to those of the 'old-camp' gully. Again, the heights of these overfalls are variable, with some more than 10m (Figure 4.41.b). Potholes also occur at the base of the overfalls, where fine sediment accumulates. Despite sediment accumulation in places, there is no vegetation growth in the gully channel.

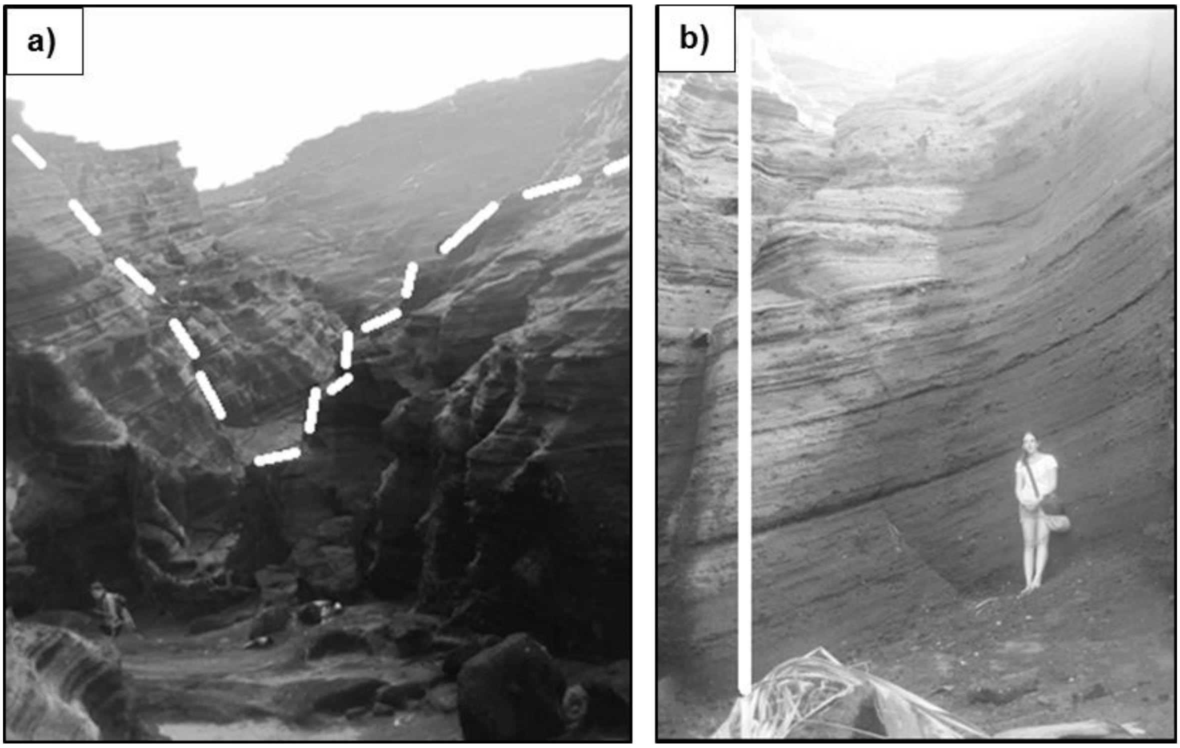


Figure 4.41: a) View upslope of Tributary B of the 'big' gully showing V-shaped morphology; and b) vertical headcut near cross-section 8 of Tributary B.

There appears to be a change in the bedrock texture (slightly less friable) and colour (from yellow tuff to dark brown) and Schmidt Hammer values decrease in the lower region of the 'big' gully. Mean R-values for the lower section range from 13.5 to 30.5. At cross-section 7, the R- values were particularly low at the base of the gully (Figure 4.42), as well as rock moisture conditions at this point and onward toward the endpoint to sea, due to salt spray being channelled through the gully system.

In the lower section of Tributary B, the frequency of joints increases notably. Quartz fissures associated with fault lines occur and increased in width. A particular quartz fissure, around 10cm in width, occurs at cross-section 9. Schmidt Hammer readings taken at cross-section 9 on the quartz is higher (64.0 ± 12.0) compared to the tuff bedrock Schmidt Hammer readings (Figure 4.42).

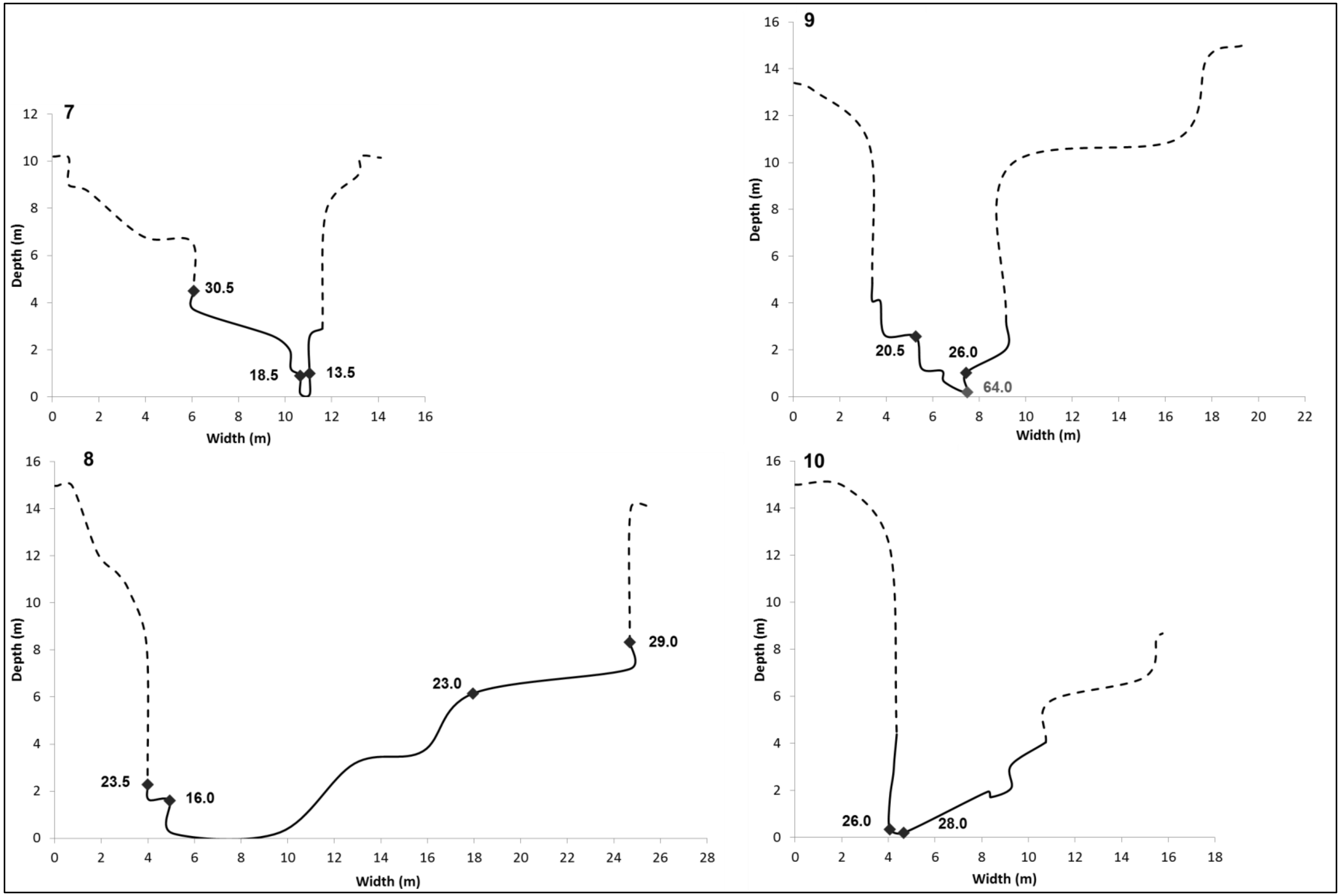


Figure 4.42: Cross-sections 7 to 10 of the lower region of Tributary B, ‘big’ gully, including mean Schmidt Hammer R-values, where dashed lines represent extrapolations at inaccessible locations (see Figure 4.35 for locations).

Tributary E of the 'big' gully network begins at approximately 118m above sea level and runs a total length of 150m downslope before joining into Tributary B (just below cross-section 6 of Tributary B, Figure 4.36, page 71). The gully is well vegetated throughout its course. A semi-continuous soil cover is present within the gully channel that rarely exceeds a depth of 10cm. The gully channel begins with a V-shaped morphology in its upslope region although takes on a flat bottomed U-shaped morphology down course (Figure 4.43 and Figure 4.44). Tributary E is very wide throughout its course with a mean maximum width of 8.80m. It also has a moderate mean maximum depth of 3.67m resulting in a width: depth ratio of 2.66 (Table 4.8). In general, the overall morphology of the gully form is irregular, with few similarities within the cross-sectional profiles of Tributary E as it progresses its course. In general, the sidewalls have numerous overhangs indicative of weaker tuff layers within the gully profile causing the irregular gully profile (Figure 4.43). Sidewall collapse is common (e.g. Figure 4.43.a). Erosion for Tributary E is classified as moderate bedrock gully erosion (G_b3) with associated moderate sheetwash occurring within the channel. Mean Schmidt Hammer R-values are low for Tributary E ranging from 16.0 to 30.5 (Figure 4.44).

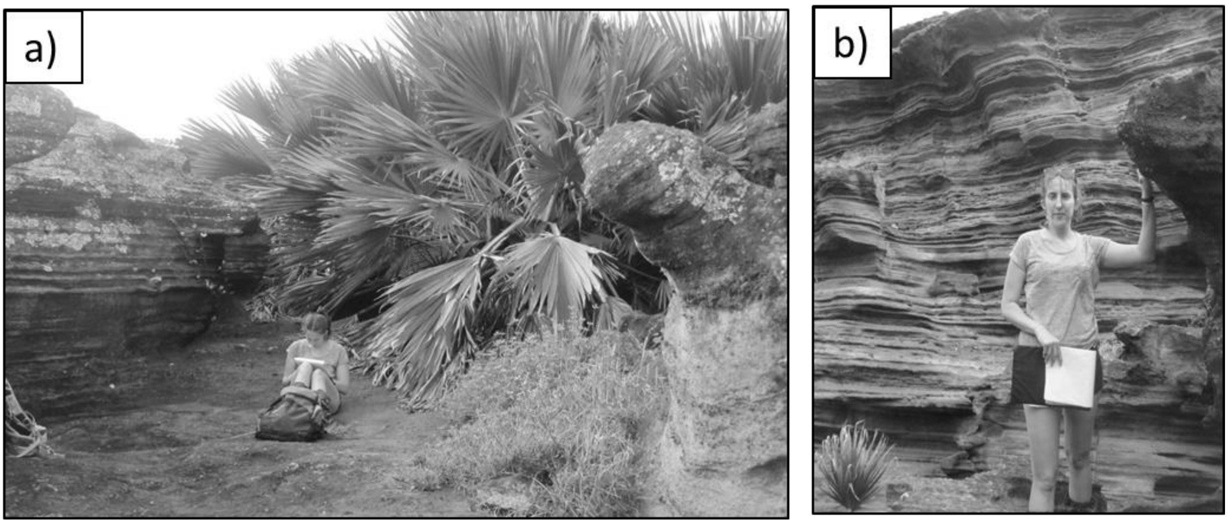


Figure 4.43: a) View upslope of cross-section 2, Tributary E of 'big' gully with sidewall collapse evident at the right hand side of gully channel; and b) right sidewall of cross-section 5, Tributary E of 'big' gully.

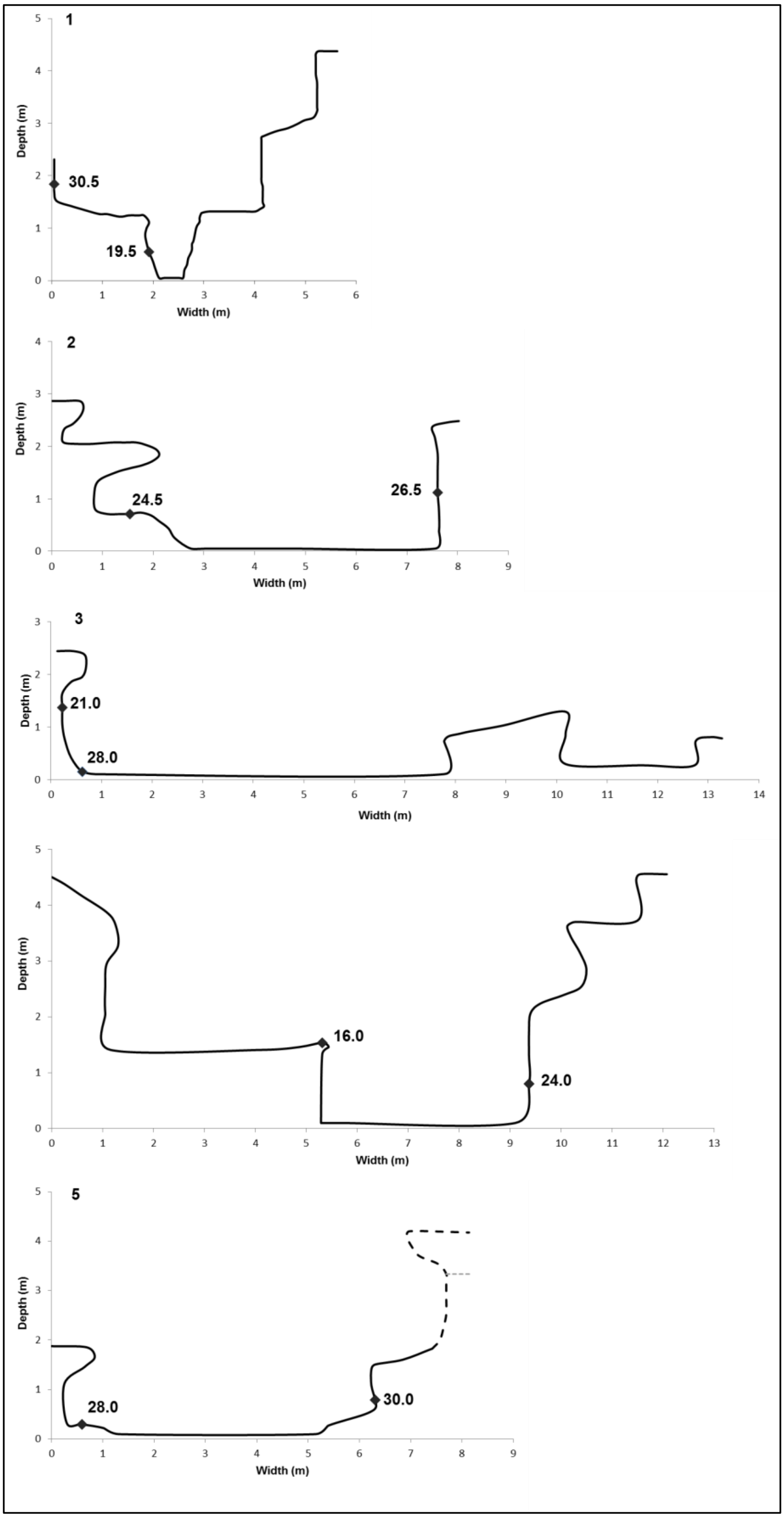


Figure 4.44: Cross-sections 1 to 5 of Tributary E, 'big' gully, including mean Schmidt Hammer R-values, where dashed lines represent extrapolations at inaccessible locations (see Figure 4.35 for locations).

Tributary G of the 'big' gully network starts at approximately 115m above sea level progressing around 120m downslope, before joining the lower end of Tributary E (Figure 4.45). The gully is densely vegetated throughout its course although soil cover is sparse and shallow rarely exceeding 5cm. Mean maximum width is 6.40m and mean maximum depth is 3.61m, resulting in a mean width: depth ratio of 2.42 (Table 4.8). This is, however, highly variable within Tributary G. The overall form of the gully profile in its course is irregular (Figure 4.46). Sidewalls again have numerous overhangs with evidence of sidewall collapse (Figure 4.45.b). Vertical incision is evident by means of active erosion areas on the channel floor at all cross-sections of Tributary G. Erosion within Tributary G is classified as moderate bedrock gully erosion (G_b3), with sheetwash occurring within the channel. Mean Schmidt Hammer R-values are in general very low for all cross-sections of Tributary G, ranging from 15.0 to 28.0.

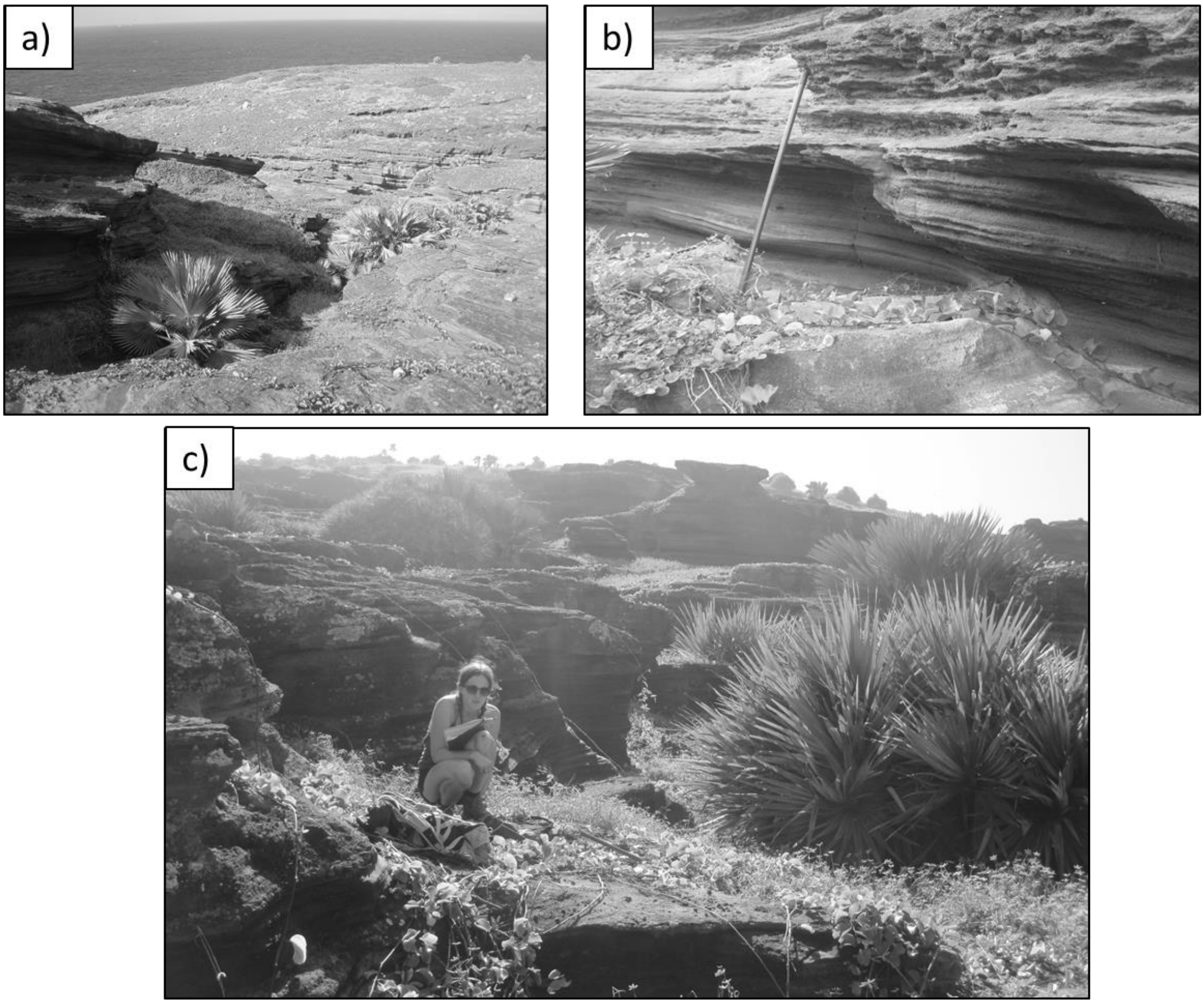


Figure 4.45: a) View downslope of Tributary G, 'big' gully network; b) lower right hand sidewall of cross-section 2, Tributary G with vertical incision and undercutting evident; and c) cross-section 4 of Tributary G where gully channel is well vegetated.

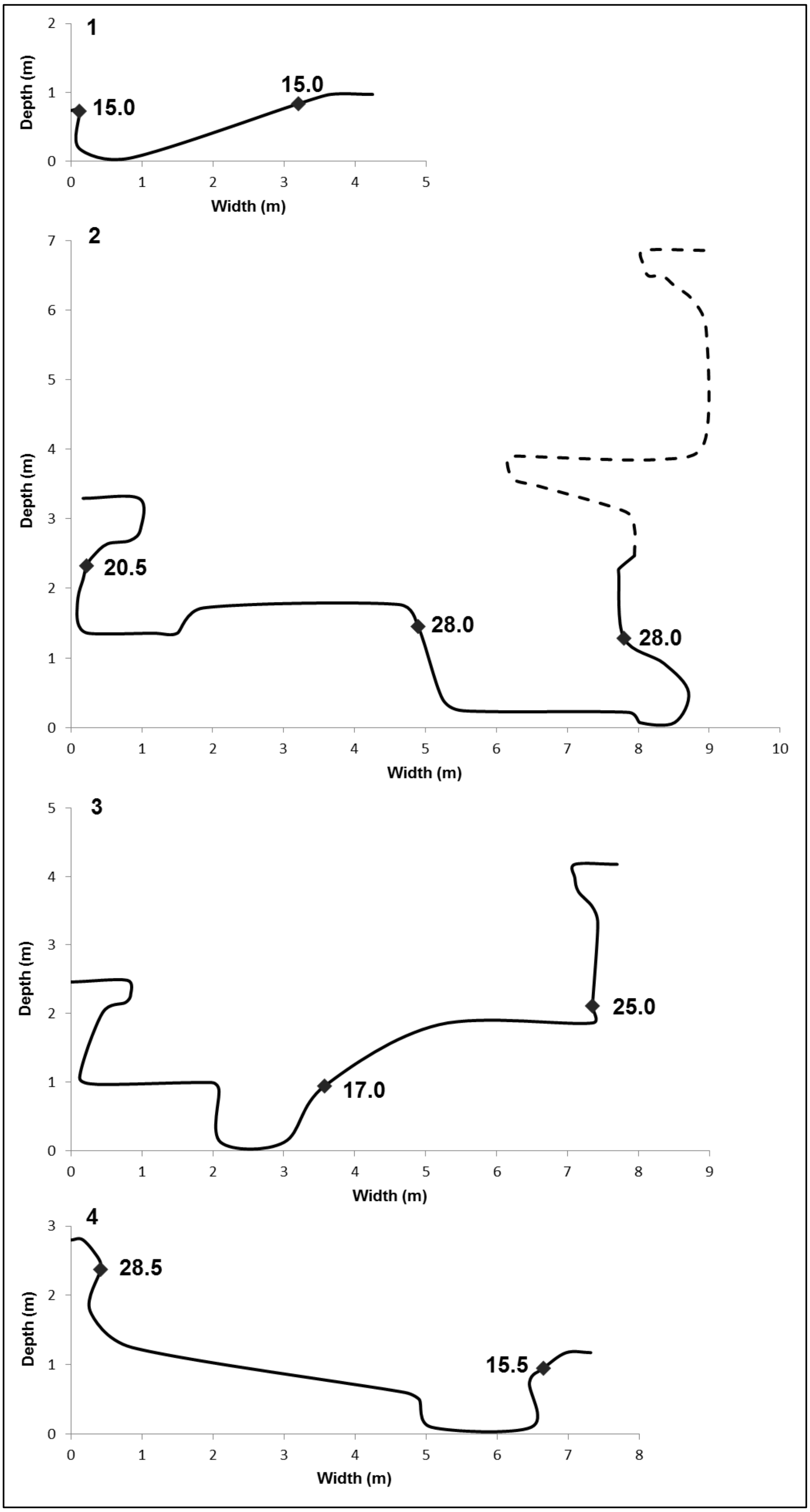


Figure 4.46: Cross-sections 1 to 4 of Tributary G, 'big' gully, including mean Schmidt Hammer R-values (see Figure 4.35 for locations).

In summary, this chapter has presented the results with important findings highlighted. Erosion occurs throughout Round Island but specific established study sites were identified to highlight erosion phenomena on the island characteristic of each habitat type. Soil physical characteristics were described based on statistical analyses. Erosion features were mapped and classified according to the MSC. The cross-sectional morphology of erosion features along their course was drawn to aid the classification of such erosion forms. Mean Schmidt Hammer readings were also described at various points within the profile of gullies. Chapter 5 provides a detailed discussion based on the findings of the results presented in this chapter. The chapter then highlights some key limitations of this research project and where scope for future research should be directed.

Chapter 5 : Discussion

This chapter presents a discussion on the results presented in Chapter 4. A discussion is provided on the location of study sites chosen to represent erosion on Round Island. This is followed by a description of the soil properties for Round Island at the chosen study sites. The erosion phenomena occurring at each study site is described, as well as recommendations for soil conservation on the island. This chapter draws to a close with a discussion on the applicability of the Modified SARCCUS Classification (MSC), followed by research needs and recommendations.

Soil and bedrock erosion forms are located throughout the island indicating its extensive nature. It was therefore decided that to assess the island as a whole was impractical. Seven habitat types have been identified on Round Island according to vegetation type and substrate (Johansson, 2003). Within these habitat types, permanent one hectare quadrats have been established where research and environmental monitoring projects are carried out. Five of these quadrats were used as sampling sites for the soil and erosion assessment. Five habitat types were chosen for the erosion assessment. The Summit, Rock Slab and Palm Savannah habitat type on the western slope provide an overview of erosion along a profile from the summit toward the coastline. The Mixed Weed habitat occurs in areas of deeper soils and where active planting activities take place and the Helipad habitat acts as an important sediment source to its western areas (Cheke, 2004). In addition, two gully systems (‘camp’ and ‘big’ gully network), located on the southern slopes of Round Island were examined to enable the mapping and analysis thereof of entire erosion systems on Round Island. The chosen study sites give a representation of the general erosion situation on the island and the most severe erosion areas.

5.1. Soil characteristics

Soil samples were taken from five habitat study sites and analysed to determine their influence on erosion processes. The soils of Round Island have very little resemblance to mainland Mauritius olivine basaltic soils (Johnston, 1993); instead they appear to have characteristics which are representative of its unique environmental setting in terms of volcanic history, topography, climate and vegetation.

In general, Round Island soils are very thin and not continuous. Mean soil depth results indicate that the Summit, Rock Slab and Palm Savannah study sites have slightly higher soil depth recordings than the Mixed Weed region although none of these results are significantly different. This is not expected as according to Johnston’s (1993) general soil survey of Round Island, the Mixed Weed habitat had the greatest soil depth and cover. The

Mixed Weed does have the highest vegetation cover and it can be expected that soil depth is also greatest overall in this habitat region. It must also be noted that the standard deviation for the Summit, Rock Slab and Palm Savannah sites is higher than that of the Mixed Weed. Observations made in the field show that soil cover is not continuous throughout these three sites and sampling was confined to where soil cover was present, thus higher variations can be expected. There is little to no profile development of soils in accordance with Johnston's (1993) results, suggesting that the soils in various areas are more like sediment which has been deposited through downslope movement than as a consequence of physical weathering of the tuff rock.

There is not much variation in soil characteristics between the different study sites (with the exception of pH). This may be due to the size of the island which is relatively small (219ha) resulting in little scope for environmental variations in terms of volcanic history, climate, vegetation type, land use and topography[1]. A significant difference is found in pH between the sites. The Summit has a significantly lower pH than the Rock Slab and Helipad habitat regions. A possible factor could relate to organic matter in the soil which reduces pH. The Rock Slab and Helipad regions both have very little vegetation cover and low animal habitation thus reducing the amount of organic matter input into soils. The Summit is relatively well vegetated with grasses and herbaceous species and also has large tortoise and seabird populations. Johnston (1993) found that the input of guano on Round Island was responsible for many of the soil properties.

The results of the organic matter content of Round Island soils (7.1% ± 4.2 overall average) are higher than those of Johnston's soil survey in 1993 (5.4% average). This may be due to an increase in vegetation over time as a result of plant rehabilitation efforts by the Mauritian Wildlife Foundation or perhaps, due to differences in experimental and sampling procedures. The Helipad hsd the lowest organic matter relating to the lack of vegetation. The Helipad is directly exposed to the prevailing South East Trade Winds resulting in the removal of fines (Cheke, 2004) thus reducing the amount of growing medium for vegetation growth. Wind erosion generally occurs in open landscapes that offer little resistance to the prevailing wind as is the case for the Helipad. Overall the organic matter content of Round Island is still lower than results provided from other studies where soils derived from volcanic ash and tuff soils have a high organic matter content (Yatno & Zauyah, 2008). Organic matter plays an important role in lowering the erodibility of soils as it increases water holding capacity and infiltration, and aids in structure formation (FitzPatrick, 1980).

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[1] Information from personal communication from Mr. Barend Van der Merwe, Junior Lecturer, University of Pretoria, Pretoria, September 2013.

Bulk density results for the sites are relatively low, but correspond to other results for tuff derived soils (e.g. 0.67- 0.95g.cm^{-3} in Lembang, West Java Island of Indonesia, Yatno & Zauyah, 2008). Furthermore, volcanic soils are known to have low bulk densities (Ugolini & Dahlgren, 2002). A high bulk density is caused by soil compaction from agricultural activities which lowers infiltration and increases runoff, thereby increasing susceptibility to erosion (Morgan, 2005). Soils on Round Island are uncultivated soils and therefore are not subject agricultural activities, which may cause compaction. The Summit habitat, however, has the highest bulk density of all the sites (0.88 g.cm^{-3}), possibly relating to the higher density of tortoises at the Summit, as trampling by animals causes soil compaction, thus increasing bulk density (Evans, 1998).

The cumulative percent frequency curves for particle size distribution show the similarities and differences in particle sizes between sites. All the sites are negatively skewed, with the exception of the Helipad (symmetrical skewness), representing coarser particles. According to the Wentworth Grade, all sites fall within the sediment size of sand with the Mixed Weed and Helipad being coarse sand and all other sites as medium sand. The Helipad habitat has the largest mean particle size, which is indicative of the removal of fines by wind (Cooke et al., 1993; Cheke, 2004). In addition, all the sites are very poorly sorted thus have a mixture of different particles.

The nature of the soils on Round Island, which are thin and not continuous, indicates that they are not associated with the erosion of the bedrock gullies. Soils may actually be beneficial in reducing erosion rates of the bedrock gullies as they create a lag time during water flow through the gully channels.

5.2. Assessment of erosion phenomena

Erosion features were identified in the field and classified according to the MSC system. The spatial distribution of these features was subsequently mapped. To aid in the classification of erosion features the morphometric parameters of the identified forms were analysed. The morphology is an indicator of past and present erosion processes (Heede, 1970). The erosion processes occurring are explained in terms of the physical environmental setting for each site and Round Island as a whole. The erosion assessment is discussed for each chosen study site to allow a logical structure to understanding erosion phenomena on Round Island.

Little is known about the role of parent material properties and their influence on the resistance to gully erosion processes (Poesen et al., 2003). Rill and gully formation usually occurs in the soil layer of a landscape and ends at the bedrock level where there is a sharp increase in resistance to erosion. However, the erosion features identified on Round Island are bedrock dominated rill and gully systems. Erosion processes which occur on the soils are mainly in the form of sheetwash and aeolian erosion processes (finer material able to be picked up by wind energy). Erosion occurs mostly on the tuff bedrock creating linear erosion forms. This is in contrast to erosion forms found in other regions based on the host material in which they form. South Africa, for example, has gullies which predominantly form in colluvium or partially weathered bedrock (Dardis et al., 1988). In Belgium, gullies are common in loess-derived soils (Poesen et al., 1996) and in southern Navarra, Spain; ephermal gullies are also common in loamy soils (Casalí et al., 1999). These studies that describe gully morphology are based upon soil erosion. The morphological characteristics of Round Island gullies are thus determined by the nature of the volcanic tuff rock. The tuff bedrock has a high erodibility in places as evident by the sheer magnitude of the gully systems that largely dissect the landscape. This creates opportunity for future research on a comprehensive geological study of the tuff bedrock on Round Island to better understand the volcanic history and erosion phenomena.

The Schmidt Hammer was used to quantify rock hardness characteristics of the Round Island tuff to determine its resistance to erosion. The factors controlling the strength of rocks are structure and texture, mineral composition, bedding, jointing and anistrophy, water content and the state of stress in rock masses (Dickson et al., 2004). Schmidt Hammer values for Round Island are, in general, very low. This relates to the inherent properties of volcanic tuff which is, in general, a weak rock. Other studies have shown that tuff rock produces lower rebound values (for example mean R-values of 17-26 were found for different tuff rock types in southern Anatolia, Turkey, by Kihç & Teymen, 2008) compared to other volcanic rock types such as granite (R-values of 53.48, at Big Creek, Idaho, USA, Lifton et al., 2009), basalt (mean R-values ranging from 42.2 to 62.3 on Lorde Island in the southwest Pacific Ocean, Dickson et al., 2004; mean R-values of 57 in southern Anatolia, Kihç & Teymen, 2008) and quartzite (mean R-values of 63 in southern Anatolia, Kihç & Teymen, 2008). The rate of erosion of the bedrock dominated channels depends on various factors such as rock strength, sediment supply and grain size (Sklar & Dietrich, 2001). As the geology of Round Island is predominantly tuff which is a friable and relatively weak rock, bedrock erosion rates can be expected to be relatively high for Round Island.

Lifton et al. (2009) argue that lithology alone may not be diagnostic of rock strength parameters or channel morphology. Other factors such as degree of weathering and the presence of joints and fractures must also be taken into account when measuring rock strength (Selby, 1980). Numerous joints occur throughout Round Island's bedrock; however, their influence on rock strength was not quantitatively taken into account. Joints, fractures and faults occur in almost all rock masses and act as a plane of weakness (Dickson et al., 2004; Valentin et al., 2005; Lifton et al., 2009). Whipple et al. (2000) suggest that jointing is a very important control on erosion processes. Fewer joints would provide higher Schmidt Hammer values, suggesting higher rock strength.

5.2.1. Summit

At the Summit study site, only two short moderate bedrock rills were classified and mapped. These rills have an MSC of slight bedrock rill erosion and moderate sheet erosion within and between rills. The rills are shallow and wide as shown by their high width: depth ratios. Undercutting of erodible tuff layers was present possibly due to overland flow. No other major linear erosion features are present, possibly due to the gentle gradient of the Summit and its negligible drainage area. The Summit is directly exposed to the prevailing South East Trade Winds and the soils in this region are subject to deflation where fines are displaced from the south eastern area to the north western side of the Summit. An increase in soil depth in the north-west is present to support this with a gravel pavement (Cooke et al., 1993) in the south west.

5.2.2. Rock Slab

The Rock Slab study site has numerous bedrock rills and two gullies running downslope which were identified and mapped. The MSC severity for these rills is moderate. The morphometric parameters indicate that they are wide and shallow as explained by their high width: depth ratios, with the exception of Rill 7 which was narrow, yet still shallow. This is unusual as Rill 7 had the greatest length.

In the upslope region of the Rock Slab study site, the rills and gullies have distinctive headcut features. The rills and gullies may have started by the upslope migration of these headcuts. Evidence for this is that the top layer of the bedrock surface has undergone partial weathering. Howard (1998) suggests that because runoff or debris flows strip partially weathered bedrock from slopes before they would fail by weathering or gravity these energetic flows are concentrative erosive agents that can create channels. This appears to be the case due to the nature of the steep slopes in combination with a lack of soil or vegetation cover where surface runoff is extensive and thus erosive. Over time, runoff and rill erosion has incised the bedrock. Increasing depth and headcut erosion has possibly resulted in the upslope migration of the channels (Selby, 1994). Sheetwash on the sidewalls may be responsible for the large width of the Rock Slab rills, where the sidewalls are stripped during runoff.

Schmidt Hammer values are, in general, low for the tuff bedrock at the Rock Slab study site which is consistent with previous studies. In terms of grain size, the Rock Slab site was comprised of medium sand grains (mean of 0.547mm). Erosion rates of bedrock dominated channels depend on various factors such as rock strength, sediment supply and grain size (Sklar & Dietrich, 2001). This can mean that during (erosive) rainfall events, these particles are capable of eroding the bedrock surface when moving in bedload.

5.2.3. Palm Savannah

In the Palm Savannah habitat, gullies are the predominant erosion features present, with only one short bedrock rill being recorded. Some gullies have distinctive starting points within the study site, yet others are linked to those from rills or gullies of the Rock Slab habitat, further upslope. Four gullies were identified in the Palm Savannah and are, in general, moderately deep with a resulting MSC of moderate bedrock gullies; one severity class higher than those from the Rock Slab study site. This may be due to the ash flow sidewalls which appear to increase depth of the Palm Savannah gullies. The sidewalls have a blocky nature due to tension cracks and fault lines. Vegetation growth within these cracks enhances tuff breakage through root wedging due to the minimal resistance to stress and thus increasing susceptibility to sidewall collapse. Schmidt Hammer values are high for the region, with the exception where fault lines and cracked tuff occur which, is on the gully sidewalls related to the ash flows. Joints, fractures and faults occur in almost all rock masses and act as a plane of weakness (see Dickson et al., 2004; Lifton et al., 2009). In particular, gully 3 has fault lines on the channel floor creating opportunity for increased vertical incision which is supported by the higher depth of Gully 3.

5.2.4. Gully networks

On the southern slopes of Round Island two large gully networks (‘camp’ and ‘big’ gully network) largely dissect the landscape. These two gully systems were mapped and assessed according to the MSC. The ‘camp’ gully network consists of ‘old-camp’ gully and ‘new-camp’ gully networks, which have their starting point on the midslopes (approximately 110 to 120m above sea level) of Round Island. ‘Big’ gully begins on the upslope region at approximately 180m above sea level by a serious of shallow and narrow rills which become deeper and wider downslope due to channel erosion (Selby, 1884) developing into gullies on the midslopes. The starting location of these gullies being upslope is atypical. This is in contrast to, for example, the Drakensberg of South Africa (Dardis et al., 1988) and south-eastern Spain (Oostwoud Wijdenes et al., 1999) where gully starting points are commonly located on the footslopes of valleys. This may be due to the topography where the general slope shape of Round Island is convex - concave in contrast to the concave - convex slope shapes found in South Africa and other regions. The ‘camp’ and ‘big’ gully system both consist of tributaries which join the main gullies at various points along their vertical profiles. This is indicative of the dendritic type gully form as described by Ireland et al. (1939). Both gully networks increase in depth and width before ultimately ending at sea. This is expected due to drainage accumulation downslope, but may also be attributed to lithological changes. Schmidt Hammer values are variable along profiles and within cross-section, but lithological changes have not been quantified in this study to verify this.

The morphological characteristics of the ‘camp’ and ‘big’ gully networks is strikingly different to those of the rill and gully features found at other study sites on Round Island, such as the Palm Savannah. The Palm Savannah gullies maintained their MSC classification throughout their course section which was studied. This is in contrast to both ‘camp’ and ‘big’ gully networks, which gained considerable depth in their course beginning as bedrock rill features and ending as large ‘ravine’ style gullies with an MSC classification of very severe bedrock gully erosion. Furthermore, the Palm Savannah gullies run relatively parallel to one another downslope, similar to the description provided by Ireland et al.’s (1939) parallel gully form pattern (although in this case, do not join to become one main gully channel). The ‘camp’ and ‘big’ gully networks retain a dendritic gully form (Ireland et al., 1939) with numerous tributaries joining at various points along the vertical profile. Headcut erosion of the tributary gullies accentuates the dendritic character over time (e.g. Ireland et al., 1939). The differences in plan form and morphology may be related to drainage area size and sediment input, although the accuracy of this is uncertain. However, the ‘camp’ and ‘big’ gully networks have larger contributing drainage areas, which may be responsible for the variation in spatial distribution between the gullies on the western slope (Palm Savannah) and those located on the southern slopes of Round Island.

The gullies have an irregular morphology along their course and between cross-sections, which is unusual in comparison to the morphology of gullies described in other studies. For example, the classification of gullies described by Dardis et al. (1988) of soil erosion forms in southern Africa describe three types of open ‘gully-style’ channels which may be either U- or V-shaped depending on the processes acting on them. Processes such as overland flow, headcut erosion and sidewall collapse are occurring on Round Island gullies as described elsewhere. The differences here are the subsurface processes (e.g. piping and subsurface flow) resulting in the particular geometry, for Dardis et al.’s (1988) described forms appear to not be applicable for the bedrock gullies found on Round Island. Similarly, Imeson and Kwaad (1980) describe four types of gullies as either U- or V-shaped depending on host material and processes. Again, subsurface flow is not relevant in this case. Overhangs are present, which appear to be a result of undercutting by overland flow of the erodible tuff sidewalls. Subsequent sidewall collapse creates a U-shaped cross-section (see also Dardis et al., 1988).

The bedrock nature of the gullies has implications based on climatic factors. During the tropical cyclone season, high rainfall occurs which is generally erosive (Nigel & Rughooputh, 2010). Due to a lack of infiltration capacity of the tuff bedrock, rapid runoff occurs during rainfall events causing continual erosion. It was noticed in the field that 'ponding' had occurred in potholes evident from flow during rainfall as described by Galang et al. (2007). The amount of flow the gullies are subject to is a function of the size of the contributing drainage area and position in the landscape (Galang et al., 2007). Active gullies are known to exhibit hydrologic behaviour which has implications for sediment transport from upland areas to downslope areas (Poesen et al., 2003). This is particularly important for Round Island, as the 'camp' and 'big' gully systems begin relatively high upslope and have their ending points at sea. Ultimately the transported sediment is lost, resulting in the loss of potentially large amounts of nutrients for faunal and floral growth. This is in contrast to other environments where normally sediment is displaced into water courses or at the foot of hillslopes in fan formations (Poesen et al., 2003).

Numerous vertical overfalls within the vertical profile of the main channel of 'camp' and 'big' gully exist, which appear to be similar to headcuts found in bedrock rivers and gullies (Bennett, 1999). The headcuts also have potholes at their base which are caused by a plunge-pool erosive effect. The formation and migration of headcuts have been linked to rill and gully erosion and the erosion of bedrock channels (Miller, 1991; Seidl et al., 1994) and are also susceptible to erosion processes. In terms of the tuff bedrock, washout along the headcut face and plunge-pool scour, as described by Bennett (1999), appear to be dominant in this case. Washout along the headcut face continuously removes material because of fluidised mass wasting. This creates cantilever failure at the headcut brinkpoint which causes upslope migration of the headcut over time (Bennett, 1999). Overland flow over headcuts causes initial scour hole development at the base of the headcut. Depending on flow power, the eroded material may either be transported downstream or deposited within the plunge-pools and immediate area of the gully channel.

Due to the impracticality of doing Schmidt Hammer readings at every tuff layer at the cross-section points, it was not possible to wholly determine the influence of rock strength on gully morphometric parameters. It is interesting to note, however, that Schmidt Hammer values appear to increase in Tributary A of the 'old-camp' gully as it precedes downslope. This is unusual as one would expect values to decrease with increasing severity of the erosion forms, but runoff accumulation, increasing erosivity, may counter this. In the mid-section of Tributary B of 'new-camp' gully, mean Schmidt Hammer values are higher than values obtained at the upper and lower sections. Erosion also appears to be most active in this region. This is supported by Lifton et al.'s (2009) argument that lithology alone may not be diagnostic of rock strength parameters or channel morphology. When channel sidewalls are oversteepened they are susceptible to erosion and slope mass wasting processes will remove material from oversteepened slopes into the gully channel. When water flow occurs it will remove the material and the gully channel floor will widen if there is enough transporting capacity (Lifton et al., 2009). Thus, in the case of the Round Island gullies the weak tuff bedrock is prone to lateral erosion and easily fails when oversteepened and thus facilitating gully widening. This is particularly evident in the mid-sections of both the 'camp' and 'big' gully networks where the gully channels are wide and with frequent sidewall collapse.

5.3. Soil conservation on Round Island

Active soil conservation management has been ongoing since 1993 after Johnston's (1993) soil survey to give practical effect to the objectives of Round Islands Management Plan. This includes the recovery of degraded soils or the protection of areas with deep soils to favour regeneration of plant communities. Specific activities include establishment of pioneers (grasses and shrubs) to increase vegetation that favours soil formation and protecting planted areas from Wedge-tailed Shearwater (*Puffinus pacificus*) burrowing. The regeneration of *Latania loddigessii* and *Ipomea pes-caprae* has shown positive results in reducing soil loss in gullies (Johnston, 1993). Various mechanical methods of soil conservation have previously been applied although in an *ad hoc* manner (Johnston, 1993; MWF, 2008). Soil traps have proven to be effective, but only locally trap soil and thus do not treat the source of the problem. Thus the most appropriate steps toward rehabilitation should focus on the wide-scale establishment of vegetation, as it would appear that due to the extensive nature of gullies on Round Island and its steep topography, erosion is a natural phenomenon.

Tortoises were introduced in 2007 (Griffiths et al., 2009) and naturally tend to populate the Mixed Weed and Summit habitats. Animals impact directly on soils by creating and expanding areas of bare soils, upon which the weather acts, and indirectly by facilitating runoff. The impacts on erosion are, however, dependant on grazing intensity and frequency, grazing area size and the physical environment (Evans, 1998). Tortoises do impact on the vegetation and soils, as can be seen through grazing and the formation of wallows for resting. However, at the current tortoise density, these impacts are localised with no substantial soil loss. It is important to consider the severity of these impacts in contrast to the benefits which tortoises provide. Tortoises are ecosystem engineers in that they will graze the faster growing exotic species and disperse the seeds of indigenous species, thus promoting growth of such species. Griffiths et al. (2009) observed tortoises eating and dispersing large seeds of the endemic Latania species. Therefore the introduction of tortoises supports native plant regeneration plans and can potentially be beneficial to soil conservation.

5.4. Research limitations and scope for future research

The classification of erosion forms entailed field observations describing erosion by water or wind using descriptors of each erosion feature, such as the type and severity of erosion. Classifying erosion processes and features is an important step that strongly influences the final accuracy of the erosion assessment (Van Dijk et al., 2005). However, the identification of such features in the field is not uniform and difficulties tend to arise when differentiating between forms and degrees of erosion grouped under one term and between stages of development (Dardis et al., 1988; Herweg, 1996). In addition, there are different views of classifying erosional forms based upon morphology, climate, lithology, the erosive agent and type of water flow. The use of the SARCCUS (1981) classification in this research was possible, provided it was modified to take into account bedrock erosion processes. This indicates that there is no one such classification scheme for erosion phenomena, but rather site specific classifications can be developed. Furthermore, exact morphometric parameters are not provided for by the original SARCCUS classification. Instead, morphometric parameters were developed and integrated from other existing criteria and classifications from previous research studies (e.g. Dardis et al., 1988; Menéndez-Duarte et al., 2007).

An important constraint of this research was the limited availability of base-line data. No geological or soil cover maps currently exist for Round Island and thus could not be used to relate erosion processes to the physical template. This also implies a level of uncertainty of the observations made on erosion phenomena made in this study and previously. Prime examples are the gullies which extend to below sea-level. Cheke (2004) noted a misconception that the gullies were formed as a result of the introduction of goats and rabbits. In partial support of Cheke’s (2004) argument, the rills and gullies on Round Island are bedrock-incised and do extend below sea level, indicating that the gullies may have been formed when the sea level was lower than it currently is. The rock formations extending into the sea were not considered within the scope of this research. However, this is an interesting aspect to Round Island’s geological and geomorphological history and provides scope for a study on the dating of the gullies which extend below current sea level. Within the gully systems, many plant species have established at the base of the gullies. If the age of the older species could be established, it would be possible to determine a minimum age of the gullies at that depth. As erosion phenomena appear to be geologically and topographically controlled, it is therefore recommended that complete maps of the geology of Round Island be developed. An accurate contour and topographical map is also required.

Spatial scale is an important consideration in terms of assessing erosion (Boardman, 2006) and the choice of scale depends on the purpose of the survey and size of study area (Williams & Morgan, 1976). Erosion mapping is most viable at a local scale (Boardman, 2006) as was the approach used in this research. However, this study was limited by the scale that could be assessed due to the small size of Round Island. Thus, it makes it inherently difficult to compare this study to other erosion mapping studies which generally cover a larger area.

The impact of tortoises and nesting seabirds on vegetation and soil loss creates scope for a quantitative study on the impacts of these animals on Round Island. Research focus should be directed on the effects of tortoise density and their impacts on soil properties such as bulk density which influence soils' susceptibility to erosion. Furthermore, soil loss should be monitored on a seasonal basis through tortoise activities. In terms of seabirds, the shearwaters also impact on the soil environment in which they nest. Observations were made of differentiating soil structure as a result of burrows. In order to better understand the effects of animals on soil characteristics and processes, a zoo-geomorphic study is recommended.

Erosion intensities are yet to be quantified for Round Island, thus it is also recommended that studies should attempt to quantify soil loss or sedimentation rates through the use of soil traps. Erosion should also be assessed at other sites which were not covered in this study to provide a more comprehensive understanding over the whole island. Lastly, research should focus on assessing soil movement on Round Island by evaluating wind and water sediment sources and sinks. This could help focus conservation efforts.

Chapter 5 has presented a discussion on the results that were shown in Chapter 4. Specific study sites were chosen which were representative of the widespread erosion processes occurring throughout Round Island. Soil physical characteristics were described for the study sites. Erosion processes occurring at each study site were described based on the results of the classification and mapping process. Erosion features were classified based on morphometric parameters and explained within the volcanic environmental setting. This research project concludes in the following chapter based on the findings and observations.

Chapter 6 : Conclusion

This project aimed to assess erosion phenomena occurring on Round Island, Mauritius. Erosion is a widespread occurrence on Round Island and given the size of the island specific sites were chosen where research quadrants were already established. Five habitat quadrants were chosen which were representative of the different slopes aspects, erosion features and vegetation types present on the island. The Summit, Rock Slab and Palm Savannah habitat type on the western slope provide an overview of erosion along a profile gradient from the summit toward the coastline. The Mixed Weed habitat occurs in areas of deeper soils and where active planting activities take place and the Helipad habitat which acts as an important sediment source to its western areas (Cheke, 2004). In addition, two gully systems (‘camp’ and ‘big’ gully network), located on the southern slopes of Round Island were examined to enable the mapping and analysis of entire erosion systems.

Soil physical characteristics are different for Round Island in comparison to Mauritius (Johnston, 1993) as a function of its distinct volcanic history. Soils are thin and discontinuous throughout the island with little variation between sites. Particle size analyses showed coarser soils with a sandy texture. The Helipad study site had the coarsest particles indicative of wind erosion through the deflation of fines (Cooke et al., 1993), in support of previous observations made by Cheke (2004). Soil pH was significantly lower at the Summit compared to the Helipad and Rock Slab habitats which may be a function of vegetation and input of guano from seabirds at the Summit. Organic matter appears to have increased over time in comparison to previous research (Johnston, 1993), possibly due to increased vegetation. Many regions of Round Island have soils which are representative of sediment transported down the steep slopes. However, these soils do not appear to be the cause of erosion forms found on the island.

Erosion at each site was assessed using a field-based method where erosion forms were mapped and classified according to a Modified SARCCUS Classification (MSC) system. Rill and gully formation usually occurs in the soil layer of a landscape and ends at the bedrock level where there is a sharp increase in resistance to erosion (Dardis et al., 1988; Poesen et al., 1996). In contrast, the erosion forms present throughout Round Island are bedrock incised rills and gullies. No linear erosion features were identified in Round Island soils, possibly as a function of the shallow soil layer. However, Johnston (1993) has previously noted rills occurring within soils as a result of shearwater burrows. Rills and gullies begin as smaller features and generally increase in width and depth downslope. The morphology of erosion forms is irregular between cross-sections and between rills and gullies. In addition to morphology, rock hardness was assessed using a Schmidt Hammer for the bedrock incised forms. Erosion rates of bedrock dominated channels depend on various factors such as rock strength, sediment supply and grain size (Sklar & Dietrich, 2001). The predominant rock type on Round Island is tuff, which is a relatively weak volcanic rock type as indicated by low mean Schmidt Hammer R-values which is consistent with previous studies (Dickson et al., 2004; Kihç & Teymen, 2008).

The Summit study site is relatively flat and is exposed mainly to moderate sheetwash and wind erosion. The Rock Slab habitat is devoid of vegetation and soils with shallow moderate rills and slight gullies running downslope into the Palm Savannah habitat where deeper gullies are present. Gullies of the Palm Savannah have an MSC of moderate bedrock gully erosion which run parallel downslope toward the sharp coastline. The morphology of these gullies represented a U-shaped form with undercutting of sidewalls. Adjacent to the gullies and within gully channels, soils are exposed to slight to moderate sheetwash. 'Camp' and 'big' gully systems represent erosion phenomena of the highest severity on Round Island with very severe bedrock gully erosion at their respective end points at sea. These networks begin in drainage areas on the upslope regions of Round Island as a series of rills and precede downslope, with an increase in width and depth. It is interesting to note the irregular morphology of the gullies between cross-sections indicating active incision at localised areas. Morphology at their end points is distinctly more V-shaped, particularly for the 'big' gully. During periods of intense rainfall, the bedrock incised gullies act as transport channels for sediment, which is ultimately lost to sea. Little sediment is able to remain and this is exemplified by a lack of vegetation. This is a natural cycle where conservation efforts will remain ineffective.

The MSC was an appropriate tool for classifying erosion forms on Round Island, provided it was modified. Mapping erosion used principles of geomorphological mapping and was a quick and cheap procedure, however, limited by a lack of base-line data and inaccessibility of various parts of the island to produce a comprehensive geomorphic map of Round Island.

Introduced goats and rabbits severely degraded soil and vegetation resources on Round Island. Conservation activities of soil and vegetation have been ongoing since the 1970s with management plans putting objectives into practice. In terms of soil conservation, vegetative and mechanical methods have been utilised. Active planting activities have increased vegetation cover, thus promoting soil stabilisation and re-development, as seen in stabilising gullies. Mechanical methods have predominantly been in the form of soil blocks to trap sediments moving downslope. The soil traps are effective but only localised. Instead, it is recommended that wide-scale planting on the island be the focus for conservation activities.

There is a large scope for future research on Round Island in order to better understand erosion phenomena and its dynamic interaction with its physical template. A full geological study is required in order to better understand the role that the tuff bedrock has in erodibility. Further, based on the climatic exposure that Round Island is subjected to through wind and rain, a study of sediment transport on Round Island is recommended. Lastly, research efforts should focus on quantifying the impacts that animals have on the soils and vegetation structure on Round Island. Observations during fieldwork indicated that the animals do have an impact on their surrounding environment through removal of vegetation, modifying soil structure and the formation of hollows for resting, thus exposing soils. This was particularly evident in the case of tortoises at the Summit and Mixed Weed habitat regions which they naturally populate. However, not all of their impacts are negative, as tortoises are ecosystem engineers and, in fact, provide functionality within their environments through seed dispersal (Griffiths et al., 2009), promoting vegetation regrowth. Furthermore, impacts on soils are localised and do not create linear erosion forms, but rather expose soils to sheetwash during rainfall. It is recommended that monitoring of the situation is conducted.

Prior to this research, little information was available concerning erosion phenomena on Round Island. This study aimed to improve the understanding of erosion processes on the island which is important for conservation efforts. Round Island has a distinct volcanic history which makes it different to Mauritius. Soils are thin and discontinuous throughout the island and appear to not be the main cause of erosion processes occurring on Round Island. Rather the erosion phenomena are a function of its topography and geology where steep slopes, friable tuff bedrock and tropical climate subject Round Island to various erosive processes. This can be seen in the bedrock incised rill and gully forms throughout the island.

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Appendix 1: SARCCUS (1981) classification system

Original SARCCUS classification system: Types and classes of erosion caused by water and wind (SARCCUS, 1981).

Type of erosion	Class of erosion	Symbol	Description and remarks
Sheet	None apparent	S1	No visible signs of erosion.
	Slight	S2	Erosion deduced from poor cover, sediment deposits and plant pedestals.
	Moderate	S3	Small rills present. Poor plant cover and extensive sediment deposits.
	Severe	S4	Rills and gullies present. Much or all of A-horizon removed.
	Very severe	S5	Very severe gully erosion.
Rill	None apparent	R1	No visible signs of erosion.
	Slight	R2	Small, shallow (<0.1m) rills present.
	Moderate	R3	Rills with considerable depth (0.1-0.3m).
	Severe	R4	Abundance of deep rills (<0.5m). Subsoil may be observed.
	Very severe	R5	Large well-defined rills. Associated with gully erosion.
Gully	None apparent	G1	No visible signs of erosion.
	Slight	G2	Usually up to 1m in depth.
	Moderate	G3	Intricate pattern of gullies (1-3m) exposing entire soil profile in some places. “Islands” of topsoil observed.
	Severe	G4	Landscape dissected and truncated by large gullies (3-5m); 25-50% of area unproductive.
	Very severe	G5	Large and deep gullies (>5m); over 50% of area denuded.
Wind	None apparent	W1	No visible signs of erosion.
	Slight	W2	Not readily observed. Field checks may show evidence of removal and deposition and loamy soils (15-35% clay and 65-85% sand) may predominate.
	Moderate	W3	Easily observed. Sand deposited against obstructions and small dunes are formed. Soils are mostly sandy.
	Severe	W4	Large parallel sand dunes. Sparse vegetation and soils very sandy.
	Very severe	W5	Over 50% of area rendered unproductive.

Appendix 2: Cumulative percentage particle size distribution for Round Island Soils

Individual and site specific cumulative percentage curves of particle size distribution for Round Island soils.

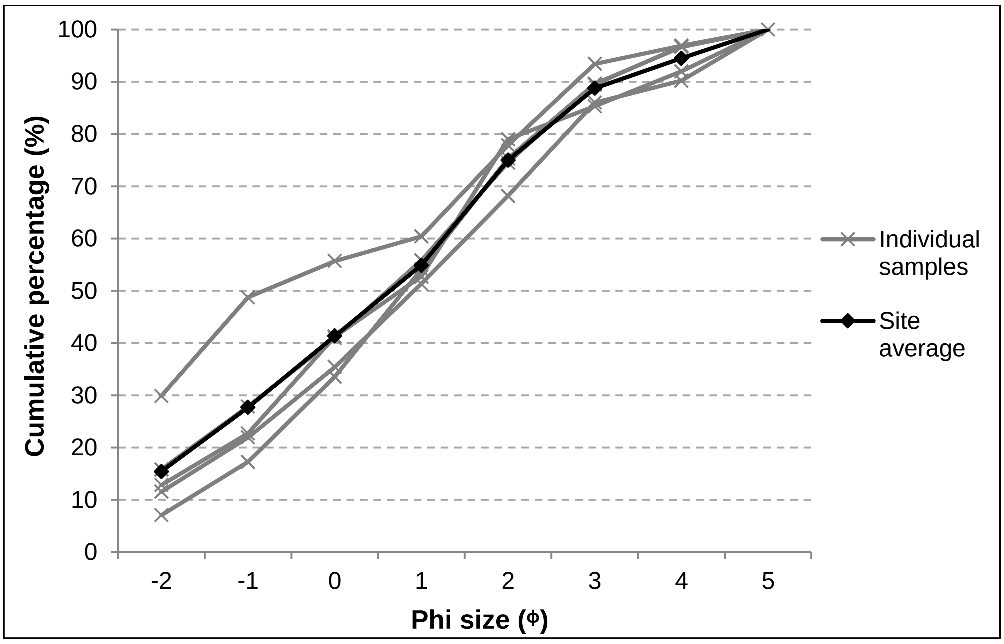

Figure 1. Cumulative percentage particle size distribution for Mixed Weed soils.

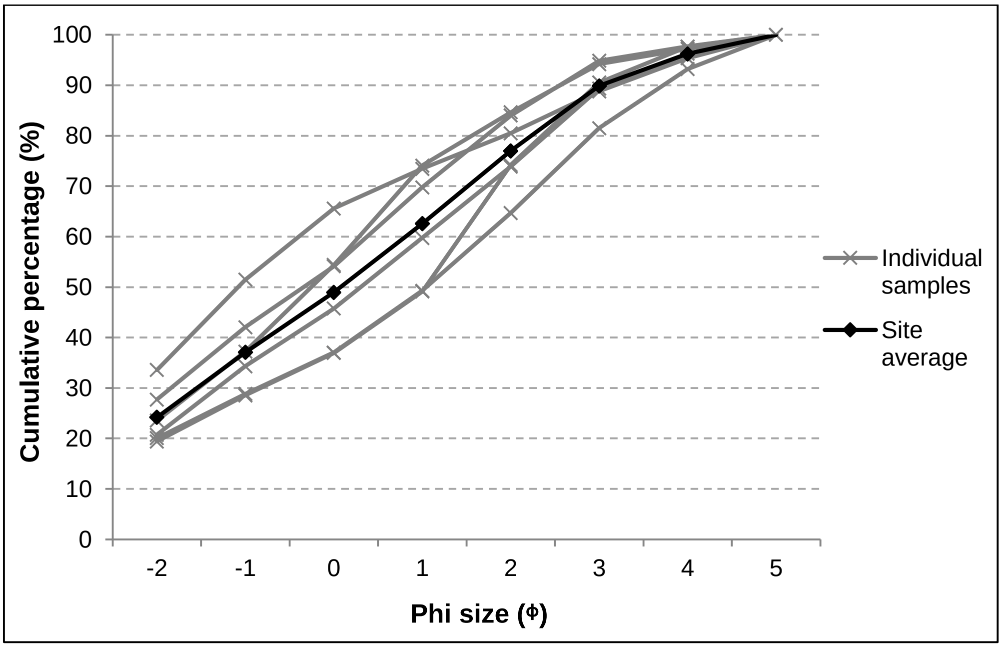

Figure 2. Cumulative percentage particle size distribution for Helipad soils.

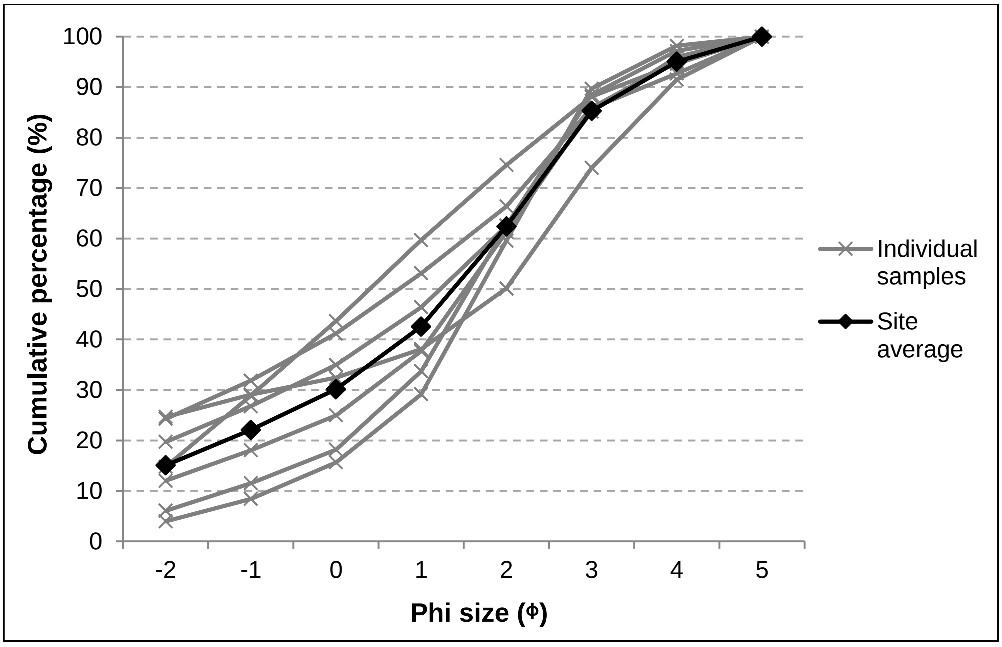

Figure 3. Cumulative percentage particle size distribution of Summit soils.

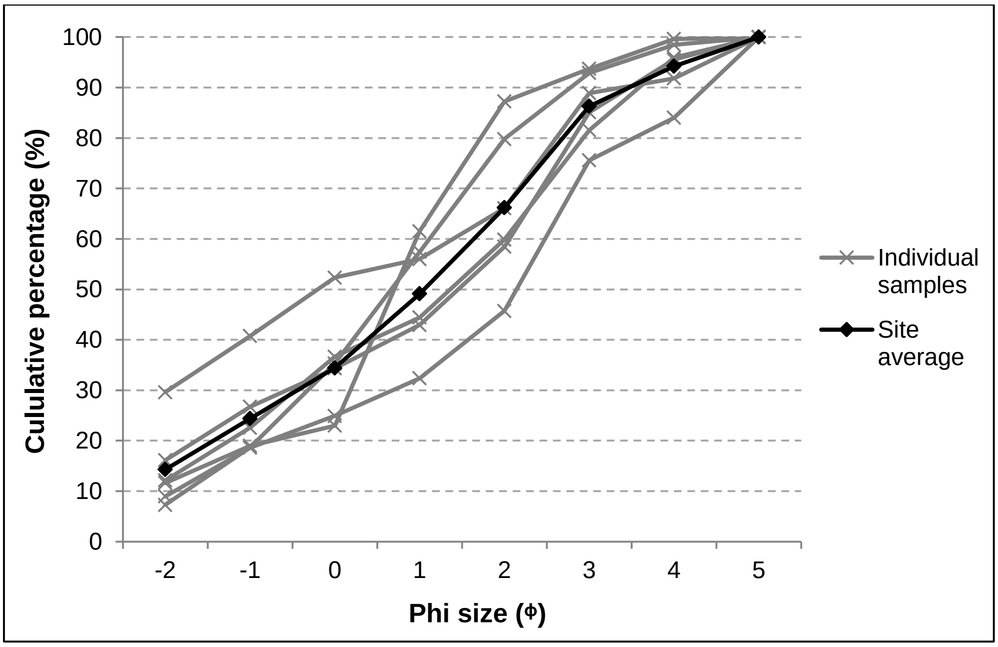

Figure 4. Cumulative percentage particle size distribution of Rock Slab soils.

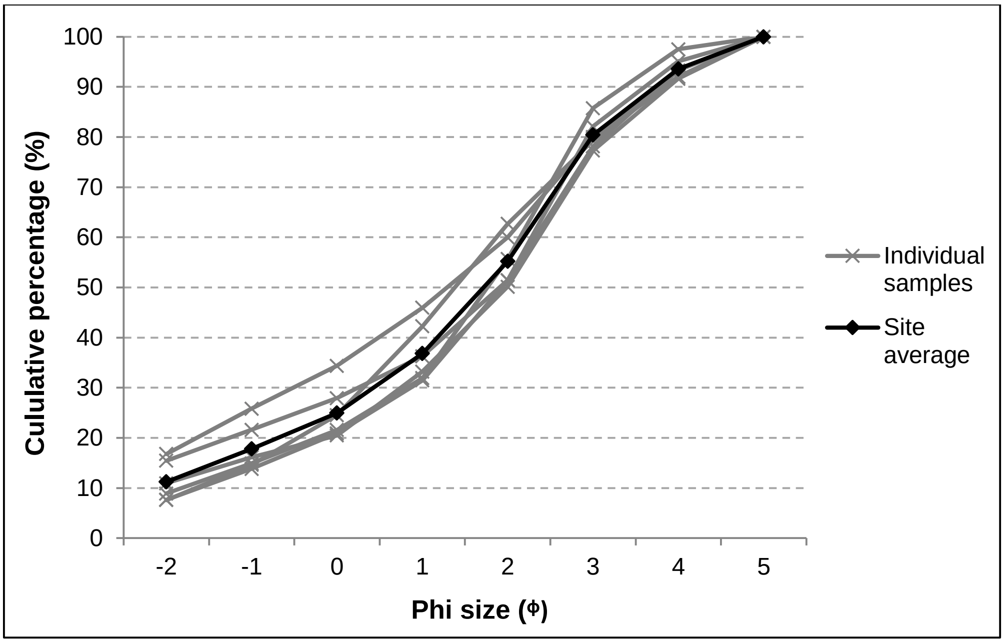

Figure 5. Cumulative percentage particle size distribution of Palm Savannah soils.