Threatened Species and Farming

Giant Gippsland Earthworm

Case study 1

Management of farm habitats in South Gippsland.

Authors

Beverley Van Praagh
C/o Department of Primary Industries
621 Burwood Hwy
Knoxfield 3180
bvpraagh@optusnet.com.au

Alan Yen
Department of Primary Industries
621 Burwood Hwy
Knoxfield 3180
alan.yen@dpi.vic.gov.au

Neville Rosengren
Department of Physical Sciences and Engineering
La Trobe University
Bendigo
n.rosengren@latrobe.edu.au

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SUMMARY

This study was funded by the *Ecologically Sustainable Agriculture Initiative* (ESAI) of the Department of Primary Industries. It is one of seven case studies investigating management techniques for threatened species in the context of improvements in agricultural production that are ecologically sustainable over the long-term.

The GGE has co-existed with agricultural land use since European settlement of South Gippsland in the 1870s and has survived major changes to its habitat mostly associated with agricultural development and expansion. However, the overall effects of these habitat changes on GGE populations and their distribution are not clearly understood. The GGE distribution is confined almost entirely to privately owned agricultural land. Therefore, identifying the effects of agricultural and land management practices on GGE remains crucial to the conservation management of this species. One of the key requirements in furthering our understanding of threatening processes on GGE populations is to more clearly understand the factors responsible for influencing earthworm distribution. The aim of this project was to determine the main topographical and hydrological soil factors influencing the distribution of the GGE within the landscape of an individual farm, and to identify the effects of land management on these factors.

The distribution of the GGE was determined on a dairy farm at Jumbunna, 8 km south of Korumburra and correlated with past and present land use factors, topographical and hydrological features.

The landowner identified three sites where he had found GGE in the past. However the present study found GGEs at six sites, in four distinct habitat types within the study area. These included: (1) minor creek and drainage lines, (2) flat to gentle sloping alluvial terraces above present flood levels, (3) steep south facing hillslopes with terracettes and (4) colluvial footslopes without terracettes. Examination of the GGE distribution at these sites in relation to geomorphology of the study area identified various landscape features that may play a role in influencing GGE distribution. These include the nature and depth of the soil, slope, micro-topography and aspect of the steep hillslopes, in addition to site soil and surface hydrology. Density of re-vegetation may also impact upon GGE populations with earthworms found in the more open sections of re-planted stream banks. Each of these habitat types are influenced by different geomorphological processes and may require different management considerations for GGE conservation.

When management of the study area over the last 50 years is considered, there is only one instance where a known GGE population has become extinct through agricultural activity. This involved the concentrated movement of cattle to use one crossing point over a stream. This property has been subject to fairly low stocking rates and minimal cultivation. At least one population of the GGE known to the landowner has survived for over 50 years. Old GGE burrows were also found at a site subject to a landslip some 5 years previously. However, no signs of earthworm activity were visible and the earthworm appeared to no longer be present at the site.

The results and recommendations from this study are limited by the difficulty in obtaining replicable quantitative data for a threatened subterranean species. Any attempts to quantify sampling techniques to obtain valid statistical data may have resulted in the destruction of local populations of the GGE. Therefore some of the results are more hypotheses that need to be tested in the future by undertaking similar studies on a much larger number of farms.

Conservation of GGE on individual farms may need to consider the different habitat types in which the worms are found e.g. minor creek banks and steep slopes as each habitat type may require different types of management. The main processes identified that may impact on GGE survival include soil erosion, changes in soil and surface hydrology and micro-topography of

slopes. Agricultural activities that may contribute to these processes include: cultivation, stocking rates on wet soils (pugging), infrastructure development, water run-off, and effluent production and treatment.

While the general occurrence and abundance of GGE is ultimately dependent upon broader factors operating at the landscape scale, GGE are often very localised in their distribution because they are also likely to be influenced by small scale factors such as soil hydrology dynamics. Consequently, isolated populations can be managed for GGE conservation independently of farming activities.

1. INTRODUCTION

1.1 Ecologically Sustainable Agriculture Initiative (ESAI)

"Threatened Species and Farming" is a sub-project of the ESAI. This project will identify how agricultural practices might be modified to help conserve selected threatened species as part of working toward ecological sustainability. The project will document case studies of selected threatened species in four bioregions: the Victorian Riverina, Wimmera, Victorian Volcanic Plain and Gippsland Plain. The farms considered include examples from the meat, wool, dairy and grains industries. This case study focuses on the Giant Gippsland Earthworm *Megascolides australis* McCoy 1878 in the Gippsland Plain region.

1.2 The Giant Gippsland Earthworm

The Giant Gippsland Earthworm (GGE) is considered one of the largest species of earthworm in the world, reaching lengths of over 1 m. The GGE has International, National and State conservation significance. It is listed as Vulnerable by the IUCN (IUCN 2004), Vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and as Threatened under the Victorian *Flora and Fauna Guarantee Act 1988*. About 90 hectares of its habitat has also been listed on the register of the National Estate (Coy 1991).

1.2.1 Distribution and habitat

The GGE is endemic to a small area of approximately 40,000 ha in the Bass River Valley of south and west Gippsland, Victoria. Distribution of the GGE is confined to an area roughly bound in the north by Warragul, and in the south by Loch and Korumburra. Within this range, GGE distribution is fragmented and populations can be restricted to very small areas of habitat. Populations are usually associated with creek banks, gullies and soaks or hillslopes with a southerly or westerly aspect. Anecdotal information regarding historical distribution patterns suggests that numbers have declined and the range of the species has contracted through farming activities and infrastructure development, although precise factors responsible for this decline are unclear.

The habitat of the GGE occurs predominantly in permanent pasture with agriculture representing the major land use throughout its range. Farms with dairy cattle and/or beef cattle predominate, with some growing potatoes, vegetables and fruit (Taylor *et al*. 1997). The GGE occurs at Mt Worth State Park, on the eastern edge of the species range. The Park represents one of the few remaining areas supporting the original Wet Forest (mostly Mountain Ash) that would have once been widespread throughout the GGE's range (Gippsland CRA 1999). This vegetation has now been almost entirely removed with only small pockets of remnant vegetation remaining along some creek banks, roadsides and gullies. However, revegetation and habitat restoration of stream banks and gullies is currently undertaken by a large majority of landowners in the region, although the amount of replanting varies widely (J. Bowman pers. comm. 2004).

1.2.2 Biology

The GGE is of conservation concern because of its limited distribution and life history characteristics. Particular aspects of the biology and ecology of the GGE such as long life span, low reproductive and recruitment rates, and low dispersal ability render the fragmented populations vulnerable to threatening processes (Van Praagh 1992; McCarthy *et al*. 1994). The GGE is a hermaphroditic species. Breeding occurs predominantly in spring and summer. Large amber coloured egg cocoons ranging in size from 5 to 9 cm are laid in chambers branching from the adult burrow at an average depth of 22 cm (Van Praagh 1994). Only one embryo is found in each egg cocoon, which is thought to take over 12 months to incubate. Egg production appears to be very low (0.36 per annum) and may not occur every year, depending on seasonal conditions. Although the life span of the species is unknown, field and limited laboratory studies suggest that it is long lived, possibly taking up to 5 years to reach sexual maturity. Field studies show the population consists predominantly of adults at all times of the year (Van Praagh 1994). This suggests a slow growth rate and population turnover, with a low rate of recruitment. Individuals are extremely fragile and even slight bruising or damage may result in death. Populations of GGE appear isolated from others and the opportunities for genetic exchange may be limited.

The GGE live in complex, permanent burrows that extend to around 1 to 1.5 m in depth. They appear to remain underground, feeding on the root material and organic matter ingested in the soil. Occupied burrows are always wet, even in summer, probably aiding the earthworm in movement and gas exchange. GGE can be locally abundant with a mean density of 2 per m^3 with up to 10 worms per m^3 recorded (Van Praagh 1994).

1.2.3 GGE and agriculture

The GGE has co-existed with agricultural land use since European settlement of South Gippsland in the 1870s and has survived major changes to its habitat mostly associated with agricultural development and expansion. While the species has survived major vegetation clearance and the activities associated with grazing and dairy farming, the overall effects of these changes on the soil habitat occupied by GGE's, and the effects on their distribution and survival are not clearly understood. Most of the information regarding effects of agricultural practices on earthworm populations are derived from observations of European earthworms, primarily because native megascolecids are absent from most pastures having died out after habitat clearance. Therefore we have very little direct knowledge of the effects of these activities on indigenous earthworms surviving under pastoral systems.

1.2.4 Threatening processes

The GGE appears to have some tolerance to disturbance as evidenced by its presence in pastures, under vehicle tracks and sections of pine plantations (Van Praagh and Hinkley 1999). However, while the GGE co-exists with the current agricultural systems of South Gippsland, the relationship may be very fragile because of the species fragmented distribution and life history characteristics.

Whilst not all threatening processes operating on the GGE are known or understood, some key threats can be identified. These threats include physical disturbances and chemical inputs (e.g. pesticides, herbicides, biocides) to the soil, and altered hydrology (e.g. changes in water-table level and drainage patterns). Many of the actions responsible for these threatening processes are interrelated and are associated with infrastructure development and agriculture.

Given that the species distribution is confined almost entirely to privately owned land used for agriculture, conservation of the GGE will rely largely on farmers maintaining areas of suitable habitat on their properties, and appropriately managing activities that might otherwise adversely affect the GGE. Therefore identifying the effects of agricultural and land management practices on GGE remains crucial to the conservation and management of this species. One of the key requirements in furthering our understanding of threatening processes on GGE populations is to more clearly understand the factors responsible for influencing earthworm distribution.

This information should form the basis for developing sound guidelines for the management and conservation of Giant Gippsland Earthworms on farming properties in South Gippsland.

1. 3 Aim of Project

To determine the main topographical, hydrological, physical and chemical soil factors influencing the distribution of the GGE within the landscape of individual farms, and to ascertain the effects of land management on these factors.

2. METHODOLOGY

Field work and interviews were undertaken between March-August 2004.

Two replicate farms within the range of GGE distribution have been selected for study. The first farm is located on the alluvial and colluvial grey clay soils at Jumbunna and the second one is located in the red Basaltic clays near Warragul. Only the first is considered in this report. On each farm, the distribution of the GGE will be determined and correlated with past and present land use factors, and topographical and hydrological features.

In the first property at Jumbunna, the following was undertaken:

1. The distribution of GGE was mapped by surveying for GGE burrows or the gurgling sounds made by the GGE while moving through their burrows.

2. Current and historical aerial photographs of the study site for the past 50 years were examined to ascertain changes in landscape.

3. The landowner was interviewed via questionnaire and discussion to obtain present and historical information of land management.

4. Detailed analysis of topographical features at GGE and non GGE sites including aspect and microtopography of terracettes and other surface irregularities were undertaken to determine site dynamics. The most recent vertical aerial photograph was orthorectified. Qasco Vic Image was contracted to prepare an orthorectified colour digital aerial photograph overlain by 10 metre contours, and a 1947 image of the same areas was also prepared.

5. Information from tasks 1-4 was integrated to investigate the possible effects of past and present land management practices on GGE distribution.

2.1 Identification of suitable habitat

The study site was examined on foot and via aerial photographs to identify areas of suitable GGE habitat. While precise habitat parameters for the species are unknown, several factors that characterise potential GGE habitat have been identified (Smith and Peterson 1982, Van Praagh 1994). These include proximity to water, soil moisture and soil type. The earthworm is often associated with creek banks, in particular smaller tributaries, soaks or wet south facing terraced slopes but is generally absent from areas where there is a high level of waterlogging and compaction. The species is generally found in acidic, silty clay loam soils, generally blue grey or red in appearance and found in the Strzelecki, Warragul and Ripplebrook associations described by Sargeant (1975) and is absent from soils with a high coarse sand content.

2.2 Detailed Surveying areas of suitable earthworm habitat

Sites identified as suitable habitat were surveyed to establish the presence of the earthworms. The most reliable way of locating the GGE is by digging and looking for burrows. This involves digging soil quadrats of approximately 50 cm x 50 cm. Burrows are easily identified and, if wet, represent burrows that are occupied. If the ground is wet, presence of the GGE can also be established by banging the ground with a spade and listening for gurgles, the sound that is made when the earthworms retreat down their wet burrows.

2.3 Study location

This study was conducted at Jumbunna on the property of Cheryl and Brian Enbom. Jumbunna is situated approximately 8 km south of the township of Korumburra, South Gippsland. A detailed description of the geology and geomorphology of the study area can be found in Appendix 1.

The Enbom property lies on the upper reaches of Foster Creek, a major tributary of the Powlett River (Fig 1). The two major upper tributaries of the creek join just outside the northern boundary of the farm. The property encloses diverse terrain and includes representative examples of the major landforms that occur across this section of the Strzelecki Ranges. A variety of slope form, angle and aspect is represented. Elevation ranges from below 100 metres along the Foster Creek channel to more than 220 metres on the ridge and summit along the farm western boundary (Fig 2; Fig 3). Maximum relief and steepest slopes (locally in excess of 30^0) with southeast to southerly aspect are along the western and northern boundaries above the creeks. The rest of the property has gentler, broadly convex to straight slopes. Flat surfaces are restricted to the floodplain and alluvial terraces bordering the creeks and to the ridge crests. Rock outcrop is restricted and exposed only along part of the Foster Creek channel, in farm track side-cuts, at the base of a major slope failure and as a natural scarp high on the upper western boundary slope. Surface materials, and the parent materials of soils are of limited variation. There is only a single bedrock lithology present (the volcanogenic sediments), and soils are derived directly from this or from residual and modified rock material transported down slopes or along the stream channels.

The original property of approximately 42 ha was purchased by Brian Enbom's father in 1947. Brian Enbom purchased the property in 1976 and extended the farm with the addition of 2 adjoining properties in 1978 and 1982, taking the total area of the farm to its present size of 148 ha.

2.4 Geomorphology

The geomorphology of the property is described as a series of slope units, defined principally on the basis of elevation and slope morphology. These units are described in Appendix 2 and illustrated as profile diagrams on Fig 4. The investigation for evidence of GGE for this project concentrated on the lower slopes and colluvial and alluvial terrain adjacent to the streams, (the lower part of unit MS and units CF, AT, MF). All these units are areas where alluvial and colluvial processes have increased the thickness of regolith and soil.

Unit MS

The lower slopes of this unit face south to southeast and have a complex surface developed from past and contemporary slope movement. Soils are of variable thickness and include rock fragments that have fallen from outcrop upslope. There is active soil creep, particularly in areas of seepage. This unit grades laterally into the colluvial footslope unit (CF).

Unit CF

These are more stable slopes and have a greater soil and regolith thickness. Seepage occurs at sites of lower slope.

Unit AT

These are the areas of thickest regolith. They are former floodplains comprised of silty clay with lenses of fine sand and silty sand. The surfaces are flat to gently sloping with shallow depressions marking the course of prior stream channels. They are deeply incised with narrow, active channels draining from the surface and seepage from the adjacent slopes. Upslope they merge with the CF unit, while the downslope edge is marked by a distinct low escarpment above the modern floodplain or creek channel.

Unit MF

This is a narrow unit bordering the stream channels. The soils are broadly similar to those of the alluvial terraces but are more variable with gravel lenses and wood fragments.

2.5 Landform Dynamics

Landscape processes are determined by the rapid rate of rock weathering, high annual rainfall and steep slopes. Exposed or buried rock is already deeply weathered and rock fragments are readily broken down. There are minimal areas of surface stone and not much stone in the soil profile. A major, active slope failure occurs on a steep slope on the northern property boundary where a deep rotational slump above Foster Creek has developed an elongate hummocky toe. Surface soil creep, as indicated by terracette development, is widespread but not universal, and is best developed on steeper slopes with south to southeast aspect. Soil creep is episodic and appears here to be a result of soil moisture loading causing lateral movement, rather than a result of soil heaving with wetting and drying. Soil creep may also result from rising water tables causing soil saturation. Soil creep movement affects the upper soil rather than the whole soil profile and the rate and extent of movement appears to decrease with soil depth.

Fig 1 Topography (Digital Terrain Model) and drainage of the Strzelecki Ranges around the study site.

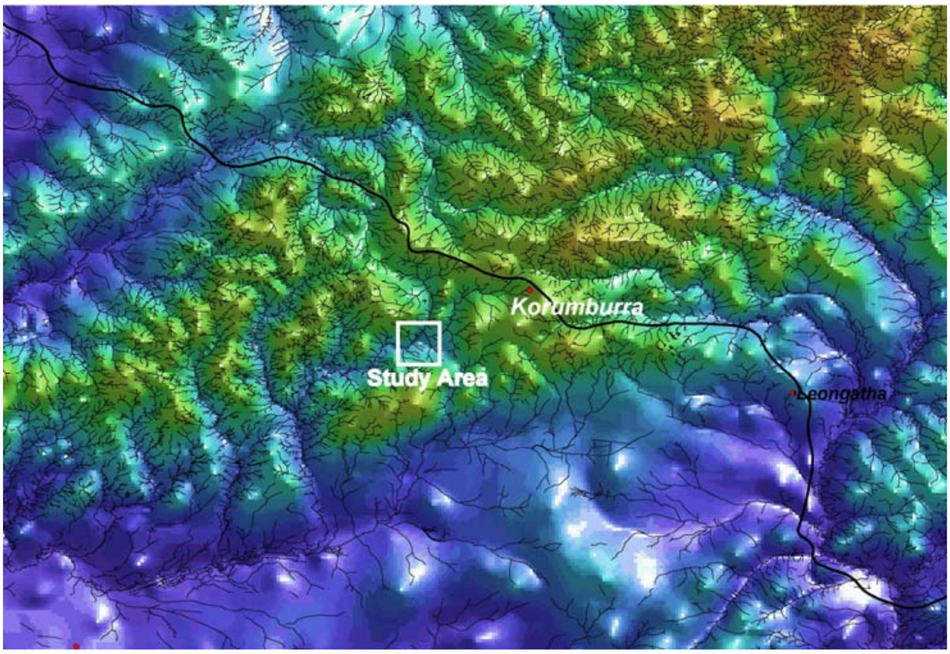


Fig 2 Topography of study site shown by 10 metre contours. Cross section is drawn along line A-B.

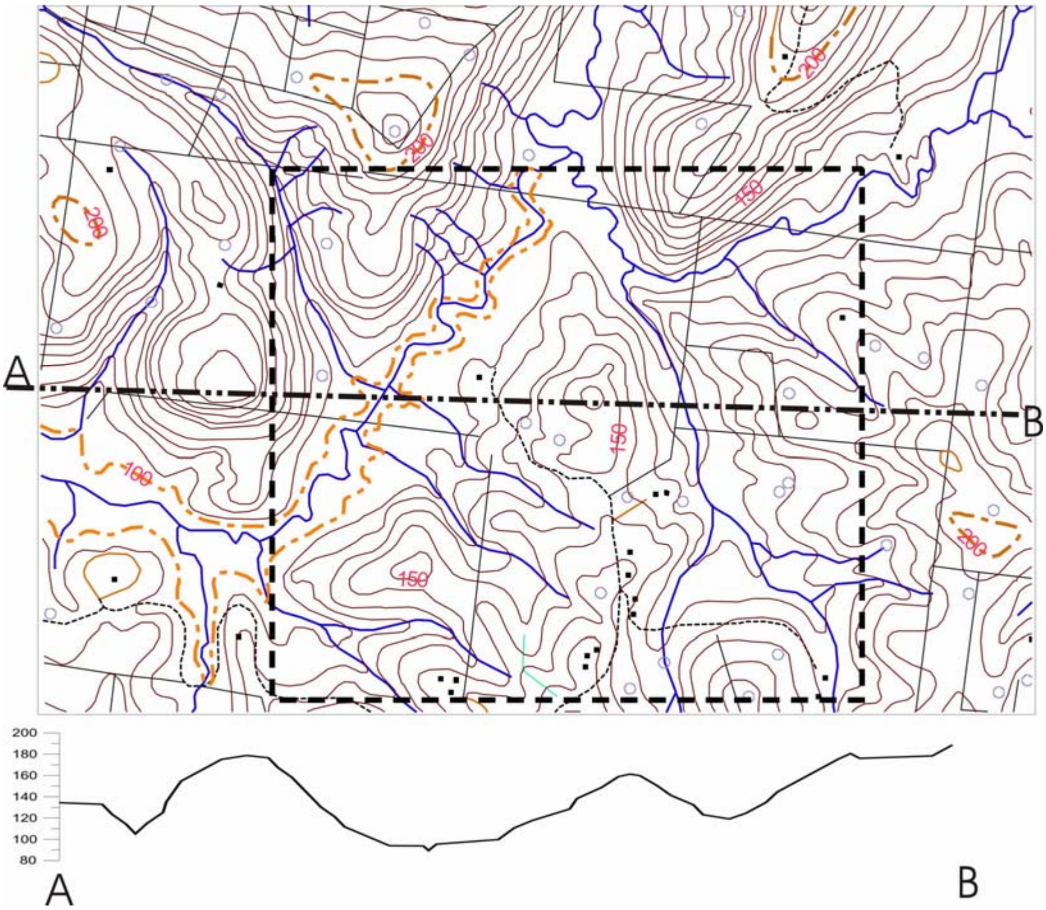
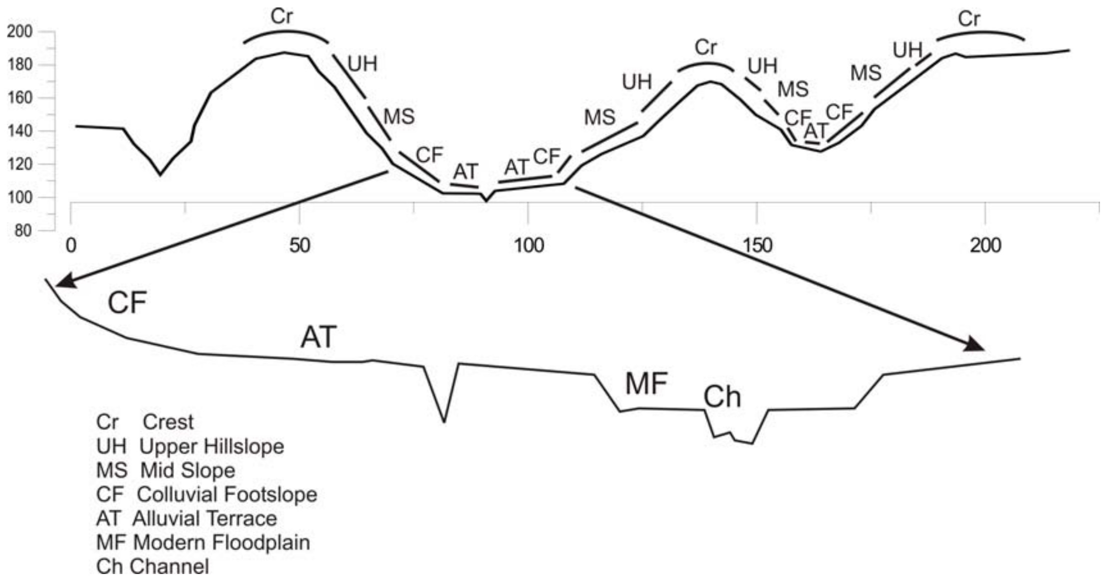


Fig 3 Orthorectified vertical aerial photograph taken November 2002, showing 10 metre contours and drainage lines.

Fig 4 Geomorphological units shown on a topographical profile (see also Figure 2).



3. RESULTS

3.1 Management History

A major historical consequence of converting the study site into pasture has been to increase the rate of run-off, particularly during storms by removing the rainfall interception once provided by the forest canopy. This has increased the quick-flow of streams and provided more energy for streams to incise channels and to scour the bed and banks of alluvial material. This process has affected the Foster Creek and tributaries, causing deepening and widening of the main channels and exposing bedrock on the channel floor. A further consequence of this would be an increase in the rate of surface and groundwater drainage and probable lowering of the water table. However, this would in part be offset by the lowered transpiration demand as a result of removing the forest canopy and suppressing tree regeneration. Overall, surface and ground water movements are now probably more volatile than prior to European settlement. The rate of soil loss by surface wash and soil creep would also have increased with exposure of the soil surface and removal of the retraining factor provided by tree roots. Soil loss would have increased in the immediate post-clearing time but then stabilised as sown pasture has been maintained.

There is no information available on the management of the property before 1947. It has been operating as a dairy farm since at least 1947. In 1947, the property had around 38 milking cows and up to 50 stock in total, and this increased to about 100 cows in the 1970s. Today the herd is around 200 milkers in addition to some young cows. This is considered to be a low to average stocking rate for the region (B. Enbom pers. comm.). The average stocking rate for the region is 2.5 cows/ha (Sargeant *et al.* 1996).

Approximately 2/3 of the property has been ploughed at various stages but not on a regular basis. In the past, ploughing was done with horse and plough, and only small sections were ploughed at one time, usually in spring and summer. The soil was ploughed to a depth of around 4 inches. In the 1980s, there was some strategic ploughing for fodder crops and re-sowing of pasture. No ploughing has occurred for the past 8 years.

Fertilisers have been applied annually and lime added approximately every 5 years. In general, the creek banks were not fertilized. There have been small scale trials of organic fertilisers to encourage microbial activity. No pesticides have been used but there has been spot spraying of herbicides for the control of blackberries and other weeds. Irrigation is not practiced on this property.

Little remnant vegetation remains on the property apart from some large eucalypts. The property supports the threatened Strzelecki Gum (*Eucalyptus strzeleckii*). Some creek banks and gullies have been revegetated and fenced based on advice from the Powlett Project Land Care Group and Greening Australia. Planted areas include an overstorey of around 20% consisting of Mountain Grey Gum (*Eucalyptus cypellocarpa*), Manna Gum (*E. viminalis*), Messmate (*E. obliqua*), Swamp Gum (*E. ovata*), Strzelecki Gum (*Eucalyptus strzeleckii*) and Blue Gum (*E. globulous*). The understorey is composed of a variety of plants including Hazel Pomaderris (*Pomaderris aspera*), Daisy Bush (*Olearia* sp.), Blackwood (*Acacia melanoxylon*), Silver Wattle (*A. dealbata*), *Kunzea* sp., and *Hakea* sp., in addition to *Lomandra* and grasses such as *Poa* sp. Cypress trees have been planted as wind breaks and in several areas prone to tunnel erosion.

3.2 Landscape and Land Use Changes Since 1947

Landscape and recent land use change on the study site was evaluated by comparing two vertical aerial photographs taken 16 November 2002 [colour] and 10 December 1947 [black and white] (Fig 5). Both photographs were enlarged 6 times from original to a scale of 1:25 000.

The 2002 photograph was orthorectified and overlain with the 10 metre contours from the state digital topographic data base.

The most evident changes are:

- A number of large (probably native) trees along the banks and floodplain of Foster Creek have gone. There is an increase in the continuity and density of tree and shrub vegetation lining the creek, but this has probably had little impact on the flow dynamics of the creek as much of the stream bank is exposed and undercut. There are now a number of windbreaks (exotic species) planted on the slopes above the floodplain.

- The north-flowing tributary of Foster Creek (east of the Enbom's farm house) was an active gully in 1947 with bare bed and banks and very little bordering vegetation. It is now fenced and revegetated and a formerly extensive area of sheetwash above (west) the gully has also been reclaimed.

- There are several small dams in some of the drainage lines.

3.3 GGE distribution at study site

For the purposes of this study, a GGE earthworm population is defined as an area in which GGE's appear to be relatively isolated from other areas supporting GGE's. An active GGE population refers to sites where GGE gurgles were heard.

The current study found active GGE 'populations' at 6 sites (Fig 6). These included sites in;
a) minor stream banks/drainage channel (revegetated) (Plate 1)
b) minor stream banks/drainage channel stream banks (open) (Plate 2,3)
c) alluvial terraces above the present flood plain (Plate 4)
d) steep terraced south facing slopes (Plate 5)
e) colluvial footslope without terracettes (Plate 6)

The landowner knew of three areas on the property where he had observed GGE in the past. There was also one site that the landowner knew that GGE had become locally extinct; GGE were observed during grading and construction of a culvert at this site 25 years ago. The grading directed and concentrated the movement of cattle traffic towards the newly constructed track and over the drainage channel. This resulted in the GGE site receiving a large amount of cattle traffic resulting in heavy pugging and compaction of the site. Only a few GGE were dug up and killed during the earthworks.

Old GGE burrows were also found at a site of a slope failure some 5 years previously (Plate 7). However, no signs of earthworm activity were visible and the earthworm appeared to no longer be present at the site.

Each of the different habitat types can be used to illustrate various geomorphological/landscape features that may play a role in influencing GGE distribution. Each may require different management considerations for GGE conservation.

a) Revegetated creek bank

GGE were observed along this small tributary of Foster Creek by the landowner approximately 50 years ago. The creek was revegetated 8 years ago with wattles, gums, daisy bush etc. During the current survey the GGEs were found in the more open areas in the shallow embankment adjacent to the creek (see Plate 1). GGEs were absent from areas that are submerged when the creek channel is flowing. A small number of burrows were found further up the embankment, mainly in the more open sections, which supported relatively dense vegetation in parts. It is not clear whether these old, unused burrows were present before the site was revegetated or whether they did support GGE not located during sampling. The soil in the embankment was significantly drier and contained a large number of tree roots.

Management implications

- High density revegetation of stream banks and gullies may have a negative effect on GGE populations.

b) Minor creek bank

GGE were located along several tributaries and drainage lines into Foster Creek. These sections were either lightly vegetated with scattered remnant eucalypts (understorey) or consisted of pasture with little overstorey (see Plate 2 & 3). No GGE were found on the banks of Foster Creek in the areas of current flood regimes. These soils were dominated by coarser and sandier soils and are apparently unsuitable for GGE.

Management implications

- Manage stock access in wet soil conditions to reduce excessive pugging caused by concentrated cattle access to one section of creek.
- Changes to the flow regime of tributary creeks may reduce habitat area and quality by increasing or decreasing the incidence of flooding.
- Increased submergence time may cause a rise in the water table leading to waterlogging of previously aerated soils
- Divergence and drainage may have the opposite effect leading to excessive drying of soils.

c) Alluvial terraces above the present flood plain

This habitat type occurs where streams have incised channel into alluvial material over time forming terraces above the flood plain of the creek (see plate 4). The soil is of a more silty nature.

Management implications

- Maintain existing overland flow (natural runoff) and flow regimes in channels to avoid waterlogging or dehydration of soils.
- Manage stock access in wet soil conditions to reduce excessive pugging and soil erosion caused by concentrated cattle access to the flood plain.

d) South facing hillslopes with terracettes

Several south facing hillslopes with varying degrees of micro-terracing were observed at the study site. However, not all of them supported GGE populations. Two adjacent south facing slopes, both with well-developed teracettes, were examined. One site supported a relatively extensive GGE population (see Plate 5), whereas no GGE were located at the other site. The major difference in the two sites was the soil substrate. The site that did not support GGE was very steep (approx 30^o) and had a very rocky substrate with shallow soil. The hillslope supporting GGE was not quite as steep, had a much deeper soil profile without stony colluvial debris. Size (depth and width) and activity of terracettes may be important indicators of potential GGE habitat. The terracettes present an irregular surface that provides temporary pondage during run-off, allowing retention and recharge of soil moisture.

Management Implications

- Manage stocking rates to reduce excessive pugging and soil erosion.
- Maintain natural water flow and recharge at top of hillslope to ensure appropriate hydrological patterns for GGE are maintained.

e) Small colluvial footslope without terracettes

This site was brought to our attention by the landowner when he was advised of the common co-occurrence of yabbie mounds and the GGE. He knew about the yabbie mounds but he did not consider this a GGE site. The site is a small, very exposed south facing colluvial footslope located above a very minor a drainage channel/soak. (see Plate 6). The site was at the base of a very large catchment. The GGE were very localised at this site and confined to approximately a 30 m strip adjacent to the drainage line.

Management implications

- Avoid regrading the slope and maintain the existing runoff from upslope.

3.4 Occurrence of GGE in relation to geomorphology of the study site

Examination of the geomorphological characteristics of the habitat types in which the GGE were found has revealed several factors that appear to influence GGE distribution. These are;

- GGE are located in areas where regolith (soil and decomposed rock) is at least 1.0 m thick and generally is greater than 1.5 m thick.
- The greatest density occurs in areas where the regolith is party or wholly composed of alluvial accumulation.
- The alluvium is silty clay or very fine sandy clay that is weakly stratified and over 2.0 m thick.
- This alluvium occurs as level to gently sloping surfaces of former floodplains (terraces) of Foster Creek elevated ±10 metres above the bed level of Foster Creek.
- The alluvial terraces are areas of seepage and several springs occur at the upper edge of the terrace. The springs are not GGE sites but sites occur below the springs on the better-drained areas of the terrace.
- The alluvial terraces are incised by steeply cut drainage lines that provide a means of lowering the water table of the terraces.
- The terraces show little other surface topography – they do not have terracettes and are therefore very stable.
- Other dense GGE sites occur on steep ($\pm 20^0$) lower hillslopes and colluvial slopes with south-east, south and south-west aspects.
- Many of these slopes have a substantial terracette development but GGE are not found in sites where there is stony colluvial debris.
- These sites are damp, partly due to aspect but also as a result of the irregular terrace surface providing temporary pondage during runoff, and thus allowing retention and recharge of soil moisture.
- GGE did not occur on the lowermost, active floodplain or in the banks of Foster Creek.

Fig 5 Vertical aerial photographs taken November 2002 (top) and December 1947.

Fig 6 GGE sites shown on topographical map of study area (above) and orthorectified aerial photograph of study area (below).

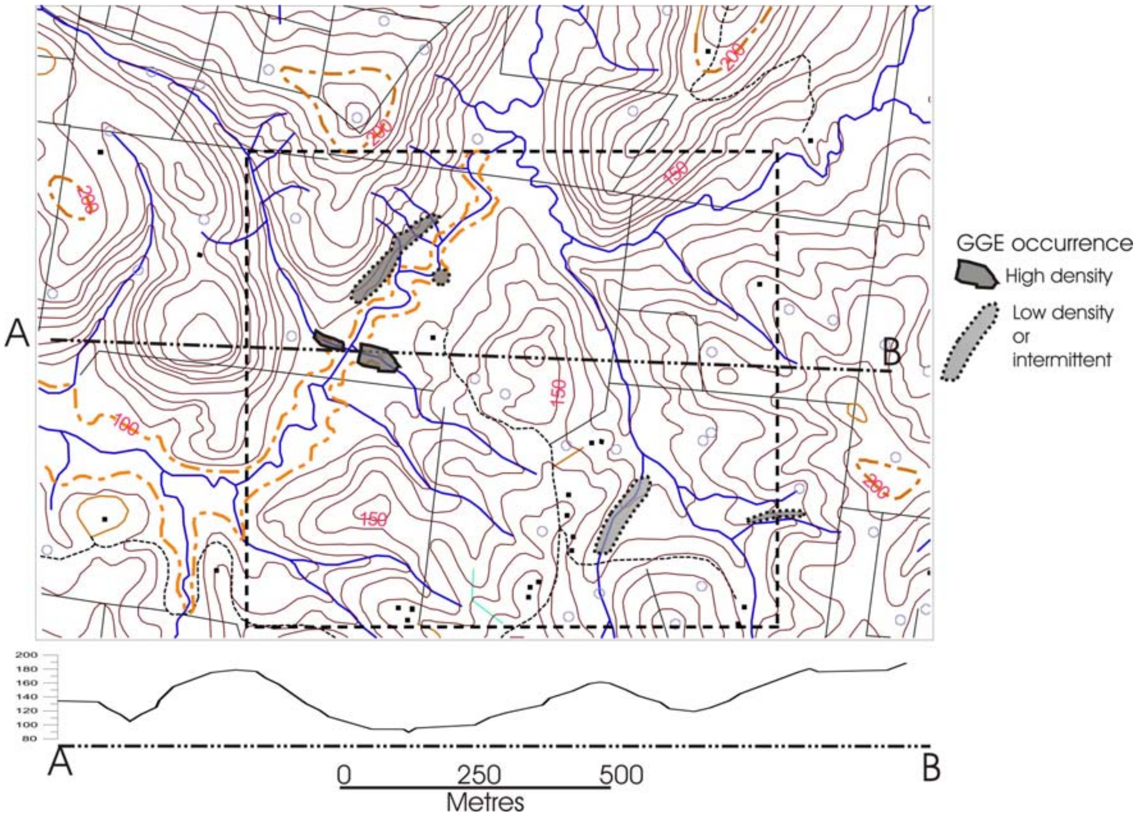


Plate 1. GGE site- revegetated drainage channel.

Plate 2. GGE site- tributary of Foster Creek (open habitat).

Plate 3. GGE site- drainage channel with small amount of remnant vegetation.

Plate 4. GGE site- alluvial terrace above present flood level.

Plate 5. GGE site- south facing slope with terracettes.

Plate 6. GGE site- colluvial footslope without terracettes.

Plate 7. Site of landslip where old GGE burrows observed.

4. DISCUSSION

4.1 GGE distribution in relation to past and present land–use

The current distribution and abundance of the GGE would have been determined by (a) pre-European landscape factors; (b) immediate changes associated with European settlement; and (c) past and present agricultural activities.

a) Pre-European settlement landscape factors

The pattern of GGE distribution pre-European settlement is not known. It is most likely to have been influenced by large scale landscape processes that determined availability and suitability of GGE habitat although suitable habitat need not have been occupied by GGE. The main factors are topography, soil dynamics, catchment size, hydrological processes, degree of vegetation cover, and fire.

b) Land form changes associated with European settlement

Since the mid 1800's, extensive forest clearing, introduction of grazing animals and the maintenance of a more-or-less continuous ground cover of sown pasture has greatly altered the surface and sub-surface hydrology of the Strzelecki Ranges. The landform changes resulting from settlement are most likely to have been an increase in the occurrence of rapid and extreme events, such as flooding, sediment movement from stream bed and banks and large slope failures. There has been soil loss from upper and steeper slopes and accumulation on the lower slopes, terraces and floodplain. Weathering rates, although relatively rapid, are still too slow to have compensated for soil loss on upper slopes. Although this means the soil profile on these upper slopes is thinner, there is clear soil profile differentiation as new topsoil soil horizons have formed from the biomass provided by crop and pasture plants over the past 100 years or more. Similarly, as the soil material washed onto the lower slopes and terraces was originally topsoil from upslope, the impact on the residual soil has been less severe than if this transported debris was stony or from subsoils. The direct impact of these changes on GGE's is not known. It is possible that some of the subsurface hydrological changes, for example, increased soil moisture in some areas may have been beneficial to the species.

The effects of initial vegetation clearance on soil habitat would have been pronounced in the upper soil horizon where increased exposure after tree removal would have resulted in decreased moisture levels. However, the deeper soil horizon primarily occupied by GGE would have been buffered from the initial changes in soil micro-climate and probably experienced an increase in available moisture due to the absence of large trees transpiring and removing soil moisture. The GGE's are non-selective, geophagous feeders, relying on organic matter, bacteria and fungi digested from soil passed through the gut. This generalised diet and their depth in the soil profile may have enabled them to tolerate (even benefit from) the change from forest to permanent pasture.

c) Past and present agricultural activities

We do not have a clear understanding of the effects of agricultural activities on GGE populations. These activities may lead to different interacting factors that affect physical and hydrological properties of the soil that in turn affect the GGE. Furthermore, it is difficult to identify specific factors because each type of activity is a complex combination of factors. The following is a list of agricultural activities with potential adverse effects on the GGE.

Cultivation

It is known that physical damage to GGE's or to GGE habitat can result from cultivation (ploughing). The effects of cultivation on the GGE will be dependent upon the time of the year in which it occurs; detrimental effects will be greatest if cultivation occurs when the soil is wetter and GGE are more active closer to the surface. It could also destroy GGE egg capsules which are generally located closer to the surface.

Cropping
The establishment and management of fodder cropping and commercial cropping could affect GGE habitat either through cultivation (discussed above) or through application of chemicals (insecticides and herbicides).

Stock
The activity of stock, especially cattle, can affect the GGE. Pugging caused by either high stocking rates or high stock activity on wet soils and stock activity near streams and gullies that may lead to soil erosion are adverse effects of inappropriate stocking. Stocking rates may be particularly important on the steeper hillslopes supporting GGE populations.

Chemicals
Chemical inputs may affect soil moisture availability and chemistry, changing of soil pH from acidic to more alkaline (e.g. addition of fertilisers, pesticides, weedicides, animal drenches). However there is no information regarding the impact of these chemical inputs on GGE survival.

Farm infrastructure
This includes roadways (tracks), dams, ponding and buildings. Roadways introduce impenetrable surfaces (e.g. hard rock/fill) that may present a barrier for GGE movement; dam construction may locally increase the water table upstream, ponding for effluent treatment may result in introduction of inappropriate chemicals, and dairy sheds may change movement patterns of animals and run-off, as well as producing effluent and chemicals.

Tree planting
One of the key recommendations for conserving GGE's has been to replant known sites with indigenous vegetation. This was based on the assumption that most native species would benefit from restoration back to their original habitat. However, the precise areas occupied by the GGE within their original forested habitat are not known. It is possible that they were found in the more open areas of the forest or in areas of natural disturbance. Distribution of GGE along the more open sections of the revegetated creek and similar findings in other studies at Mt Worth State Park where the species was found in the open pastured areas and clay service tracks adjacent to native vegetation (Van Praagh and Hinkley 1999) tends to support this. Spacing of the large mature trees in the original forest may present a quite different environment than that created when stream banks and gullies are more densely replanted with shrubs, trees and grasses. It is thought that pre-European settlement, the area was covered by wet forest – continuous canopy cover, but old forests probably dominated by fewer larger trees with more open understorey. The ground layer was more grassy and with more logs and coarse woody debris. The thick regrowth often associated with this type of wet forest was due to fires, but the area did not experience many fires, and most of the forest was thought to be mature. The lower slopes were dominated by *Eucalyptus strzeleckii* and higher slopes probably *Eucalyptus regnans* (David Cameron and Josh Dorrough, pers comm. 2004). The GGE may not be dependent on the presence of native vegetation for survival. However, whether revegetation of earthworm habitat is actually detrimental to the species is unknown at this stage.

4.2 GGE at the study site

Active GGE populations were found at 6 sites in the 148 ha farm, in 4 distinct habitat types including minor creek lines, flat to gentle sloping alluvial terraces above present flood levels, steep south facing hillslopes with terracettes and a small colluvial footslope without terracettes.

Examination of the GGE distribution in relation to geomorphology of the farm site identified various landscape features that may play a role in influencing GGE distribution:

- The nature and depth of the soil (GGE prefer deep alluvial soils of a silty clay nature, absent from sandy soils and floodplains).
- The aspect of steep slopes (south).

- Slope and micro-topography of the steep hillslopes (presence of terracettes providing increased soil moisture through temporary pondage during run-off).
- Site hydrology- ground water levels and seasonal changes.
- Density of re-vegetation may also impact upon GGE populations with earthworms found in the more open sections of re-planted stream bank.
- Association with streams but not channels and active stream banks.

Each of these geomorphological processes may require different management considerations for GGE conservation. Specific management recommendations for the habitats identified at the study site are outlined below:

Revegetated creek bank

- High density revegetation of stream banks and gullies may have a negative effect on GGE populations.

Minor creek bank

- Manage stock access in wet soil conditions to reduce excessive pugging caused by concentrated cattle access to one section of creek.
- Changes to the flow regime of tributary creeks may reduce habitat area and quality by increasing or decreasing the incidence of flooding.
- Increased submergence time may cause a rise in the water table leading to waterlogging of previously aerated soils.
- Divergence and drainage may have the opposite effect leading to excessive drying of soils.

Alluvial terraces above the present flood plain

- Maintain existing overland flow (natural runoff) and flow regimes in channels to avoid waterlogging or dehydration of soils.
- Manage stock access in wet soil conditions to reduce excessive pugging and soil erosion caused by concentrated cattle access to the flood plain.

South facing hillslopes with terracettes

- Manage stocking rates to reduce excessive pugging and soil erosion.
- Maintain natural water flow and recharge at top of hillslope to ensure appropriate hydrological patterns for GGE are maintained.

Small colluvial footslope without terracettes

- Avoid regrading the slope and maintain the existing runoff from upslope.

When management on the study site over the last 50 years is considered, there is only one known instance where a known GGE population has become extinct through agricultural activity. This involved concentrating movement of cattle to use one crossing point over a stream. The study site has been subject to fairly low level stocking rates and very low levels of cultivation. At least one population of the GGE known to the landowner has survived for over 50 years. Old GGE burrows were also found at a site subject to a landslip some 5 years previously (and this landslip may have been due to either cattle trampling near the gully and/or altered hydrology due to vegetation clearance). However, no signs of earthworm activity were visible and the earthworm appeared to no longer be present at the site.

5. CONCLUSIONS

The GGE has co-existed with agricultural land use for over 100 years, apparently surviving major changes to its habitat mostly associated with agricultural development and expansion. However, the overall effects of these habitat changes on GGE survival and distribution are not clearly understood. Identifying the effects of agricultural and land management practices on the GGE remains crucial to the conservation management of this species. A key requirement in furthering our understanding of threatening processes on GGE populations is to more clearly understand the factors responsible for influencing earthworm distribution.

Active populations of GGEs were found at 6 sites in 4 distinct habitat types within the study site. These included; minor creek and drainage lines, flat to gentle sloping alluvial terraces above present flood levels, steep south facing hillslopes with terracettes and colluvial footslopes without terracettes. Examination of the GGE distribution at these sites in relation to geomorphology of the farm site identified various landscape features that may play a role in influencing GGE distribution. These include the nature and depth of the soil, slope, micro-topography and aspect of the steep hillslopes, in addition to site soil and surface hydrology. Density of revegetation may also impact upon GGE populations with GGE found in the more open sections of the re-planted stream bank. Each of these habitat types is influenced by different geomorphological processes and may require different management considerations for GGE conservation.

The main processes identified that may require mitigation for GGE conservation include soil erosion, changes in soil and surface hydrology, and micro-topography of slopes. Agricultural activities that may contribute to these processes include: cultivation, stocking rates (pugging), infrastructure development, water run-off, effluent production and treatment, dams and drainage. The density and nature of revegetation of GGE habitat may need re-considering.

Management options for GGE conservation are to be developed jointly with DPI Agriculture staff, land-holders and other key stakeholders in the final phase of the project. GGE are often very localised in their distribution; hence managing and protecting populations by abatement or exclusion of threats can be feasible and effective. Farmers will usually be able to include habitat protection in their property plans (e.g. for pasture development, fence lines, tracks, drainage, dam construction) to assist conservation of the GGE. However, broader landscape factors, such soil hydrology dynamics upslope of a GGE site, could have major local impacts on GGE populations.

The results and recommendations from this study are limited by the difficulty in obtaining replicable quantitative data for a threatened subterranean species. Any attempts to quantify sampling techniques to obtain valid statistical data may have resulted in the destruction of local populations of the GGE. Therefore some of the results are more hypotheses that need to be tested in the future by undertaking similar studies on a much larger number of farms.

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APPENDIX 1. Geology and Geomorphology of Worm Environments on the Headwaters of Foster Creek

Context

The area studied lies inside the Strzelecki Ranges (also referred to as the South Gippsland Hills), a major geomorphological subunit of the Southern Uplands of Victoria. The Southern Uplands (including the Otway and Hoddle Ranges), is a distinctive geological and topographical domain in Victoria. They are comprised dominantly of Mesozoic (Lower Cretaceous) terrestrial volcanogenic sandstones (sediments derived from rapid denudation of nearby erupting volcanoes), deposited in wide, shallow river channels and on bordering floodplains, swamps and small lakes. They are rich in volcanic rock fragments and feldspar minerals and contain only minor quartz fragments. They occur as fault-bounded, northeast-trending structural blocks with well-defined geological and topographical boundaries. They are landscapes of hills and elongate ridges, typically soil-covered with narrow alluvial valleys. The best rock exposure is on coastal cliffs and shore platforms between San Remo and Inverloch, Inland, apart from road and rail cuttings and quarries, outcrop is restricted to occasional upper slopes and stream channels.

The Strzelecki Ranges

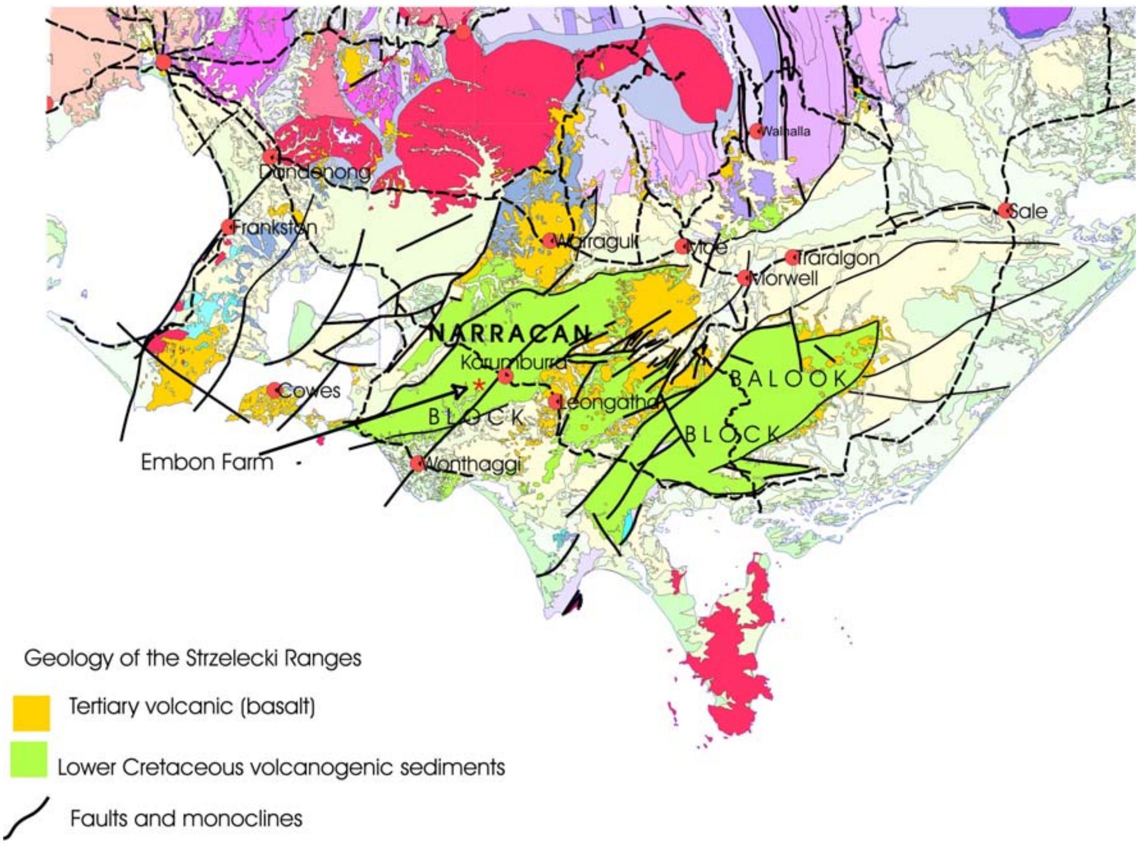
The Strzelecki Ranges is a well-defined structural and geomorphological region east of Westernport Bay and south of the LaTrobe Valley (Appendix 1.1). There are two main geological units elongated northeasterly and bounded by faults and monoclines - the Narracan Block and the Balook Block. These form three broad landform subunits:(a) the western Strzeleckis, a dissected area of rounded ridges and straight to convex valley slopes, comprising the catchment of the Bass River to the west and the Powlett River to the south; (b) a central zone of more diverse topography including tablelands and areas of subdued relief of the catchment of the Tarwin River; (c) the eastern Strzeleckis between Morwell and Yarram, an area of deep dissection with narrow interfluves and very steep valley slopes of the Morwell River and Albert River catchments.

The basement geology of all three units is Strzelecki Group sedimentary rock of Lower Cetaceous age. The dominant material is coarse to fine-grained sandstone with minor siltstone and mudstone and thin, discontinuous black coal seams. Beds are thin (10cm) to massive (1 metre or more) with little variation in composition and structure. As a broad geological unit, the rocks have traditionally been referred to as arkose, suggesting that feldspar is the dominant mineral. Although feldspar is an important component, the major clastic constituent is lithic (rock) fragments of various volcanic rocks, apparently derived from contemporaneous explosive volcanic activity and deposited rapidly in subsiding terrestrial basins. Hence the term volcanogenic sediments or volcanic litharenites are more correct to describe the Strzelecki Group. Post-deposition, the Strzelecki Group beds have been uplifted and undergone east-west compression. This has resulted in doming and tilting of the rocks producing gently dipping beds and broad monoclinal folds and the elongate faults that define the margins of the structural blocks.

Extensive, deeply weathered basalt lava flows occur along the northern margins of the Narracan Block around Warragul and Thorpdale, and as scattered remnants in the central Strzeleckis northeast of Leongatha and around the northeastern edge of the Balook Block at Carrajung. There are no basalt remnants at Korumburra or in the Strzeleckis to the west and south including the present study area.

The composition of the Strzelecki Group beds (high proportions of feldspar and low silica minerals and with only minor quartz), means the beds weather rapidly. Slope form is straight to convex and slope angles of 25^0 to 30^0 are common. Thicker, resistant beds produce minor escarpments. Although there is a widespread regolith cover one to 1.5 metres thick, soils are relatively thin as the steep slopes and high rainfall combine to produce rapid rates of mass movement at various spatial and temporal scales. Topsoils are light silty clay loam, predominantly with light to medium clay subsoils. Elongate, sub-parallel and converging terracettes ("sheep tracks") with treads up to one metre wide and risers 30cm to 70 cm high are common. Terracettes are or compound origin, and while animal treading certainly maintains a flattened and bare upper surface, the incipient patter was probably formed prior to clearing and introduction of grazing animals. This suggests that slow surficial movement has been a long-term process in this landscape. Upper hillslope scars and blocky debris fans indicate sites of larger slope failures.

Appendix 1.1. Geology of South Gippsland showing study area.



APPENDIX 2. Terrain Units of the Enbom Farm Study Area

UNIT (Name & Origin)	ELEVATION RANGE (m)	SLOPE MORPHOLOGY	REGOLITH & SOIL	DRAINAGE	SURFACE CONDITION	PROCESSES
Crest Residual of long term denudation.	200 - 170	Undulating to flat 3^0 - 5^0	≤1 metre Gradational light grey clayey silt to 0.3 m over yellow-grey mottled to medium to heavy-textured clay to >1.0 m over rock and decomposed rock.	Good - low run-on and high runoff. Minimal ponding. Vertical subsurface soil water movement.	Dry. Continuous grass cover. Surface intact and regular.	Wind exposure gives high evaporation rate. Stable surface when vegetated.
Outcrop slope Rocky slopes below crest with outcrop of thicker, resistant sandstones.	±160	Very steep convex to planar ±50^0.	Rock outcrops - pockets of shallow grey-brown silty clay and gravelly clay.	Good	Dry, stony.	Rock fall and slide.
Upper hillslope Denudation slope.	170 - 140	Convex to straight - locally very steep 15^0 - 40^0	≤1 metre Some rock outcrop. Gradational to duplex soils - light grey clayey silt to 0.2m over yellow-grey silty clay to 0.5m over rock and decomposing rock.	Good - local seepage. Impeded on areas of irregular and hummocky slope failure surfaces.	Wet during twinter. Surface irregular to highly irregular.	Transportational slopes - rock fall, soil creep, solifluction, bulk slope failure.
		Straight to weakly		Good - to locally	Wet during winter.	Transportational

Mid-slopes Back-wearing and colluvial accumulation.	140 - 120	concave 10^0 - 15^0	± 1 metre Irregular depth of regolith and soil. Gradational to duplex soils - light grey clayey silt to 0.2m over yellow-grey silty clay to 0.5m over rock and decomposing rock.	impeded. Seepage from upslope and through deposited mass movement material. Surface and sub-surface water movement.	Surface irregular to highly irregular. Poorly compacted colluvium.	and depositional slopes - soil creep, solifluction.
Colluvial footslope Past and modern colluvial slope deposition.	130 - 110	Concave 5^0 - 10^0	≥1 metre Irregular depth of regolith and soil. Gradational grey to grey-brown silty clay to 0.3m over yellow-grey weakly mottled medium to heavy-textured clay to 0.6m over decomposed rock.	Poor - locally impeded. Surface and sub-surface water movement.	Surface irregular - local seepage. Poorly compacted colluvium.	Depositional slopes, soil creep, solifluction.
Alluvial terrace Higher level, former floodplains of Foster Creek and tributaries.	100 - 110	Straight 1^0 - 5^0	1 - 2+ metres. Uniform to stratified brown to grey-brown clayey silt, silty clay, fine sandy silt. Charcoal and rock fragments.	Moderate to poor - locally impeded on clay lenses.	Flat to irregular surface with impressions representing former channels.	Minimal deposition - probably in reach of 100 year flood events. Local recent incision (post-settlement).
Modern floodplain Overbank flow.	±100	Straight, flat.	As above but also gradational grey-brown silty clay to	As above	As above	Irregular deposition.

			0.3m over yellow-grey mottled medium to heavy-textured clay over rock outcrop, gravel.			
Active channels - bed and banks.	±100	Irregular	Banks (as above), sand, logs.	Perennial, intermittent, ephemeral.	N/A	Baseflow, quickflow, bank collapse, channel deposition and incision. Major incision post-settlement.