1. Introduction

The tropical peat swamp forest of the Sungai (River) Sebangau catchment, Central Kalimantan, Indonesia, represents a complex interaction between two different ecosystems – peatland and rainforest. The integrity and structure of this fragile environment is being increasingly threatened by the rampant spread of illegal logging and other associated activities. The main objective of this paper is to investigate the suspected impacts of these practices on the hydrology of the peat dome, which have been outlined by Page *et al*. (1999). As a single ‘ecohydrological unit’ the hydrology of one part of this unit is intrinsically linked to that of another. Furthermore, “one of the most important factors in determining the organic matter accumulation potential of the peat, and the biodiversity and structure of the forest it supports, is hydrological intactness” (Page *et al*., 1999 p.1895). The contention is that the use of extraction canals for illegal logging may significantly enhance the drainage from the peatland dome, thus lowering the water table and affecting the regeneration of the peat swamp trees. The construction of extraction canals and logging skids also leads directly to the destruction of a relatively high proportion of the total forest area, although as yet there is little quantitative data on this. The consequences for the indigenous species are considerable. Successive surveys have repeatedly shown that Orang-utan densities are directly linked to the scale and location of logging activity (Husson *et al*., unpubl.). This study will outline the extent and nature of illegal logging practices within the catchment area and analyse their impacts on the ecosystem.

Fig. 1.1 Indonesia

Fig. 1.2 Kalimantan

1.1 Tropical peatlands

Tropical peatlands cover an estimated 40 Mha of the earth's surface, which equates to some 10% of the total global peatland area. By far the largest area is found in Indonesia, where estimates range from 16 to 27 Mha (Page *et al*., 1999). Most of this is located at low altitude in the coastal and sub-coastal lowlands of Irian Jaya (4.6 Mha), Kalimantan (6.8 Mha) and Sumatra (8.3 Mha) (Rieley *et al*., 1997a). Anderson (1983) has described how these lowland peatlands form extensive, gently domed deposits that can extend for many kilometres and attain thicknesses of up to 20m.

Rieley *et al*. (1997a) have identified two major categories of peatland in Indonesia – topogenous and ombrogenous. The distinction lies mainly in the supply and accumulation of organic material. The former are freshwater swamps in which there is only a shallow accumulation of material (<50 cm), sustained by either riverine or tidal flooding. The latter are said to be true peat swamps (organic matter >50 cm) and are generally found straddling the watersheds between catchments. Their water and nutrient supply is derived exclusively from aerial precipitation (Rieley *et al*., 1997a).

The investigation of tropical peatlands is important for three principal reasons:

1. peatlands globally have acquired increased scientific and socio-economic importance arising from their important role in the global carbon cycle and climate change processes;

2. the forest resource in the tropics is decreasing at an alarming rate thereby increasing the importance of that which remains; and
3. the human requirement for land and an increased standard of living in a region of high population density.

(Rieley *et al*., 1997a, p.42)

Recent studies have also shown that the biological diversity of tropical peat swamp forest, which was formerly considered to be much less significant than that of other terrestrial tropical forests, is in fact quite high (Page *et al*., 1997a).

1.2 Illegal logging and the timber trade in the tropics:

The most common forestry practice in the tropics is selective logging because only a few of the many tree species are commercially marketable. Indonesia, for example, has about 3000 species of trees but only 107 are utilised (Grainger, 1993). While some trees are inevitably damaged and there will be temporary changes in biomass and species composition, if it is managed sustainably then the forest can regenerate over time - perhaps 30 to 40 years (Grainger, 1993).

However in practice this is rarely the case. Even within regulated concessions poor logging practices can cause excessive damage to the remaining trees. Studies in the Philippines and Sabah found that up to 40% of the residual stand was damaged, and in Indonesia the proportion was as high as 50% (Grainger, 1993). Moreover many concessionaries remove more timber than they should, breaching regulations on minimum diameter and minimum number of remaining trees, and sometimes exploiting logged forest again before the concession agreement ends. Soekotjo (1977) found that not one of the nine concessions he studied in East Kalimantan had the required number of trees left behind for the second rotation.

The principal concern now though is the spread of illegal logging, which is rife throughout Southeast Asia. The WWF report *Bad Harvest?* (Dudley *et al*., 1995) shows conclusively that the timber trade is the most important cause of forest degradation around the world. According to World Bank estimates, 5,000 km^2 of tropical forests were logged illegally each year in the early 1990s (EIA 1996). Almost all of the logging for export in Cambodia, India, Laos, the Philippines, and Thailand is illegal (Dudley *et al*., 1995). In Indonesia the situation is not much better. Glastra (1998) reports that more than 85% of concessionaries were breaking logging rules in 1992/3 and that just 30% of the log production in Kalimantan was reported to the government. Similarly Callister (1992) found that in 1989/90 sales of confiscated illegally harvested logs were expected to earn the government around 2.3 million US Dollars. The country has a huge processing industry which far exceeds its ability to supply timber from legal sources and means that it is increasingly dependent on illegal supplies (Glastra, 1998). The government hoped that massive logging schemes in Central Kalimantan and Irian Jaya could relieve the supply problems of the industry (Glastra, 1998).

Qualitatively the impacts of illegal logging are not inherently different from, or worse than the effects of legal activities. However illegal activities aim to maximise profits and so any regulations that might incur additional costs are simply ignored (Grainger, 1993). Grainger (1993) also suggests that illegal logging can create a climate of lawlessness and corruption in which other illegal practices can thrive, such as poaching and the trade in endangered wildlife species.

Plate 1.1 Evidence of illegal logging in the Sungai Sebangau catchment

1.3 The Orang-utan (*pongo pygmaeus*):

The orang-utan (*pongo pygmaeus*) (see Plate 1.2) is one of mankind's closest relatives, yet it could soon be extinct. They were once found all over Southeast Asia, on the islands of the Malay and Indonesian Archipelago, as well as on the mainland. Now the species only survives on the islands of Sumatra and Borneo. Only a decade ago, the estimated population was approximately 27,000; today it has declined dramatically to an estimated 15,000. Orang-utans are threatened by deforestation, poaching, the illegal pet trade, and the isolation of dwindling wild populations (Nadler *et al*., 1995). But of all of these the most significant threat confronting the conservation status of this species is rain forest degradation. Illegal logging, illegal fire starting and the conversion of forests to timber and oil palm plantations have resulted in a loss of over 80% of orangutan habitat over the past two decades (EIA, 1998). One of the differences between this Asian ape and the two African apes (the chimpanzee and gorilla) is that the orang-utan is exclusively dependent upon trees for its existence (Sugardjito, 1995). Many believe it is a miracle that the red ape has survived as long as it has (Nadler *et al*., 1995). It is owing to the coincidence that only after 1970s were much of the rainforests of Borneo and Sumatra subjected to the greed for land and natural resources. It was only recently that the rapidly growing human population, supplemented with transmigrants and aided by timber-exploitation encroached into these refuges and ran into the last surviving red apes. A further problem facing conservation efforts is that the effects of habitat disturbance are often compounded by hunting. As with other primate species, the orang-utan is a source of meat for human consumption in some areas (Nadler *et al*., 1995). Orang-utan skulls have been seen on sale in most of the lager cities of Kalimantan, Borneo (see Plate 1.3). Young apes are also offered for sale as pets. The slow-moving orang-utan makes an easy target for an experienced hunter who can kill his prey from a distance (Nadler *et al*., 1995). In some areas, the forest sustains so few orang-utans that even slight hunting pressure is enough to decimate the local population. As a result of timber cutting activities, moreover, the area became accessible to humans. The more accessible the area, the more rapidly the population disappears (Husson *et al*., unpubl.). Furthermore, the orang-utan prefers exactly those habitats which are preferentially converted to agricultural uses, namely, fertile lowland soils, usually close to the rivers. Recent studies however suggest that viable populations may remain in the extensive peat swamp forest of Borneo – areas like the Sungai Sebangau catchment (Husson *et al*., unpubl.).

Plate 1.2 The Orang-utan (*pongo pygmaeus*)

Plate 1.3 Carved orang-utan skulls

The objectives of this project are twofold. Firstly, to assess the impacts of logging canals on the hydrology of the peat dome of the Sungai Sebangau catchment; and secondly, to quantify the destructive influence of illegal logging on the tropical rainforest in the same area. The following chapter introduces the study area in more detail and provides background information on the local vegetation and biodiversity. Chapter 3 reviews previous literature on both the characteristics and importance of peat swamp forest, and illegal logging activities. Chapter 4 outlines the methods that were employed in the field to gather data. The results are tabulated and graphically presented in the next section and also discussed at some length. The final chapter summarises the project findings, interprets their significance and also looks at possible management strategies for the future.

2. Study Site

Research was carried out in the 500km^2 Natural Laboratory, a semi-protected area of tropical peat swamp forest in the northern Sungai Sebangau catchment about 15 km south of Palankaraya, the provincial capital of Central Kalimantan.

Fig. 2.1 The Sungai Sebangau catchment

2.1 Peat swamp forest types:

The Natural Laboratory is located on an extensive ombrogenous peat dome of the kind which is familiar throughout Southeast Asia. Previous studies (Page *et al*., 1999; Rieley *et al*., 1997a, 1997b; Shepherd *et al*., 1997) have identified the following phasic communities of vegetation stretching from the rivers edge inland:

- Sedge Swamp: this occupies the first kilometre and has replaced riverine forest, which was destroyed by fire (Waldes & Page, unpubl.).
- Mixed Swamp Forest (MSF): This is found between 1 and 3 km from the river and has the greatest species diversity (Anderson, 1964). The forest is tall (up to 35m) and 'stratified' with an open layer between 7-12m and a more closed layer between 15-25m (Page *et al*., 1999; Rieley *et al*., 1997b). The forest floor itself is uneven and is marked by a system of 'anastomosing channels and depression' which drain the forest into the river (Shepherd *et al*., 1997).
- Low Pole Forest (LPF): After kilometre 3 there is a transition from mixed swamp towards a forest characterised by shorter, smaller trees. This low pole forest establishes itself by kilometre 6 and extends for another 5 kilometres. The forest floor is more uneven still and tree growth is concentrated on island-like hummocks separated by permanently waterlogged hollows (Rieley *et al*., 1997b). As a result there are numerous pneumataphores. Again two canopy levels are discernible; a lower closed one between 12-15m and a more open one that reaches a maximum height of 20m (Page *et al*., 1999). There is also a very dense growth of several *Pandanus* and insectivorous pitcher plants (most commonly *Nepenthes ampullaria* – see Plate 2.1) which has been attributed to higher levels of light penetrating the canopy and the permanently high water table (Shepherd *et al*., 1997).
- Tall interior forest: Beyond 12 km from the river the forest type changes once again. In contrast to the general trend of decreasing dbh and height the forest here is dominated by a low density of tall trees with large diameters (Waldes & Page, unpubl.). The species type is more limited though the proportion of commercial species (e.g. *Gonstylus bancanus, Shorea teysmanniana* and *Dactylocladus stenostachys*) favoured by loggers is highest here (Shepherd *et al*., 1997). Rieley *et al.* (1997b) distinguished three canopy

layers: a sparse under canopy at 8-15m, a middle canopy at 15-25m and an additional layer of emergent trees reaching a maximum height of up to 45m. The forest floor also differs distinctly from the other two forest types. It is relatively flat and *pandans* are largely absent. Pneumataphores too are far fewer, a virtue of the fact that the water-table here is permanently below the surface (Page *et al*., 1999). Of most significance however is the fact that this type of forest has not been identified anywhere else in the peat swamps of Southeast Asia (Rieley *et al.,* 1997b).

Plate 2.1 *Nepenthes ampullaria*

2.2 Biodiversity

While there is no question that peat swamp vegetation is less diverse than that of dry land rainforest, the importance of these environments to plant diversity in Southeast Asia has been acknowledged (Whitmore, 1984). A key factor in this argument is that many species of plant (e.g. *Gonstylus bancanus*) are endemic, in other words they are restricted to peat swamp forests. Rieley *et al.* (1997b) explain that, in contrast, accounts of fauna in the same environment have suggested that diversity is low. However a recent study (Page *et al*., 1997a) has shown that, while densities are again lower than in terrestrial dipterocarp forests, the biological diversity of tropical peat swamp forest is in fact quite high. To quote:

> "…this ecosystem has been undervalued as a habitat for several rare and threatened species. It is an important habitat for orang-utan and may play a similar role for other endangered and vulnerable species of mammal and bird." (p.239)

Indeed estimates of orang-utan density in the western Sebangau catchment have suggested that the total population may exceed 6,000 individuals. If true, this would almost certainly constitute the single largest concentration of this species remaining in the world (Husson *et al*., unpubl.).

3. Literature Review

Despite the considerable extent of the peat swamp forests of Kalimantan, previous papers have highlighted the considerable paucity of data that existed on all aspects of the ecosystem, from species composition and structure to hydrology and peat water geochemistry (Rieley *et al*., 1997b; Page *et al*., 1997b). However since the establishment of the Kalimantan Peat Swamp Forest Research Project (KALTROP) in 1993, led by scientists from the Universities of Nottingham and Leicester in Britain and the University of Palangkaraya, Indonesia, much has been done to rectify this situation. Consequently the bulk of literature reviewed in this section is derived from research that has been conducted under the auspices of this project.

3.1 The Importance of Peat Hydrology:

Page *et al*.'s, (1997b) study of peat water chemistry in the Sungai Sebangau catchment revealed quite a high acidity and a low nutrient value that suggests that the peat dome is indeed ombrogenous i.e. the only source of water and nutrients is aerial precipitation. If it is assumed that the chemical composition of rainwater is the same over the whole catchment, then it can be hypothesised that any differences in surface peat chemistry simply reflects variations in nutrient uptake by the vegetation (Shepherd *et al*., 1997). The general consensus is that since the differences recorded in species composition and structure, described by Anderson (1964) as a catenary sequence, cannot be readily explained by reference to peat or peat water geochemistry, then differences in forest type are more likely to be a function of variable peat depth and hydrology (Brady, 1997; Page *et al*., 1997b; Shepherd *et al*., 1997). As Page *et al*. (1999) explain the peat dome should be treated as a single ecohydrological unit. There are two distinct soil layers; the acrotelm and the catotelm. The acrotelm has been described by Bragg (1997) as "a thin living skin within which the system's biological functions are concentrated" (p. 137). Its extent is determined by the depth of the water table and it is the main zone of all significant water movement. The catotelm is the bulk of the peat deposit where the hydraulic conductivity is generally assumed to be negligible (Bragg, 1997). Childs (1969) proposed the following equation to relate the physical dimensions of the dome to the ratio of water supply and hydraulic conductivity:

$$P - E - U_{acr} - U_{cat} - G - \Delta W = 0$$

Where: p = ppt.

E = evapotranspiration

Uacr = acrotelm seepage

Ucat = centrifugal seepage in the catotlem

G = vertical seepage ('leakage')

ΔW = the increase in storage over the period considered

Fig, 3.1 shows how the different peat surface altitudes and gradients strongly influence local hydrological conditions.

Vegetation towards the periphery of the peat dome receives an increased water flow and consequently an increased supply of nutrients and dissolved oxygen. This helps to explain the greater height and girth of trees in the mixed swamp compared to the low pole. To quote Page *et al*. (1999):

> "The most important factors in determining the organic matter accumulation potential of the peat, and the biodiversity and structure of the forest it supports, are hydrological intactness and nutrient availability. The former creates the conditions necessary to maintain a viable peatland system while the latter determines the nature of the forest that can grow upon it." (p.137)

However the importance of the hydrology of the peat dome extends beyond maintaining 'a viable peatland system'. It has been suggested that peat covered catchments also have an important flood control function (Rieley and Page, 1997). By
storing rainwater and regulating the release of run-off, peatlands act as reservoirs which can substantially reduce the effects of flooding downstream. Moore (1974) though, has questioned the significance of this function. His opinion is based on the work of Baden & Egglesman (1954) who compared the water balance of two areas of ombotrophic mire near Hamburg. One area was of intact mire under vegetation dominated by *Calluna vulgaris*, the second adjacent area had been drained in 1912 and was under grass. The results showed that the drained mire had a much more pronounced effect in controlling the runoff than its undrained, natural counterpart. As Moore (1974) explains once a mire is fully charged with water the reservoir has no further capacity and flash runoff may occur. Since any active mire must be fully charged with water for the bulk of the year, a partly drained mire should be more effective in controlling flash runoff. As reasonable as this conclusion is, a heather-covered peatland in Germany cannot compare to the peat dome of the Sungai Sebangau catchment where the presence of a forest canopy has a significant additional effect

on precipitation detention times (Rieley & Page, 1997). Grainger (1993) agrees that the role of forest in regulating flows of water is extremely important. As the KALTROP (1993) statement makes clear:

> "This ecosystem has, … important roles in water catchment, storage and supply and in the mitigation of both drought and flood conditions within the immediate catchment and downstream. These important landscape functions, especially the hydrological integrity of the entire peatland landscape, should be protected." (source: http://www.geog.nottingham.ac.uk/~rieley/kalhome/index.html)

3.2 The environmental effects of deforestation and logging:

The tropical peat swamp forests of Indonesia are of considerable economic value to the country. The unhealthy balance between logging practices and nature and wildlife conservation is evident in Figure 3.1. The main commercial species which are logged include ramin (*Gonstylus bancanus*), which is unique to this habitat, and certain merantis (*Shorea* spp.) (Rieley *et al*., 1997a). Even while the forest was logged under the 'regulated' control of concessions there was concern that the time allowed for regeneration, based on that of terrestrial dipterocarp forests, was too short (Rieley *et al*., 1997a)

Fig. 3.1 The extent of peatlands in Indonesia and their landuse (hectares)

Peat Swamp forest land use	Sumatra	Kalimantan	Irian Jaya	Sulawesi	Halmahera and Seram	Total	%
Unclassified	3,637,150	3,722,600	314,550	NA	NA	7,674,300	38
Unlimited production	2,950,125	312,250	1,892,675	61,125	12,060	5,228,235	26
Production and conservation	822,450	1,994,050	998,250	82,450	47,050	3,944,250	20
Nature conservation	477,225	246,875	646,275	NA	4,890	1,375,265	7

Limited production	199,250	411,350	530,750	77,800	24,150	1,243,300	6
Protected Forest	166,250	100,425	241,650	90,075	9,075	607,475	3
Totals	8,252,450	6,787,550	4,624,150	311,450	97,225	20,072,825	100

Rieley *et al*. (1997a)

However the main concern now, as outlined in the Introduction, is the rampant spread of illegal logging. Using Remote Sensing and GIS (Boehm & Siegert, unpubl.) were able to determine that most of the 44% increase in the logged over area in Central Kalimantan between 1997 and 2000 was attributable to illegal logging.

Grainger (1993) identifies three risks associated with illegal logging: depleting commercial timber species; introducing other species characteristic of secondary forests; and, by modifying or removing animal habitats and food sources, having detrimental effects on animal populations. This last point is of particular importance in the catchment of the Sungai Sebangau. Husson *et al*. (unpubl.) have shown that the disturbance caused by illegal logging has resulted in significant shifts of orang-utans away from these activities, often into areas of sub-optimal habitat. The inevitable overcrowding this promotes leads to ‘increasing stress, juvenile mortality and decreasing fecundity’ (Husson *et al*., unpubl.). Moreover Grainger (1993) suggests that by removing even just a few species from the forest, logging could disrupt the ‘complex annual calendars’ of food sources that enable many rain forest animals, like the orang-utan, to cope with the ‘low density and irregular flowering and fruiting regimes of the plants they eat’. Other plants may also be affected if the animals on which they rely for pollination or dispersal leave to search for food elsewhere (Grainger, 1993). A further threat to the rainforest fauna is the poaching and illegal wildlife trafficking that logging activities encourage and enable.

Grainger (1993) also highlights the risk of erosion that results from the network of skids and logging roads, which can act as convenient channels for increased surface water runoff and soil erosion. His writing is concerned with terrestrial dryland rainforests but a similar scenario may apply in peatland ecosystems. The extraction canals, which are unique to logging activities in this environment, may significantly enhance surface runoff. Furthermore by drying the peat out, they promote drainage and increase the risk of fire (Husson *et al*., unpubl.; Boehm and Siegert, unpubl.).

In addition illegal logging has a direct, destructive impact on the environment. Neighbouring trees are often linked to one another by vines, so felling one tree can bring down or damage others (Grainger, 1993). According to Whitmore (1990) for every tree logged, a second tree is damaged and another is damaged but later recovers. Mabberley (1983) suggests that in Southeast Asia, some third or two-thirds of the residual trees are damaged irreparably while up to a third of the area is left as bare ground. It is simply a question of economics; greater care in extraction would lead to reduced profits. The repeated exploitation of the forest to remove the best species, which characterises illegal logging, can be defined as ‘polycyclic’ (Mabberley 1983). This causes repeated damage to the forest, including the saplings of desirable species, and as Grainger (1993) argues, lead to the genetic erosion of the crop.

Both Mabberley (1983) and Grainger (1993) point out that with the advent of new processing methods the species, age and timber quality of trees, which formerly exercised some control over logging practices, are no longer limiting factors. The demand for pulp for paper is rapidly expected to outweigh that for timber production (Grainger, 1993) and the inevitable result will be a much larger impact on the forest ecosystem.

4. Method

As already outlined in the introduction, the two aims are:

1) to assess the impact of extraction canals on the hydrology of the peat dome;

2) to quantify the damage inflicted on the forest ecosystem by illegal logging activities.

4.1 Extraction Canals:

Investigation of the impact of extraction canals was based upon three main sources of information:
- mapping of the canal network;
- measurement of the canals' hydraulic properties (x-section, flow rate etc.);
- measurement of water tables.

The canal network which criss-crosses the Sebangau catchment is extensive and it was soon realised that it would not be possible to follow the path of every canal in the short time available. It took two days to measure and record just 1 km along a single canal. Fortunately another approach presented itself. KALTROP's research is based at Pt. Setia Alam Jaya, a former logging concession, which ceased production in 1997. The old logging railways provides the basis for two makeshift transects which extend for 24.5 km and 11 km respectively into the interior. For the purposes of estimating orang-utan density, 12 permanent line transects had been cut perpendicular to this former railway at intervals of 1 km (see Fig. 4.1).

These transects provided the ideal opportunity to survey the distribution and density of the canal network over a fairly large area. Six of these transects were followed, in addition to two new ones which were cut during July 2001 (transects 0 and 0.8). In every instance that canals or logging skids were encountered the following measurements were taken:
- Distance along the transect from the railway
- Bearing
- Width*
- Depth (at each bank, and in the middle of the channel)*
- Flow Rate*

*Canals only.

By marking the relative position of the canals and skids along the transect as well as taking a rough bearing it was hoped that it might be possible to establish an outline of the network. Measurements of width, depth and flow rate were intended to provide data on potential discharge. Flow rate was measured by recording the length of time that a small twig took to travel a distance of 5 m. In most instances this was repeated three times to obtain an average.

Information on the depth of the water table was obtained by inserting five piezometers into the peat at regular intervals either side of an extraction canal in Plot 0 (one of ten permanent vegetation study plots established by Professor Rieley) (see Fig. 4.2). These piezometers were 1 m lengths of plastic pipe bought from the local market, into which two sets of ten evenly-spaced holes were drilled, to allow the water to seep in. Readings were taken by inserting a thin bamboo cane into the tubes and then measuring the length of the wetted area (minus the length of pipe protruding from the peat surface). The small diameter of the pipes meant that some water displacement was inevitable, with implications for the accuracy of the readings. However, since this error was constant at each observation, it would not have masked the general trend of the water table across the surveyed distance of 100m.

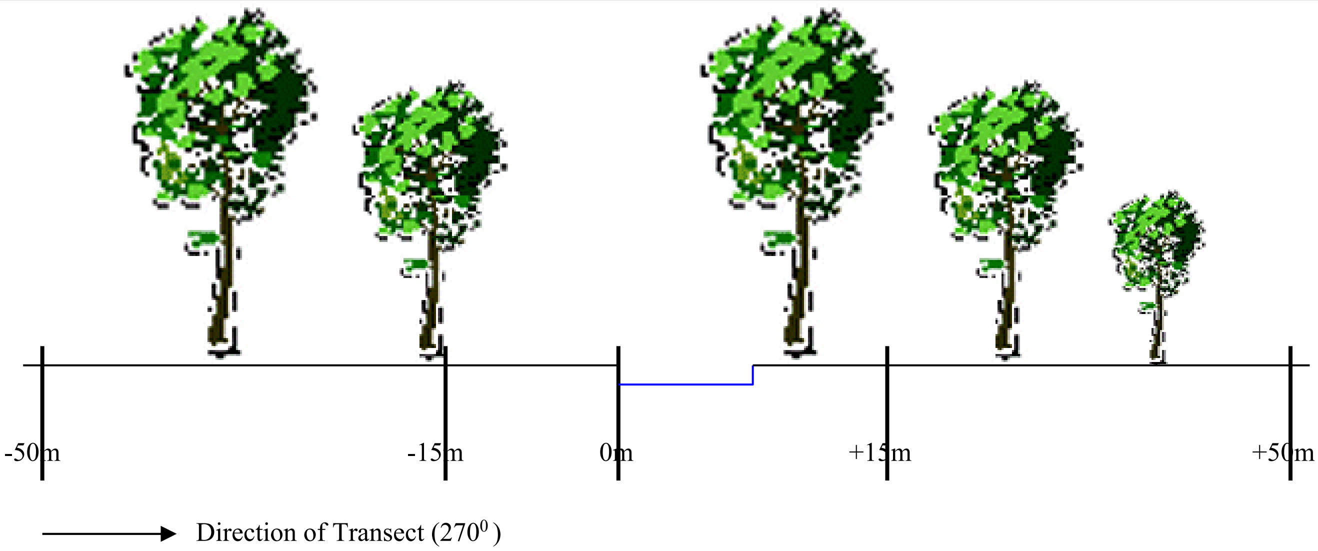


Fig. 4.2 Location of the five piezometers

An effort was made to insert the pipes at the same relative altitude, but given the hummocky nature of the terrain, as described in Chapter 3, this proved quite a difficult task.

4.2 Vegetation survey

The second aim was satisfied by establishing two 30 x 10 m study plots across both a logging canal and a skid in the TIF. These were divided into three 10 x 10 m grids and the location of every tree (with a DBH of more than 5) recorded using a system of xy co-ordinates. Measurements were also made of the following parameters:

- tree height
- DBH (diameter at breast height)
- Canopy diameter

Tree height was calculated using trigonometry, from the angle (x) read off a clinometer at a pre-recorded distance (d) (see Fig. 4.3). 1.5 m was added to this figure to account for the height of the clinometer above the ground i.e. the height of the person operating the instrument.

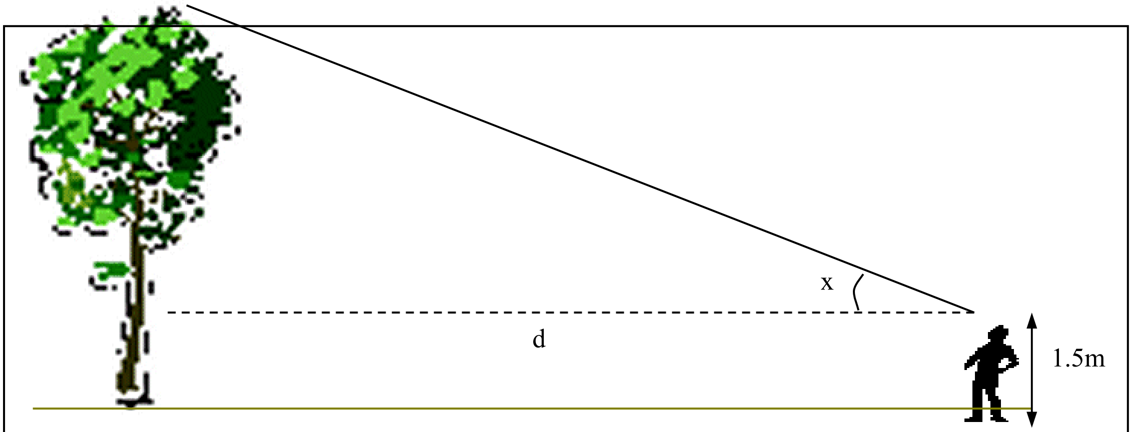


Fig. 4.3 Measurement of Tree Height.

5. Results

In line with the method, the results have been divided into sections that reflect the separate avenues of enquiry. These are:

- **5.1** An example canal path
- **5.2** Canal and skid distribution and density
- **5.3** Canal Dimensions and flow properties
- **5.4** Water Tables
- **5.5** Vegetation Survey

Graphs of orang-utan nest counts and population densities, derived from data in Husson *et al.* (unpubl.), have also been included as a point of interest (section 5.6).

5.1 An example canal path:

Distance from transect (to the right) (m)	Bearing (^{0})
0 - 8	340
8 - 65	360
65 - 77.5	320
77.5 - 138.5	360
138.5 - 165.5	340
165.5 - 231.5	360
231.5 - 255.5	320
255.5 - 335.5	340
335.5 - 413.5	360
413.5 - 450	340
Distance from transect (to the left) (m)	Bearing (^{0})
0 - 10	150
10 - 23	140
23 – 103	190
103 – 204	250
204 – 223	310
223 – 288	270
288 – 303	240
303 – 344	200
344 – 365	230
365 – 393	250
393 – 481	200
481 – 505	180
505 – 559	160
559 - 600	170

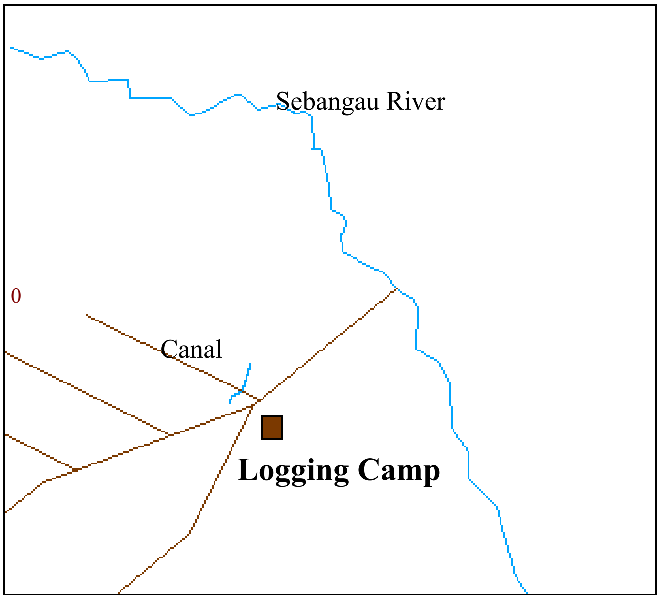


Fig. 5.1.1 Location of the canal

The most important observation from Fig. 5.1.2 is that while the canal is quite sinuous at a small scale, its general trend is to head north towards the Sebangau River. This fact was assumed to apply to every canal and formed the basis for attempts to outline the network, which is presented in the next set of figures.

5.2 Canal and skid distribution and density:

	Canals		Skids	
	Distance along transect (m)	Bearing (^{0})	Distance along transect (m)	Bearing (^{0})
Transect 0	270	340	539	
			865	
			900	
Transect 0.8	67	210	741-850	210
	67	280	1070-1100	340
	77	360	1070-1100	270
	800	232	1100	210
	850	190	1128	200
	1100	290	1140	280
Transect 1	794	305	1100	270
	873	270	1142	315
	921	230	1250	270
	1272	338	1372	330
	1340	300	1400	270
	1445	310	1520	200
Transect 2	425	332	1640	
	674	240	1840	
	732	340		
	1097	350		
	1230	300		
	1260			
	1300			
	1380			
	1390			
	1440			
	1450	230		
	1550	340		
	1940	170		
Transect 3	1405	310	209	195
	1460		211	195
			480	360
			990	360
			1030	
			1105	340
			1220	
			1240	360
			1300	255
			1370	330
			1420	240
			1500	300
			1720	300
			1860	210
			1940	350
Transect 4	1065	320	210	310
	1827	210	240	220
			480	320
			533	360
			660	360
			820	320
			960	340

		970	320
		1305	300
		1325	200
		1410	190
		1700	320
Transect 5	no canals	no skids	
Transect 6	no canals	no skids	

Fig. 5.2.1 The possible canal network between transects 0 and 1

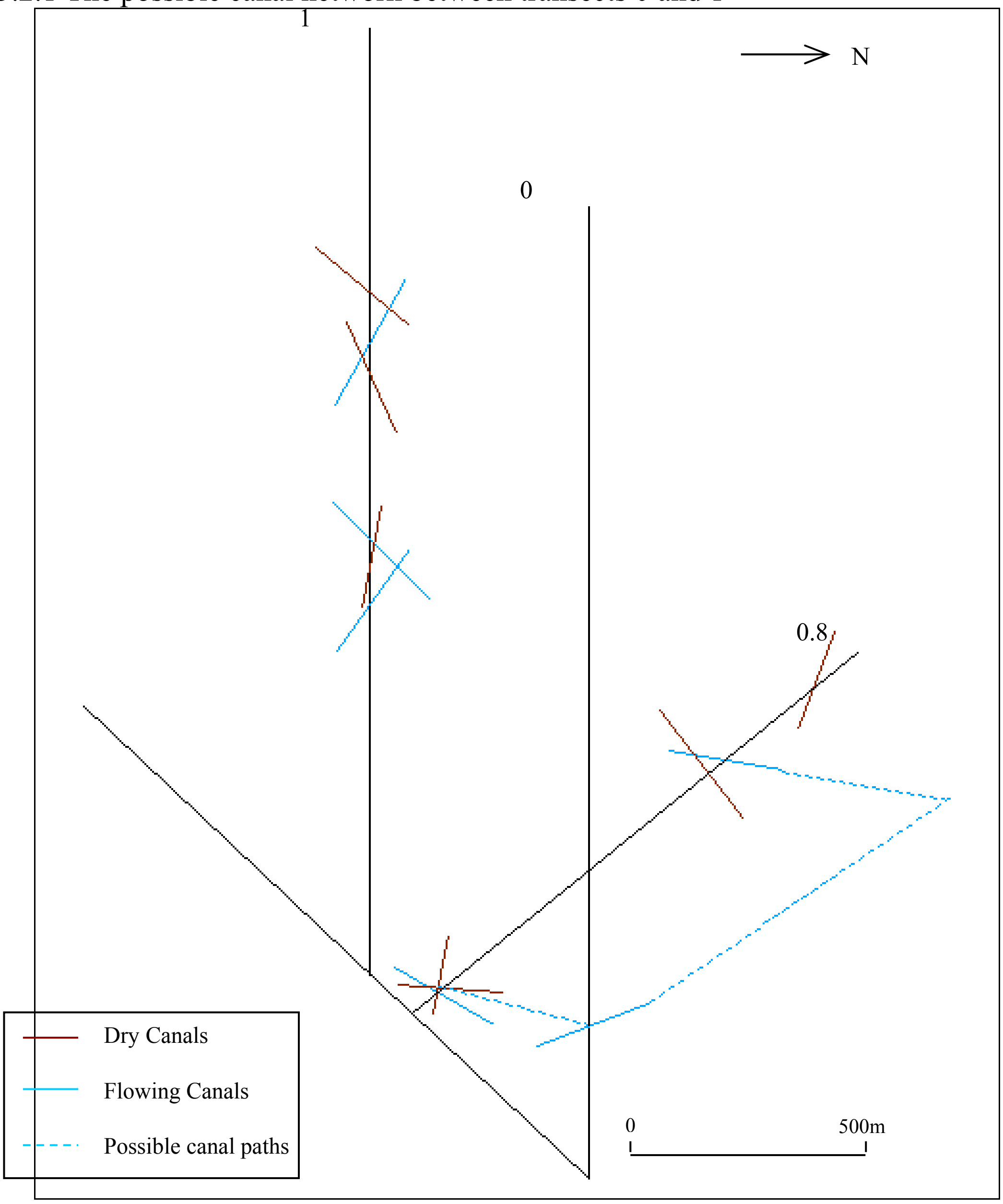


Fig. 5.2.2 **The possible canal network between transects 1 and 4**

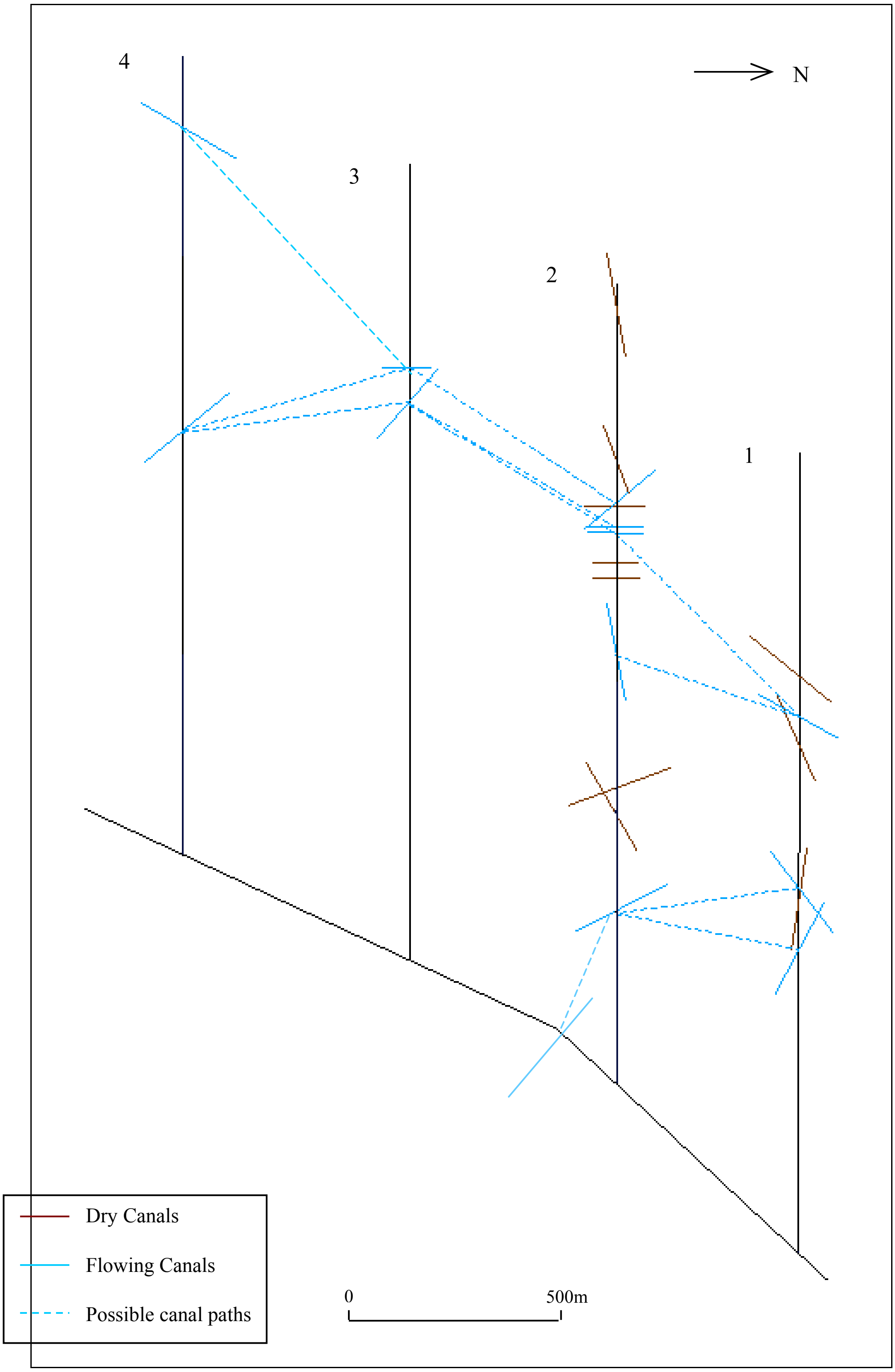

4
3
2
1
N
Dry Canals
Flowing Canals
Possible canal paths
0
500m

Fig. 5.2.3 Skid distribution on transects 0-1

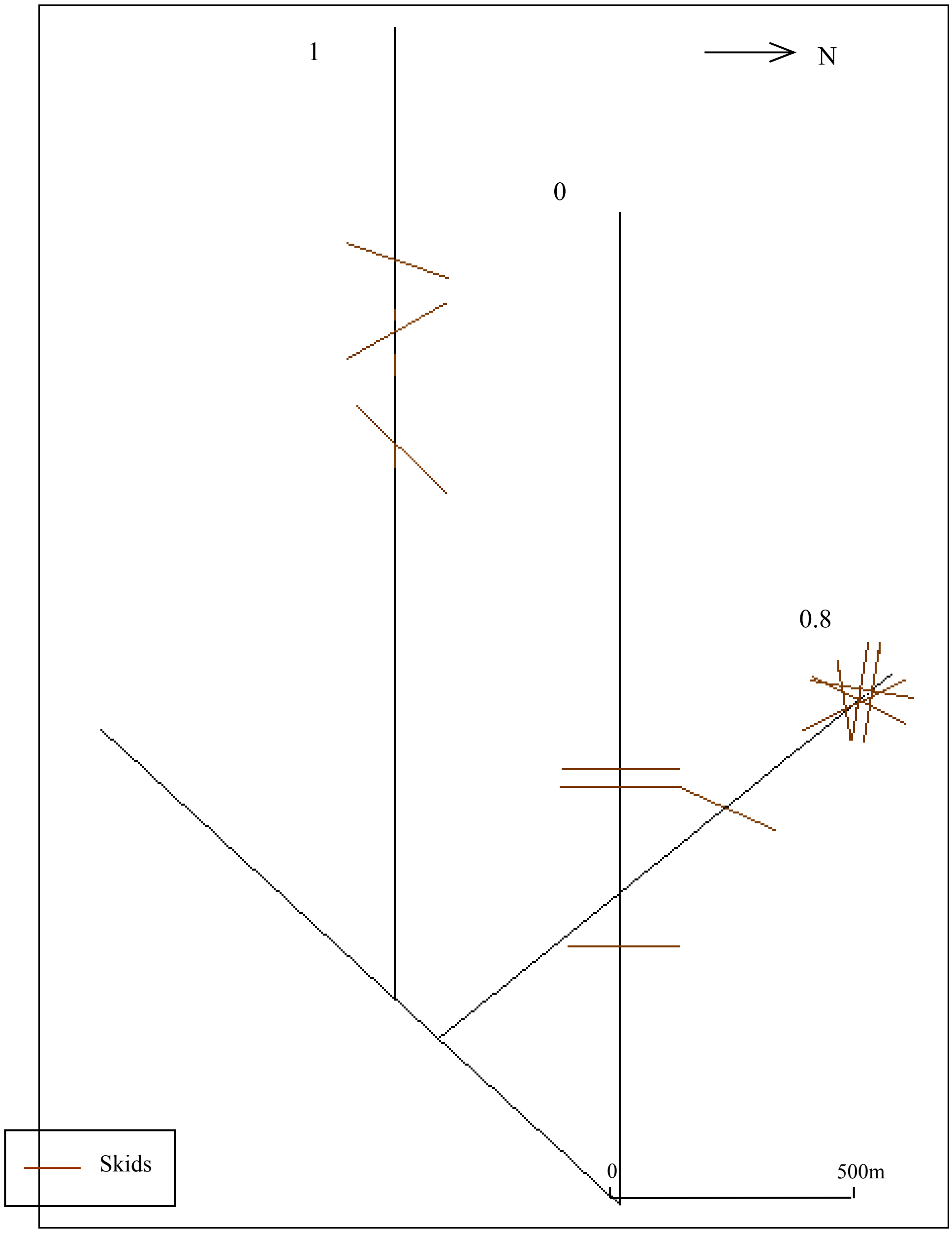
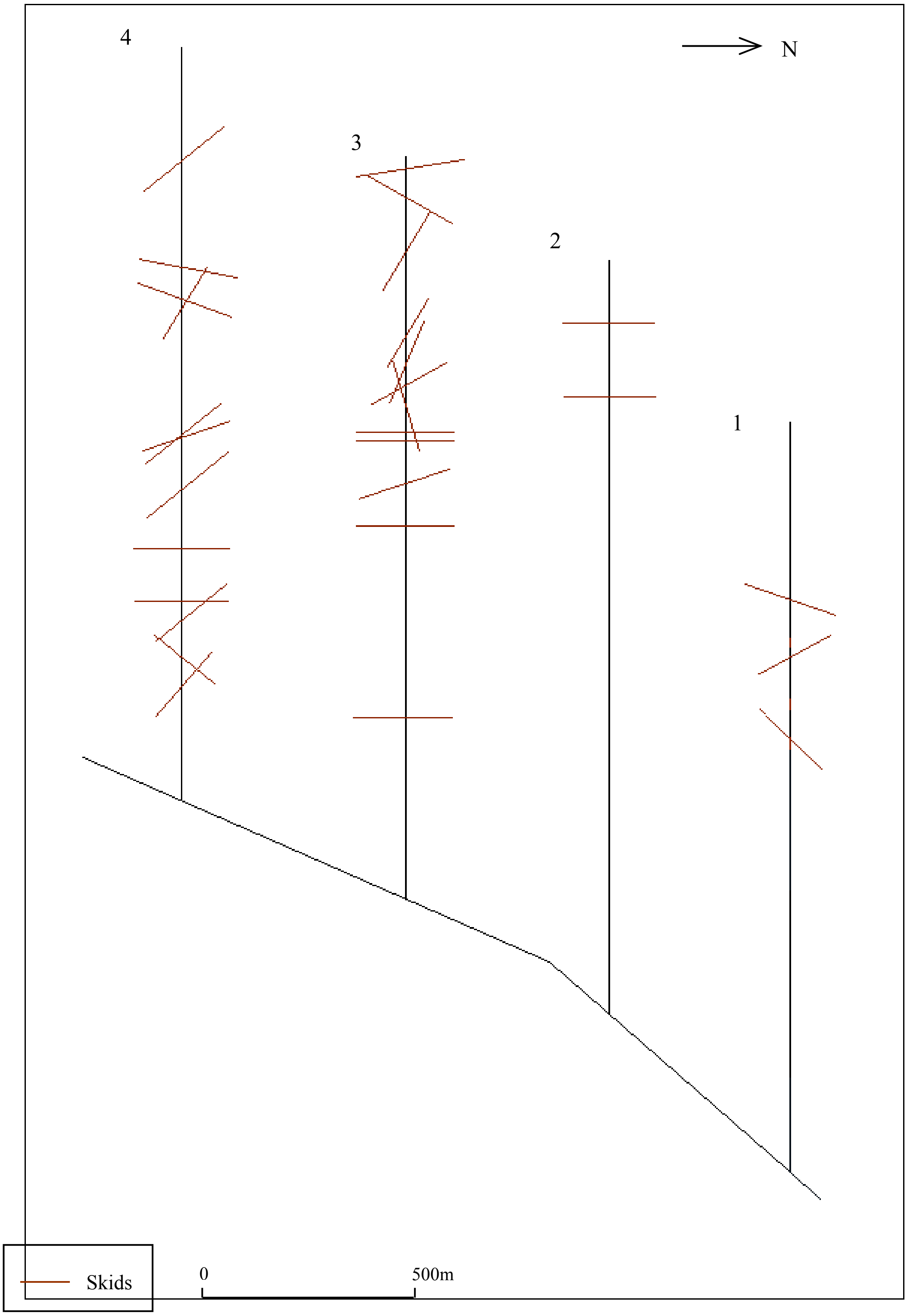


Fig. 5.2.4 Skid distribution on transects 1-4



Canals

Distance along transect (m)	**Transect No.**							
	0[1]	**0.8**[2]	**1**	**2**	**3**	**4**	**5**	**6**
0-99		3						
100-199								
200-299	1							
300-399								
400-499				1				
500-599								
600-699				1				
700-799			1	1				
800-899		1	1					
900-999			1					
1000-1099				1		1		
1100-1199		1						
1200-1299			1	2				
1300-1399			1	3				
1400-1499			1	2	2			
1500-1599				1				
1600-1699								
1700-1799								
1800-1899						1		
1900-2000				1				
Total	1	5	6	13	2	2	0	0
Density / 100m	0.10	0.42	0.30	0.65	0.10	0.10	0.00	0.00

Skids

Distance along transect (m)	**Transect No.**							
	0[1]	**0.8**[2]	**1**	**2**	**3**	**4**	**5**	**6**
0-99				1				
100-199								
200-299					2	2		
300-399								
400-499					1	1		
500-599	1					1		
600-699				1		1		
700-799		1						
800-899	1	1		1		1		
900-999	1			2	1	2		
1000-1099		2			1			
1100-1199		4	2		1			
1200-1299			1		2			
1300-1399			1		2	2		
1400-1499			1		1	1		
1500-1599			1		1			
1600-1699				1				
1700-1799					1	1		
1800-1899				1	1			
1900-2000					1			
Total	3	8	6	7	15	12	0	0
Density / 100m	0.30	0.66	0.30	0.35	0.70	0.60	0.00	0.00

[1] 1 km in length; [2] 1200m in length

Fig. 5.2.5

In their analysis of land use change and (il)-legal logging in Central Kalimantan using remote sensing and GIS, Boehm and Siegert (unpubl.) stated that:

> "Illegal logging could be often discriminated from legal logging operation in Landsat ETM images by its specific spatial pattern." (p.2)

What exactly this pattern is, is not expanded upon. However, the unregulated and rampant nature of illegal logging would suggest a more random, complex spatial pattern than that of concessionaries. This is evident from both the density and distribution of canals and skids in Figs. 5.2.1 – 5.2.4.

What is immediately apparent from Figs. 5.2.1 and 5.2.2 is that the highest concentration of logging canals are found in the area adjacent to transects 1 and 2. The fact that many of the canals (50% and 62% respectively) were either dry or silted up also suggests a longer history of logging activities in this area. Indeed those found within the first 500m of each transect may be remnants of the old logging concession, whose activities were concentrated in this strip. New prospectors have to move deeper into the forest and this is where the most recent signs of disturbance are evident, like the four canals on transect 3 and 4 which were aged within the last year.

Logging skids (see Plate 5.1) vary considerably in size, from those designed to reach a single tree to those which serve as the main transport arteries en route to canals. The networks are very complex indeed and far more localised than that of the canals, because in most cases they are built to supply these primary extraction features.

Plate 5.1 A logging skid

This can be observed in the distinct clustering of groups of three or four skids together. It also explains why it is not reasonable to try and outline a similar network for skids in Figs. 5.2.3 and 5.2.4, as was done for canals in Figs. 5.2.1 and 5.2.2. However the distribution of skids does have an equally distinct spatial pattern, this time though with over 52% concentrated along transects 3 and 4.

The reason for this marked split in the distribution of canals and skids along transects 1 and 2, and 3 and 4 respectively is not clear. One answer may be that the quantity and quality of commercial timber is, or was, higher in the latter area and required more extensive logging operations.

Looking at logging activity as a whole Fig. 5.2.5 shows that the density is highest along transect 0.8 with an average of more than one canal or skid every 100m. This may be a result of the bearing on which the transect was cut (320^0) which meant that it crossed a wider swathe of forest. Otherwise activity was concentrated at a greater distance from the base camp along transect 2. This decreased at both km 3 and 4 and was completely absent along transects 5 and 6. The explanation for this is obvious. By km 5-6 the transition from Mixed

Swamp Forest to Low Pole Forest, outlined in Chapter 2, is almost complete. The trees here are shorter and smaller and of little value to illegal loggers.

The surveyed area was quite small, effectively a grid of 12 km^2, but to put the scale of these operations into perspective Boehm and Siegert (unpubl.) found 11,000 km of logging railways in a 25,000 km^2 area of Central Kalimantan, representing a 44% increase between 1997 and 2000.

Insert Table 5.3 Canal dimensions and flow properties

The x-sectional areas of the canals vary considerably, as one might expect in view of the fact that they are cut out of the peat using a chainsaw. Values vary from 0.05 up to a maximum of 0.97 with about 40% of the total falling within the range 0.3 - 0.49 m^2. These canals then are fairly small-scale features; sufficient only to allow the transport of one felled tree at a time (see Plate 5.2). This fact is symptomatic of both the environment and the hierarchy of illegal logging which demand that labour costs, in terms of energy and money, be kept to a minimum. It was thought that the dimensions of the canals might reflect their age, with those in present use (flowing) having larger x-sections. Generally this proved not to be the case, but as already stated the methods involved in their construction are far from consistent.

Plate 5.2 A logging canal

The canals are not designed to actively transport felled trees; instead the water simply helps to float the heavy timber as it is pushed or pulled by human labour. This fact is reflected in the flow rates, which are relatively gentle. Fig. 5.4.3 plots the discharges that could be expected from the logging canals if they were to flow at bankfull level, in other words their maximum flow. Half the canals fell in-between 0.001-0.05 m^3/s, though the range was considerable and the maximum was 0.31 m^3/s. It is difficult to compare these figures to the natural drainage of the peat dome because as Andriesse (1988) recognised, there are problems quantifying the hydrological processes of peatswamps. Takahashi & Yonetani (1997) were unable to measure the hydraulic conductivity of the peat soil in the Natural Laboratory at less than 100 cm depth because it was too large for their piezometer methods. They could only estimate it to be greater than 10^{-2} cm/s. However there is no question, as porous as the peat acrotelm is, that groundwater flow can be as significant as open channel flow. The minimum recorded flow rate of 0.01 m/s would be close to one hundred times greater, the maximum of 0.32 m/s more than three thousand. In the wet season of course there is surface water movement from the low pole forest towards the marginal mixed swamp forest and the river, but these measurements were taken during the dry season when surface flow has ceased.

Contrary to what one might imagine this accelerated flow of water towards the periphery of the peatland dome is unlikely to benefit the mixed swamp forest. In fact the reverse situation may be true because this water, and more importantly its associated supply of dissolved nutrients and oxygen, is now being concentrated along man-made channels rather than flowing overland or through the acrotelm. Opportunities for the vegetation to take advantage of these nutrients are therefore much reduced. Moreover this effect will be magnified in an environment where the surface waters are very nutrient poor (Page *et al*., 1997b). Ironically logging activities may result in a succession from mixed swamp to trees matching those of the low pole in terms of height and girth, thus undermining their commercial value.

Although canals were not found within the low pole forest their presence at its base, in the mixed swamp around kilometre 3 and 4, must inevitably threaten the maintenance of a high water table in this area. Under normal circumstances the water table is at or above the peat surface for nine to ten months of the year and is vital to the development of the more depauperate low pole forest (Page *et al*., 1999). Last summer areas of transitional and low pole forest along transects 5 and 6 were observed to be noticeably drier than in previous years (Morrough-Bernard, personal communiqué).

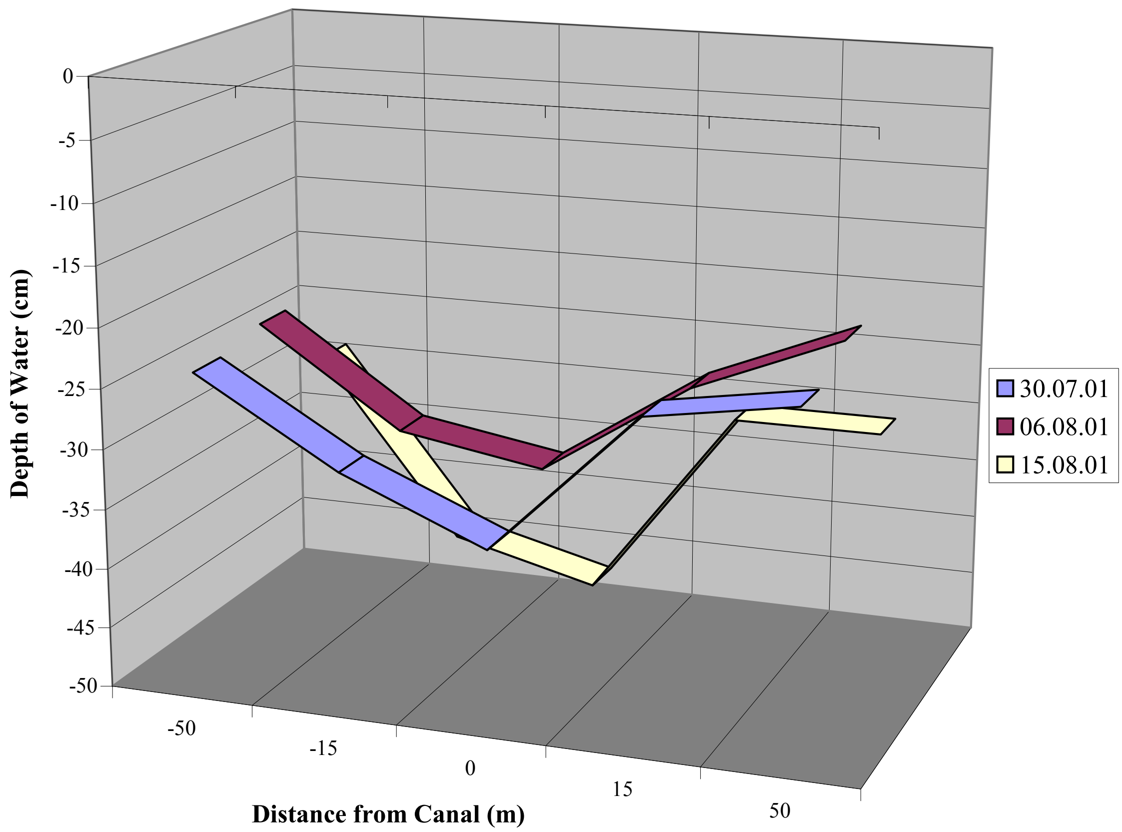
Evidence of logging activity was also found in the tall interior forest. Located at the apex of the peat dome this area supplies water to the rest of the ecosystem and as such is crucial to the sustainability of the whole ecohydrological unit. Since the water table is permanently located beneath the surface, movement occurs laterally through the deep acrotelm (see Fig. 3.1). The draining effect of logging canals threatens to significantly reduce the scale of this groundwater flow, which maintains both the low pole and the mixed swamp forest throughout the dry season.

The primary effect of the logging canals then is to undermine the hydrological function of the acrotelm by providing alternative, more efficient drainage. The threat to the integrity of the peat is obvious when you consider that its formation is entirely dependent upon poor drainage. It is difficult to quantify the scale of this impact, or more precisely the proportion of water and nutrients being lost to the ecosystem, but any change in natural conditions is bound to upset the delicate equilibrium that exists between the dual ecosystem of forest and peatland. The acrotelm is the point of contact between these two components and both are very sensitive to any changes in this layer (Page *et al*., 1999).

5.4 Water Tables:

Date	**Water Depth (cm)**				
	-50	**-15**	**0**	**15**	**50**
30.07.01	-24	-31	-36	-24	-22
06.08.01	-23	-31	-33	-25	-20
15.08.01	-29	-44	-47	-31	-31

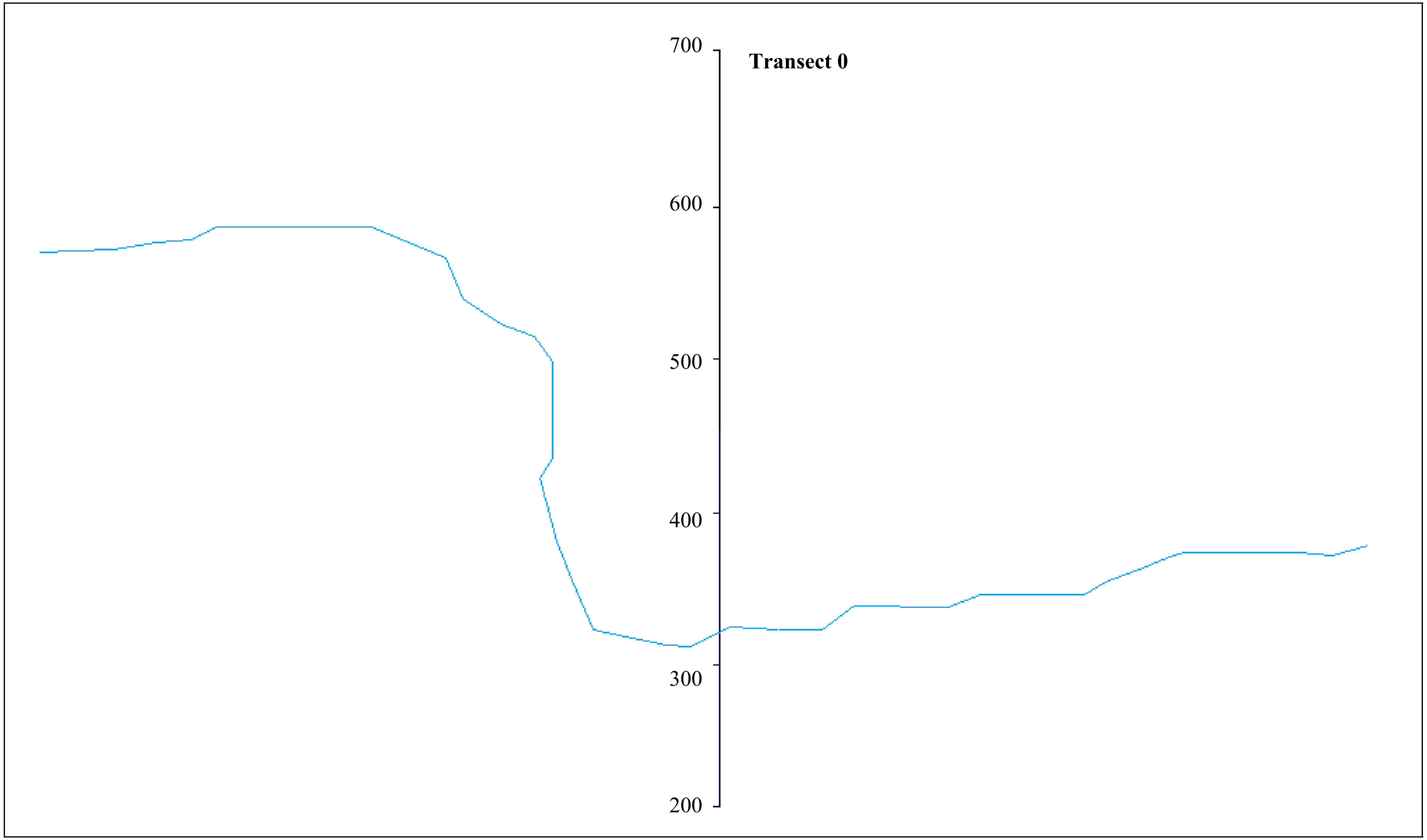
Fig. 5.4.1 Plot 0 Water Tables



All three profiles exhibit a characteristic v-shape, with the lowest water table consistently found immediately adjacent to the canal. The differences in water level between the outer limits of the survey (-50m, + 50m) and near the canal varied between 10-18 cm. The figures from the 15th August are particularly interesting because while the readings at –50m and +50m suggest that the mean depth of the water table should be about 30 cm at this time of the year, at the canal it is 47 cm – more than the maximum water-table drawdown recorded by Rieley in Plot 0 at the end of the 1993 dry season (Shepherd *et al*., 1997) (see Appendix 2C). Whether this is significant or not is open to debate, since it does not account for differences in climate and weather between the two survey years. However assuming that the data is accurate, it does suggest that the canals are actively draining the peat. Even during the rainy season the canals may accelerate drainage to such an extent that the maximum water table drawdown is achieved much earlier.

In the short term a drop in the water table allows more air to enter the acrotelm thus increasing the aerobic decomposition of organic matter and nutrient release (Brady, 1997). However drier conditions will ultimately lead to a faster rate of peat degradation in the tall interior forest, as well as reducing the rate of peat accumulation in the low pole and mixed swamp forest (Page *et al*., 1997b). This will have consequences for both the type and density of vegetation that the ecosystem can support in the future. Prentice & Parish (1992) believe that even a slight drop in the water table will affect the regeneration capacity of the peat swamp trees and may lead to changes in the whole species composition of the forest. By drying the peat out extraction canals also significantly increase the risk of fire (Boehm & Siegert, unpubl.).

Fig. 5.31 1 km section of a canal through Transect 0



5.5 Vegetation Survey

	Canal				Skid			
	Grid 1	Grid 2	Grid 3	Total	Grid 1	Grid 2	Grid 3	Total
No. of trees	33	27	87	147	24	3	29	56
No. of saplings	165	136	238	539	192	26	139	357

Fig. 5.5.1 Number of Trees

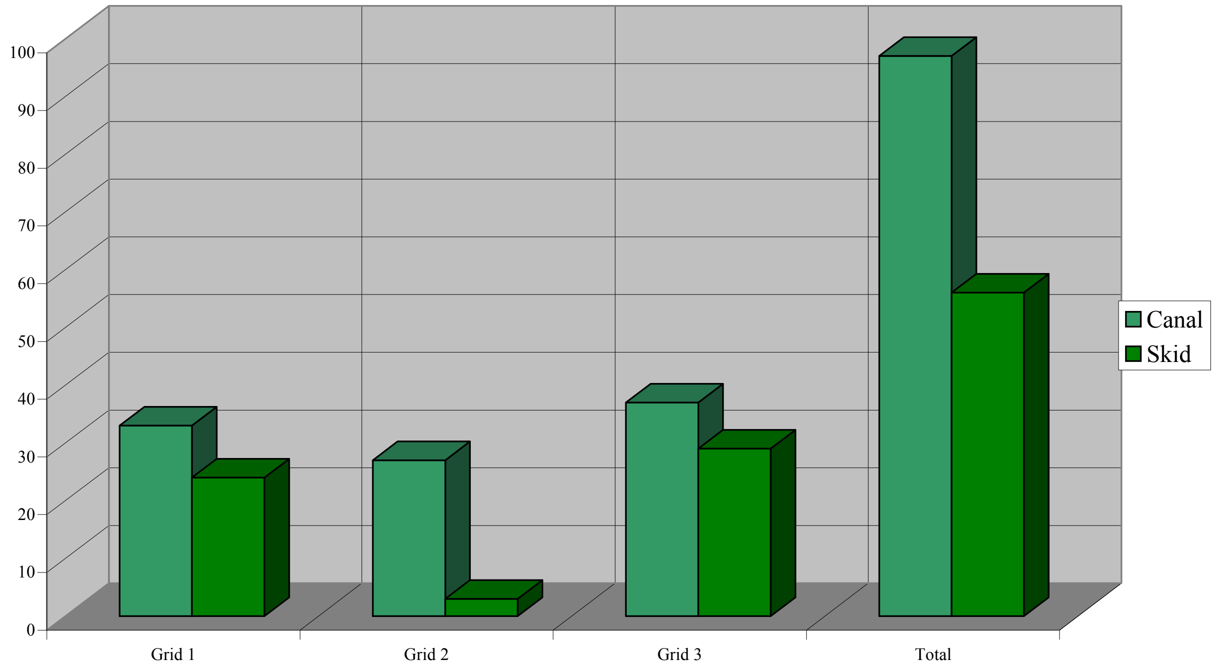
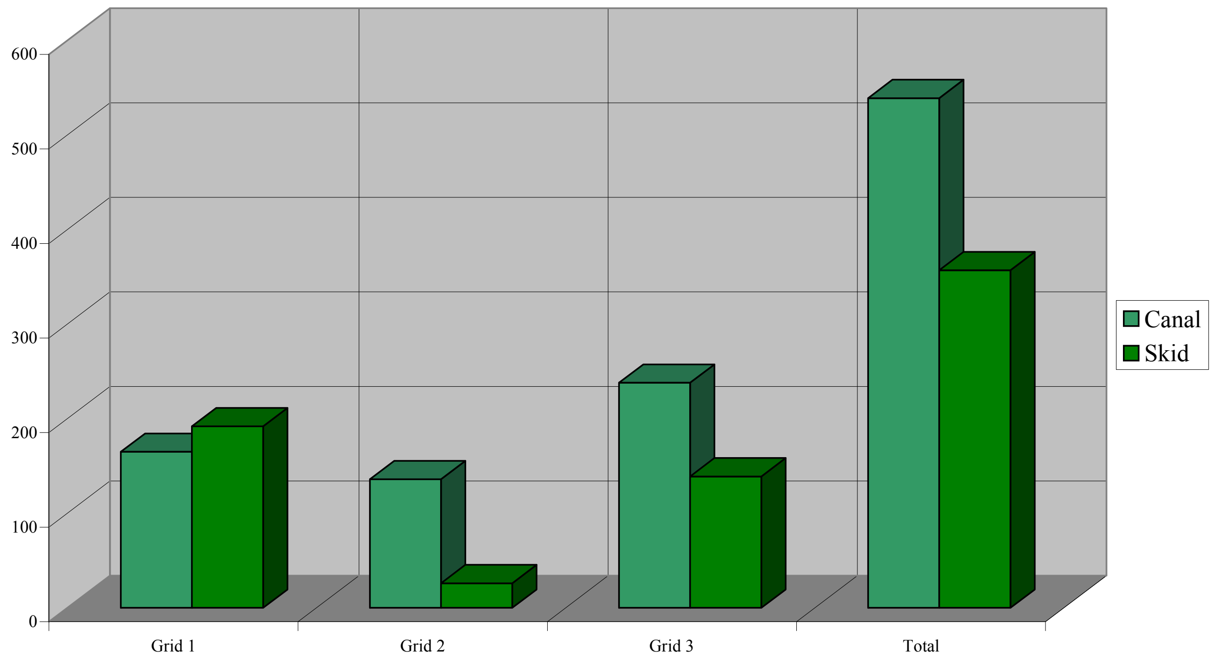


Fig. 5.5.2 Number of Saplings



While there are over forty per cent more trees in the vegetation plot over the canal, the numbers for grids 1 and 3 are fairly comparable ranging from 24 to 37. The real difference comes in the middle grid, where just three trees were found during the skid survey. Effectively the construction of a logging skid just 1.5 m wide has completely devastated a 10 m swathe through the forest (see Appendix A). Furthermore the skid in question was part of a network that extended for many hundreds of metres. Prentice and Parish (1992) described this as the 'incidental destruction of vegetation and fragmentation of the forest habitat'. Devastation around the logging canal was far less obvious although there were 20-30% less trees here than in grids 1 and 3. The reason for this contrast is that by their very nature the construction of logging skids requires the felling of trees. The open area also provides the space needed for the teams of loggers who have to physically drag logs over the skids. Canals on the other hand need be no more than the width of the logs to be transported and their construction simply involves excavating the peat. Of course those trees which block its course will be felled and this accounts for the differences in tree numbers between grid 2 and grids 1 and 3 which were mentioned above.

A similar pattern was repeated during the sapling count with more than a third more recorded overall in the canal plot. Again the main difference came in grid 2 where sapling numbers were over 80% less for the skid plot, although the variation in grid 3 was also over 40%. These results are a direct consequence of the different levels of disturbance observed in the two areas. Grid 2 over the skid has obviously been completely devastated and will suffer additionally from the effects of trampling outlined earlier. The regularity and scale of these activities will determine the ability of this grid to regenerate in the long-term.

Canal: Grid 1

Tree No.	X	Y	Angle (^{0})	Diststance (m)	Height (+1.5m)	DBH	Canopy Diameter (m)

1	0.06	0.10	37	10.0	9.04	6.1	1.6
2	1.65	0.66	64	10.0	15.26	17.7	5.9
3	2.70	0.74	49	10.0	13.00	10.7	2.3
4	3.60	2.25	48	10.0	12.61	9.2	2.4
5	3.85	4.64	47	10.0	12.22	6.7	2.9
6	4.23	4.90	51	10.0	13.85	13.4	1.9
7	4.80	5.18	20	10.0	5.14	5.2	1.3
8	5.10	5.28	60	10.0	18.82	22.6	4.5
9	5.64	5.95	42	9.0	9.60	6.7	2.2
10	4.20	5.58	41	9.0	8.32/9.32	5.4/6.1	2.0
11	2.60	6.28	50	9.0	12.23	12.6	3.3
12	1.90	4.78	46	6.5	8.23	5.1	2.2
13	1.80	6.38	38	8.0	6.84	6.3	2.5
14	0.70	6.17	39	8.0	7.98	5.4	1.5
15	1.40	7.63	32	8.5	6.81	6.9	1.8
16	1.90	8.77	21	9.0	4.95	5.5	1.0
17	2.46	8.56	52	9.0	13.02	10.4	2.9
18	4.83	7.84	51	8.0	11.38	7.6	3.1
19	5.30	9.93	46	9.5	11.34	6.1	1.8
20	5.88	0.48	45	8.5	10.00	9.1	3.0
21	6.81	3.42	57	7.6	13.20	13.2	1.3
22	8.28	3.20	58	8.0	14.30	10.2	2.3
23	9.46	1.64	64	10.0	22.00	16.2	3.2
24	8.88	2.02	45	9.0	10.50	5.1	2.1
25	7.62	2.71	53	10.0	14.77	10.7	3.0
26	9.50	4.55	21	9.5	5.15	5.6	3.2
27	8.72	5.02	69	10.0	27.55	16.5	4.3
28	6.78	4.28	52	10.0	14.30	9.1	2.5
29	8.09	5.48	51	10.0	13.85	14.0	2.3
30	7.74	7.02	12	10.0	3.63	6.7	0.4
31	8.28	9.62	57	10.0	16.90	16.2	3.5
32	6.89	8.62	47	10.0	12.22	11.8	1.9
33	9.50	10.00	54	11.3	17.05	14.9	2.5

Canal: Grid 2

Tree No.	X	Y	Angle (^{0})	Distance (m)	(+1.5m)	DBH	Canopy Diameter (m)
1	10.50	0.20	58	9.0	15.90	17.1	4.4
2	11.80	1.78	39	7.0	7.17	5.3	1.7
3	12.00	1.78	58	7.5	13.50	10.9	2.4
4	10.10	4.14	58	7.0	12.70	10.2	2.7
5	10.60	4.41	61	9.0	17.74	12.8	2.7
6	11.38	3.67	39	8.0	7.98	6.0	2.6
7	11.00	3.67	56	9.5	15.58	11.2	3.3
8	10.90	4.64	42	10.0	10.50	7.8	2.7
9	10.70	6.61	63	10.0	21.13	25.8	3.7
10	11.35	6.53	48	10.0	12.61	13.7	1.9
11	11.00	7.44	19	7.5	4.08	6.5	1.0
12	11.90	6.94	54	7.0	11.13	7.2	2.0
13	12.25	7.90	59	7.0	13.15	9.6	4.0
14	16.45	1.79	39	9.0	8.79	5.2	1.7
15	18.75	1.26	37	10.0	9.04	5.6	1.7
16	19.55	1.85	9	10.0	3.08	5.2	1.3
17	19.65	2.99	6	10.0	2.55	6.9	0.8

18	19.62	3.67	57	8.0	13.82	11.2	2.1
19	16.00	3.17	47	7.0	9.01	5.3	2.6
20	16.60	5.26	55	8.0	12.93	8.5	1.7
21	16.60	5.38	42	8.0	8.70	7.3	1.9
22	16.40	5.79	68	7.5	20.06	14.8	1.0
23	16.40	5.94	41	8.0	8.45	8.0	3.3
24	19.20	6.00	50	8.0	11.03	11.2	1.9
25	19.90	5.17	49	9.5	12.43	6.5	1.7
26	19.95	5.33	46	9.5	11.34	5.6	1.8
27	19.30	7.79	60	10.0	18.82	14.4	2.6

Canal: Grid 3

Tree No.	X	Y	Angle (^{0})	Diststance (m)	Height (+1.5m)	DBH	Canopy Diameter (m)
1	20.45	0.83	44	8.0	9.23	7.9	2.7
2	21.02	1.40	58	7.0	12.70	11.5	1.6
3	20.73	3.70	55	7.0	11.50	12.7	4.6
4	20.60	7.60	47	7.0	9.01	7.7	2.4
5	21.10	8.84	45	7.0	8.50	6.0	2.1
6	24.35	8.40	49	9.0	11.85	6.9	2.2
7	25.26	8.94	45	8.5	10.00	8.3	2.4
8	25.26	8.94	39	8.5	8.38	6.2	2.4
9	23.79	6.73	29	6.0	4.83	5.7	1.5
10	24.18	6.21	60	6.0	11.89	13.0	3.8
11	23.21	2.68	33	7.5	6.37	5.5	crown 4.6m away @ 120^0 2.0
12	23.54	1.13	42	7.5	8.25	7.4	crown 2.5m away @ 104^0 1.6
13	22.30	0.39	68	7.0	18.82	17.6	3.0
14	25.08	3.39	73	8.0	27.67	22.3	4.6
15	27.00	2.55	36	8.0	7.31	6.0	2.1
16	25.76	4.75	30	9.0	6.70	6.9	2.8
17	26.76	4.97	60	9.0	17.09	14.5	3.5
18	27.26	5.00	69	7.0	19.74	18.9	4.8

19	26.86	6.12	46	7.0	8.75	5.3	2.9
20	26.22	6.27	56	9.0	14.84	10.9	3.4
21	25.72	6.85	56	9.5	15.58	11.3	2.1
22	25.96	7.27	37	10.0	9.04	7.2	3.2
23	26.38	9.06	31	10.0	7.51	5.7	1.5
24	28.00	6.89	44	8.0	9.23	5.3	1.5
25	28.80	6.99	34	8.0	6.90	6.8	crown 3.2m away @ 230^0 1.3
26	29.10	7.90	52	9.0	13.02	8.1	2.3
27	29.13	8.05	42	9.0	9.60	6.4	2.1
28	28.91	8.72	57	10.0	16.90	12.0	3.6
29	29.45	7.78	57	9.0	15.36	7.5	3.0
30	29.45	6.98	41	7.0	7.58	6.0	2.3
31	29.80	2.30	71	7.0	21.83	23.0	3.6
32	29.55	1.43	62	6.0	12.78	15.0	3.0
33	28.99	1.20	55	7.0	11.50	7.4	2.4
34	28.64	0.83	52	7.0	10.46	11.0	2.2
35	28.37	4.40	41	8.0	8.45	5.1	1.6
36	27.37	1.19	43	7.5	8.49	5.5	1.9
37	26.66	0.15	40	9.0	9.05	5.0	1.0

Skid: Grid 1

Tree No.	X	Y	Angle (^{0})	Diststance (m)	Height (+1.5m)	DBH	Canopy Diameter (m)
1	0.20	8.00	38	10.0	9.31	6.2	1.7
2	0.30	7.58	43	10.0	10.83	5.4	1.0
3	0.10	6.70	60	10.0	18.82	19.0	4.0
4	0.00	6.31	25	10.0	6.16	6.3	0.8
5	0.50	6.46	50	10.0	13.42	8.2	2.7
6	1.30	5.75	41	10.0	10.19	7.8	2.0
7	0.87	3.37	49	9.0	11.85	8.7	2.2
8	1.79	3.67	45	9.0	10.50	6.6	1.6
9	10.83	1.10	37	9.0	8.28	5.2	1.4
10	1.60	1.77	35	9.0	7.80	11.2	3.8
11	1.60	0.16	25	9.0	5.70	7.6	0.5
12	2.02	5.59	46	9.0	10.82	8.5	1.2
13	1.78	7.08	46	9.0	10.82	6.4	2.2
14	4.12	8.28	35	10.0	8.50	6.0	1.8
15	5.32	5.71	34	10.0	8.25	7.1	1.1
16	6.58	4.87	37	8.0	7.53	7.7	1.0
17	4.70	1.30	28	10.0	6.82	6.9	3.6
18	5.92	7.46	28	11.0	7.35	7.2	1.0
19	6.11	8.06	26	7.0	4.91	5.3	1.0
20	8.25	9.21	40	10.0	9.89	10.0	2.3
21	7.08	2.95	47	10.0	12.22	6.6	1.9
22	7.06	2.90	50	10.0	13.42	10.9	3.6
23	8.51	2.92	48	10.0	12.61	6.2	2.8

24	9.45	2.88	47	10.0	12.22	7.6	2.3

Skid: Grid 2

Tree No.	X	Y	Angle (^{0})	Diststance (m)	Height (+1.5m)	DBH	Canopy Diameter (m)
1	10.20	7.06	36	8.0	7.31	6.0	2.1
2	10.05	6.78	54	9.0	13.89	12.3	5.0
3	10.73	3.24	69	10.0	27.55	20.9	6.1

Skid: Grid 3

Tree No.	X	Y	Angle (^{0})	Diststance (m)	Height (+1.5m)	DBH	Canopy Diameter (m)
1	28.23	1.95	61	10.0	19.54	9.8	2.8
2	27.33	0.79	34	10.0	8.25	7.4	1.6
3	27.84	2.43	51	10.0	13.85	8.0	2.2
4	27.90	2.84	53	9.0	13.44	7.9	2.3
5	27.73	2.83	49	9.0	11.85	5.6	1.8
6	29.77	5.43	37	8.0	7.53	7.3	3.4
7	29.88	7.91	51	8.0	11.38	6.5	1.9
8	28.88	8.04	48	10.0	12.61	10.8	1.5
9	28.88	9.60	37	10.0	9.04	5.1	0.8
10	29.08	10.00	41	10.0	10.19	6.2	1.1
11	27.11	9.91	49	10.0	13.00	16.4	1.2
12	26.96	9.32	55	10.0	15.78	17.2	2.3
13	25.92	9.40	35	10.0	8.50	5.8	1.5
14	26.47	7.44	39	10.0	9.60	8.8	3.9
15	27.02	6.02	43	10.0	10.83	7.4	1.4
16	26.46	4.72	48	10.0	12.61	12.1	2.0
17	26.53	2.58	47	10.0	12.22	11.9	2.5
18	25.93	1.47	54	10.0	15.26	19.3	5.8
19	24.47	0.23				7.7	1.4
20	21.83	1.85	19	10.0	4.94	7.6	1.8
21	21.80	2.44	18	10.0	4.75	10.5	2.1
22	24.88	4.82	41	10.0	10.19	5.7	1.3
23	21.73	3.94	47	10.0	12.22	11.7	3.6
24	22.49	4.77	49	10.0	13.00	10.9	3.2

25	22.40	6.45	43	10.0	10.82	10.4	2.9
26	24.84	6.83	34	10.0	8.25	5.6	1.2
27	24.87	9.12	40	10.0	9.89	7.0	3.2
28	20.96	6.61	71	10.0	30.54	24.6	7.0
29	20.70	6.60	72	10.0	32.28	24.2	5.0

Rieley *et al.*'s (1997b) analysis of tree height from a vegetation plot in the tall interior forest revealed a fairly even distribution of trees (16-18%) in the four categories between 10 and 26 m (see Appendix 2A). The proportion of trees then declines linearly as height increases. Significantly as well less than 1% of trees had a height of less than 10 m. Data from the canal and skid plots differs markedly from this pattern. Both distributions are more positively skewed so that 67 and 80% respectively of all trees, measured between just 6 and 10 m in height. The canal plot had nearly three times as many trees between 14 and 30 m as the skid plot although the tallest trees were found in the latter, reaching a maximum of over 32 m. However while Rieley *et al.*(1997) found that 9% of trees were between 34 and 46 m tall, no trees were found in this range in either the canal or the skid plot. The emergent layer described in Chapter 2 is missing.

A comparison of DBH values from the canal and skid surveys with data from a study plot established by Waldes & Page (unpubl.) (see Appendix 2B) reveals a very similar distribution. As with the analysis of tree height the key difference is that the larger trees, those with a DBH of more than 25 cm, are almost completely absent. The canal and skid plots differ themselves in that the latter has a higher percentage of trees in the lowest range (5-9.9 cm) and a lower proportion between 10 – 14.9 cm.

The histogram of canopy diameter has a similar pattern in terms of distribution as that for tree height (no other published data was available for comparison). The great majority of trees (70% canal; 71% skid) fell between 1 and 3 m. Significantly though the modal category in the skid survey was 1.0 – 1.99 m compared to 2.0 – 2.99 m for the canal survey. While the maximum canopy diameter in the skid plot did exceed that of the canal plot this can be explained by the presence of just three large trees. Evidently of a non-commercial species, they must also have been deemed too large to be of use in the construction of the skid.

Overall the three graphs reveal a higher percentage of shorter, smaller trees in the skid plot compared with the canal plot. The sketches in Appendix A also show more breaks in the canopy and more trees lying at an angle in the former area. This reflects a higher level of disturbance and the fact that areas adjacent to logging skids will inevitably be the first to be exploited. Comparisons with other study plots in relatively untouched parts if the tall interior forest confirm the obvious – that logging activities significantly reduce the forest biomass. Trees greater than 34 m in height or with DBH's of more than 30 were simply not in evidence. Bodmer *et al*. (1991) have suggested that logging operations can damage up to 40% of rain forest habitats while only removing 10% of the trees. The implications of this for the sustainability of the whole forest ecosystem are clear from a study by Page *et al*. (1997b). They showed that the aerial biomass in the forest contained most of the inorganic nutrients and so was vital to the growth of subsequent generations of plants.

None of the six graphs (Figs. 5.5.6 – 5.5.11) show any pattern of increasing height, DBH or canopy diameter with distance from the canal or skid. There is however a definite waveform present in all three variables. This may reflect the different canopy layers identified by Rieley *et al.* (1997b) or more specifically the natural growth patterns of vegetation in any forest ecosystem. Larger trees will be interspersed by those fighting for both light and nutrients, thus establishing a natural hierarchy in terms of height, DBH and canopy diameter.

There is little surprise that the expected pattern of larger trees towards the periphery of each plot did not materialise because of the small-scale of the survey. However if the study was extended sufficiently, away from these immediate logging areas, then the structure of the forest could be expected to change, perhaps resembling more closely the plots surveyed by Rieley et al. (1997b) and Waldes & Page (unpubl.).

5.7 Orang-utan population data:

Number of Nests		
	1999	**2000**
Mixed Swamp Forest km 1-3	19	75
Mixed Swamp Forest km 4-6	53	73
Low Pole Forest	41	85
Tall Interior Forest	122	61

Nest Density			
	1996	**1999**	**2000**
Mixed Swamp Forest km 1-3	599	115	344
Mixed Swamp Forest km 4-6	599	603	623
Low Pole Forest	284	501	558
Tall Interior Forest	636	618	339

Orang-utan Density			
	1996	**1999**	**2000**
Mixed Swamp Forest km 1-3	2.99	0.46	1.39
Mixed Swamp Forest km 4-6	2.99	2.45	2.53
Low Pole Forest	1.41	2.04	2.26
Tall Interior Forest	3.18	2.5	1.56

(Husson et al., unpubl.)

The habitat destruction caused by illegal logging highlighted in previous sections has led to large shifts in orang-utan distribution between 1996-2000. Data from orang-utan nest counts obtained from line transects is used to estimate population densities based on techniques developed by Rijksen (1978) and van Shaik *et al*. (1995) amongst others (see Appendix 3A). In 1996 the Mixed Swamp Forest and Tall Interior Forest supported the bulk of the orang-utan population. Densities in the mixed swamp decreased by over 300% at km 1-3 between 1996 and 1999, a fact that can be directly linked to the increased logging operations in this area (Husson *et al*., unpubl.). Densities also declined in the tall pole in 1999 and again in 2000. Husson et al. (unpubl.) suggested that the orang-utans were displaced firstly by the fires of 1997/1998 and then again by illegal logging activities which peaked in 2000. The result of such disturbance in both habitat sub-types has been a marked shift in orang-utan densities towards the low pole, which is clearly visible in Fig. 5.6.3. This habitat is far from optimal (see Appendix 3B), a fact evident from the low densities found here in 1996 before the onset of illegal logging.

The orang-utan can be seen as an indicator species detailing the impacts of illegal logging on the peat swamp forest ecosystem. Every aspect of the operations outlined so far has consequences for the sustainability of this area as a habitat for orang-utans. The logging canals that are draining the peat and lowering the water table will inevitably affect the fruiting potential of the trees (rooted as they are in the acrotelm). Orang-utans are large-bodied frugivores that require a constant supply of fruit to sustain their energy requirements (Bodmer *et al*., 1991). On top of this the general degradation of the forest is reducing the carrying capacity of the environment and leading to overcrowding. This results in increasing stress, juvenile mortality and depressed fecundity and breeding rates (Husson *et al*., unpubl.). Husson *et al*. (unpubl.) feel certain that if illegal logging activities do not cease, so that the population distribution can return to normal, then the inevitable consequence will be a substantial decline in the numbers of this already highly endangered ape.