The Effectiveness of Riparian Buffer Zones for Protecting Waterways during Harvest in the Pipiwai Forest in Northland, New Zealand

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Abstract

The harvest of plantation forests has the potential to cause significant negative impacts on the waterways that flow through them. It has been proposed that to mitigate any such impacts waterways should be protected by undisturbed riparian buffer zones (RBZ). As such, this research has been conducted to investigate if RBZs protect plantation waterways during harvest. To do this a case study was carried out in the Pipiwai forest, one of Carter Holt Harvey Forests (CHHF) Northland plantations. In the investigation, 15 first order streams were sampled using an extended version of NIWA's stream health monitoring and assessment kit (SHMAK). The samples were taken from three different stream treatments, those harvested with undisturbed buffers, harvested with no buffers (clearcut) and standing mature pine forest. Each site had the quality of its aquatic and riparian habitats and invertebrate communities assessed via the SHMAK, which presented a rating for each streams health. Statistical analysis was also carried out to determine if any differences in the results were significant or simply an expression of the variation that could be expected in a single population. The management of the plantation was also investigated. CHHF managers were interviewed to determine the activities that could have impacted on the forest's waterways.

The results showed that clearcut streams had degraded riparian and aquatic habitats through the loss of vegetation, exposed and eroding soil, and increased streambed sedimentation. This degradation was reflected in the invertebrate communities which were dominated by high numbers of pollutant tolerant species such as mollusks and midges. Buffered waterways, however, had no such degradation and their invertebrate communities had high numbers of pristine requiring invertebrates such as mayflies. Statistical analysis showed that the habitat and invertebrate scores of the clearcut sites were significantly lower than the buffered and pine sites, and it also showed there was no significant difference between the buffered sites and the mature pine sites.

The results also showed that the management of the Pipiwai plantation was conducted to industry and council standards, but that this was insufficient to prevent the degradation of the waterways in the clearcut catchments.

The two main conclusions of this research were that RBZs in the Pipiwai forest protected waterways from degradation during plantation harvest and maintained them in a state similar to that of standing mature pine forest, and that management practices and regulations in use at the time of harvest, though within industry and government standards, were unable to prevent waterway degradation and achieve results equal to those of the RBZs.

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Introduction

Chapter One

1.1 Overview

Timber production from plantation forests is one of New Zealand's largest industries. The wood produced is used in the manufacture of chips, pulp, paper, various types of board, as well as sawn timber, logs and poles. It uses approximately 7% of the country's land area and comprised 11.3% of its exports in 2004 earning $3.117 billion (New Zealand Forest Owners Association, 2005). It is an industry in which profit margins can at times be small and as with all export commodities, its profitability is affected by the value of New Zealand's dollar.

New Zealand's land use has been dominated by pastoral farming for many years (New Zealand Forest Owners Association, 2005), and as a result, plantation forests have largely been grown on land unsuitable for pastoral farming, land that has typically been steep with low fertility (Maclaren, 1996). Trends have changed a little over the last 10-15 years as farmers have diversified their enterprises and turned areas of farmland into plantation forest (Maclaren, 1996). The majority of plantations throughout the country are planted in *Pinus radiata*, a species originating in North America. It is the dominant species as it is fast growing, can grow well on many different soil types, and can be used in a diverse range of end products (Maclaren, 1996).

A typical forest rotation from planting to complete harvest, will take approximately 28 years. For the majority of this time the plantation will largely be left undisturbed.

Seedlings will be planted and in the first couple of years there may be some spraying carried out to eliminate weed competition, or the addition of fertilizer. Then for the next 25 to 26 years the trees will largely be left to grow with the only disturbances being thinning and possible pruning. As such, the plantation becomes part of the landscape, a constant feature to regular passersby or recreational users. However, at the completion of the rotation when the trees are harvested, drastic changes are made to the physical and visual environment. Seventy percent of the environmental disturbance that occurs through the entire rotation can take place at that time (Hicks and Harmsworth, 1989). Extensive earthworks are carried out to construct the infrastructure required to extract the timber. When this is completed the trees are then felled and removed from the site. In a matter of days large areas can be harvested, changing the landscape from green forested countryside, to a landscape of bare earth strewn with dead and dying tree debris. This not only results in drastic visual impacts, but it also causes significant disturbance to the physical environmental. In a very short period, an area that has existed under a forest cover for around 20 years (since canopy closure) is reduced to a de-vegetated open environment. This process can have significant negative impacts on the ecosystem of that area. For these reasons, plantation forestry has been a topic of much debate and one into which considerable research has been conducted.

An area that has come under particular scrutiny has been the impact that plantation activities have on waterways. In the past, practices such as large scale burning, poor infrastructure construction, and careless tree extraction, have filled waterways with nutrients, sediment and slash, and caused significant negative impacts to these habitats and the aquatic communities they supported (Rosoman, 1994). In more recent years, following passage of the Resource Management Act 1991, there has become a greater requirement to minimize the negative effects that our activities have on the environment. This requirement is not only from government sectors but pressure is also coming from environmental and community groups (Rosoman, 1994). The forestry industry has also taken its own initiatives and has been conducting research into the effects of its activities and the means by which negative impacts can be mitigated or minimised. This has occurred to the point where some companies have developed environmental standards that lift their operating practices above those required by local government regulations.

Despite the changes that have been made to forestry practices in the last 10-20 years, there are still issues regarding the environmental sustainability of forestry practices. These include increased solar radiation inputs due to the removal or riparian vegetation, increased sediment inputs due to soil disturbance, particularly immediately adjacent to waterways, (Hicks, 1998) and the significant amounts of slash that can be deposited into waterways during harvest. To address these issues and protect waterways from degradation during harvest, the use of riparian buffer zones has been proposed (Quinn *et al,* 2004; Baillie *et al,* 2005). This would be a controversial requirement as there would be financial ramifications for forestry owners if such a practice was employed. On this basis, there is a need for sound and independent research to be carried out in order to provide reliable data on the effects of plantation forestry practices and the most efficient means of addressing any negative impacts.

1.2 Research Problem

There has been considerable controversy over the environmental effects of plantation forestry and the sustainability of the industry within New Zealand (Rosoman, 1994; Maclaren, 1996). It has been both accused of causing significant environmental degradation and used as a method of environmental protection. With the passage of the Resource Management Act in 1991 there came a requirement to identify, and minimise or mitigate, any negative environmental effects of land use activities. As such, plantation forestry came under this new legislation. Combined with this Government initiative, the forestry industry has carried out significant amounts of research into its environmental effects and the means of mitigating them. One focus of both agencies has been the effects on waterways and water resources. As a result, forestry management has undergone many improvements in its practices over the last 15-20 years. Despite this, there is still little doubt that aspects of forestry management cause at least short-term and possibly long-term waterway degradation.

To protect waterways from the impacts of forestry activities, particularly plantation harvest, it has been proposed that undisturbed native riparian buffer zones be compulsory for all plantation waterways. This is a controversial proposal as the impacts of plantation harvest may only be experienced in the short term, while the ramifications of buffer zone inclusion last for the long term. Such a requirement would impact negatively on the profits of forestry owners, on the efficiency of plantation harvest, and possibly on the environment. Furthermore, there have been few specific investigations into the effectiveness of riparian buffer zones at protecting plantation waterways, and the knowledge that is available is largely theoretical.

1.3 Aim

The aim of this study is to determine the effectiveness of riparian buffer zones at protecting the waterways in the Pipiwai forest from the impacts of plantation harvest and the implications this has for forest management.

1.4 Research Questions and Objectives

In order to achieve the above aim three research questions were proposed.

1. How has tree harvest impacted waterways with and without riparian buffer zones?

2. Has the quality of the buffered waterways been maintained at a significantly higher level than that of the clearcut waterways?

3. What implications do the answers to questions one and two have for plantation management?

In order to answer these questions, the following objectives were set:

1. Determine the quality of the invertebrates within the waterways under different plantation management regimes.
2. Determine physical water quality of the waterways under different plantation management regimes under different plantation management regimes.
3. Determine the quality of the waterway aquatic habitats under different plantation management regimes.
4. Determine the quality of the riparian habitats under different plantation management regimes.
5. Determine if there are significant differences in the stream ecosystem quality under the three management regimes.
6. Identify any management practices related to the plantation harvest that contributed to any waterway degradation or waterway protection.

1.5 Research Approach

Currently there is much interest in protecting waterways from degradation caused by various land use practices, with forestry being one of these. A measure highlighted as a means of achieving this has been the use of riparian buffer zones (RBZ). Such a move is controversial as it significantly impacts on forestry owners. As such, research is needed to determine the specific waterway impacts caused by plantation harvest and whether there are definite benefits produced by utilising RBZ. To this point there is a limited amount of data available in this area and knowledge is largely based on theory. This research therefore, will contribute more specific data on the effectiveness of riparian buffer zones at protecting waterways during plantation harvest, and help to build an accurate understanding of sustainable plantation management.

To obtain data for this research, waterways within the Pipiwai forest that were both clearcut and buffered, as well as running through standing mature plantation, were sampled using an extended version of the Stream Health Monitoring and Assessment Kit (SHMAK) developed by the National Institute of Water and Atmosphere (NIWA) and Landcare Research. Analyses of the results from the SHMAK were used to determine how effective buffer zones were at protecting waterways from the impacts of plantation harvest.

1.6 Thesis Layout

Following this introductory first chapter, chapter two presents a review of the literature relevant to plantation forestry including: the theory of sustainability, plantation forestry activities, local government regulations and industry operating standards. Chapter three presents the background to the research, including information regarding plantation forestry in Northland, the history, geology and climate of the Pipiwai plantation and an overview of the management regime employed by Carter Holt Harvey Forests (CHHF) for the plantation. Chapter four presents the methodology of the research, including its assumptions and limitations. Chapter five presents the results of the research, which are discussed in chapter six. The final chapter presents the conclusions and recommendations of this research, including recommendations for further research.

Literature Review

Chapter Two

2.1 Introduction

This chapter presents a review of the literature that is relevant to this study and as such forms its theoretical foundations. The first section presents a working definition of sustainability and how this is applied to waterways. The second section deals with plantation forestry in New Zealand and its impacts on waterways. The third section presents the regulatory controls on plantation forests and the measures taken to minimise its negative environmental impacts. The final section examines riparian buffer zones, what they are and the pros and cons of their use.

2.2 Sustainability

Before the environmental effects of an activity can be assessed a working definition of environmental sustainability must first be established. The following definition was made in the 2005 Environmental Sustainability Index, by the Yale University Centre for Law and Policy (Yale University, 2005); sustainability is the characteristic of a dynamic system that allows that system to maintain itself over time.

Sustainability can be conceptualised as either 'weak sustainability' (Figure 2.1) or 'strong sustainability' (Figure 2.2) (Perman *et al,* 2003). Perman *et al* (2003) identified the components of sustainability as labour, human-made capital and natural capital. In a report by the parliamentary commissioner for the environment they were identified as social, economic and environmental capital (Parliamentary Commissioner for the Environment, 2002). In either case, weak sustainability requires that total capital stock be maintained for the system to be sustainable. The implication of this is that one type of capital can be substituted for another, and as long as the sum of human and natural capital is non-declining, the system is sustainable. Strong sustainability, however, says that natural capital must be non-declining and that there is little room for substitution between natural capital and other forms of capital. It treats the system as a whole rather than three equal and separate entities that interact at some point, and it shows the environment supporting both society and the economy, which operate within its bounds.

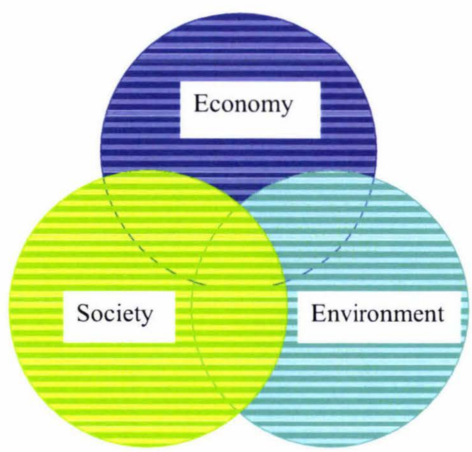


Figure 2.1 The weak sustainability model (Parliamentary Commissioner for the Environment, 2002)

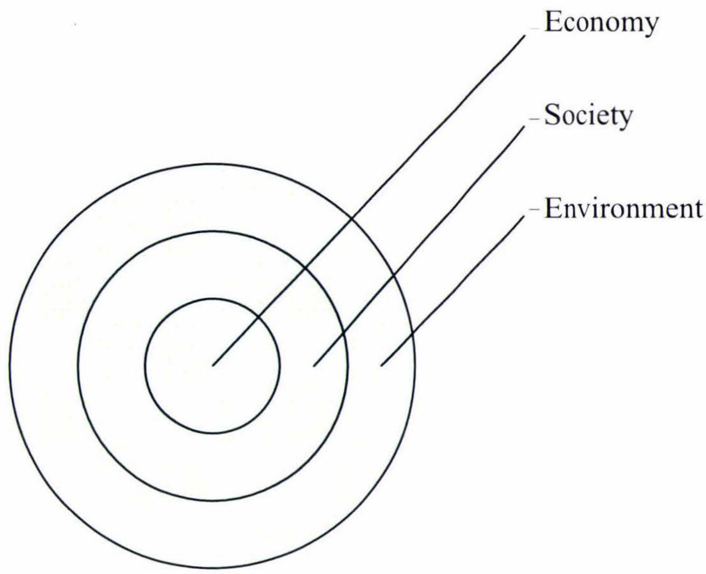


Figure 2.2 The strong sustainability model (Parliamentary Commissioner for the Environment, 2002).

The shortcoming of the weak model of sustainability is that it fails to recognise that both society and the economy are constrained by the limits of the environment; that they are contained within and supported by the environment or ecosphere and cannot grow beyond its ability to supply resources and absorb the effects of our activities (Perman *et al,* 2003). The strong sustainability model, however, acknowledges this and shows society as a sub-set of the environment, with the economy as a sub-set of society. This model acknowledges that the economy only exists in the context of a society and that society can only exist in the context of the environment. As such, it shows the environment to be the primary focus for sustainability, not the economy, as the economy can only operate within the constraints of the environment and is not independent from it. This model therefore requires that this environmental basis be integrated into the thinking of both society and the economy (Larsen, 1995).

This is a key point in assessing the sustainability of an activity, it means that the first step in any assessment is to determine if the activity is environmentally sustainable. If it is not, all subsequent tests regarding social or economic sustainability are irrelevant. The failure of an activity to be environmentally sustainable is a failure at the very foundational level of the resources that sustain our existence. If the activity fails to be environmentally sustainable, it undermines the resources that support our society and our economy.

An ecosystem is an open system that is characterised by inputs and outputs of energy and matter (Larsen, 1995). To ensure ecosystem sustainability Larsen (1995) states that we must maintain ecosystem stability, which is characterised by a dynamic equilibrium achieved through interactions among functional groups of organisms and the physical environment. He cautions that manipulating an ecosystem may permanently interfere with the fundamental self-regulating processes which are responsible for system stability and productivity. He goes on to discuss a system's resistance and resilience in this regard. He defined the resistance of a system as its ability to prevent a change occurring in that system, and system resilience as its ability to return to its original state after a disturbance. When a disturbance exerts sufficient force on a system to overcome its resistance, it causes a change to occur in that system (Larsen, 1995). Once that force is removed the system's resilience will return it to its original state (Larsen, 1995). The time this takes will be determined by the magnitude of the disturbance and the resilience of the system. If, however, the disturbance was continual it would prevent the system from returning to its original state and would cause a permanent change to occur in the system. These changes would occur in the system's structure and/or function (Larsen, 1995). Structural changes affect such features as habitat diversity, flora and fauna diversity, biomass and spatial distribution. Functional changes affect such features as energy dynamics, element cycling and organism interaction (Larsen, 1995). Such changes would then lead to formation of a new stable system different from the first system (Larsen, 1995). Such a change that alters a system's structure and/or function fundamentally changes that system and is identified by Blanco *et al* (2005) as causing that system to become unsustainable. A pivotal indicator of the sustainability of a land management system and of environmental health is water quality as waterways can be affected by all the land use activities that occur in their catchments (Ochola *et al,* 2002).

2.3 Sustainability and Waterways

Waterway ecosystems are particularly vulnerable to disturbances as they are affected not only by activities directly related to them, but also indirectly by activities occurring within their catchments. Activities that result in point source discharges, such as farm effluent disposal are obvious disturbances; not so obvious and easily overlooked disturbances are non-point source discharges such as those resulting from fertiliser application, soil disturbance and road usage. Also important is the proximity at which disturbances occur to waterways. The closer they occur the greater the potential for waterway disturbance.

Waterway disturbances (structural and/or functional) can cause a change to occur to the physical and/or biological properties of a waterway (Larsen, 1995). These changes can be evident in physical measurement such as water chemistry, clarity and temperature. These types of measurements however, provide only a "snapshot" of the waterway condition (Biggs *et al*, 2002). They give little or no record of past events that could have impacted the waterway and provide only an indication of the organism that may live there. Biological measurements however, provide a much more holistic indicator of the waterway conditions (Biggs *et al*, 2002). As such, waterway macro-invertebrates have been used both in New Zealand and overseas for assessing and monitoring the condition of running water systems for a number of years (Stark *et al*, 2001). They have been used for this purpose as they live in waterways for long periods of time, are found in almost all waterways, are easy to sample and identify, and different taxa show varying degrees of sensitivity to pollution and other impacts (Stark *et al*, 2001). Assessment methods that have been developed include the macro-invertebrate community index (MCI) and the quantitative macro-invertebrate community index (QMCI) (Stark *et al*, 2001). These assessment methods use standard macro-invertebrate scores (from 1 to10) which are based on a macro-invertebrate's sensitivity to waterway pollution to obtain a score that indicates the health of the waterway (Biggs *et al*, 2002). The following formulas are used for calculating the MCI and QMCI for a waterway (Stark and Maxted, 2004).

$$\text{MCI} = \frac{\sum_{i=1}^{i=S} a_i}{S} \times 20$$

Where *S* = the total number of taxa in the sample, and *ai* is the score for the ith taxon.

$$\text{QMCI} = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N}$$

Where *S* = the total number of taxa in the sample, *ni* is the abundance for the ith scoring taxon, *ai* is the score for the ith taxon and *N* is the total of the coded abundances for the entire sample.

Biggs *et al* (2002) have combined the MCI method of waterway assessment with habitat observations and some simple water quality measurements such as temperature, clarity, pH and conductivity to develop the New Zealand Stream Health Monitoring and Assessment Kit (SHMAK). This kit was designed for use by farm families and others in New Zealand to monitor the "health" of the streams that flow across their land (Biggs *et al,* 2002). This approach, though not as detailed in the area of water chemistry, yields the necessary information required to make an accurate assessment of water quality. Examining the invertebrate communities shows if the waterway is a good quality habitat, which includes the quality of the water. If the quality of the invertebrates is low, there is sufficient other data acquired that will indicate where the degradation has occurred and where further investigation is required to identify the specific cause or causes of that degradation (Biggs *et al,* 2002).

2.4 Plantation Forestry in New Zealand

Plantation forestry in New Zealand is spread throughout the entire country. Forests have been planted from Southland through to Northland. Despite the resulting variation in climatic conditions plantations all around the country are managed in a similar way. The three regions with the largest areas of plantation forest in the country are; the central North Island with 31.6%, Southland and Otago with 11.6% and Northland with 11.2% (New Zealand Forest Owners Association, 2005). The most predominant plantation tree species in the country is *Pinus radiata* (also referred to as pine or radiata pine in this study), which covers 89.2% of plantation area (New Zealand Forest Owners Association, 2005), the second is Douglas Fir with 6%, and the remaining 4.8% is comprised of all other species. Douglas Fir is a species that prefers colder climates and as a result 73% of the trees are grown in the South Island (Mosely *et al,* 2004), and none is grown in Northland. Radiata pine makes up 94.1% of the species in the North Island and 97.4% in Northland (New Zealand Forest Owners Association, 2005).

There are four management regimes for *P. radiata* plantation forests in New Zealand; pruned without production thinning, un-pruned without production thinning, pruned with production thinning and un-pruned with production thinning(New Zealand Forest Owners Association, 2005). Trees are planted at approximately twice the final stocking rate then they are either thinned to 400-450 stems per hectare at around six years old, when thinnings are left to rot where they fall (thin to waste) or at 10 years old, when they are production thinned for use as posts, poles and/or pulp (Forestry Insights, 2006). Pruning is carried out to produce a high quality log that is 4-6m long with knot-free timber and will require two or three pruning lifts (Forestry Insights, 2006). As of 2003 production thinning (both pruned and un-pruned), had dropped to 21% of plantations (In the Central North Island production thinning has dropped from 65% in 1995 to 33% in 2003). The most popular management regime was pruned without production thinning which comprised 50% of all plantations, second was un-pruned without production thinning, which made up 29% of plantations (New Zealand Forest Owners Association, 2005). A plantation's rotation from planting to complete harvest takes 28-30 years for *P. radiata.*

As *P. radiata* is the most dominant plantation species in the country, and in Northland it makes up over 97% of plantation trees and is the species grown in the Pipiwai forest where this research was conducted, the review into the effects of plantation forestry will focus solely on this species.

P. radiata is an introduced species which originates in North America (Moran and Bell, 1987); as such its establishment in New Zealand required the clearance of other land cover. In the early years of plantation establishment, scrub and native forest were cleared to make way for the plantations. In more recent times the trend has been to use pasture land for plantation establishment (Ministry of Agriculture and Forestry, 2003). In 2002, of the total land in plantation forestry in New Zealand 1.2% (22 000ha) was established on new land. Of that new land, 80% (17,600ha) of new forest establishment occurred on either improved or unimproved pasture, with the remaining 20% (4,400ha) being on scrub land (Ministry of Agriculture and Forestry, 2003).

2.5 Overview of a Forestry Rotation

A basic forestry rotation is made up of three stages; plantation establishment, growth and harvest.

2.5.1 Plantation Establishment

The majority of plantation establishment is re-stocking of a harvested plantation, with only a small fraction involving planting of new areas (New Zealand Forest Owners Association, 2005). As such, the most common practices associated with this stage in a plantation's rotation are site preparation, seedling planting, weed spraying and possible fertiliser application (Forestry Insights, 2006). Site preparation varies from site to site, it may be as little as an aerial or spot application of herbicide to remove weed competition to slash racking or roller crushing, spot cultivation of compacted soil with an excavator and herbicide application.

Planting of seedlings is usually carried out by gangs of workers walking across the area on which a plantation is to be established and planting the seedlings by hand as they go (Maclaren, 1996). There is specifically designed machinery which can mechanically plant seedlings but this is expensive and only useful on flat ground (Maclaren, 1996).

Seedlings may then be spray released once or twice in 18 months (the first time at three months) (Maclaren, 1996) to eliminate weed competition and allow the seedlings to outgrow their competition. During this time there may be an application of fertiliser where soil tests show this is necessary.

2.5.2 Plantation Growth

During this phase in the rotation there are few activities occurring. Tree thinning would take place at approximately ten years old and there may be up to three pruning lifts during this phase. Pruning slash is left to rot where it falls. Trees are usually thinned to waste rather than used in timber production (production thinning). This management option is most commonly employed as production thinning is only marginally beneficial in the short term. The low returns are due to the standard cost of harvest irrespective of tree age combined with the lower value of the immature trees (compared to mature trees). When production thinning is undertaken it can also cause a loss in the value of the main timber crop as the time delay for thinning can reduce the level of timber production in the main tree harvest. To undertake production thinning a plantation must have terrain flat enough to allow the use of ground based machinery and have soil with a high sand content to prevent soil compaction due to the significant machinery movement (Peter Houston, CHHF Forestry Manager, personal communications, July 5, 2005).

2.5.3 Plantation Harvest

This phase in the rotation not only includes the actual removal of trees but also the earthworks to establish and/or upgrade the infrastructure required to remove the trees. Earthworks are carried out to construct roads, skid trails, landings, drainage and possible waterway crossings while harvest involves felling, extracting, processing and transporting the trees.

During the earthworks phase of construction heavy earthmoving machinery is used to construct roads, landings, drainage and any waterway crossings. On flat land, roads and landings only require the removal of topsoil and the application of gravel for transport roads. On steep terrain, hillsides and hilltops need significant excavation to construct roads and landings. This can be done by either flattening off ridge tops or making hillside cuttings (figures 2.3 and 2.4). In both cases the soil that is removed is deposited over the edge of the excavation site. This soil can either be simply pushed over the cutting edge and left to form its own natural gradient, or a bench can be cut onto which fill is placed and compacted (figure 2.4). The second method is more time consuming but it makes a more stable construction that is less prone to mass movement (a significant problem in the past with plantation earthworks). Skid trails do not always need specific earthmoving machinery in their construction as they are only a simple three to four metre wide bare earth track with no drainage and can often be constructed using the blade of the skidder (Dykstra and Heinrich 1996). They are typically located on ridge lines so follow the construction method shown in figure 2.3.

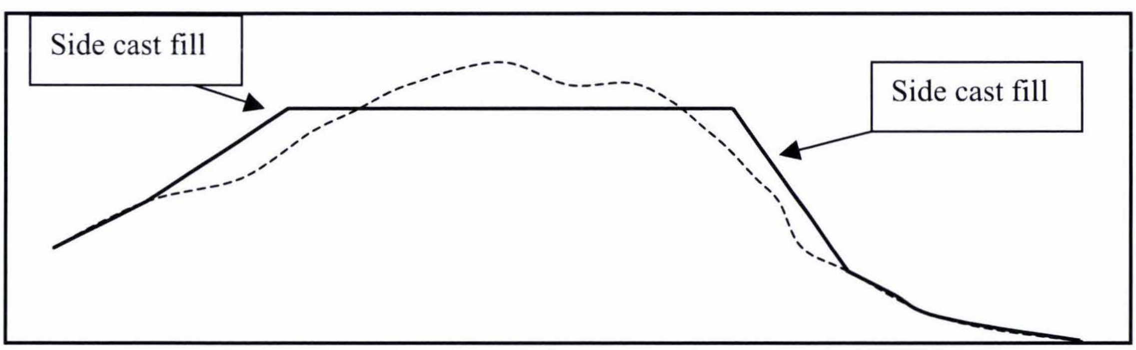


Figure 2.3. Ridge top excavation to form a road, skid trail or landing site.

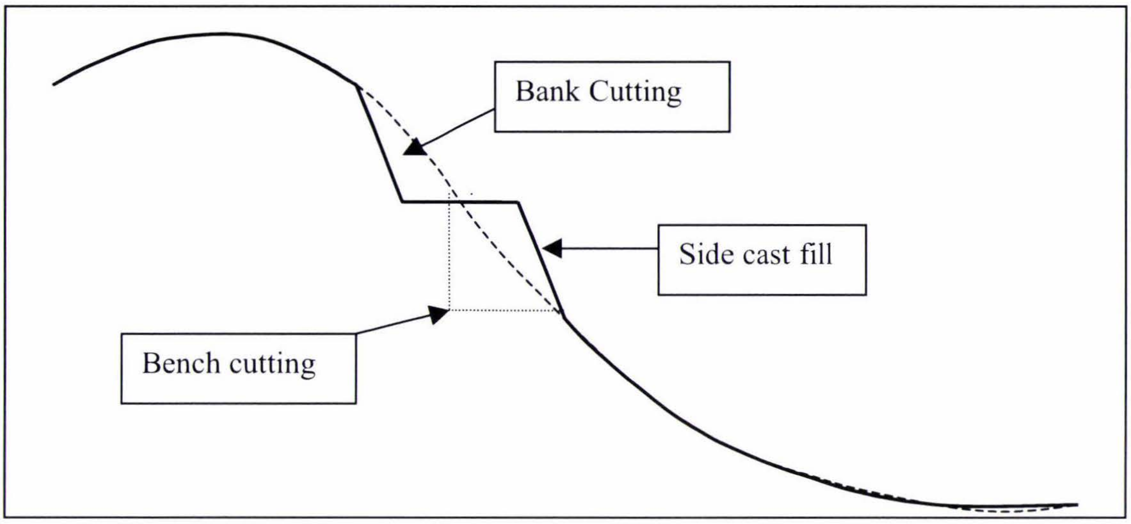


Figure 2.4. Hillside excavation including bench cutting to form a road skid trail or landing site.

There are a number of different types of waterway crossings used in plantation forests. They can either be categorised as fords, which allow machinery to pass through the water, or bridges, which carry machinery over the water. Both types of crossing require earthworks and/or construction to be carried out very close to or even in waterways (Vaughn *et al,* 1993).

Drainage is installed for all transport roads, landings and stream crossings to control run-off and prevent damage to earthworks and trap sediments before they reach waterways.

During harvest trees are felled manually with a chainsaw, they are then extracted using skidders and/or cable haulers. Skidders can haul logs from some distance away using a cable winch. While being pulled on the winch logs are dragged across the ground. Once they reach the skidder butt ends are lifted and held off the ground for transport to the processing and transport area. Logs on the cable hauler can undergo a combination of being dragged across the ground and hauled under partial or full suspension. Once they reach the landing site logs are processed and transported from the plantation on logging trucks.

2.6 Plantation Forestry's Impacts on Waterways

In a plantation forest rotation there are multiple activities that have the same waterway impacts and therefore also have the same waterway implications. As such, to avoid repetition and for ease of reading these sections have been separated. This section will present the impacts plantation activities have on waterways and the following section will present the implications of these impacts.

The review of the effects of plantation activities includes the identification of the impacts they can have on waterways. It does not attempt to provide an absolute quantification of these impacts, as specific site conditions play an important role in such outcomes (Larson, 1995; Blanco *et al,* 2005). Figures that are provided give an indication of the range of quantifiable impacts that can be expected.

2.6.1 Establishment

There is considerable variation in the degree of impact that plantation establishment can have on waterways. This variation is related to the specific site conditions and the establishment practices employed. On an ex-plantation or ex-pasture site that has no more site disturbance than hand planting seedlings, there is little potential for negative waterway impacts. On ex-pasture sites, plantation establishment will usually benefit waterways by eliminating the presence of livestock. This removes the potential for waterway sedimentation and nutrient enrichment due to stream bank trampling (when stock has access to waterways) and direct and indirect faecal contamination (Maclaren, 1996). On ex-plantation sites where practices such as v-blading and root racking occur significant soil disturbance also occurs. Such practices therefore, have the potential to increase waterway sedimentation (Forestry Insights, 2006). Where a plantation is being established on a site covered by scrub there is also significant potential for negative waterway impacts (Maclaren, 1996). In the past, areas of scrub were cleared by burning and the use of heavy machinery. This caused significant soil disturbance and deposition of ash into waterways resulting in increased sedimentation and nutrient inputs (Maclaren, 1996). The use of this type of land is now very limited as are the clearance methods

(Maclaren 1996). Heavy machinery is still used however, for line-dozing or line-crushing to make way for seedling planting (Forestry Insights, 2006). Herbicides can also be used to eliminate weeds and scrub which then has the potential to enter a waterway through direct application or run-off. The removal of the vegetation also increases the potential for waterway sedimentation as the removal makes soil vulnerable to surface erosion via run-off (Quinn *et al*, 2001).

2.6.2 Growth

After a plantation has become established at approximately two years old, it enters a stable regime which will last for approximately 25 years until harvest. For the first six to eight years of this regime, trees are in a juvenile stage in which there is no canopy closure and they do not form a forest cover. The following 17-19 years form a stable forest environment similar to that of native forest. As such, it provides similar environmental benefits to the waterways flowing through it as those of native forest (Maclaren, 1996; Harding *et al*, 2000; Quinn *et al,* 2004). These benefits are outlined below.

Waterway sedimentation is reduced due to soil stabilisation, minimisation of run-off and run-off filtration. Trees help to stabilise the soil by adding mechanical strength through their root systems, modifying soil moisture distribution, and providing a ground cover of organic matter (O'Loughlin, 1984). Fine root systems near the soil surface help soil to resist the mechanical action of run-off and prevent sediments being carried into waterways (Calder and Newson, 1979; Bosch, 1982). The root systems of *P. radiata* trees begin to effectively stabilise soil from five to ten years old. At this age trees are able to resist shallow failures (mass movement near the surface) and as their root systems expand, so does their resistance to soil mass movement (O'Loughlin, 1984; Marden *et al,* 1992). The trees also trap water on their foliage, trunks and branches where it is held and evaporated at varying rates. This interception of rain water reduces the amount of surface runoff and water available for soil saturation. The reduction in run-off also reduces the mechanical action it performs on the soil surface, and therefore reduces surface erosion and the reduction in soil saturation helps to prevent soil mass movement (Calder and Newson, 1979; Bosch, 1982; Dons, 1986). In their study into the effectiveness of trees at reducing erosion Marden *et al*. (1992) found that soil loss under pine plantations was ten times less than that under pasture. Hicks (1991) supported this finding in a soil loss study which also included indigenous forest. He concluded that soil loss under both types of forest were much less than under pasture. The reduction in surface run-off can also reduce waterway flow levels. Dons (1986) found that aforeststion of 28% of a 250 km2 catchment resulted in a 13% drop in waterway flow levels.

As the plantation trees grow, they provide shade to waterways which helps to minimise water temperatures and light inputs. The extent of their shading will depend on the width of the waterway and the age of the trees. At age eight to ten canopy closure will occur for the main body of the plantation, if five metre planting setbacks have been observed during plantation establishment it may take longer for canopy closure over small first order streams while larger second and third order stream/rivers will likely never have full cover (Quinn *et al*, 2004).

Reducing water temperature is important for stream invertebrates as increased water temperatures cause stress and can be fatal (Quinn *et al,* 1994; Boothroyd *et al,* 2004). Increased water temperatures have also been associated with a decrease in dissolved oxygen levels, which can cause stress on all stream fauna (Baillie *et al,* 2005). Reducing solar inputs also reduces the amount of light reaching the water, which helps to limit periphyton growth within the waterway (Quinn *et al,* 1997; Boothroyd *et al,* 2004).

During the first 20 years of a plantation's growth phase, the trees utilise significant amounts of nitrogen and phosphorus to fuel their growth (Quinn, 2003). This results in minimal amounts of the nutrients entering waterways and causing contamination. In a study on the comparisons of nutrient exports from native forest, plantation forestry and pasture, Cooper and Thomsen (1988) showed that land under forestry (native or plantation) exported 3-10 times less nitrogen and 15 times less phosphorus than land under pasture. These reductions would have been a result of not only tree utilisation but also lower application from fertilisers and animal waste, resulting in lower levels of nutrients carried on soil particles (Maclaren, 1996; Mosley *et al,* 2004).

Trees that grow beside and overhang waterways add leaf litter, woody debris and insects to the aquatic environment. These inputs are important for aquatic ecosystems as they provide a food source and habitats for stream invertebrates (Quinn and Scarsbrook, 2001; Boothroyd *et al,* 2004). These benefits are not only contributed by the plantation trees but also by the predominantly native under-storey vegetation which thrives under the canopy they provide (Davies-Colley and Quinn, 1998; Boothrody *et al,* 2004). Quinn and Scarsbrook, (2001) found that pine needles offered the same benefits to aquatic ecosystems as leathery native leaf litter from trees such as rewarewa and tawa. These leaves persisted in waterways for over six months where as other native leaf litter from trees such as wineberries decayed within a month.

It has been found that mature plantation forests create aquatic ecosystems similar to that created by native forests. These ecosystems provide sufficiently high quality habitats that they support pristine-requiring macro-invertebrates and native fish (Collier and Winterbourn, 2000; Mosley *et al,* 2004; Quinn *et al*, 2004). There are instances during some plantations first rotation when this may not be the case. When a plantation is established on an ex-pasture site, the waterways undergo spatial changes. Pastoral streams are generally narrower and deeper than forest streams. This is a result of grass encroaching onto the stream bank and spreading onto exposed parts of the streambed. When plantation trees achieve canopy closure the grass dies and the stream begins to widen and return to its natural forest regime. This results in a release of the stored sediments and an increase in streambed sedimentation and increased suspended solids in the water (Davies-Colley, 1997; Collier and Winterbourn, 2000; Boothroyd *et al,* 2004).

2.6.3 Harvest

Plantation harvest, which is made up of infrastructure construction and tree harvest is responsible for approximately 70% of the disturbance that occurs throughout the plantation's 28year rotation (Hicks and Harmsworth, 1989). The significant soil disturbance during the earthworks phase results in both immediate and ongoing soil erosion. Historically, roading has been identified as the major cause of soil erosion in the forestry operation (Dykstra & Heinrich, 1996; Maclaren, 1996). One of the most significant problems Dykstra & Heinrich (1996) identified was the mass movement of the loose excavated soil. This is supported by LaHusen (1984) who attributed 70% of landslides to road construction, with the greatest number being side cast fill failures and Fransen *et al* (2001) who attributed 80% to side cast fill failures. In the last 10-15 years, there have been significant improvements in earthworks construction (Hicks 2000). One of these improvements has been the utilisation of benches to place and compact loose fill on (as shown in figure 2.4 on page 28). If this is not done, when fill is pushed out over the edge of the cutting it becomes vulnerable to mass movement due to its lack of cohesion, especially when saturated or when the toe of the fill bank is eroded (Schroeder & Brown, 1984, Wallis & McMahon, n.d).

Bank cuttings are also areas that are susceptible to mass movement, the steeper and higher these are the more likely they are to experience mass movement (LaHusen, 1984; Wallis & McMahon, date unknown). The chances of any mass movement are further increased when soil becomes saturated. In his study, LaHusen (1984) showed that 85% of mass movement occurred in poorly drained soils with periodic saturated conditions. In a New Zealand study of forest road erosion, bank cuttings were found to contribute nine times more sediment than the erosion of gravelled roads and ditches combined (Fransen *et al,* 2001).

Road use is also a source of sediment generation (Maclaren, 1996; Fansen *et al*, 2001). Fansen *et al* (2001) found that 20 passes of a truck on a gravelled road can produce as much sediment as that generated in one year by natural surface erosion on a lightly used road. Coker *et al* (1993) found that during 30 minute simulated rain events, trucking on gravelled roads increased sediment yields 15 times more than that generated prior to use.

Also associated with earthworks is the increase in surface erosion from run-off. Once the vegetation cover is removed and the soil horizon is exposed, there is limited protection to prevent soil being washed away. Soil that has been excavated is even more vulnerable than undisturbed soil as it has less cohesion (Heede, 1984). As the water runs across the surface of the ground it forms gullies or tracks. This then concentrates greater volumes of water into one place which causes greater erosion (Burroughs *et al,* 1984).

Many of the activities associated with harvest preparation and tree harvest increase sediment generation and the potential for increased waterway sedimentation, so the following figures have been presented to give an indication of the impacts harvest activities can have. Mosley *et al,* (2004) found sediment yields (in t/km^2/year) for a forest in Southwest Nelson of 37 for mid rotation, 320 during land preparation and 160 at harvest and 62 during mid-rotation rising to 218 at harvest for a forest in the Marlborough Sounds. Though both forests showed a marked increase in sediment yields, as a result of harvest and land preparation, they were still well below estimated background rates of erosion of 500 and 300-600 t/km^2/year respectively (Mosley *et al,* 2004). These figures are supported by Hicks (1990, 1998, 2000) who states the following range of sediment yield figures;

- Un-logged plantation forest – 1.7 to 600 t/km^2/year (Hicks, 1990, 1998).
- Forest landing and road construction – 37 to 570 t/km^2/year (Hicks, 2000).
- Clear felling – 1.8 to 202 t/km^2/year (Hicks, 1998).

These figures from both Hicks and Mosley show that there are increases in sediment yields due to plantation activities but that the increases are within the natural yields for standing forests. Furthermore, these increases only last until two years post harvest (Mosley *et al,* 2004; Hicks, 1998; Maclaren, 1996). Sediment generation figures for other land uses that can be compared to the above plantation forest figures are contained in appendix 6.

Despite the significant increase in sediment generation due to earthworks, Hicks (2000) states that waterway sedimentation is not elevated above the ranges experienced by waterways under standing trees. The reason for this apparent discrepancy is that the majority of the sediments are deposited in drains and on vegetated areas and trapped by slash before they reach the waterways (Maclaren, 1996; Hicks, 2000; Fansen *et al*, 2001). In his report Hicks (2000) states that if slash is left on harvested slopes less than 5% of eroded soil will reach the waterways. Without this proviso Maclaren (1996) states that 10% of sediment generated from earthworks will enter waterways.

When the trees are extracted from the plantation, they are either dragged by skidders and/or crawler tractors or hauled out by a cable hauler. If this process is carried out without having the butt ends of the trees elevated above the ground they can act like a plough breaking up the topsoil and sub-soil, destroying soil structure (Rosoman, 1994) and making it vulnerable to erosion (Heede, 1984). This can be particularly damaging to waterways if it occurs in the riparian management zone (Hicks, 1998).

When ground based harvest methods are employed, skid trails have been highlighted as a cause of significant environmental degradation (Dykstra & Heinrich, 1996). They not only cause soil compaction but soil tracking and soil disturbance. Overseas research has shown that when crawler tractors and skidders are used for log extraction, operators tend to make unnecessary tracks with their blades (Gayoso & Iroume, 1984; Dykstra & Heinrich, 1996). Gayoso & Iroume (1984) found that actual surface alteration was 3.7 times higher than designated by harvest plans when skidder logging was employed. New Zealand studies show that erosion rates are two to over five times higher under ground-based extraction than under cable hauler extraction (Hicks, 1998; Mosley *et al,* 2004). Mosley *et al* (2004) quotes sediment yield figures from a forest on the west coast of the South Island of 139 $t/km^2/year$ for skidder extraction (ground based) and 25 $t/km^2/year$ for hauler extraction. The difference in the sediment yields is a result of the increased length and use of skid trails and roads needed for ground based harvest (Mosley *et al,* 2004).

When skidders and crawler tractors are used to extract logs, they are repeatedly travelling over the same areas of ground. These repeated movements cause soil compaction, which reduces porosity and therefore permeability (Gayoso & Iroume, 1984). In their study in southern Chile, Gayoso and Iroume (1984) found that after 100 passes, rubber-tired skidders compacted the soil to 80-90% higher densities than undisturbed soil. They also found that these effects were made worse as the terrain became steeper and when soil was saturated. When soil is compacted, permeability and water infiltration are reduced, which in turn causes an increase in run-off. When this is combined with bare and loose or disturbed soil and vehicle tracking, there is the potential for increased surface erosion (Schroeder & Brown, 1984).

When trees are being extracted, there can be significant direct negative impacts on waterways. If trees are felled into and dragged through waterways, stream banks can be damaged, channels can be scoured, and aquatic and riparian habitats destroyed (Hicks, 1998). This can result in stream bank erosion, a change in channel direction and the structure of stream habitats, and increased sedimentation (Boothroyd & Langer, 1999). Further damage can be caused if heavy machinery is operating in the riparian management zone (see appendix 2 for a full definition of the riparian management zone). Stream banks can be eroded and soil can be disturbed resulting in greater waterway sedimentation.

When trees are felled and hauled across waterways they can also leave large amounts of slash including pine needles in and suspended over the waterway (Collier *et a*l, 1997).

Besides the direct effects of logs and machinery during harvest, there are also the indirect effects of the removal of the trees. This reverses all the benefits the trees provided as discussed in the growth phase of the plantation. The removal of the trees results in the death of their root systems which stabilised the ground. The root systems lose their stabilising effect over the two years following harvest at which time the ground again becomes vulnerable to mass movement (Sidle *et al,* 1985; Hicks, 2000). This state continues until approximately eight years into the second rotation when the new trees' root systems begin to stabilise the ground once again (O'Loughlin, 1984, .Madden *et al,* 1992).

Once plantation trees have been harvested, they no longer intercept rain or ground water. As a result there is an increase in run-off and therefore an increase in water yields for the catchment. This results in higher flow levels for streams and quicker responses to rainfall, which can cause an increase in stream bank erosion (Mosley, 1992). These effects then gradually decline as the next rotation of trees becomes established. The increased run-off also causes an increase in surface erosion as there are greater volumes of water exerting mechanical action on the soil (Collier and Winterbourn, 2000). Gayoso and Iroume (1984) found that soil loss from bare ground after clear-cutting was 22.4 times higher than soil under mature pine trees. Removal of the trees also leaves more water available to penetrate the soil matrix and cause it to become saturated. This problem adds to the susceptibility of the soil to mass movement (LaHusen, 1984). Tree removal will also initially cause an increase in the amount of nutrients with the potential to enter waterways through ground leaching. This lasts for only the first two years after harvest, and by the third year, nutrient usage by growing trees reverses this situation (Quinn, 2003).

The removal of the vegetative cover also removes the shading benefits of the plantation trees, causing an increase in solar radiation inputs (Quinn *et al,* 2004). For small first order streams, streamside vegetation can provide shade and help to regulate solar radiation inputs within a few years (Harding *et al*, 2000). For larger streams, conditions are not restored until canopy closure of the following plantation rotation.

2.7 Implications of Waterway Impacts

2.7.1 Sedimentation

When sediments enter a waterway they affect both the water quality and the quality of the streambed habitats. Sediments suspended in the water reduce clarity, can help to increase water temperatures by increasing solar radiation absorption (Northland Regional Council, 2002), can clog the gills of fish (Richardson and Jowett, 2002), reduce light penetration and therefore aquatic plant growth (Maclaren, 1996) and clog or cause wear on machinery extracting water from a waterway. When sediments cover a streambed they smother the habitat. This can kill fish eggs by reducing oxygen flow (Richardson and

Jowett, 2002) and destroy the habitats of macro-invertebrates (Death *et al,* 2003). Quinn and Hickey (1990) in their survey of 88 rivers found that both numbers of taxa and total invertebrate density were lower in rivers where sand and/or silt covered a significant proportion of the riverbed. Baillie *et al* (2005), in their study on the effects of slash removal on two Northland streams, also found where sand and silt dominated the streambed substrate, invertebrate numbers and diversity were negatively impacted. When streambed sedimentation occurs, mayflies, Dobson flies and stoneflies are commonly absent or of low diversity and the habitat becomes dominated by species of snails and worms (Death *et al,* 2003). In their study into the effects of sediment on fish communities, Richardson and Jowett (2002) found that steams with high sediment loads had lower numbers and less diversity of native fish species than streams with low sediment loads (low sediment loads had up to nine species, high sediment loads had only two). Though the effects of waterway sedimentation from forest harvest are reasonably extensive, recent research suggests that they are only short term and that they return to pre-harvest levels within two years (Hicks, 1998, 2000).

2.7.2 Increased Solar Radiation Inputs

Increased water temperatures can be fatal to aquatic life. In a laboratory study by Quinn *et al* (1994), tests showed that sensitive invertebrates such as the mayfly species (Deltidium) experienced a 50% death rate at temperatures of 22.6^0C over four days. It was also noted that the sensitive stoneflies (Plecoptera spp.) were restricted to rivers with summer temperatures typically below 19^0C. In another laboratory study, Richardson *et al* (1994) studied the water temperature tolerances of eight New Zealand freshwater fish species. They found that the most sensitive species had fatal limits at 25^0C, while some of the most tolerant could survive at temperatures well into the 30s. They found that many of New Zealand's fish species could thrive in a wide range of water temperatures. Also related to water temperature is dissolved oxygen (DO). In their study on the effects of forest harvesting and woody debris removal on two streams in Northland, Baillie *et al* (2005) found that in waterways with little primary production (plant photosynthesis), minimum DO levels coincided with maximum water temperatures. The effect of removing riparian vegetation has the potential therefore to impact on waterway invertebrates for many years. These effects are not reversed until stream shade is re-established sufficiently to lower water temperatures. From their study in the Coromandel Peninsula, Quinn *et al* (2004) stated that this can take as long as 8-10 years (canopy closure) for small streams and possibly longer for larger streams.

The increase in light can also fuel the growth of aquatic plants which shifts the balance of the aquatic communities to favour plants and plant feeders rather than dendrite feeders (organisms that feed on wood and leaf litter) (Quinn & Scarsbrook, 2001). The growth of aquatic plants can reach a point where they choke waterways, and when they die, their decomposition can deplete the water of dissolved oxygen, placing stress on aquatic life as well as fuelling another cycle of growth (Maclaren and Cameron, 1999).

2.7.3 Waterway Slash

Slash that is suspended across a waterway can provide shade that helps to minimise solar radiation inputs and keep water temperatures down (Collier *et al,* 1997; Boothroyd *et al,* 2004; Quinn *et al,* 2004). Slash that is in the water in small amounts can provide habitats, trap food and be a food source for aquatic life (Collier *et al,* 1997; Meleason *et al,* 2002). When it is in large quantities however, slash can cause damming and excess nutrient inputs and depleted oxygen levels in the water through vegetation decomposition (Collier *et al,* 1997; Quinn *et al,* date unknown). This can then result in the accelerated growth of aquatic plants, especially when there are additional sunlight inputs (Stark, 1994).

2.7.4 Increased Disturbance Frequency

Compared to the 28 year rotation length of a plantation forest, the cycle of disturbance due to harvest and plantation re-establishment is relatively short. The long term effects of this however, are still uncertain, but research has shown that disturbance is one of the principle factors affecting invertebrate communities (Death & Zimmerman, 2002) and that substrate stability is one of the principle determinants of invertebrate assemblage diversity, abundance and composition (Harding *et al*, 2000). Disturbances include deposition and removal of slash, increased water flow, stream bank disturbance and increased sedimentation. Harding *et al* (2000) found that the greatest stream disturbances were a result of increased bank disturbance, mechanical disturbance of the streambed and deposition of slash into the waterway, and that the least disturbance occurred with the least bank disturbance and where slash covered the stream but was not in it. The more often disturbances occur in a waterway and the greater the magnitude of these disturbances, the longer the recovery period that is necessary for stream life to return to their pre-disturbance state (Maclaren, 1996).

2.8 Current Management of Waterway Impacts

2.8.1 Local Government Regulation

Since the passing of the Resource Management Act 1991, each regional and district council has been responsible for the promotion of the sustainable use of certain natural resources in their areas (Ministry for the Environment, 2006). As such they have had to develop an effects-based Soil and Water Plan to regulate all activities that utilise these resources (Ministry for the Environment, 2006). The Northland Regional Council (NRC) has been no exception, and their soil and water plan became operative in August 2004. Their plan specifically addresses plantation forestry and the activities that may occur. The establishment of a plantation forest is classed as a permitted activity as long as certain criteria are met. These criteria, taken from the Northland Regional Soil and Water Plan, section 32 (Northland Regional Council, 2004) are summarised below, (a full copy of the relevant sections from the regional plan are contained in appendix 1):

- Any vegetation clearance on erosion prone land is not greater than five hectares and is replanted within two years of the commencement of clearance.
- No vegetation clearance occurs in the riparian management zone.
- Trees cannot be planted within 5m of a water body or coastal marine area.

- No vegetation, slash, soil, earth, rock, or any other debris shall be allowed to enter or shall be placed in a position where it could readily enter, or be carried into, a river, lake or wetland, that may result in:
  - Diversion or damming; and/or
  - Bed or bank erosion; and/or
  - Adverse effects on ecosystems that are more than minor.
- No vegetation, slash, soil, earth, rock or any other debris shall be allowed to enter or shall be placed in a position where it could enter and have more than minor adverse effects within the Coastal Marine Area.
- Machinery must not operate within 5m of the bed of a river.
- No storage or mixing of fuels, oils, agrichemicals or other similar substances can take place in the Riparian Management Zone

Until harvest, the plantation rotation can continue without any restriction but those listed above. Prior to harvest, it is likely that resource consent will be required for the earthmoving operations. There are some instances where consent is not required; this depends on the size of the earthworks that will be undertaken and the slope gradient and the susceptibility to erosion of the land on which the earthworks are being carried out. Where earthworks are to be carried out on erosion prone land with a slope greater than 26 degrees or on non-erosion prone land and the earth being moved is greater than $5000m^3$, resource consent is required as these are discretionary activities. When the land is erosion prone with a slope less than 26 degrees and the earth being moved is greater than $1000m^3$ or exposes more than $1000m^2$ it becomes a controlled activity. This too requires resource consent but is only controlled on specific grounds and is non-notifiable (no public notification of the activities being carried out is required) unless special circumstances exist. The following is a summary of the earthworks requirements taken from section 33 of the Regional Soil and Water Plan for Northland (Northland Regional Council, 2004) that must be met under both classifications. These are followed by the matters subject to control under the controlled activity (The full set of rules are contained in appendix 1).

- Soil loss must be minimised by re-vegetation of exposed areas in the spring or autumn following the completion of an operation. Or when operations have ceased for the winter, the exposed areas must be over sown with a temporary cover or mulched in autumn or have some other measures in place to minimise soil loss.
- Batters and side castings must be stabilised to avoid slumping of up-slope land and movement of soil offsite such that it can enter a water body or the Coastal Marine Area.
- Roads and tracks must be maintained or re-vegetated when no longer in use, to avoid or minimise erosion and sediment discharges.
- All earthworks must include storm water controls to prevent scour from channelled water and to prevent sediment discharges.

The matters over which the Council exercises control are listed below.

- The adequacy of sediment and runoff control measures.
- The location and extent of any earthworks.
- The adequacy of site rehabilitation and re-vegetation measures to control sediment discharge and adverse effects on soil conservation.
- Information and monitoring requirements.

During plantation harvest there is little restriction placed on loggers. The following four points regulate this aspect of plantation forestry:

- Where practicable and safe to do so, trees must be directionally felled or pulled back from water bodies, indigenous wetlands or coastal marine areas. Trees that are felled into any of these areas must be extracted in such a way as to minimise damage to the beds or banks.
- During cable logging all stem butts must be raised above the ground when they pass through the riparian management zone. When logs are being hauled through this area, damage to the remaining riparian vegetation must be minimised.

- Machinery used for ground harvesting operations shall not operate within 5 metres of a water body, indigenous wetland or the Coastal Marine Area other than at a designated crossing, on existing roads or tracks or to assist with directional felling or to lift the stem butt out of any water body, indigenous wetland or the Coastal marine Area. Turning or 'screwing' of machines must not occur within 5 metres of the bed of a river, lake, indigenous wetland, or the Coastal Marine Area.
- Harvesting in or adjacent to the Riparian Management Zone must be undertaken in such a way as to minimise the disturbance of riparian edge vegetation (other than that which is part of the plantation forest that has formed part of the riparian vegetation).

2.8.2 Industry Regulation

There are no compulsory industry initiated standards operating in Northland or in New Zealand. There are a number of accords and voluntary operating standards specifically designed for the forestry industry in place as well as individual company policies. The following is a list of New Zealand accords and operating standards;

- The New Zealand Forestry Accord 1991 (New Zealand Forest Owners Association, 1991).
- New Zealand Code of Forest Practice (Vaughn *et al*, 1993).
- Principles for Commercial Plantation Forest Management in New Zealand (New Zealand Forest Owners Association, 1995).
- National Standard for Certification of Plantation Forest Management in New Zealand (New Zealand Forest Owners Association, 2005).
- The Forest Stewardship Council Principles and Criteria for Forest Stewardship (Forest Stewardship Council, 2005)

The New Zealand Forestry Accord is focused on the protection of indigenous forest and as such does not deal specifically with waterways or plantation activities which impact on them (New Zealand Forest Owners Association, 1991).

The New Zealand Forest Code of Practice is a handbook for forestry management and covers all aspects of forestry operations and how to minimise their impact on the environment. As such it deals specifically with water-bodies. The last edition was printed in 1993 and is now somewhat dated, as more up to date literature has been published since that time.

The Principles for Commercial Plantation Forest Management in New Zealand address waterway impacts in a brief and general way. It requires that plantation management safeguards the life-supporting capacity of water, minimises erosion to maintain water quality, and safeguards stream margins and waterbodies with the objective of achieving healthy aquatic ecosystems (New Zealand Forest Owners Association, 1995).

The National Standard for Certification of Plantation Forest Management in New Zealand has a more detailed and thorough set of management standards. It stipulates that the forest owner shall comply with all regulatory requirements and forestry industry codes of practice relevant to minimising the adverse effects of forestry operations on water quality. It prohibits commercial planting within five metres of waterbodies or requires the use of management practices that maintain water temperatures, sediment and nutrient levels. Earthworks within the riparian zone are prohibited unless they are for a designated crossing or for the purpose of maintaining existing roads and owners are required to identify water catchment areas and fisheries that may be compromised by management operations (New Zealand Forest Owners Association, 2005).

The Forest Stewardship Council Principles and Criteria for Forest Stewardship have fewer but no less prescriptive requirements. It requires that streamside zones and wildlife corridors be incorporated into a plantation's layout and that plantation forestry causes no adverse impacts on water quality (Forest Stewardship Council, 2005).

2.9 The use of Riparian Buffer Zones

To protect waterways from the effects of plantation forestry activities, the use of undisturbed riparian buffer zones is being promoted by community groups and investigated by researchers (Quinn *et al* 2004). A riparian buffer zone (RBZ) is an area beside a water body in which undisturbed vegetation grows. It serves to protect, or buffer a waterway from the activities of the surrounding land use. RBZs have been found to offer the following benefits to waterways: reduced sedimentation, reduced slash inputs, and reduced solar inputs.

The reduction in sedimentation occurs both directly and indirectly. Directly, the buffer zone can act as a filter, trapping non-point source surface sediments, before they reach the water (Maclaren, 1996) while tree roots help to stabilise stream banks and prevent erosion (Quinn *et al,* 2004). Indirectly, having the buffer zone prevents logging activities occurring close to and across waterways which eliminates the associated soil disturbances and sediment inputs (Maclaren, 1996). In their investigation into the effects of RBZ in a plantation forest in the Coromandal Peninsula, Quinn *et al* (2004) found that the harvest of areas with RBZ caused no increase in stream bank erosion. Whereas areas that were clearcut (had no RBZ) had an increase in stream bank erosion from 9% to 30.2%. Boothroyd *et al* (2004) found that sites with RBZ underwent only minor changes to waterway sedimentation compared to unbuffered sites.

When harvest slash is deposited in a waterway it can increase stream bank erosion, waterway sedimentation, and the formation of debris dams and cause a drop in dissolved oxygen levels (Collier *et al,* 1997; Meleason *et al,* 2002). When RBZ are present slash inputs are reduced as no harvesting activities are conducted in or close to the waterways. As such, this leaves little potential for any slash to be deposited in a waterway.

Retaining stream side vegetation keeps the water shaded (the degree of this depends on the height of the vegetation and the width of the waterway), which helps to minimise water temperatures and limits periphyton growth. In their study in the Coromandel

Peninsula, Quinn *et al* (2004) found that RBZ were able to increase waterway shading by as much as 40% over clearcut areas. Baillie *et al* (2005) found that when riparian vegetation was removed, there was a 50% increase in light reaching the waterway. The benefit of the stream shade provided by the buffer zone is reflected in the water temperatures. Boothroyd *et al* (2004) found that pre-harvest waterway sites with riparian buffers had average temperatures of 16^{0}C, and a range of 12-21.2^{0}C. Post-harvest, the average temperature was 16.6^{0}C with a range of 11.6-23.9^{0}C. At clearcut sites, (no buffers) the average post-harvest temperature was 18.7^{0}C with a range of 12.2-30.2^{0}C. Diurnal temperatures at the buffered sites varied by 3-4^{0}C while at clearcut sites the variation was 10-12^{0}C. These results were statistically significant ($p=0.014$) and show that the buffers were able to reduce both peak water temperatures and minimise the variation in water temperatures, findings that were also supported by Quinn (2005). Waterway shading was also correlated to less periphyton biomass; Boothroyd *et al* (2004) found that periphyton biomass was at times 100 times greater in open canopy sites than in sites with vegetation cover.

The three individual benefits provided by the RBZ together help to maintain a stable, undisturbed waterway environment. In their study into the effects of substrate stability and canopy cover on stream invertebrates, Zimmermann and Death (2002) found that macro-invertebrate numbers at disturbed sample sites were half that at undisturbed sites. They also found that there were slightly more species at undisturbed sights than disturbed sights (21 vs 18) though the difference was not significant at the 10% level.

There have been few studies which have compared the effects of plantation harvest with and without RBZ on fish and stream invertebrates. Rowe *et al* (2002) conducted a study into these effects on native fish. They found that total fish abundance and species equitability were highest at the logged sites with buffer zones and concluded that RBZ enhanced the native fish communities within the logged catchments. As part of their study into the effects of RBZ, Quinn *et al* (2004) found that compared to waterways with RBZ, clearcut reaches had lower taxonomic richness; lower relative abundance and richness of mayflies, stoneflies and caddisflies; fewer shredders; and lower IBI values;

and half of the clearcut reaches were classified as ''severely impaired'' relative to a native forest reference. Though not studying the effects of RBZ's, Baillie *et al* (2005) concluded that RBZ's would have mitigated most of the adverse impacts they observed as a result of plantation harvest and subsequent slash clearance in two Northland streams.

2.10 Implications of Riparian Buffer Zones

The inclusion of RBZs in plantation forests has two main drawbacks for forestry owners; reduced timber production and increased management costs. If land must be set aside for RBZs, it must be taken out of production and this loss of productive land results in a corresponding loss in income. A study of one plantation found that there was a 13% loss of production land to RBZ's (Quinn *et al,* 2004).

Retaining undisturbed buffer zones will also increase the cost of tree harvest. This occurs for several reasons. Plantation trees at the edge of RBZ's need to be directionally felled to avoid damage to the buffer zone. On flat land this is a relatively simple process but on steep land it may require overhead cables or wincher cables to be attached to pull trees away from the buffer zone. On very steep slopes, this may call into question the financial viability of harvest as many of the trees would need to be controlled by cables to prevent them sliding into the RBZ. This process is much more time consuming (and potentially dangerous) than felling with the slope of the land, and therefore, increases the cost of and time for harvest. Having RBZs also limits the routes by which trees can be extracted and results in an increase in the number of landing sites and length of roading required to access and extract all trees (Quinn *et al,* 2004). Quinn *et al* (2004) found that retaining RBZs in a 296 hectare catchment increased the number of landing sites from 30 to 38 and increased the roading density from 33.2 to 40.4m per hectare. This obviously increases the cost of earthworks and the time taken before harvest can begin. Another issue with the retention of RBZ is the ability of foresters to effectively aerial spray areas before planting. If an area to be sprayed is crossed by one or more waterways with undisturbed buffers a helicopter operator must 'freehand spray' around the buffered areas rather than making straight flight paths allowable with no buffers. This necessity increases the helicopters flight time and therefore the overall cost of the operation.

A potentially negative impact for waterways when RBZ's are retained is that the increased roading and skid trail length and the number of landing sites required would increase the amount of sediment being generated. RBZ's would do little to prevent such sediment reaching waterways (Maclaren, 1996; Quinn *et al,* 2004) as it is usually a point source contamination from concentrated run-off from road drainage (Maclaren, 1996).

Background

Chapter Three

3.1 The Northland Context

The information in the following three paragraphs has been taken from the 2002 State of the Environment Report for Northland (Northland Regional Council, 2002) unless otherwise stated.

The Northland region covers an area of 1 262 000 hectares, it has 1700km of coast line with the farthest distance from the coast being 40km. It has many lakes and rivers; lakes are typically shallow and rivers short with small catchments. The rivers are generally slow flowing with high sediment loads of clay particles up to 1kg m^{-3}. Most of the major rivers discharge into harbours rather than directly into the sea. Northland's waterways are significantly affected by rainfall. There were once significant wetlands in this region but drainage for agricultural purposes has reduced them to small scattered areas that are vulnerable to changes in the hydraulic regime.

The topography of Northland is typically steep or rolling hills. There are few mountain ranges with the highest point in the region being 774m above sea level. There are also few areas of flat low lying land. Much of the soil in the region is strongly leeched mature heavy clay, while top soils are generally thin and sub-soils are of low fertility. This has been influenced by the warm moist climate, absence of recent ash showers and the vegetation cover. The region has an average annual rainfall of 1000-1300mm for low lying coastal areas to over 2500mm for higher country areas. The average temperatures vary from 15.5-16°C in the far north to 14-15.5°C in the south west. Trees with acid litter such as kauri, totara and rimu have produced strongly leached soils, with the best known soils being the gum-land soils formed under kauri forests. Broad leaf trees such as the puriri, kohekohe, tarire and tawa have formed fertile top soils due to the rapid decomposition of their leaf litter.

Northland's land use capability is not very diverse, with nearly 50% being made up of class six, and 85% being made up of classes four, six and seven. Of the three classes, six and seven have steep terrain, and all three have erosion problems, with class six being the worst with a significant proportion listed as moderate to serve. The erosion is mainly from gully erosion with some sheet erosion and is a result of native vegetation clearance in order to make way for pastoral farming. To combat this problem exotic forestry has been encouraged with the rationale that 25 years of erosion control outweighs any negative environmental effects of tree harvest. A significant amount of aforestation to prevent erosion and consequent waterway sedimentation occurred in the 1970s in the upper catchments of some of Northland's larger rivers. Currently Northland has 204,057ha or 16% of its land in plantation forests (Ministry of Agriculture and Forestry, 2003). Historically, almost 85% of the land owned by forestry corporations was in class six and seven, which was a disproportionate amount as compared to the total land in these classes making up just under 61% of the total land area in Northland (Wheeler & Moran 1985). Of the total plantation forests in Northland 97.4% is planted in radiata pine (Ministry of Agriculture and Forestry, 2003). Some early forestry establishment occurred by clearing indigenous forest, but by the early 1980s, the increase in forestry was coming primarily from conversions from low production pastoral land as that in Land Use Capability (LUC) classes six and seven (Wheeler & Moran 1985). In 1991 the New Zealand Forest Accord was signed which helped to ensure this trend continued and that native forest was no longer converted to plantation forest (New Zealand Forest Owners Association, 2006).

3.2 Pipiwai Forest

The information regarding the Pipiwai forest has been supplied via personal communications from the CHHF (Carter Holt Harvey Forests) office in Whangarei unless otherwise stated.

The Pipiwai forest, where this research was conducted, is located northwest of Whangarei and covers 6436.6ha (Figure 3.1). This area contains a 700ha kiwi reserve and a quarry and is used recreationally for pig hunting and tramping. It is owned by Carter Holt Harvey Forests Limited and was planted mostly in the 1980s with some areas being planted in the late 1970s and early 1990s. The main waterway that flows through the forest is the Tokawhero stream; this is fed by over 40 tributaries and flows into the Tawapuku and then the Awarua Rivers. Also present in the forest is the Te Karaka Stream, which is a much smaller stream fed by three tributaries that joins the Tokawhero after it has left the forest. The land the forest was established on is low value rural land and is surrounded by pastoral farmland, Maori owned land and DOC estate. The soil in the forest is dominated by Te Kie steep land soils, which are a combination of stony clay loams and clay loams. The underlying geology has marine origins and is comprised of limestone and shale. The topography of the plantation is rolling to steep hills with the highest point being 313m above sea level. There are few areas of flat land that are located in narrow valley bottoms.

There are a number of environmental controls which affect the management of the plantation forest, including the Northland Regional Council Water and Soil Plan, Northland Regional Council Air Quality Plan, Whangarei District and Far North District Plans, and the Historic Places Trust. CHHF has its own environmental controls monitored and administered by its own environmental planner.

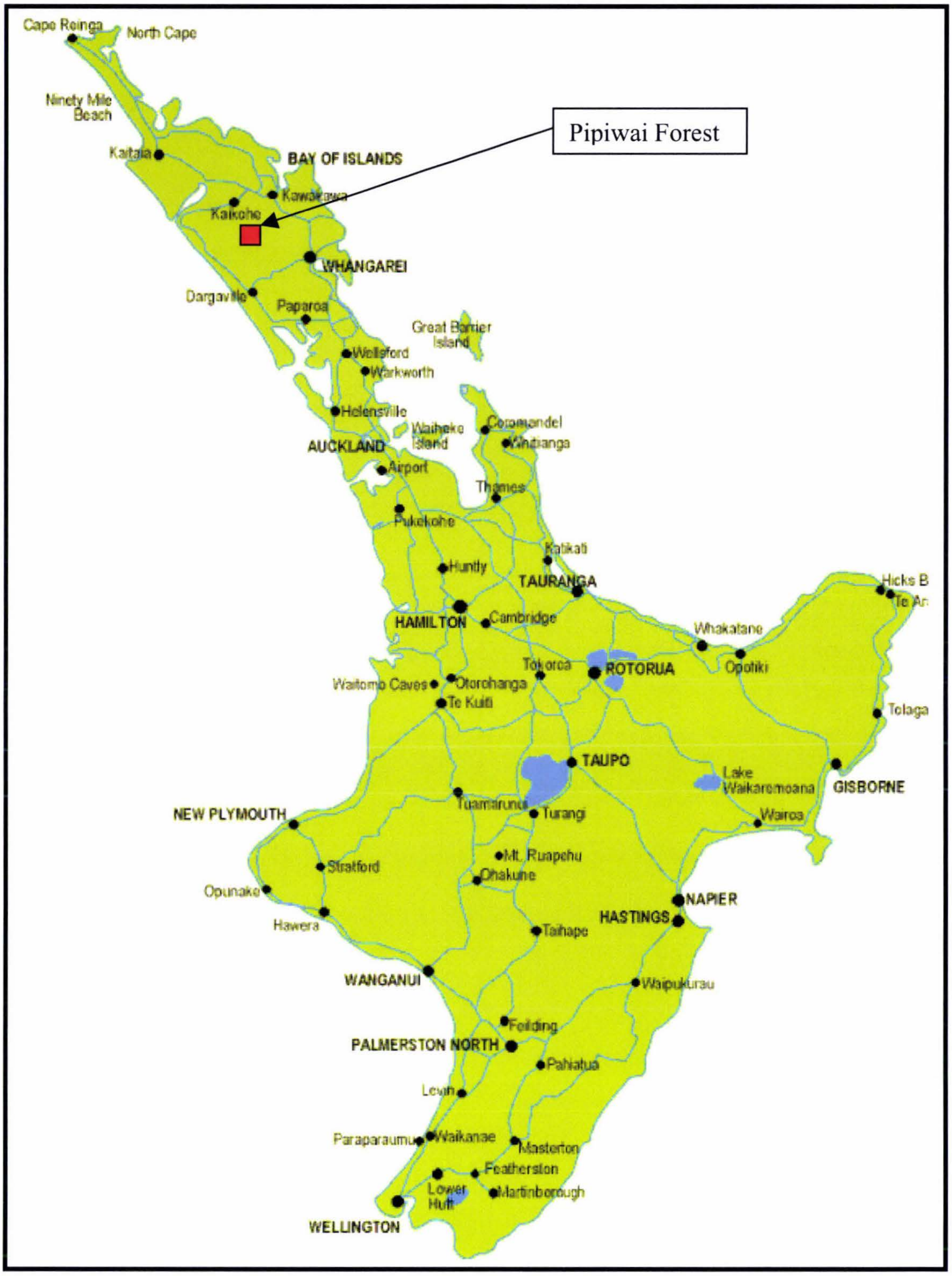


Figure 3.1 Map of the North Island of New Zealand showing the location of the Pipiwai Forest.

3.2.1 Plantation Management

The plantation was first harvested in 1982 for a short period of time before clear-felling began in 1990 and has been harvested off and on since. The present harvest completes the plantation's first rotation, as such all infrastructure necessary for harvest have been constructed as each new area is ready for harvest. The first rotation has been managed under both a pruned and un-pruned regime. The southern half of the plantation has been pruned and thinned while the northern half has only been thinned.

3.3 Climate

There is a rain gauge located a few kilometres down river from the Pipiwai forest at the Twin Bridges. This gauge showed that the average annual rainfall for the area over the past six years was 1413mm. Historical data from a previous site had an annual average of 1436.2mm. The monthly averages show that February to April is the time of lowest rainfall (Figure 3.5) and therefore the time when streams are likely to be at their lowest flow levels. This time also coincides with high summer temperatures and likely results in increased stress levels on waterway communities.

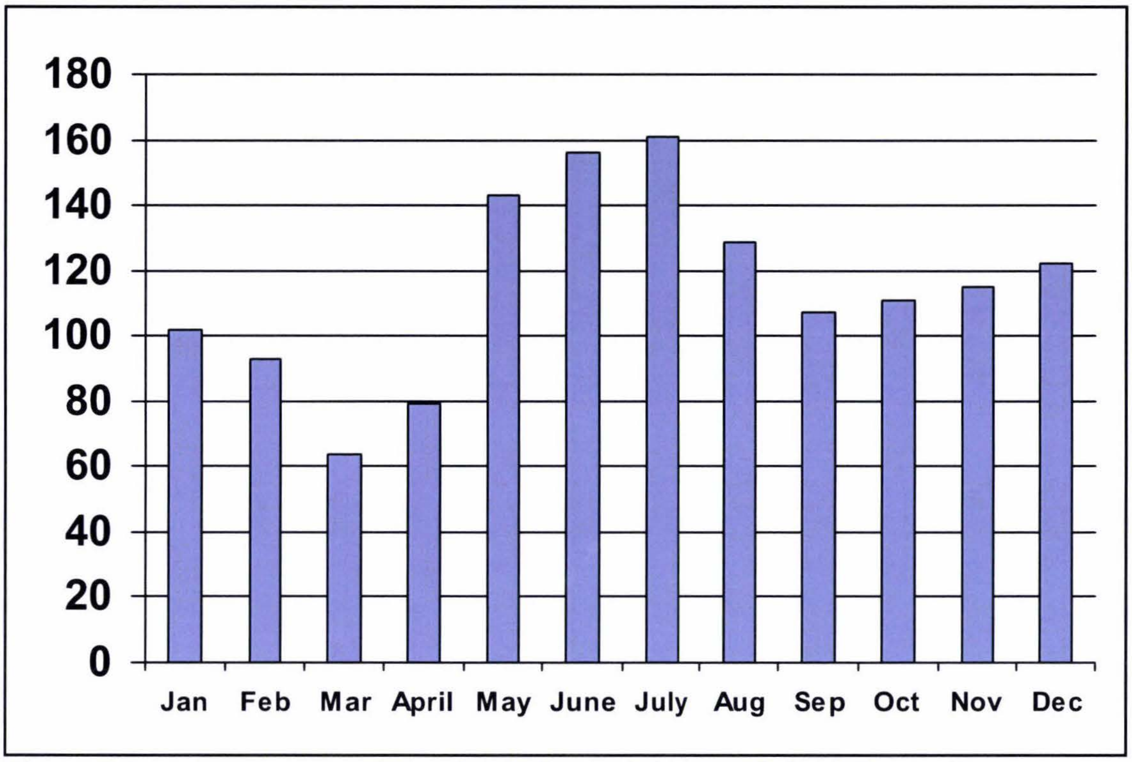


Figure 3.2 Average monthly rainfall (in mm) for the Pipiwai Forest (Data supplied by Kathy Walter from NIWA and Dale Hansen from the Northland Regional Council).

Methodology

Chapter Four

4.1 Introduction

This research involved an investigation into the effectiveness of RBZ at protecting waterways from degradation during forestry harvest. The Pipiwai Forest was selected for this research as it had harvested areas both with and without RBZ and also had blocks of standing mature pines. As such, it was a case study yielding results pertaining directly to the plantation and the management regimes employed there. The results also contributed to general theory on the subject which in turn could be useful for similar cases.

Waterways under mature pine forest and in harvested areas with and without riparian buffer zones were sampled using the Stream Health Monitoring and Assessment Kit (SHMAK). This sampling was undertaken at 15 sites; five sites per stream treatment. At each site samples of the stream invertebrates, observations of riparian and aquatic habitats and physical water tests were taken. These data were then used to determine the health of each of the waterways sampled. From this information, conclusions were then drawn on the protection that buffer zones provided for waterways during harvest, and the implications that this has for plantation management. Interviews with CHHF managers were also conducted to determine the specific harvest practices that were employed in the harvest of the Pipiwai forest and the overall plantation management that was used for the first forest rotation and will be used in the second forest rotation.

4.2 Research Approach

4.2.1 Research Design

The aim of this study was to determine the effectiveness of riparian buffer zones for protecting the waterways in the Pipiwai forest from the impacts of plantation harvest, and the implications this has for forest management. To achieve this, the research was separated into two parts. The first part dealt with determining the effectiveness of the buffer zones at protecting the waterways from the impacts of harvest, and the second part dealt with the implications the results from part one had for plantation management. This separation was necessary as the data involved in both aspects of the research were different and therefore required different acquisition and analyses methods.

To achieve the overall aim of the research, two questions pertaining to part one and one question pertaining to part two needed to be answered: how had tree harvest impacted waterways with and without riparian buffer zones? Had the quality of the buffered waterways been maintained at a significantly higher level than that of the clearcut waterways? And, what implications did the answers to the first two questions have for plantation management?

To answer the first question, the state of all of the waterways had to be determined. This was achieved through assessing the quality of the riparian and aquatic habitats, the physical water quality and the quality of the macro-invertebrates present in the waterways. The riparian habitats were assessed as they significantly influence the quality of the water in the waterways through temperature and light regulation (Quinn *et al* 2004), leaf litter inputs (Quinn and Scarsbrook 2001), and sediment inputs (Maclaren, 1996; Quinn *et al,* 2004). Physical water quality assessment was undertaken as it was a direct measurement of the physical conditions at the time of sampling. The use of aquatic macro-invertebrates to assess water quality has been used extensively in New Zealand and overseas for many years to assess the quality of running water (Stark *et al*, 2001). It was used in this investigation as it provided a holistic measure that reflected past events, rather than relying solely on the "snapshot" provide by physical measurements and habitat observations (Biggs *et al*, 2002). The combination of these three assessment methods is commonly used in water quality testing and is seen in the SHMAK, which was designed for farmers and other landowners wanting to assess the health of waterways crossing their land (Biggs *et al*, 2002).

To answer the second question, the condition of the waterways was compared using statistical analysis to determine if any differences were the result of the samples being taken from different populations, or simply the variation that would be expected in a single population. This means of analysis gave an objective, mathematical measurement that determined the likeliness of different sample results coming from the same population. Without such a measurement, decisions on whether the buffer zones had protected the waterways would have been subjective and difficult to defend.

Once the effectiveness of the buffer zones had been determined, the implications these had for forestry management were identified. This process was essential to gain a practical application from this research. Identifying management practices that failed to prevent waterway degradation, or ones that helped to prevent waterway degradation, could aid in better harvest management of the Pipiwai forest and add to the literature available on this topic.

4.2.2 Data Acquisition

The approach to data acquisition and analysis for part one of this research was focused on the waterway sample sites at the Pipiwai forest. This required sound experimental design to ensure meaningful data were collected and statistical analyses would provide objective results. The acquisition and analysis of the management data for part two of the research was focused on gaining information on how the harvest was carried out, including CHHF environmental policies, and interpretation via comparison with current literature and experimental results.

The acquisition of the data from the Pipiwai forest came from under three different waterway management regimes: harvested with RBZs; undisturbed, mature pine forest;

and harvested without RBZs. Data were gathered from five sites under each management regime, giving a total of fifteen sample sites. At each of these samples sites data were recorded on the riparian and aquatic habitats and the physical quality of the water. Macro-invertebrates data were gathered by taking five samples at each site, which gave a total of 25 samples per management regime and 75 samples over all three management regimes. Five sample sites were chosen as this number was sufficient to provide robust data for analysis but not too many to make data acquisition unmanageable in the timeframe allowed. This was the same reason that five macro-invertebrate samples were taken per sample site.

The group of data gathered from the buffered waterways was considered representative of the management regime under investigation, while the data from the undisturbed, mature pine forest and the unbuffered waterways served as control groups. The first of the control groups, waterways with undisturbed mature pine forest, provided a representative sample of the condition of the waterways in the plantation prior to harvest. The second control group, harvested without RBZs, provided a representative sample of the condition of waterways that experienced harvest without RBZs. As such, the first of the control groups was a reference point to which the buffered and unbuffered waterway data were statistically compared in order to determine if either group had changed significantly as a result of plantation harvest. The data from the buffered group were also statistically compared to the data from the unbuffered group to determine if their conditions were significantly different.

The aim of the questions, that the CHHF managers were asked, was to identify all the actual and potential threats to the waterways through the management of the plantation's first rotation. It was important to gather data on the plantation management prior to the actual harvest, as these practices could have impacted the waterways and influence the results. Practices such as fertiliser and spray application, tree pruning and thinning, have the potential to impact waterways and cause an elevation in the levels of waterway chemicals, nutrients and sediments. As such, if this had occurred it would have affected the results and therefore needed to be identified. Questions relating to the timing of the harvest were designed to ensure that there was a similar time lapse between harvest and sampling for all of the sites. Considerable differences in the time lapse could have biased the results, as it would have been possible for waterways with a greater time since harvest to have recovered significantly more than those with a shorter time lapse. The questions that were asked regarding the plantation harvest were designed to provide data that could be used in the interpretation and explanation of the results, and that could add to practical improvements to plantation management in regard to water quality management.

4.2 Site Selection

Before any site visits were made, geology, catchment size and stream order data on the Tokowhero and Te Karaka streams and their tributaries were examined to identify waterways with similar characteristics. These data were obtained from two NIWA databases, the River Environments Classification and the Freshwater Environments of New Zealand. These data showed that the geology and catchment sizes of the waterways within the plantation were similar and that there were a number of both first and second order streams potentially suitable for this research. It was important to carry out this investigation to ensure only streams with similar geology and catchment size and the same order were chosen as differences in these factors could influence the results. Two site visits were then carried out to identify a total of 15 sample sites in either first or second order streams, five with RBZ, five without RBZ (clearcut) and five under undisturbed mature (20yrs +) plantation trees. Mature native sites were not sampled as they are very similar to mature pine sites (Maclaren, 1996; Quinn *et al,* 2004).

During the first site visit, buffered and clearcut waterways were selected based on their order, size and the time of tree harvest, and the undisturbed mature pine waterways were selected based on stream order and size. First order streams were chosen as there were an insufficient number of second order streams under the three management regimes. The waterways with and without buffer zones were selected from areas harvested within the previous 24-30 months. There were an insufficient number of waterways for this research in areas harvested more recently. All of the waterways had their depth and width measured to ensure only those of similar size were chosen. This was done to eliminate any influence size difference could have had on the results. There were only four buffered waterways suitable for use in this research, therefore one of these had two sample sites on it.

During the second visit to the plantation, the waterways selected in the first visit were individually walked to find suitable sample sites. The sites were chosen based on their size, accessibility and location within their catchment and are shown in figure 4.1. The sites needed to be as uniform in size as possible across all the management regimes to reduce any possible influence of size on the results. To ensure this was achieved the waterway at each site was measured for width and depth. Sites also needed to be safely accessible on foot and have at least a 10m length of stream bank that could be walked so data could be gather without having to enter the waterway. The sites that were chosen were located at the bottom of each waterway catchment before they entered a different catchment management regime or before they enter a stream of higher order. This ensured that the sites were located at the point on the waterway where the maximum affect of the management regime would have been experienced. Two of the streams selected had more than one sample site on them; one had two sample sites, one in its buffered headwaters and the other in the downstream clearcut area. The other had three sample sites, one in the upper buffered headwaters, one further downstream in the same buffer and the third downstream in a clearcut area. This buffer was selected for two sample sites because it was the longest length of suitable buffered waterway, which allowed the sites to be separated by a substantial distance and be located in areas that had been harvested at different times using different methods.

Figure 4.1 Map of the Pipiwai stream sample sites, clearcut sites are marked by red dots, RBZ sites with blue and pine sites with black.

4.4 Site Descriptions

The following photographs and descriptions show each of the 15 sample sites, starting with the buffered sites, followed by the clearcut and then the pine sites. All of the photographs were taken facing upstream apart from RBZ site five. As such, the true left bank of the stream is on the right of the photograph and the true right bank is on the left. At the buffered sites only the most common vegetation has been identified; no attempt has been made to list all the vegetation present.

4.4.1 Riparian Buffer Zone Sample Sites

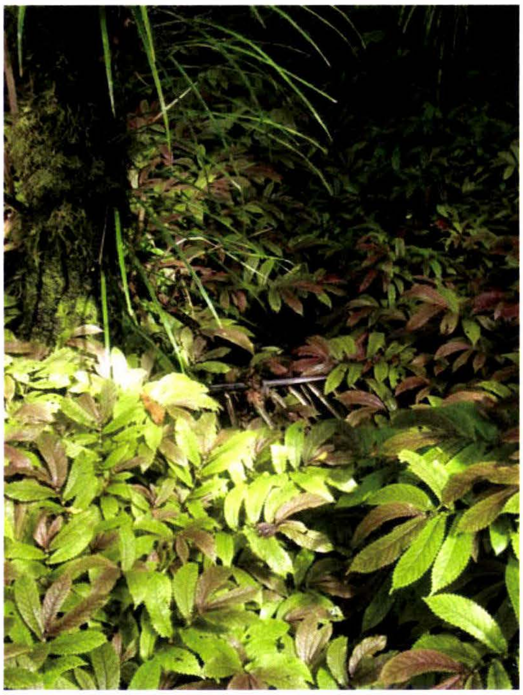


Figure 4.2 RBZ sample site one

RBZ sample site one. The native trees forming RBZ sample site one are over six metres tall and comprised of various species, including *Beilschmiedia tarairi* and *Podocarpus totara* with dense streamside undergrowth dominated by *Elatostema rugosum*. The rest of the under-storey is made up of common native species such as tree ferns, *Rhopalostylis sapida* and *Geniostoma rupestre*. The buffer zone is on average 15m wide on the right bank and over 30m on the left bank. The stream banks are clay while the bed is dominated by gravel and sand. The stream bank vegetation almost totally overhangs the stream giving it 90% shade all day.

Figure 4.3 RBZ sample site two.

RBZ sample site two. The trees in RBZ sample site two are mainly mature *Beilschmiedia tarairi* over six metres tall, while the undergrowth is mostly sparse with ferns and a few shrubs. The removal of the plantation trees had increased the amount of sunlight penetrating the vegetation and caused an increase in weed growth. The buffer zones are 10m wide on both banks and gave 60% shade to the stream. There was woody and leaf debris in the stream from mainly native vegetation.

RBZ sample site three. RBZ sample site three is comprised of mainly mature *Beilschmiedia tarairi* trees over six metres tall that formed a closed canopy. There were large amounts of native leaf litter in and around the stream. The stream has a partial clay bed overlaid with stones. Under-storey vegetation was sparse, comprised mainly of ferns and *Rhopalostylis sapida* palms but the canopy and bank overhangs gave 80% shade to the stream. Buffer zones are over 30m wide on both banks.

Figure 4.4 RBZ sample site three.

Figure 4.5 RBZ sample site four.

RBZ sample site four. The stream at RBZ sample site four is buffered mainly by *Leptospermum scoparium* and *Schefflera digitata* that are between three and four metres tall. On the stream banks there are weeds as well as native *carex* grasses and ferns. The streambed is comprised of mainly fine gravel and sand with some clay, and as such contained few stable substrates. The buffer zone on the left bank is 5m wide and the right bank is 30m wide. There was 60% shading by the native vegetation.

RBZ sample site five. The trees at RBZ sample site five are mature native *Beilschmiedia tarairi* and *Agathis australis* which are over 6m tall and form a closed canopy which provides 95% shade for the stream. The stream is wide and shallow with a very soft mud bottom and contained large amounts of leaf litter which in places formed dams. The buffer zone on the right bank is 30m wide while the one on the left bank is over 40m wide. Under-storey plants were again typical of other sites with ferns, *Rhopalostylis sapida, Geniostoma rupestre* and seedlings.

Figure 4.6 RBZ sample site five.

4.4.2 Clearcut Sample Sites

Figure 4.7 Clearcut sample site one.

Clearcut sample site one. Clearcut sample site one was harvested in the autumn of 2004 using ground based harvest machinery. Trees were harvested within 2m of the stream and left slash next to and in the stream. Outside the sample area small debris dams had formed. The photo shows tall weeds growing on the right bank and low growing weeds and regenerating native vegetation on the left bank. The sparse vegetation and bank overhangs gave the stream 10% shade.

Clearcut sample site two. Clearcut sample site two was harvested at the end of 2003 using ground based harvesting. Trees were harvested within 1-2m of the stream with no slash left in or near it. There were a significant number of aquatic plants growing in the stream, including watercress and green filamentous algae. The banks were covered with grass and weeds, (which included the natives *Carex comans* and *Cyerus ustulatus)*. There were also some ferns present but very few woody plants. The dense and overhanging vegetation provided the stream with 40% shade.

Figure 4.8 Clearcut sample site two.

Figure 4.9 Clearcut sample site three.

Clearcut sample site three. Clearcut sample site three was harvested in the summer of 2004 using a cable hauler. Trees were harvested within 2m of the stream as well as hauled across it. There were large amounts of slash on both banks (which can be seen on the left of the photo) but none in the stream. This had been cleared from the stream by hand. The dense weed and grass growth (including natives *Carex comans* and *Cyerus ustulatus)* combined with the high stream banks and narrow stream provided 95% stream shading.

Clearcut sample site three.

Figure 4.10 Clearcut sample site four.

Clearcut sample site four was harvested in 2004 using ground based machinery. Harvesting occurred within 2m of the stream and left slash on both banks, suspended across the stream and in the stream. The right hand stream bank was unstable and active erosion was depositing soil near the water's edge. There were a few native plants growing or regenerating in the riparian management zone, but the area was mostly bare ground covered with slash. As a result there was very little cover and only 30% shade.

Figure 4.11 Clearcut sample site five.

Clearcut sample site five.

Clearcut sample site five was harvested in 2004 using ground based machinery. Harvesting occurred within 1-2m of the stream. The soil that overlaid the bedrock stream banks was unstable and eroding. The eroded soil was being deposited directly into the stream and piling at the waters edge. There was very little stream side vegetation, subsequently, the 30% stream shade came mainly from bank overhangs and slash.

4.4.3 Pine Sample Sites

Pine sample site one. Pine sample site one has a stony bottom with sloping banks approximately three metres high. There are no pine trees planted on these banks, the closest were five metres from the waters edge. The pine trees had formed a closed canopy and there was an under-storey of native vegetation including ferns, tree ferns *Ripogonum scandens*, *Elatostema rugosum* and other shrubs and seedlings. The very thick tree cover provided 95% shade.

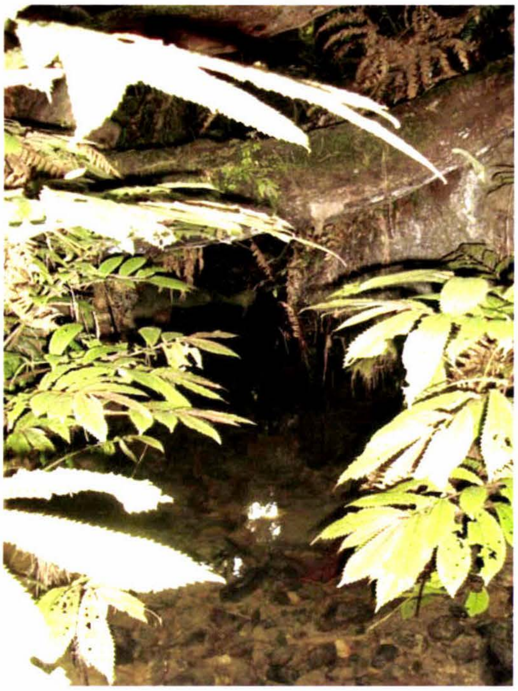


Figure 4.12 Pine sample site one.

Figure 4.13 Pine sample site two.

Pine sample site two. The stream at pine sample site two has a stony and bedrock bed. Its bedrock banks rise steeply out of the stream to five metres on the right bank and over 10 on the left bank. This part of the plantation had no pine trees within 15m of right bank and 25m of the left bank. The riparian vegetation is comprised of native trees over six metres tall which form a closed canopy and an under-storey of shrubs and plants. The canopy is dense and provides 95% shade; despite this there were very few needles or leaves in the stream.

Pine sample site three. Pine sample site three is a flat site with pine trees planted to within 1m of the stream. The stream banks are clay, as is part of the streambed, which is also comprised of stones and gravel. Growing beneath the closed pine canopy was a dense under-story of native plants and trees. The vegetation provided 95% shade, and added pine needles, pieces of wood and other plant material to the stream.

Figure 4.14 Pine sample site three.

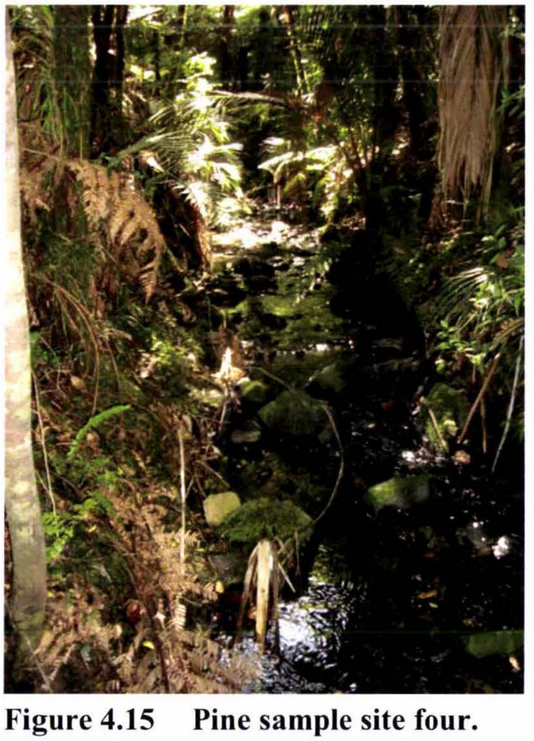


Figure 4.15 Pine sample site four.

Pine sample site four. The pine trees at pine sample site four were set back 15-20m from the left bank while the right had no pine trees present. The right bank, at the sample site is a wedge of ground that divides this stream from the stream used for sample site five (the two streams joined a short distance downstream of the sample sites). Native vegetation makes up the forest around the stream. The canopy trees are over six metres tall and have made closure, this, combined with the under-storey of ferns and smaller trees, give the stream 95% shade. The stream is stony and contained leaf litter and pieces of wood.

Pine sample site five. The left bank of pine sample site five formed the right bank of pine sample site four. The pine trees growing on the right bank were further than 20m away from the stream. The stream has clay banks and a partial clay bed which is overlaid with stones and sand. The native vegetation that surrounds the stream provides a closed canopy over six metres tall with a dense under-story of ferns, tree ferns and other trees and shrubs. This vegetation and the bank overhangs provide almost 100% shade.

Figure 4.16 Pine sample site five.

4.5 Fieldwork

Fieldwork was scheduled to be carried out at the end of January 2006 when summer temperatures are generally at a maximum and stream communities would therefore have been exposed to annual environmental extremes and possible stress. However, there was a storm at that time in which 80-100mm of rain fell and therefore fieldwork was postponed for seven weeks until March 13, 2006. This meant sampling did not take place during the hottest time of the year but it was during the month with the historically lowest monthly rainfall for the year and, therefore, stream communities were still exposed to annual extremes and possible stressful conditions. Fieldwork was carried out on three consecutive days from 13-15 March, 2006 under similar weather conditions.

4.5.1 SHMAK

Each site underwent standardised data acquisition using a modified version of the New Zealand Stream Health Monitoring and Assessment Kit (SHMAK) developed by NIWA and Federated Farmers of New Zealand Inc (Biggs *et al*, 2002). The basic kit was designed for use by farm families and others in New Zealand to monitor the "health" of the streams that flow across their land using scientifically robust methods of data acquisition (Biggs *et al*, 2002). The data collected using this kit fall into three categories:

- Biological data – based on common and easily recognised "indicator organisms" which are known to be characteristic of certain stream health conditions;
- Data about the stream habitat – measurements and observations of conditions at each sample site; and
- Land use and farm management data which are required for interpretation of the stream assessment result, and cover both the area immediately upstream of the site and the whole stream catchment.

There are two levels of monitoring using the SHMAK:

- Level one involves basic presence/absence observations to give a quick, less precise assessment of the stream health; and
- Level two is a more detailed investigation in which organisms are counted and a more reproducible and accurate assessment of the stream's health is made.

The SHMAK assigns each variable a score, and these scores are added up to give totals for different aspects of the stream. The overall scores are recorded on the monitoring record form. The observation scores can also be entered into SHMAK software which calculates scores and constructs graphs of the results.

The following data were gathered from each site:

(a) Habitat quality:

- water velocity
- water pH
- water temperature
- water conductivity
- water clarity

- composition of the stream bed (e.g., rocks, gravels, sand, plants, etc.)
- presence and extent of loose, silty deposits on the stream bed
- stream-bank vegetation at the site.

(b) Biological data:

- types and number of invertebrates.
- types and percentage cover of periphyton.

Data were also gathered on the amount of light reaching the water surface. This is not a variable that is examined in the SHMAK but one that is seen as important in its influences on waterways.

4.5.2 Data Acquisition

Upon arrival at each sample site, the time and weather conditions were recorded and then a 10m length of each waterway was measured and marked out as the sample site and photos were taken.

Streambed composition over the 10m length was recorded by estimating the percentage (to the nearest 10%) of cover of the following types of material; bedrock, boulders (>25cm), large cobbles (12-25cm), small cobbles (6-12cm), gravels (0.2-6cm), sand, mud or silt, man-made, woody debris and water plants (rooted in the stream bed).

Streambed sedimentation was recorded by determining its presence or absence and the depth and degree of coverage. The categories were: not present or fine (less than 1mm) and mainly in edge areas, moderate (up to 3mm) in edge areas and elsewhere, moderate to thick (3mm or more) patchy over most of the bed, and thick (over 5mm) on most horizontal surfaces.

Bank vegetation was estimated and recorded by the percentage (to the nearest 10%) cover on both banks individually to a width of 5m. The SHMAK kit has 10 categories but only the ones relevant to this research are recorded here: native trees, wetland vegetation, introduced conifers, scrub, rock, gravels and bare ground. The width of riparian buffer zones was also measured and recorded.

The amount of sunlight reaching the waterways was estimated based on the average amount that would have reached the surface of the water throughout the entire day.

Water pH, temperature and conductivity were measured by placing a Hanna pH, EC/TDS and temperature combo meter (that had been calibrated in the laboratory prior to use in the field, using pH4 and pH7 buffer solutions) in the main stream flow, and recording the results.

Biological data were then gathered using a $0.1m^2$ surber sampler. Five samples were taken at equally spaced intervals within the ten metre study site, samples were taken working from downstream to upstream. This data acquisition was carried out at level two of the SHMAK. At this level the SHMAK requires ten samples to be taken per site; for this research however, five samples were taken per site because the surber sampling method being used was more thorough than the sampling method of the SHMAK, which involved examining a rock, plant or single sieve sample at each sample point.

Taking the samples using the $0.1m^2$ surber was done as follows. The sampler was placed on the streambed and held in place by standing on it. Stones (where present) were then picked up and periphyton growth was identified based on the thickness and colour of the growth, and the percentage of cover of the surber area was estimated. The following categories were used: thin mat/film (under 0.5mm thick), green, light brown or black/dark brown colour, medium mat (0.5-3mm thick) green, light brown or black/dark brown colour, thick mat light brown or black/dark brown colour, short filaments (< 20mm) green or brownish/reddish colour, long filaments (>20mm) green or brownish/reddish colour. Stones were then cleaned into a white tray held between the knees to collect invertebrates. Where the bed was gravel, a sieve was used to collect a sample which was then placed into the tray and the larger stones removed. Samples were then placed into containers, labelled and taken back to the utility parked on the road. On the flat deck of the utility a micro pipette was used to place 10% formaldehyde into each sample container to kill and preserve each sample for sorting and counting off site. This was done using disposable latex gloves and moving the sample containers to the bottle of formaldehyde to avoid drips or spillage of the chemicals.

Water for determining water clarity, using the clarity tube, was taken at the most upstream point of the sample area. This was done by using a container to collect water before placing it in the tube (The clarity tube is a 1-metre-long, 50mm-diameter clear acrylic tube, graduated along its length in centimetres. One end is clear (the viewing window); the other is stoppered with a matt black pipe cap after the tube has been filled with water); care was taken not to disturb the stream bed to prevent contamination of the water sample. When the tube was filled with water the black disc magnet (a 20-mm diameter black semicircle fixed onto a magnet) was placed into the tube held by the external magnet, the cap was then placed on the tube. Readings were then taken in the shade where possible or perpendicular to the suns plane to avoid a shadow being cast along the tube. Readings were taken by holding the tube horizontal and moving the black disc away from the viewing window until it disappeared, then moving back towards the viewing window until it reappeared, both distances were recorded. This process was repeated three times using the same sample and the six measurements averaged to give a clarity distance. Prior to each reading the water in the clarity tube was agitated to ensure any sediment was in suspension.

Water velocity readings were taken using a hard rod. A thin metal ruler was placed in mid stream resting on the bottom and the depth measurement recorded, the ruler was then turned broadside to the flow and the depth reading recorded again. This was repeated three times at the upper, middle and lower ends of the sample area. The velocity was then calculated for each of the three samples using the formula $V=\sqrt{g}H$, where $g=9.8m/s^2$ and H=the difference in the height of the rod readings in metres. The average of the three velocities was then calculated.

Width and depth measurements were then taken of the sample site. Width was measured at upper, middle and lower points in the sample area and averaged. Depth was measured at the same three points but three measurements were taken at each of these points left, middle and right. The results were then averaged to give measurements.

4.6 Data Analysis

All the data gathered during field work were entered into the SHMAK software program, which then calculated scores for stream habitat, periphyton growth and invertebrate communities. Scores were calculated based on predetermined values assigned to different ranges of data, for example water velocity readings below 0.1 m/s receive a score of 1, between 0.1 and 0.29 m/s 8, between 0.3 and 0.69 a score of 10 and so on (a copy of the assessment sheets are presented in Appendix 3). These scores were then graphed to give an overall assessment of the stream's health. The program also took into account the stream substrate when assessing each stream's health. Different graph templates were used based on the different substrate categories; thus a stream's assessment was not biased against those with less favourable invertebrate substrates, or towards those with more favourable invertebrate substrates.

Data on stream invertebrates was further analysed to calculate macro-invertebrate community index (MCI) scores, total number of individuals per sample, and number of species per sample. The MCI score was calculated by the formula;

$$\mathrm{MCI} = \frac{\sum_{i=1}^{i=S} a_i}{S} \times 20$$

Where S = the total number of taxa in the sample, and ai is the score for the ith taxon. The quantitative macro-invertebrate community index QMCI was also calculated. For this the following formula was used;

$$QMCI = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N}$$

Where S = the total number of taxa in the sample, ni is the abundance for the ith scoring taxon, ai is the score for the ith taxon and N is the total of the coded abundances for the entire sample.

4.7 Statistical Analysis

To assess if the differences in the numerical data gathered were a result of actual site differences or just the natural variation expected within the samples, statistical analysis was required. As there were three different treatments being analysed, unbalanced nested ANOVAs were used. These tests were carried out at the 95% confidence level, meaning that if results were identified as being statistically different, there was 95% confidence that the difference was the result of an actual difference in the populations from which the samples were taken, and not simply the difference that could be expected from random samples from within the same population. The tests identified which sets of results had significantly different treatment results within them and it also identified which treatment results within that set were significantly different from the others.

4.8 Management Data Acquisition

To obtain data on the management of the Pipiwai forest, including its harvest, three of CHHF's Northland managers (based in Whangarei) were contacted. Two of these were interviewed, and the third was questioned and supplied information via email (interview guidelines are contained in appendix 7). The details of their official positions within CHHF and the questions they were asked are presented in the following paragraphs.

Ursula Albrecht was the Northern and Southern Environmental Planner for CHHF. She was asked for information on CHHF's environmental operating guidelines and the steps that are taken to protect waterways from degradation during plantation harvest.

Greg Nielsen was the Harvest Manager for CHHF's Northern forests. He was asked for information on how the harvest of the forest was carried out, including; when and by what methods the areas used in the research were harvested, whether a harvest plan was used, if trees were felled and hauled across streams and whether slash clearance was undertaken. He was also asked what the implications of including buffer zones beside all waterways would be for plantation harvest.

Peter Houston was the Forest Leader for the Whangarei forests and was based in the Northern office, he was asked the following questions about the general management of the plantation:

- Has there been any fertiliser application? If so when and by what method?
- When was the plantation sprayed and what chemicals were used?
- When was soil compaction undertaken and how was it carried out?
- When were the trees replanted in the areas used in this research
- Were the trees pruned and thinned? If so how often and was any production thinning carried out?
- What are the management implications for the inclusion of buffer zones beside all waterways?

4.9 Research Limitations

This research is limited to streams within the Pipiwai forest that have been harvested 24-30 months prior to sampling. As such, the results will only be directly applicable to these streams. However, they will have relevance to other streams in Northland as geology, climate and plantation management across the region are relatively similar (Quinn *et al*, 2004). The results may also be useful for regions throughout the country as they will show trends that can be expected. The results and subsequent discussion and conclusions are based solely on the samples taken 24-30 months after harvest, as no samples or monitoring were undertaken prior to that time.

Results

Chapter Five

5.1 Introduction

This chapter is separated into two main sections, stream health assessment and plantation management. The first section presents the overall assessment determined by the SHMAK on the health of each of the waterways from the three treatments, followed by the results from the three areas of the SHMAK investigation; waterway habitats, invertebrates and periphyton growth. Also contained within these sections are any data gathered that was additional to the SHMAK, as well as the results of any statistical analysis carried out on the data. All of the raw data gathered using the SHMAK is presented in Appendix 5, while an example of a data acquisition sheet showing the SHMAK scoring system is presented in Appendix 3. The second section presents the information obtained from the CHHF managers regarding the management of the plantation harvest and reestablishment, general plantation management, CHHF environmental operating guidelines and the implications of RBZ inclusion in forestry plantations. It also contains site observations related to the management of the plantation.

5.2 SHMAK Stream Health Assessment

Data from the stream health assessment showed that the streams with RBZ were healthier than both the clearcut and pine streams, and that they created higher quality waterway habitats and had higher quality invertebrate communities. Graphs of the individual results for each of the streams are presented in Appendix 4. The SHMAK rated three of the buffered streams as excellent and two as very good compared to the pine streams which had one excellent, three very good and one moderate and clearcut streams which had one good, one moderate and three very poor.

5.2.1 Stream Habitats

There was a considerable difference in the average SHMAK stream habitat scores for each of the three stream treatments (Fig 5.1). Statistical analysis of these scores showed that these differences were significant at the 95% confidence level ($F_{2,12}$=21.5; P=0.0001). The Tukey HSD all pair wise comparison test showed that there was no significant difference between the pine and buffered scores, but that the clearcut score was significantly lower than the pine and buffered scores.

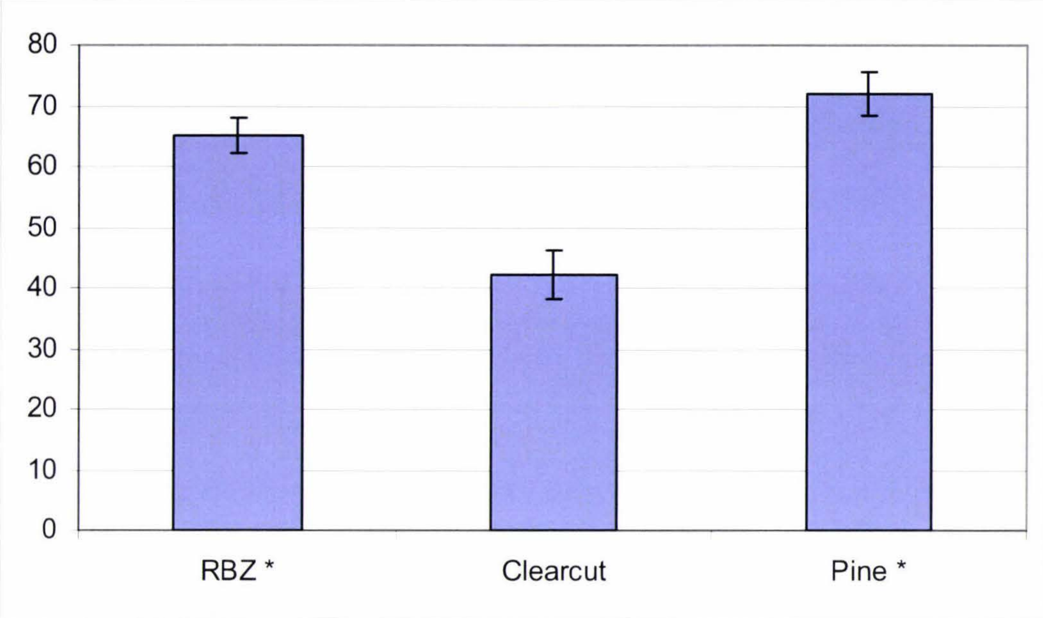


Figure 5.1 Average SHMAK habitat scores for the three stream treatments, the pine and buffered sites were significantly higher (at the 0.05 level, marked with an *) than the clearcut sites.

The low score of the clearcut sites was due to a number of low index scores that were largely a result of tree harvest. Tree harvest had left the clearcut waterways with little or no riparian vegetation and significant amounts of exposed and disturbed soil in the riparian management zone. This was most evident at sample sites four and five. At these sites dead tree root systems were exposed on the stream banks and eroded soil was actively entering the water. At the other clearcut sample sites, soil was not seen entering the waterways but it had lost its cohesion due to the disturbance of tree harvest. Both the buffered and mature pine sample sites had significant amounts of riparian vegetation and some areas of exposed soil. The exposed soil however, was undisturbed and held together by the root systems of the riparian vegetation. The SHMAK scored sites with riparian vegetation highly and imposed a penalty on sites with exposed soil. Clearcut sites therefore failed to score where the other treatment sites did, and were penalized when other sites were not.

The composition of the streambeds were also assessed and scored. There were nine categories for the streambed substrates; three of these increased the site score, four detracted from the score and two were a zero score. The pine sites had a large proportion of their substrates in the three categories that added to their site scores and very few in the categories that detracted from their site scores. In contrast, the other treatments had a large proportion of their substrates in the categories that detracted from their site scores and only a few in the categories that added to them. This therefore, helped to increase the pine site scores over the other treatments as seen in figure 5.1.

The average stream velocities of the three treatments fell within the low to moderate velocity SHMAK category (0.1-0.29 m/s) (Fig. 5.2), which was classified as being able to support both pollution tolerant and pollution sensitive invertebrates. This was the second best velocity rating in the SHMAK. There were also a number of individual sample sites from each of the treatments that were in the best velocity rating of 0.3-0.69m/s. Though the clearcut sites average is higher than that of the other two treatments, as they are all within the same SHMAK category, there was no scoring advantage for any treatment.

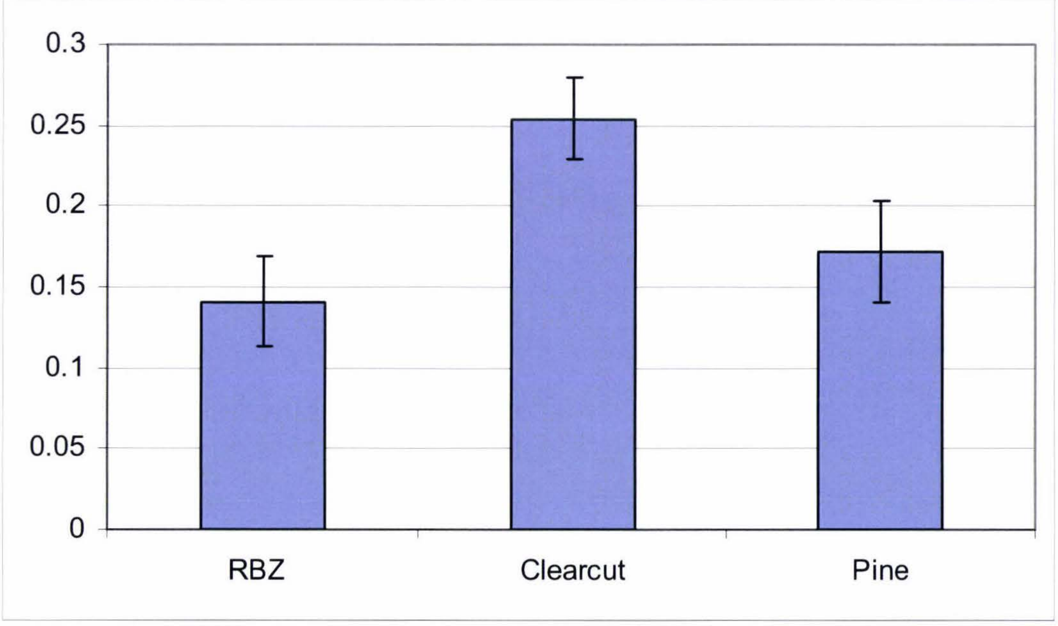


Figure 5.2 Average stream velocities (in m/s) for each of the three stream treatments

The average pH readings for the buffered and clearcut sites were within the SHMAK excellent category (6.5-7.5), while the pine sites were just outside this category but not high enough to be classified in the fair category (Fig. 5.3). All of the individual readings for the buffered and clearcut sites were in the excellent category, whereas only one of the pine sites was in the excellent catagory, the rest were between 7.5-8.0. As such, the SHMAK scored those four pine sites lower than all the other sites.

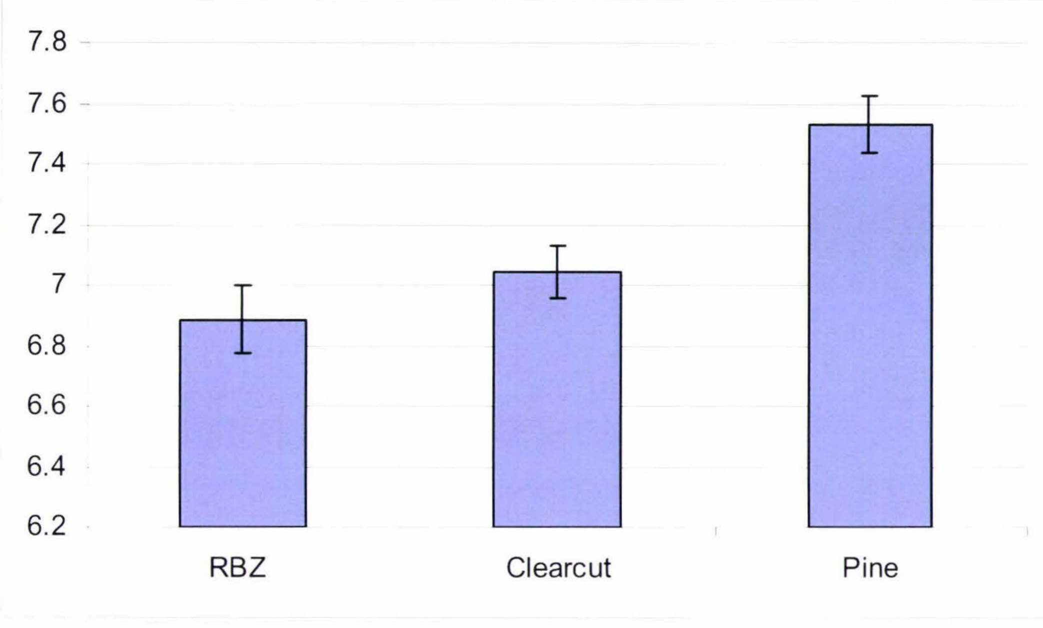


Figure 5.3 Average stream pH for the three stream treatments

Spot water temperature tests (and the time they were taken) were taken as part of the SHMAK assessment (Table 5.1). These results were not graphed, however, as they were carried out at different times of the day, which would have influenced the water temperature. The buffered and clearcut sites both had two readings outside the excellent SHMAK category (10-14.9^{0}C) and were in the category listed as beginning to be stressful for some invertebrates. As a result, these sites received a slightly lower score than the other sites which gave the pine average an advantage. It is worth noting that the highest temperature recorded at the pine sites was lower than the lowest temperature at either of the other treatments.

Table 5.1 Water Temperature (^0C) and time the sample was taken.

	1	2	3	4	5
RBZ	14.1 (10.30)	14.2 (12.30)	14.0 (11.30)	15.8 (13.50)	15.9 (14.50)
Clearcut	14.0 (09.00)	15.4 (14.30)	15.1 (15.30)	13.3 (09.20)	14.5 (10.30)
Pine	11.7 (09.30)	12.5 (11.30)	13.1 (12.25)	12.7 (13.00)	13.0 (13.10)

The graphed results of the average water conductivity appear to show a significant difference between the average conductivity of the buffered stream treatments compared to the pine and clearcut treatments (Fig. 5.4). The differences in actual nutrient enrichment however, were not large, and all the average scores fell within the SHMAK good category of 50-149 µS/cm. Of the individual readings one clearcut and two of the pine readings were in the next SHMAK category rating of fair. The SHMAK classifies nutrient enrichment in the good category as unlikely and those in the fair category as slightly enriched which could facilitate algal growth during summer low flows.

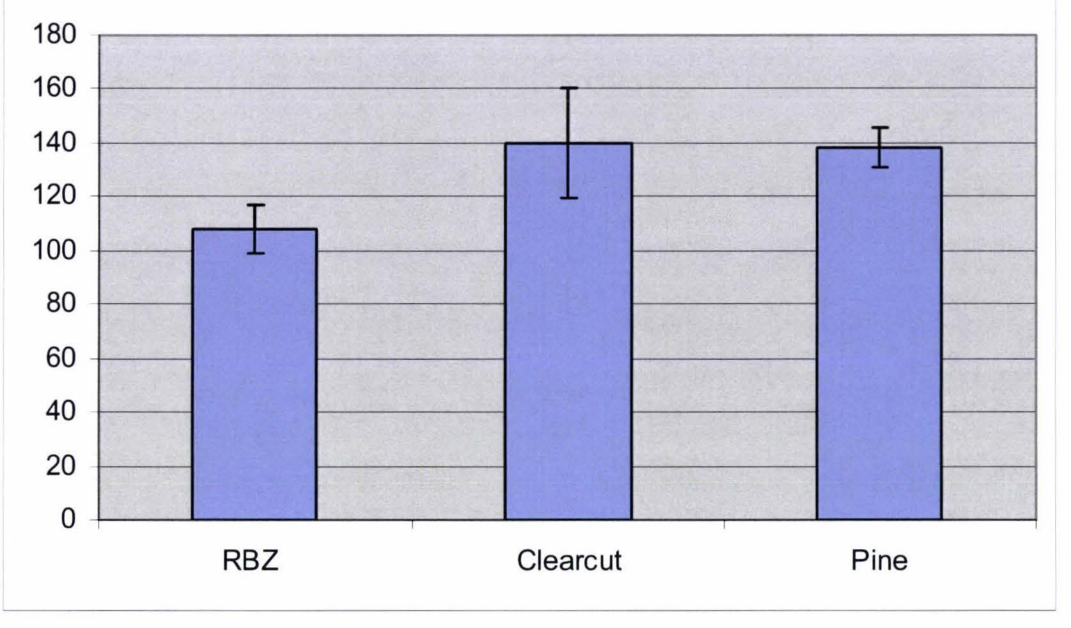


Figure 5.4 Average water conductivity (in µS/cm) for each of the three stream treatments.

There was not a large difference between the average water clarity results for the three stream treatments (Fig. 5.5). In the SHMAK classifications however, the clearcut sites fell in the second highest category (700-990mm) where the water is classed as slightly turbid. Both the pine and buffered sites fell within the moderately turbid class (550-699mm) in which turbidity would be expected to be impacting aquatic life. As a result there was an advantage for the clearcut sites from the SHMAK scoring in this category.

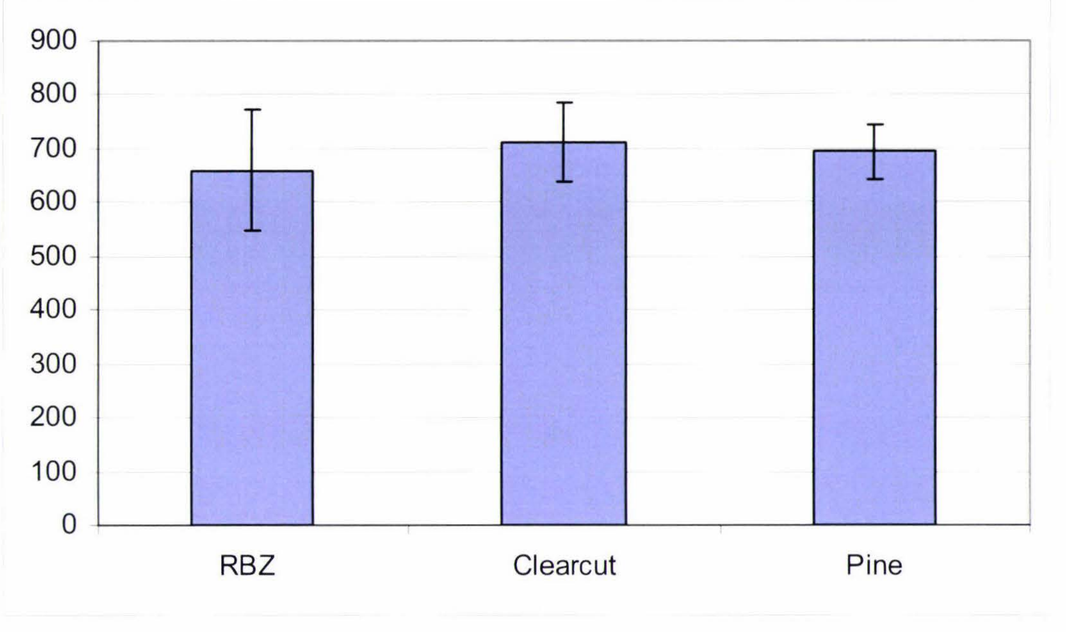


Figure 5.5 Average water clarity (in mm) at each of the three stream treatments.

None of the waterways had thick sediment deposits on their beds (Fig. 5.6). Of the five SHMAK categories, the samples only reached the third highest level of sedimentation classified as moderate (SHMAK categories moderate-thick and thick were not encountered). This level of sedimentation was described as between 1-3mm of sediment at the edges of the bed and elsewhere but not covering the entire bed. This level of sedimentation was classified as beginning to inhibit healthy invertebrate communities. Sediment up to the 1mm deep was classified as light sedimentation which was unlikely to inhibit invertebrate communities. Sample sites with no column on the graph had no sediments present on the streambed. The graph shows that at the most, both the buffered and pine sites had only light sedimentation; whereas four of the five clearcut sites had moderate sedimentation. As a result of the increased sedimentation, this category was one where the SHMAK clearcut site scores fell well behind the scores of the other treatments.

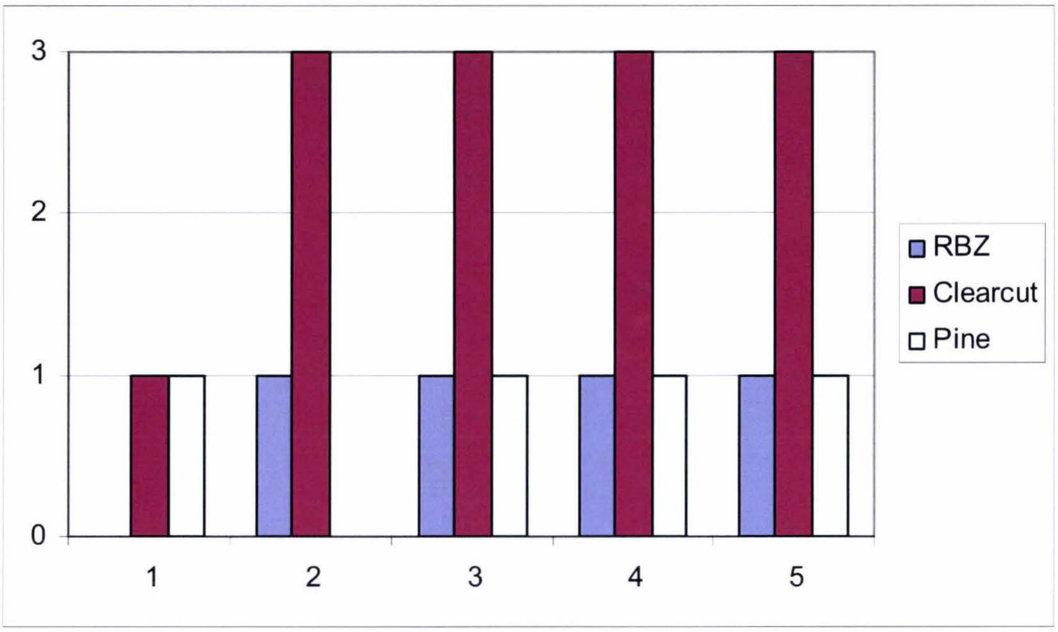


Figure 5.6 Depth of streambed sedimentation (in mm) for each sample site at the three stream treatments.

Stream shade was not a variable of the stream habitats that was directly recorded as part of the SHMAK. As it is an important aspect of a waterways habitat however, percentage of stream shade was recorded as an additional habitat measure (Fig. 5.7).

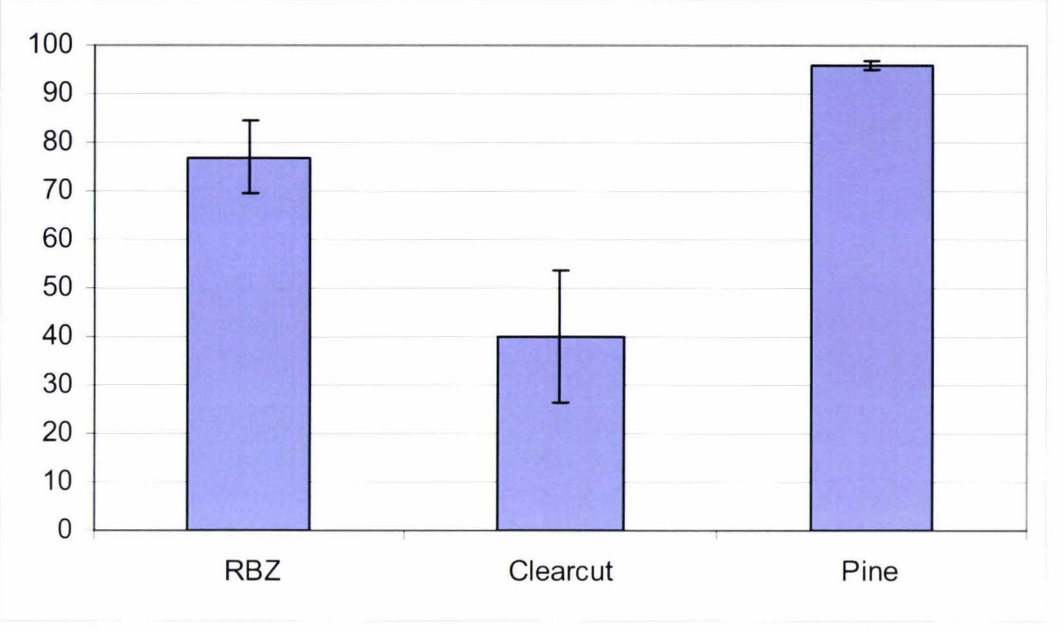


Figure 5.7 Average percentage of stream shade for each of the three stream treatments.

5.2.2 Stream Invertebrates

There was a considerable difference between the average SHMAK stream invertebrate scores for the three stream treatments (Fig. 5.8). Statistical analysis of these results showed that there was a significant difference in the scores at the 95% confidence level ($F_{2,12}$=14.7; P=0.0006). The Tukey HSD all-pair wise comparison test showed that there was no significant difference between the average buffered and pine SHMAK scores but that the clearcut score was significantly lower.

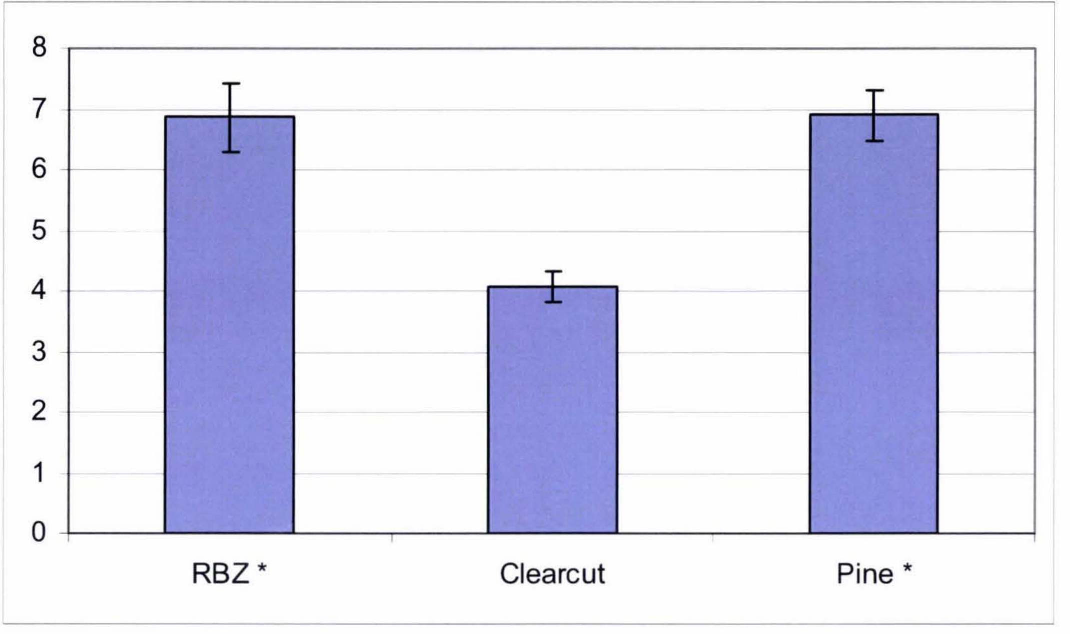


Figure 5.8 Average SHMAK invertebrate scores for the three stream treatments showing the pine and buffered sites as significantly higher than the clearcut sites.

There was little difference between the average number of species present at each of the three treatments (Fig. 5.9). Statistical analysis confirmed that at the 95% confidence level there was no significant difference between the scores.

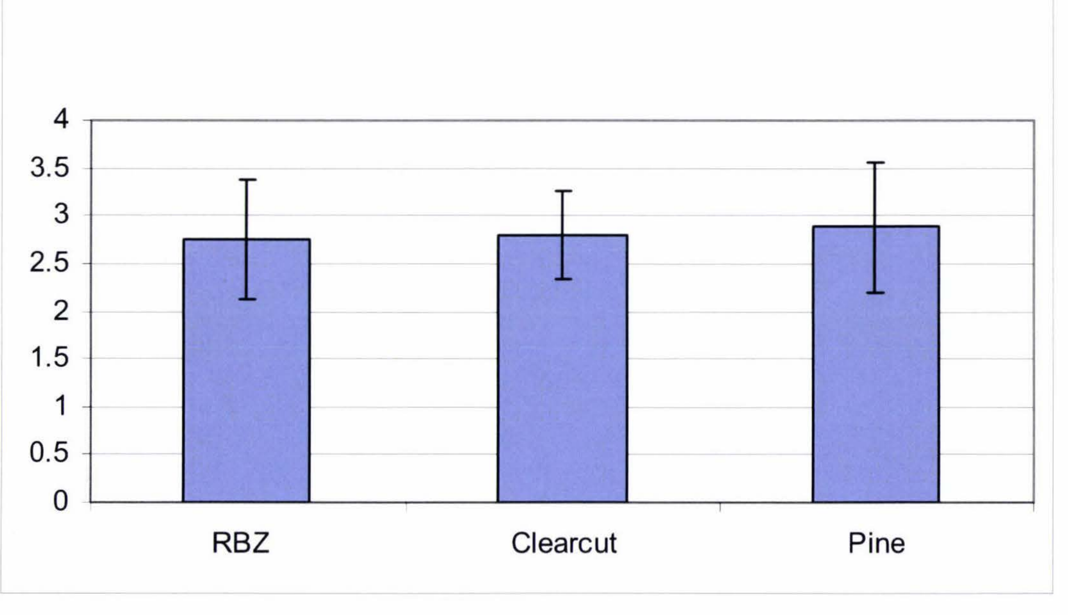
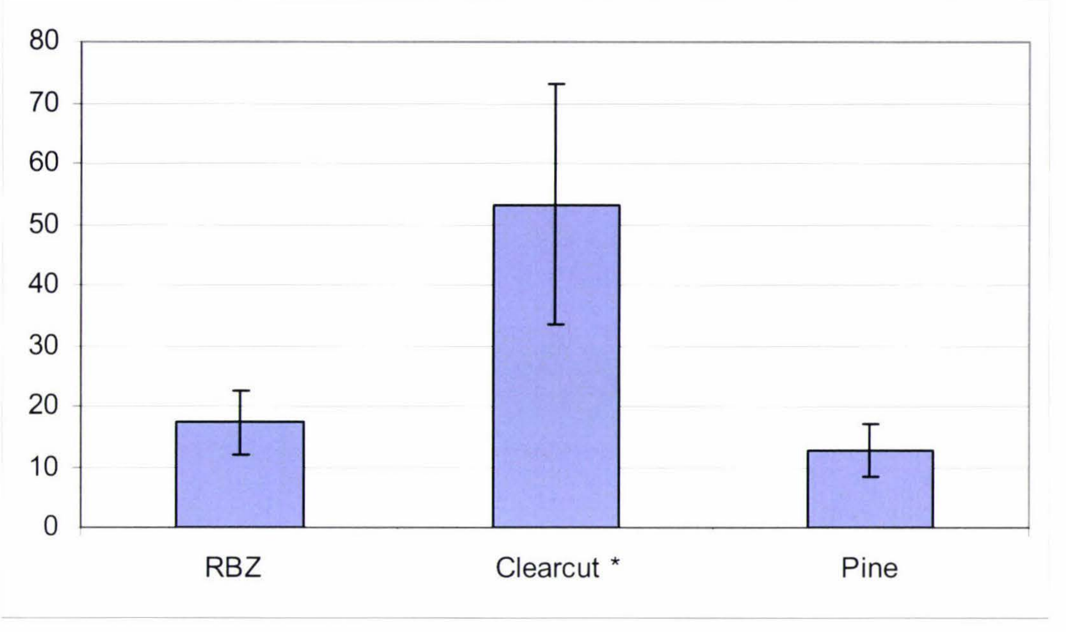


Figure 5.9 Average number of invertebrate species at each of the three stream treatments.

The average number of invertebrates present at each treatment showed that the clearcut sites had a much greater number of individuals than the other two treatments (Fig. 5.10). This difference was significant at the 95% confidence level ($F_{2, 12}$=4.67; P=0.013).



5.10 Average number of invertebrates at each of the three stream treatments.

Further analysis of the invertebrate samples showed that buffered streams had the highest average MCI score of 103.68, followed by the pine streams with 94.74 and the clearcut streams with 85.88 (Fig. 5.11). Three way statistical analysis showed that there was no significant difference between the average scores of each treatment.

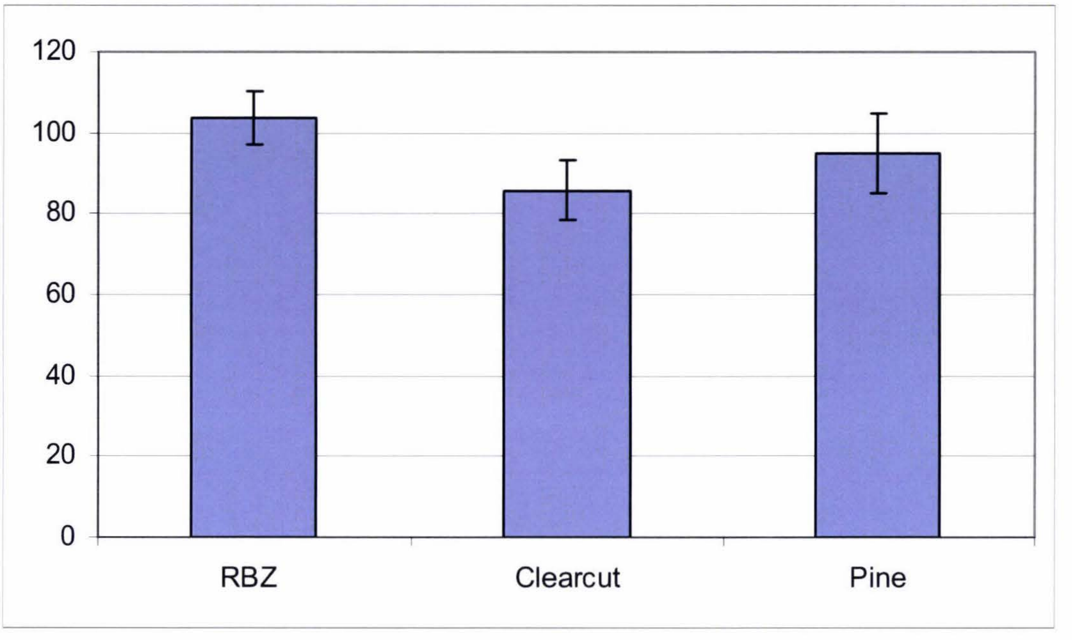


Figure 5.11 Average MCI score for each of the three stream treatments.

There was not a large difference in the average QMCI scores for the three stream treatments (Fig. 5.12). Statistical analysis of these scores however, revealed that there was a significant difference in them at the 95% confidence level ($F_{2, 12}$=3.96; P=0.0241). The difference identified was between the buffered and the clearcut streams. There was no significant difference between the pine treatments and either of the other two.

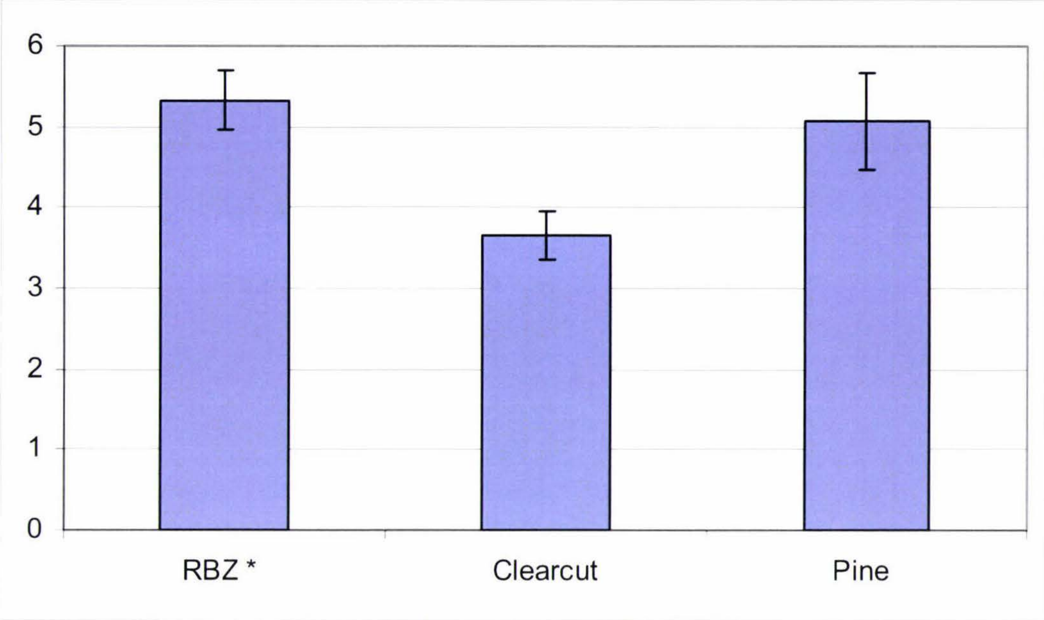


Figure 5.12 Average QMCI score for each of the three stream treatments.

Examination of the species composition of each of the sample sites at the three stream treatments showed that the pine and buffered sites had a greater proportion of high quality, high scoring invertebrates than the clearcut sites (Figures 5.13-5.15). Conversely, the clearcut sites had a higher proportion of low quality, low scoring invertebrates. The average number of mayfly larvae at the buffered and pine sites was 23.2 and 33 respectively, while at the clearcut sites it was 10.6. At the clearcut sites, the average number of the mollusc *Potamopyrgus* was 132.8, compared to 0.2 for the buffered and 2.8 for the pine sites, and the average number of the midge larvae *Chironomidae* was 60.6 compared to 0.4 for the buffered and 0 for the pine sites. Note that the scale is different for the clearcut sites, the scale is from 0 to 120, whereas the scale for the other two treatments are 0 to 40.

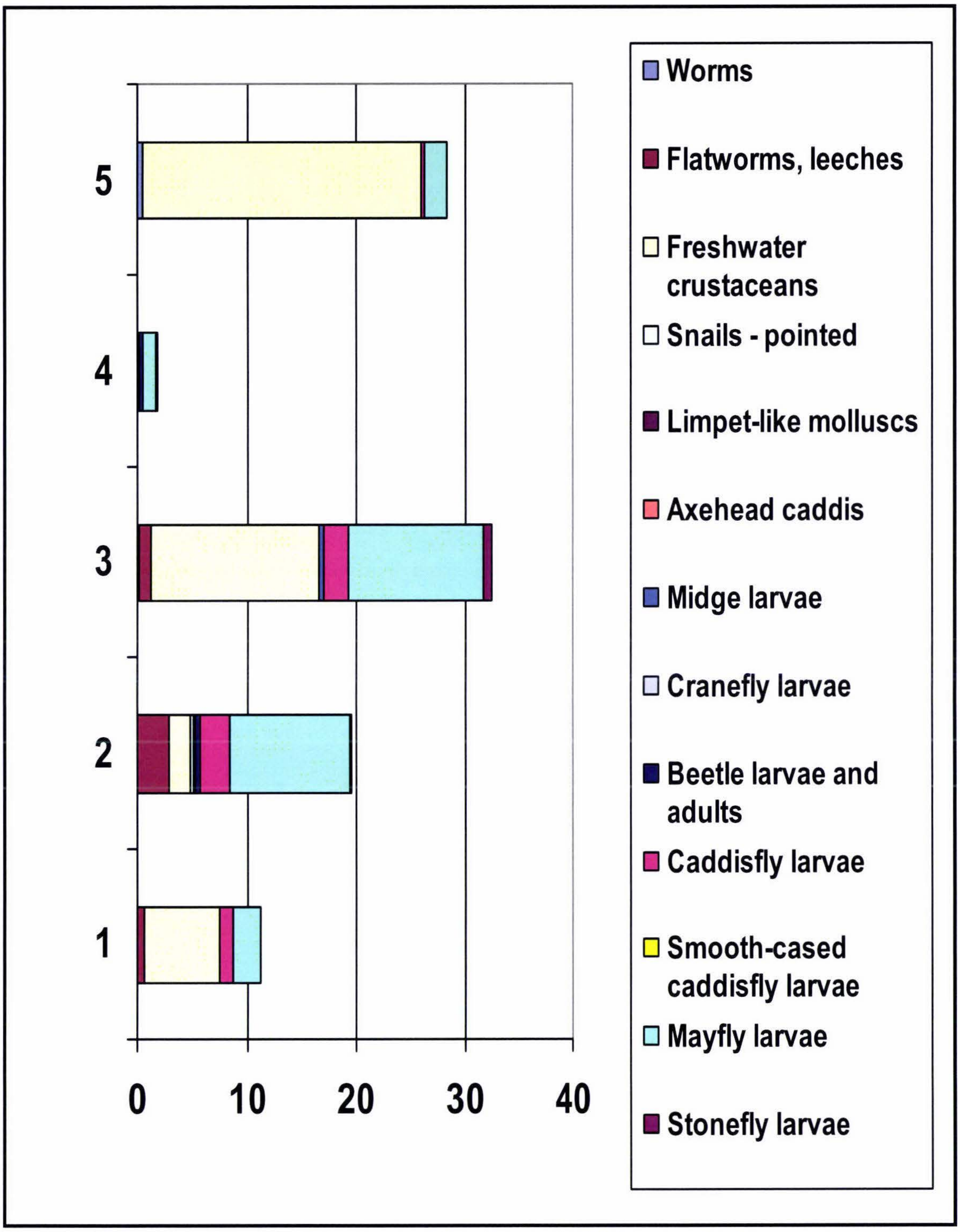


Figure 5.13 **Average species composition for each RBZ sample site.**

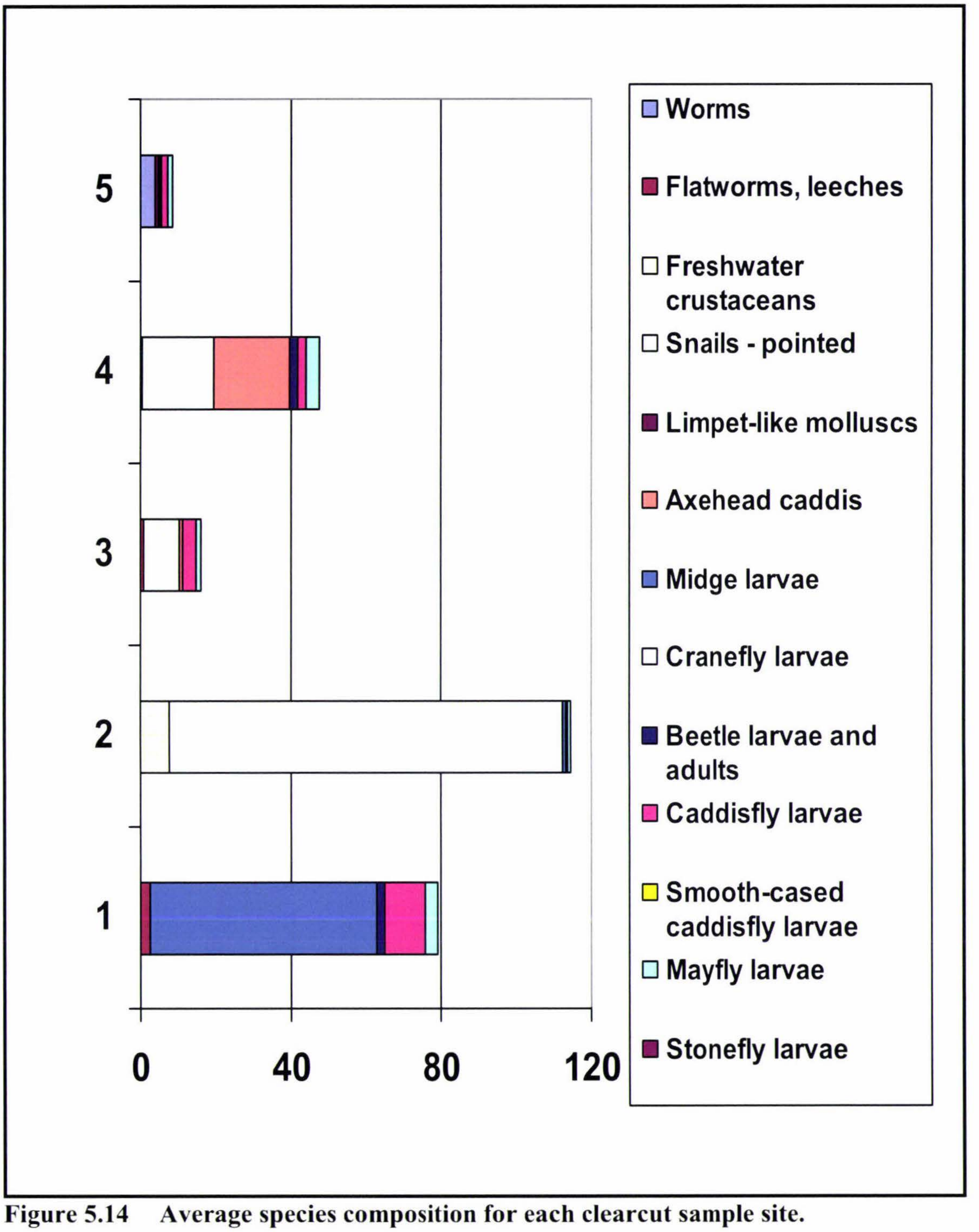


Figure 5.14 Average species composition for each clearcut sample site.

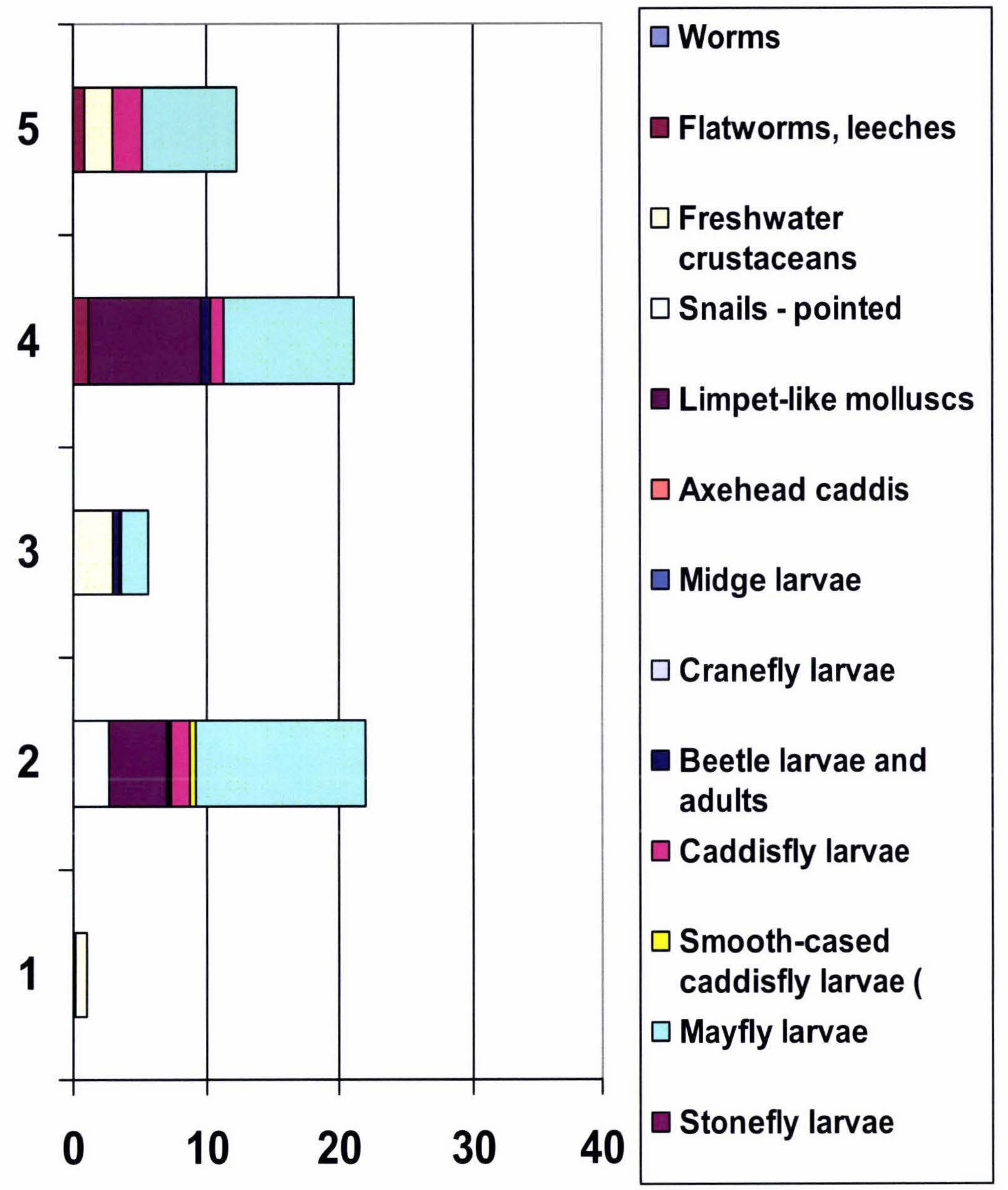


Figure 5.15 Average species composition for each pine sample site.

5.2.3 Stream Periphyton Growth

Periphyton growth in the waterways was most prominent at the pine sites. All five of the sample sites had significant amounts of their substrate covered with periphyton. The buffered and clearcut treatments, however, had two and three sites respectively, with periphyton growth. The SHMAK scores reflected these differences, with the average pine score being considerably higher than either of the other treatments (Fig. 5.16). Statistical analysis of the results found there was a significant difference in them at the 95% confidence level ($F_{2,12}$=5.27; P=0.0227). The Tukey HSD all-pair wise comparison test showed that the significant difference in the scores was between the pine and the buffered streams, but that there was no significant difference between the clearcut and buffered or clearcut and pine streams.

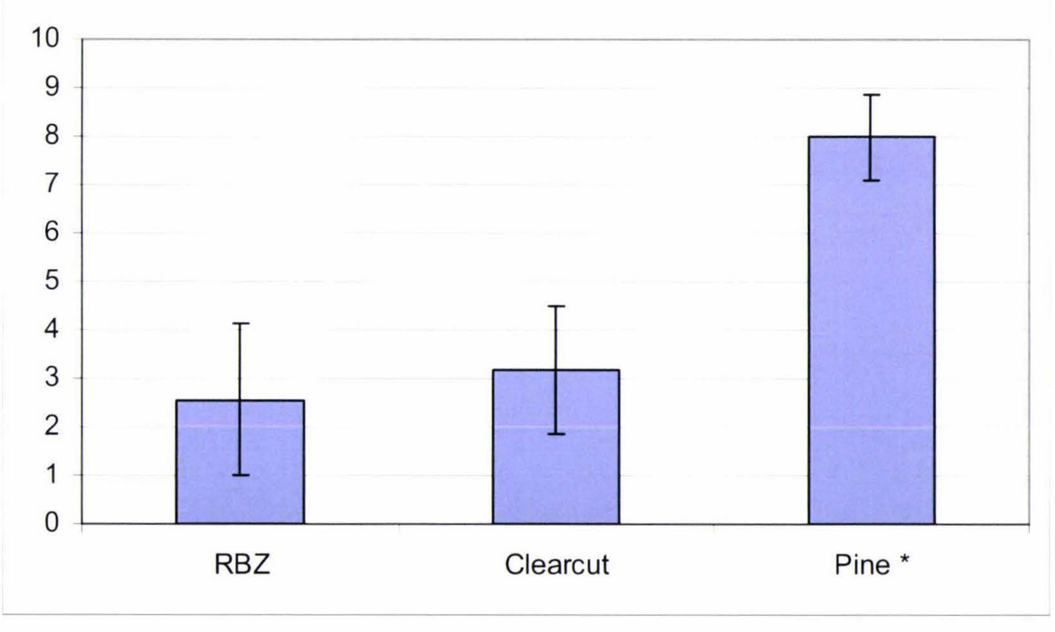


Figure 5.16 Average SHMAK periphyton scores for the three stream treatments, showing pine sites significantly (0.05) higher than buffered sites.

5.3 Management Data

The following information regarding the management of Pipiwai forest has been supplied via personal communications from the CHHF (Carter Holt Harvey Forests) office in Whangarei unless otherwise stated. This information was supplied in response to interviews with the Environmental Planner, Harvest Manager and Forest Leader.

5.3.1 Environmental Guidelines for Plantation Harvest

(The following information contained within sections 5.3.1 and 5.3.2 was supplied by CHHF's Environmental Planner). CHHF have a set of environmental guidelines for plantation harvest which are contained in an internal document produced in June 2002, entitled, Carter Holt Harvey Forest Resources Environmental Guidelines. CHHF states that the purpose of the guidelines is to provide a practical guide to the best operational practice in all aspects of forest management in their forests. The guidelines are intended as a general guide with specific requirements for each forest contained in their individual harvest plans or work prescriptions. These guidelines are also summarised in a booklet produced in June 2004 entitled, Environmental Management System, Key Supplier Glove Box Summary. This booklet is intended for use in the field by key suppliers and contractors.

The Forest Resources Environmental Guidelines addresses both the direct and indirect effects of their forestry activities on waterways. Its first stipulation is that Regional and District plans are adhered to and all other acts and accords are followed. In addition to the standards in those agreements their environmental guidelines address impacts on waterways by:

- Requiring that harvest plans must be designed to minimise the risk of soil movement, sediment generation and stream bank erosion.
- Identifying all streams within a block prior to harvest and assessing their protection requirements to minimise damage to streams and riparian areas. (Details of this procedure are presented in the next section).
- Restricting the proximity of earthworks to waterways.

- Prohibiting construction material being placed where they could enter a waterway.
- Requiring the installation of an efficient drainage system that is not impaired during forestry operations and includes sediment traps and is not directed over fill banks.
- Ensuring all drainage is fully functional at the completion of harvest operations.
- Re-vegetating fill banks and berms.
- Requiring prunings and thinnings be cleared from waterways and not be left where they can be carried into a waterway.
- Minimising the amount of slash that enters waterways and removing such slash at least by the end of harvest operations and more frequently where it is deemed the waterway is high risk.
- Maximising the lift of any logs that must be hauled across waterways or the use of corridors to minimise the area of damage.
- Having planting set backs from waterways of 5-30m depending on the size of the waterway.
- Not applying fertiliser within 5m of a waterway.
- Not washing spray equipment within 10m of a waterway or water table.

5.3.2 Harvest Planning

CHHF undertake specific management planning to protect their waterways. During the development of their harvest plans, CHHF's independent harvest planner classifies each waterway into types one to five and assigns a low, medium or high risk category to each type. This is done using a stream classification matrix which is produced by the environmental planner in consultation with operational staff (Table 5.2 and 5.3). The first matrix (Table 5.2) uses the size and amount of recreational use to determine the type classification of a water body. Type 1 waterways are greater than 10m wide, flow all year round and have high recreational use and type 1 lakes cover greater than 100ha and have high recreational use.

The risk matrix (Table 5.3) is then used to determine a risk classification for the water bodies. This matrix considers that if the risk harvest would have on waterway infrastructure, ecological and recreational values, erosion potential, public visibility and personal or stock drinking water supplies is high, medium or low. Once each stream has been classified, the operating standards matrix is used to determine the set of operating standards that must be adhered to during the harvest of the area around each stream (Table 5.4). This set of operating standards deals with waterways with structures such as culverts separately. Waterways with a high risk classification must have all slash >1m length or 10cm diameter removed for 100m upstream of a culvert and have no disturbance of the riparian vegetation 50m upstream of the culvert regardless of the type classification of the waterway. The rest of the matrix sets out what operation standards must be followed for the other stream classification.

Table 5.2 CHH stream classification matrix for determining stream type classification.

TYPE	1	2	3	4	5
	>10 Wide	3 – 10m wide	1 – 3m wide	< 1m wide	< 1m wide
	Perennial	Perennial	Perennial	Perennial	Ephemeral
		<1000 l/s	approx 100 l/s	<100 l/s	Seasonal
			2nd Order	1st/2nd Order	1st Order
	>100 ha lake	10-100 ha lake	Lake > 0.1 ha	Wetland >0.1 ha	Seasonal wetland
	High recreational use	High recreational use	Some recreational use – No boating	No recreational use	No recreational use

Table 5.3 CHH stream classification matrix for determining stream risk classification

RISK	H	M	L	Consider
	High risk to infrastructure	Some risk to infrastructure	Low risk to infrastructure	Culverts, roads, bridges, canals, water supplies, irrigation
	High risk to ecological values	Minor risk to ecological values	Low risk to ecological values	Riparian margin, aquatic life, water quality
	High erosion potential	Moderate to low erosion potential	Low erosion potential	Slope stability, soils, bedrock
	High public visibility	Moderate public visibility	Low public visibility	Access to site and downstream use
	High risk to recreational values	Moderate risk to recreational values	Low risk to recreational values	Frequency of use
	Personal/stock water supplies			

Table 5.4 CHH stream classification operating standards.

Column	1	2		3	4
Standard	**2.6 Riparian Vegetation**	**2.9 Minimum distance from a permanent waterbody that machines may operate or permanent earthworks can be constructed.**	**2.15 Limbing and heading off of trees**	**2.17 Slash Removal Standards**	**Monitoring & Removal frequency**
Structure					
H	shall not be disturbed 50m upstream of culvert			All slash > 1m length or 10cm diameter removed for 100m upstream of culvert	Daily
M				All slash > 1m length or 10cm diameter removed for a distance of 30m upstream of culvert	Weekly
L				All slash > 1m length and 10cm diameter removed for a distance of 5m upstream of culvert	End of Operation
Stream type					
All 1 and 2, and 3H	shall not be disturbed*	20m	Prohibited	All slash > 1m length or 10cm diameter removed	Daily
3M	may be disturbed	10m	Prohibited	All slash >1m length or 10cm diameter removed	Weekly
3L	may be disturbed	10m	Prohibited	All slash >3m length and 10cm diameter removed	End of operation
4H	shall not be disturbed*	10m	Prohibited	All slash >1m length or 10cm diameter removed	Weekly
4M	may be disturbed	5m	Prohibited	All slash >3m length and 10cm diameter removed	End of operation

CHHF harvest plans showed that all but one of the 10 sample sites in the harvested areas were classified as type 4 with low risk. The one exception was clearcut sample site one which was classified as type 4 with high risk. The elevated risk factor was due to the proximity of a downstream culvert. The 4L classification is not shown on the matrix, but it still had set operating standards. Streams with 4L classification could have riparian vegetation disturbed, have machinery operating within five metres of a permanent waterbody, and had to have slash cleared at the end of the harvest operation. When waterway slash clearance was left until the end of the harvest operation it could have remained there for on average up to a week. This duration coincided with the length of time taken for a crew to extract the timber from a site before moving on to another site. Clearance would have taken place prior to leaving a site.

The harvest plans also show the areas to be harvested, by which method, where landing sites were, the path trees were to take to the landings, Forest Accord native vegetation, native vegetation that could and could not be disturbed, where slash could be deposited and all access roads and waterway crossings.

5.3.3 Methods of Plantation Harvest

(The information within the following paragraph was supplied by the CHHF Forest Leader). The catchments involved with this research were harvested between the end of 2003 and the autumn of 2004 and were harvested using a combination of ground based and cable hauler systems. Of the five clearcut sample sites, only site three was harvested using the cable hauler system, the other four sites were all ground base harvested. The decision by CHHF to use ground based or hauler extraction is driven by the economics of harvesting the wider area (as roads may be used to harvest a number of stands) and practicality. It is significantly more cost effective to use ground based timber extraction than hauler extraction as there are significant costs associated with relocating haulers. For this reason CHHF attempts to maximise the quantity of timber extracted by ground-based methods. In some instances however, small areas of flatter land may still be harvested with cable haulers as the costs of additional roading needed for ground-based extraction may be greater than the high costs of harvesting by cable haulers. The decision made on the exact areas and quantities extracted by each method are site related, and is determined by the steepness of the terrain, and therefore, vehicle access, and whichever combination will be the most cost effective. In extreme cases, areas can be left unharvested or felled to waste as the costs of extraction can exceed the current returns from the timber.

(Unless otherwise stated the information contained in the following three paragraphs was supplied by CHHF Harvest Manager). During ground based harvest, and where terrain allowed, a 30-40 tonne excavator with a cutting head was used to control the felling of trees next to waterways. The excavator held and cut the trees and then placed them on the ground for skidders to haul away. This practice was employed to minimise waterway slash deposits, riparian disturbance and mechanical disturbance of the streambeds. The effectiveness of this practice was evident by the remnant riparian vegetation left standing. Along sections of the waterways where clearcut sample sites one, two, four and five were located, sparse dead and regenerating vegetation remained. This vegetation had formed the under-storey of the plantation prior to harvest and its presence was a contrast with any other harvested areas where no vegetation, dead or alive, was left standing. Riparian vegetation was at a depth of approximately five metres from the edge of the stream banks and indicated that the excavator had not tracked within that distance of the waterways.

Where the terrain was too steep for ground-based harvest, cable haulers were used. To minimise the number of trees entering waterways during felling, cutters attempted to directionally fell them parallel to the waterways. Both harvest methods resulted in activities being carried out within the minimum five metre set back zone now required by the Northland Regional Soil and Water Plan and CHHF's own guidelines (at the time of harvest these requirements were only included in the proposed Soil and Water Plan). Activities within this five metre set back zone however, were permitted by the Northland Regional Soil and Water Plan as the trees had been planted prior to the Plan becoming operative.

When the trees were being extracted by either harvest method they needed at times to cross waterways. Cable haulers did this through corridors or over the entire length of a waterway. The decision on which method was employed was determined by the stream classification designated on the harvest plan. Those with low risk could have trees hauled over their entire length, where as those with higher risk required the use of corridors to minimise waterway disturbance (some waterways were not permitted to have trees hauled across them at all). Where ground-based extraction machinery had to cross waterways, two types of temporary log bridges were constructed (information on log bridge construction was supplied by CHHF Environmental Planner). If the waterway had water in it at the time of harvesting, a steel culvert was placed in the water then a sufficient number of logs were added parallel to the pipe to allow machinery to cross. If the waterway was dry at the time of harvest logs were used in place of the steel pipe. Both types of crossing avoid the use of fill across or close to the water in an effort to minimise sedimentation. High stumps were also retained at the entry points on both sides of the crossings in order to direct the logs in behind the skidders as they crossed and to prevent them rolling into the water.

Two such bridges were constructed in the research areas, one of these was located approximately 50m upstream of clearcut sample site four, and the other was located approximately 200m upstream of clearcut sample site two. The bridges were removed at the completion of harvest. The section of the stream above sample site four where the bridge had been, appeared to have been redirected or reformed after harvest as the waterway flowed through a channel of bare clay which had unnaturally steep, smooth banks, consistent with formation from an excavator bucket. Immediately upstream of this site the whole watercourse was covered by a layer of soil and woody debris that appeared to have been deposited during the harvest operation. This was a contrast with the waterway both up and downstream of these sites, which had bedrock, stones, and gravel on its bed. The CHHF environmental planner had stated that one of the waterway benefits of using temporary log bridges was that it reduced sediment inputs. This is achieved by protecting the stream banks from machinery damage and eliminating the use of fill. In this case it does not appear to have been effective, and as a result the waterway has been significantly altered and degraded, and the site continues to add sediment to the waterway. The second temporary bridge above sample site two traversed a much wider marshy section of waterway. Not all the logs had been removed from the crossing but there was minimal alteration to the waterway and no obvious evidence of ongoing sources of sediment inputs.

5.3.4 Second Rotation Establishment

(The information contained in this section was supplied by the CHHF Forest Leader). The areas were replanted in the winters of 2004 and 2005. These areas were sprayed, via air and ground in the April before replanting in July with a mixture of metasulfuron (Escort™), glysulphate 510 (a stronger version of Round up™) and a penetrant/surfactant (Pulse™) to eliminate weeds. These operations avoided spraying any waterways. Soil compaction relief was also carried out at this time where terrain allowed. The only sample site catchment where this occurred was sample site four. This was carried out using an excavator with a Wilco head. This is a three pronged attachment with the middle prong at ninety degrees to the outside two. The middle prong enters the ground first to break the compacted pan and the outside two follow and lift the dirt out of the ground. The dirt is then replaced in the same place producing a mound of earth in which a pine seedling can be planted. The areas were then re-sprayed after planting with Valzine 500™, a pre-emergent, retardant spray to eliminate weed competition. Some areas of the plantation were fertilised by hand with 70g Di Ammonium Phosphate (DAP) placed beside each tree. This occurred in the first year after planting and coincided with the spraying operation.

5.3.5 Implications of RBZ Inclusion in Plantation Forests

From the CHHF Harvest Manager's perspective, including undisturbed RBZs beside all waterways would cause a significant disruption to operations, as well as additional costs and time. Having undisturbed buffers would mean trees could not be hauled across waterways with cable haulers, and therefore, an increased length of access roads would need to be constructed to extract the timber. Felling trees next to buffer zones without disturbing them would be difficult, as the trees grow towards the light (over the buffer zone) and would therefore be leaning in that direction. Increased infrastructure will increase soil disturbance and possible waterway soil inputs. Management practices already in place will help to minimise the negative impacts; 5-30 metre planting setbacks in place for the second rotation will eliminate much of the disturbance close to waterways, lifting butt ends above the ground when they are being hauled prevents soil and stream bank disturbance. The second rotation will cause less soil disturbance as all the infrastructure is already in place.

From the CHHF Forest Leader's perspective, including undisturbed riparian buffer zones poses no significant problems. Carrying out aerial spraying may be complicated, as no spraying could occur across the buffer zone. This will mean that aerial spray application will have to follow the line of the buffer zone which will take longer and therefore cost more than current practices.

5.3.6 General Plantation Management

The following information was supplied by CHHF Forest Leader and presents the management regime employed at the Pipiwai Forest (P = the year of seedling planting).

P-1:	Area is felled
P-3 months:	Site Spot Cultivation where flat and soil properties show cultivation is needed.
P-2 months:	Aerial Spraying to kill weeds
P:	Plant 833 stems/ha
P +3 months:	Release spray weeds
P+4 months:	Spot spray if soil testing prior to planting shows nutrient deficiencies.
P+8 months:	Survival survey (for blanking - planting failed areas following year).
P+1.5:	Release spray on small percentage of area if weeds are a problem (eg: gorse outgrowing trees).
P+4:	Foliage sampling (using results for determining whether fertilising is necessary) and re-measurement dates. Test until at least age 10.
P+4:	Pre-thinning measurement (to time thinning operations)

P+5: Inventory for yield control.

P+6: Thin to waste 400-450 stems/ha (Mean top height = 8m)

P+10: Inventory for yield control.

P+20: Inventory for yield control.

P+27: Pre-Harvest inventory

P+28: Harvest

5.3.7 General Site Observations

All of the areas that had been harvested had experienced soil disturbance. This varied from disturbance of the topsoil from machinery and log movements to disturbance of the subsoil from earthworks and skidder operation. To minimise the sediment run-off from these types of disturbance, drainage systems were installed throughout the plantation. Despite this, sediment laden run-off was still observed entering the waterway upstream of clearcut sample site four.

There was very little slash present in the waterways at any of the sample sites. There were small slash dams upstream of clearcut sample site one. These were above the water and not affecting its flow. Slash had been suspended over clearcut sample site three, but this had been cleared. There were a few pieces of slash, in and across clearcut sample site five and there was a large tree stump in the streambed (at the water's edge) at clearcut sample site four.

Discussion

Chapter Six

6.1 SHMAK Results

The SHMAK results showed that the clearcut sites had lower quality aquatic and riparian habitats and they supported more pollutant tolerant invertebrates than both the pine reference sites and the buffer sites. Statistical analysis showed that the habitat and invertebrate community scores of the pine and buffered sites were not statistically different, but the clearcut site scores were significantly lower. The statistical analysis of the average QMCI scores showed that the scores at the clearcut sites were, on average, significantly lower than those at the buffered sites. It also showed that there were significantly more invertebrates at the clearcut sites than the other two treatment sites.

6.1.1 Habitat Scores

The SHMAK scores for the treatment sites showed that the pine sites had the highest average habitat score, followed by the buffered sites and then the clearcut sites. Statistical analysis found that there was no significant difference between the pine and buffered sites and that the clearcut sites average score was significantly lower than the other two treatments. The primary reasons for the lower average habitat score at the clearcut sites were; the absence of riparian vegetation, the presence of bare ground close to the waterways and the elevated sediment levels on the streambeds. The degradation of the waterway habitats at the clearcut sites was a direct result of the plantation harvest. This will be discussed in the following paragraphs under plantation management.

6.1.2 Invertebrate Scores

The SHMAK showed that both the buffered and pine streams had almost identical average invertebrate scores that were higher than the clearcut streams. Statistical analysis showed that the buffered and pine stream scores were significantly higher than the clearcut streams at the 95% confidence level. The MCI scores also showed the clearcut sites with the lowest average score. The difference between the scores however, was not significant at the 95% confidence level. The analysis of the QMCI (quantitative MCI) scores identified a significant difference between buffered and clearcut sites, which suggested that the difference the SHMAK identified was a result of the quantity of invertebrates present. As the clearcut sites had a significantly higher total number of invertebrates than other treatments and there were no significant difference between the numbers of species present at each site, the reason for this difference could not have been solely due to the numbers of invertebrates. When the invertebrate counts were examined, it showed that the buffered sites were the only sites where stoneflies were found and both buffered and pine sites had much higher average numbers of mayflies (23.2 and 33 respectively, compared to 10.6). It also revealed that clearcut sites had much higher average numbers of pollutant tolerant, low scoring invertebrates such as the mollusc *Potamopyrgus* (132.8 compared to 0.2 for buffered and 2.8 for pine sites) and the midge larvae *Chironomidae* (60.6 compared to 0.4 for buffered and 0 for pine sites). As such, the difference in the scores was a result of the types of invertebrates present. This finding is one that has been found by other investigations related to water quality. Collier and Smith (2005), Baillie *et al* (2005) and Death *et al* (2003) all found that clear cutting forest lead to a decrease in taxa such as mayflies which require high quality habitats and an increase in molluscs and midges which are pollutant tolerant.

6.2 Periphyton

Periphyton on streambed substrates can be used as an indicator of water quality as certain types of periphyton will only grow in streams with good quality habitats (Biggs *et al,* 2002). Across all treatment types there was periphyton found. The only sites where it was not found were sites that had unstable or unsuitable substrates. These were found at both the buffered and clearcut sites. The substrates at these sites were either mainly sandy or clay with woody/leafy debris where as the pine sites, which recorded better scores, had larger stones. These scores were therefore not exclusively linked to waterway impacts but also to stream geology and as such were not relied on as primary indicators of stream health.

6.3 Water Quality

Other water habitat assessments which included; pH, conductivity and velocity all yielded similar SHMAK classifications. The pH readings for all of the buffered, clearcut and one of the pine sites were within the SHMAK excellent category. The remaining four pine sites were just outside this range but not classified as causing negative impacts. The pH readings showed that the average pH for pine sites was 7.53, 7.05 for clearcut and 6.89 for buffered sites. It is possible that this elevated level at the pine sites was due to the greater photosynthetic activity (caused by the greater periphyton growth) removing CO_2 and therefore lowering the amount of carbonic acid in the water (Biggs *et al,* 2002). Average conductivity readings, which were used to indicate nutrient enrichment (Biggs *et al,* 2002) were within the second lowest category for conductivity (50-149 μS/cm) and were classified as good by the SHMAK. The buffered site average was the lowest with 108 μS/cm, followed by the pine sites with 138 μS/cm and clearcut sites with 140μS/cm. The closeness of the pine reference sites and the clearcut sites shows that the clearcut sites did not have elevated nutrient levels. These results show that either the sources of nutrient enrichment were effectively cleared or prevented from entering the waterways, or that any sources of excess nutrients that were deposited during or since harvest had been flushed from the waterways (or a combination of both). Slash that is left in waterways to decompose can be a major source of excess nutrients (Collier *et al,* 1997; Quinn *et al,* date unknown). The absence of slash observed in the waterways confirms that CHHFs policy of slash removal at least by the end of harvest was carried out, and it is likely that it would have contributed significantly to the low levels of nutrients in the clearcut waterways. This issue is discussed further in this chapter under slash inputs in section 6.4.2. Average stream velocities were also very similar (0.14m/s for buffered, 0.172m/s for pine and 0.254m/s for clearcut) and all fell within the low to moderate SHMAK category which was classified as being able to support both pollution tolerant and pollution sensitive invertebrates.

6.3.1 Waterway System Changes

The results showed that clearcut waterway habitats and invertebrate communities had been degraded as a result of plantation harvest while streams with buffer zones were maintained in a state similar to those under mature pine forest. The changes that were observed in the clearcut waterways affected both their structure and function. The structure of the waterways was changed as the habitat and flora and fauna diversity were changed from their pre-harvest state (Larsen, 1995). Riparian habitats were changed from a forested canopy with a diversity of flora, to an open canopy with no vegetation and bare ground. The invertebrate fauna in the waterways changed from one dominated by those requiring high quality habitats such as mayflies, to one dominated by pollutant tolerant species such as molluscs and midges. The removal of the riparian vegetation also removed a significant part of the waterway system. This changed the energy dynamics of the system by removing the solar radiation regulation and the energy inputs from leaf litter, woody debris and terrestrial insects (Quinn and Scarsbrook, 2001). This also removed interaction between the waterway and its aquatic communities and the terrestrial community as the latter community was removed. These changes resulted in a change in the energy dynamics of the system and the interaction of the system's organisms, and therefore caused a change to occur in the systems function (Larsen, 1995). Blanco e*t al* (2005) identifies changes that alter a systems structure and/or function as causing that system to become unsustainable.

6.4 Impacts of Harvest Management

CHHF stated that the purpose of its environmental guidelines was to provide a practical guide to the best operational practice in all aspects of forest management in their forests. They incorporated and followed these guidelines in their harvest plans that left none of the management of the harvest to ad-hock decisions by field staff. Their operational guidelines, when compared to the Regional Soil and Water Plan for Northland, and to industry standards (through the principles for commercial plantation forest management and the New Zealand Forest Owners Association's certification standards), meets and in some instances exceeds these standards. Despite this, the results show that the clearcut waterways had been degraded. The following sections will discuss the aspects of the harvest management that could have contributed to this degradation.

6.4.1 Soil Disturbance

Due to trees from the first rotation being planted right up to the edge of stream banks, harvesting machinery had to at times operate within the five metre non-operational riparian zone now required by the Regional plan and CHHF own operating standards. As a result, soil disturbance occurred within metres of all the clearcut waterway sample sites, not only from machinery movement but also log extraction. Tree stumps that had been pulled out of the ground were seen at the very edge of stream banks and in one instance in the streambed. As a result of these disturbances, two of the clearcut sites still had active soil erosion occurring at the time of sampling that was depositing soil directly into the waterways. These disturbances could have been much greater if an excavator had not been used to control the felling of trees close to the waterways. Without this management initiative it is likely that more trees would have been felled into and across the waterways resulting in significantly more stream bank and riparian disturbance. The evidence of the lower level of disturbance with the use of the excavator was seen in the remnant riparian vegetation. All other clearcut areas had no woody vegetation, dead or alive, left standing. Ground based harvest areas had some damaged riparian woody vegetation which had formed the under-story of the plantation trees standing and regenerating at the time of sampling. The use of the excavator to control tree felling close to the waterways, complies with the NRC requirements to minimise disturbance in the riparian zone, as well as with the principles for commercial plantation forest management and with the National standard for certification of plantation forest management in New Zealand to minimise the adverse effects of forestry operations on water quality.

Of the five clearcut sites, only site three had timber extracted via cable hauler. Trees were hauled over this waterway but there was no evidence of damage to the stream banks or ploughing up of the soil immediately adjacent to the stream as a result. The CHHF harvest manager had stated that when logs were extracted using the cable hauler that the butt ends were elevated off the ground and that this prevented the soil being ploughed up and minimised damage to the stream banks. This sample site showed this to be true and demonstrated how CHHF management practice had helped to minimise soil disturbance close to the waterways and therefore minimise waterway degradation.

There were two temporary crossings constructed in clearcut areas. These crossings were designated on the harvest plan to avoided random construction of crossings and therefore unnecessary riparian soil disturbances. CHHFs environmental planner had stated that one of the waterway benefits of using temporary log bridges was that it reduced sediment inputs. This is achieved by protecting the stream banks from machinery damage and eliminating the use of fill. This practice, along with the use of high stumps to direct transported logs onto the bridge, may have helped to minimise sediment inputs at the time of harvest. However, the disturbance observed at the site of the log bridge upstream of clearcut site four was contributing sediment to the waterway. The waterway had been redirected or reconstructed at the location of the crossing which had left the stream banks and bed as bare clay. The action of the stream flowing over the clay would continually erode the surface and add sediment to the waterway (Burroughs *et al,* 1984). Immediately upstream of the crossing the whole watercourse was covered by a layer of topsoil and woody debris. This layer sat immediately above the water surface and appeared to have been deposited during the harvest operation. Any rise in the water level would cause erosion of the underside of the soil layer, and in the event of a flood the topside as well. These soil disturbances in the riparian management zone were contributing sediment directly into the waterway and illustrate the need to eliminate harvesting activities from these areas (Maclaren, 1996; Hicks, 2000). The second temporary crossing was located approximately 200m upstream of clearcut sample site two. This crossing traversed a much wider marshy section of waterway. Not all the logs had been removed from the crossing but there was minimal alteration to the waterway and no obvious evidence of ongoing sources of sediment inputs.

General soil disturbance and exposure occurred over the catchments of both the clearcut and buffered sample sites as a result of machinery and log movements during harvest. This type of disturbance and exposure of the soil makes it vulnerable to surface erosion through run-off. To prevent these sediments reaching waterways, effective drainage systems must be constructed and maintained (Hicks, 2000) and should include a filtration of run-off through vegetation and slash to trap sediments where possible (Hicks, 2000). CHHF required that an effective drainage system was installed and fully functional at the completion of harvest. Despite this, sediment-laden run-off was observed entering the waterway upstream of clearcut sample site four. This kind of disturbance and increased sediment generation is a common impact of forestry harvest (Collier and Winterbourn, 2000a; Death *et al,* 2003; Mosley *et al,* 2004; Baillie *et al,* 2005). At the buffered sites, no such observances were made despite there being exposed soil. The soil at these sites was reinforced by the roots of riparian vegetation. Run-off also had to flow through harvest slash on the edge of the buffer zones and the riparian vegetation which would have provided two stages of filtration before entering the waterways (Maclaren, 1996; Mosley *et al,* 2004).

Despite the management practices designed to minimise sediment entering waterways, the results showed increased levels of streambed sedimentation at the clearcut sites and no such increase at the buffered sites. Four of the clearcut sites were classified by the SHMAK as having moderate levels of sedimentation, which was a level the SHMAK deemed would inhibit the healthy growth of stream invertebrates (Biggs *et al,* 2002). Buffered and pine sites had either no sediment or light sedimentation which was classified as unlikely to inhibit the healthy growth of stream invertebrate communities. It is likely that the elevated sediment levels observed in the clearcut waterways was a result of the increased disturbance experienced in the riparian management zone and the lack of run-off filtration. It must also be highlighted that these levels of sedimentation were recorded 24-30 months after harvest. Research has shown that within 18-24 months after harvest, sediment generation drops and high flow levels flush waterways of excess sediments and return them to pre-harvest levels (Maclaren, 1996; Hicks, 2000). On this basis it is reasonable to assume that streambed sedimentation during and immediately after harvest would have been at higher levels than when the streams were sampled. Such changes to streambeds have been shown to result in aquatic habitats being smothered and made unsuitable for invertebrates that require high quality habitats, such as mayflies, and more suitable for pollutant tolerant invertebrates such as molluscs and midges (Harding *et al*, 2000; Death *et al,* 2003). If therefore, the sediment levels at 24-30 months inhibited the growth of healthy invertebrate communities, it is highly likely that the sediment levels prior to this would have had greater negative impacts on the invertebrate communities. As such, it is probable that the levels of sedimentation contributed to the degraded state of the invertebrate communities at the clearcut sites.

6.4.2 Slash Inputs

None of the clearcut sample sites had more than the odd piece of slash remaining in the water. Sample site three showed signs that it had been deposited in there during harvest but had subsequently been removed. The other four sample sites showed little evidence of having significant amounts of slash deposited in them. It is likely that this was the case, as the harvest plan shows that these areas were ground based harvested and trees were felled and hauled away from the waterways, not hauled across them. Upstream of these sites however, the plan shows that trees had been hauled across the waterways and in three instances there were still either small debris dams present or significant quantities of slash remaining in and over the waterways. Exactly how long slash remained in the waterways before it was removed cannot be known for certain, as no observations were made at the time. But the CHHF environmental planner stated that on average this would have been no longer than a week (Ursula Albrect, CHHF Environmental Planner, personal communications, September 11, 2006).

The management of this aspect of the plantation harvest was carried out in accordance with best practice guidelines and NRC regulations and would have avoided the negative impacts associated with waterway slash deposits. When large quantities of slash, including pine needles, are deposited into a waterway, they can smother the streambed destroying aquatic habitats, and if left to decompose can deplete the water of dissolved oxygen (Collier *et al,* 1997), and enrich the nutrient levels in the water, which can in turn fuel aquatic plant growth (Maclaren and Cameron, 1999). All of these factors can contribute to habitat and invertebrate community degradation. Conductivity tests carried out as part of the SHMAK assessment showed that there was no elevation of the nutrient levels in the clearcut waterways, nor was there any evidence of increased aquatic algal growth. These factors combined with the absence of slash at the sample sites and the slash management practices employed suggest that any possible negative impacts of slash deposits and decomposition were avoided and would therefore have not contributed to the degraded state of the clearcut waterways. It is possible that there may have been elevated levels of aquatic plant growth and/or excess nutrients in the waterways at some time prior to sampling being done, but without observations at the time, this cannot be known for certain.

6.4.3 Mechanical Disturbance

CHHF use of directional felling and ground based machinery minimised the number of trees that would have been felled into, and hauled through, waterways. The use of two temporary stream crossings would also have minimised mechanical disturbance of the streambeds by keeping transported logs from entering the waterways. There would have been disturbances in some areas from the construction and removal of the temporary crossings, tree felling and extraction and slash removal. The degree of disturbance that occurred could not be known for certain without observations at the time of harvest. The results do show however, that some degree of disturbance did occur in some areas. Zimmermann and Death (2002) found that such disturbances are a source of habitat degradation and invertebrate loss. It is likely therefore that the mechanical disturbance of the streambeds contributed to the clearcut waterway degradation at the time of harvest. It is uncertain however, whether these disturbances would have been sufficient to contributed to the degradation identified during sampling at 24-30 months post-harvest.

6.4.4 Surface Run-off

Tree harvest would have resulted in an increase in surface run-off in each harvested waterway catchment, as water intercepted by trees and held above ground on foliage, branches and trunks would no longer have occurred, and underground interception and by tree roots for use in transpiration would also have ceased, causing the ground to become and remain saturated for longer (Maclaren, 1996). This impact however, would have largely been common to both buffered and clearcut sites as buffered areas were only a fraction of each harvested catchment and as such would have only continued to intercept a fraction of the rainfall.

6.5 Impacts of Riparian Tree Removal

Removal of the riparian vegetation has various impacts on the post harvest waterways. There were no management initiatives to address these issues. The following impacts were observed as a result of plantation harvest.

6.5.1 Solar Radiation Input

Prior to harvest, clearcut sites would have experienced shade levels similar to that observed at the pine sample sites of 95%. Based on the condition of the sites at 24-30 months post harvest, it is likely that immediately following harvest (including slash removal) these sites would have been experiencing nearly 100% exposure. At 24-30 months, post harvest cover was still minimal, with four of the five sites having only 10-30% shade and all five sites having shade provided by bank overhangs and weeds and scrub grown since harvest.

Research has shown that increased solar radiation inputs can increase water temperature (Quinn *et al,* 2001; Boothroyd *et al,* 2004), cause a drop in dissolved oxygen levels (Baillie *et al,* 2005), and fuel aquatic plant growth (Boothroyd *et al,* 2004; Quinn *et al,* date unknown), all of which can negatively impact on aquatic invertebrates (Quinn *et al,* 1994; Boothroyd *et al,* 2004; Baillie *et al,* 2005). Clearcut sites showed no increase in aquatic plant growth at the time of sampling. It is possible that sometime in the previous 24-30 months this had occurred, with conditions then becoming unfavourable or high flow levels flushing it from the waterways. Without direct observations in the months following harvest, this cannot be known for certain. Spot water temperature tests showed that there were two clearcut and two buffered sites which had temperatures in the SHMAK category classified as beginning to cause stress for some invertebrates (15-19^{0}C), while all of the other sites were in the excellent category (10-14.9^{0}C), classified as very suitable for most invertebrates. Of the five clearcut sites, those with elevated temperatures were recorded in the afternoon, whereas the other three were recorded in the morning. The two buffered streams with elevated temperatures had either clearcut headwaters or only scrubby riparian vegetation. Their temperatures were also recorded in the afternoon. It is possible therefore, that the elevated temperatures in these waterways were a result of the degree and duration of their exposure to the sun (having exposed headwaters would have resulted in elevated water temperature which would then need a sufficient length of riparian shade to cool off (Quinn *et al,* 2004)). Boothroyd *et al* (2004) found that clearcut waterways in the Coromandel Peninsula had a 2.7^{0}C higher average temperature than buffered sites, and a range of 12.2-30.2^{0}C compared to 11.6-23.0^{0}C. There is little doubt that increased solar radiation inputs at Pipiwai would have at least raised water temperatures above pre-harvest levels and it is possible that they followed a similar trend to those in the Coromandel. This being the case, the increased temperatures at the clearcut sites would have contributed to the degradation of the stream invertebrate communities as it has in other clearcut streams in Northland and the Coromandel (Boothroyd *et al,* 2004; Baillie *et al,* 2005). The failure of spot temperature tests to show this could have been due to the weather conditions prior to and at the time of sampling, the time of day at which the samples were taken, and the time of year at which the samples were taken (March as opposed to January).

6.5.2 Decreased Tree Canopy Inputs

Changing the amount and/or type of energy inputs to a waterway affects the aquatic communities that rely on those inputs. The removal of riparian trees largely eliminated leaf, wood and insect inputs from the tree canopy. Quinn and Scarsbrook (2001) state, that this affects the balance of aquatic communities by reducing dendrite feeders and increasing algal grazers. Prior to harvest, trees would have contributed leaf litter, woody debris and insects to the streams (Boothroyd *et al,* 2004), as was observed in the pine and buffered streams. This would have been a source of both food and shelter for stream invertebrates and fish. At 24-30 months post harvest all that remained at the clearcut sites was the odd piece of pine slash and very little leaf litter or other woody debris. This condition will continue until trees grow sufficiently for canopy closure at around eight to ten years old (Quinn *et al,* 2004; Mosley *et al,* 2004). Results showed much higher numbers of grazers (molluscs) at the clearcut sites than at the pine or buffered sites. It is likely that such a drastic change in the food sources and habitats would have negatively impacted on the invertebrate communities (Mosley *et al,* 2004).

6.5.3 Increased Erosion Vulnerability

Clearcut sites four and five had dead and exposed tree root systems on their stream banks and eroding soil entering the water. This was a contrast with buffered sites which also had areas of bare ground but the soil was not being eroded. The soil at the buffered sites had greater cohesion than that at the clearcut sites. This difference would have been a result of the harvest disturbance (log and machinery movements) experienced by the clearcut sites (Maclaren, 1996; Hicks, 2000) and the stabilising effect of the live tree/plant root systems at the buffered sites (Quinn *et al,* 2001). Research has shown that while trees and plants are living, their root systems add stability to the soil, helping to increase its cohesion and thereby preventing its movement (O'Loughlin, 1984; Marden *et al,* 1996). When plantation trees are harvested their root systems die and over the following two years lose their stabilising benefits (Sidle *et al,* 1985; Hicks, 2000). Until

second rotation tree root systems (including under-storey plants) become established, it is probable that this erosion will continue to increase waterway sedimentation.
The removal of riparian vegetation also removed the potential for a further stage of water bourn sediment filtration. Low growing riparian vegetation and leaf litter can filter surface water that is not concentrated in gullies (Maclaren, 1996; Mosley *et al,* 2004). With the clearcut regime there was little vegetation or leaf litter left to perform this function; it is likely therefore, that this would also have contributed to a higher degree of waterway sedimentation.

6.5.4 Nutrient Cycling

The removal of the trees interrupts the nutrient cycle between the soil and plants. Trees and other vegetation are no longer present to take up nitrogen and phosphorus, and as a result these can be leached in greater amounts into waterways. Conductivity tests did not show increased levels of waterway nutrification at 24-30 months post harvest. It is possible that prior to that, levels had been elevated, but without testing at the time there is no way of knowing for certain. Research into nutrient changes after harvest suggests that any increases are of a short duration due to the demands of second rotation trees, and at times there can even be decreases in nutrient inputs (Mosley *et al*, 2004).

6.6 Riparian Buffer Zone Waterway Protection

When the results for the clearcut waterways are compared to those of the buffered waterways, there is little difference in the physical water quality of the two treatments. There is however, a significant difference in the riparian habitats, with the clearcut sites being severely degraded compared to that of the buffered sites. Clearcut sites had little riparian shade, minimal leaf litter or woody debris inputs, and increased soil disturbance and sediment inputs. The notable difference in the aquatic habitats was the increased level of streambed sedimentation in the clearcut sites compared to the buffered sites. All of these negative impacts were reflected in the invertebrate communities. The clearcut sites were dominated by a proliferation of pollutant tolerant invertebrates, such as molluscs and midges, whereas the buffered sites were dominated by invertebrates, such as mayflies, which require high quality habitats. These results showed that riparian buffers do protect waterways from degradation during plantation harvest and maintain riparian and aquatic habitats and aquatic invertebrate communities similar to those found in standing forest. This finding is in agreement with Quinn *et al* (2004) who found that logging disturbances could severely degrade the biodiversity value of waterways unless continuous buffers were in place, and with Baillie *et al* (2005) who stated that the degradation experienced by two Northland streams due to plantation harvest could have been avoided if riparian buffers had been in place.

The levels of sedimentation in the buffered and pine streams were similar; both had four sample sites with light sedimentation and one site with no sedimentation. Questions have been raised about the possible increase in waterway sedimentation when RBZs are retained due to the increased infrastructure required to harvest the plantation trees (Maclaren, 1996; Quinn *et al*, 2004). The results from this research suggest that there is no such increase in waterway sedimentation. Hicks (2000) supports this finding, he found that up-to-date infrastructure standards prevent sediment reaching waterways and was no reason to restrict forestry activities.

6.7 Plantation Management

CHHF have compiled general environmental guidelines for the management of their plantation forests. These guidelines are designed to give a practical guide to the best operational practices in all aspects of forest management. They also complete environmental plans which have specific requirements for each forest. They aim to minimise waterway degradation by minimising sediment, slash and chemical inputs. In the Pipiwai Forest, sediment management was undertaken through minimising soil disturbance and erosion risk and trapping sediments. Slash management was designed to minimise the amount of slash entering waterways either directly or indirectly and removing such slash that did enter the waterways at least by the end of harvest.

Chemical waterway inputs were managed by limiting the use of fertilisers and the washing of spray equipment close to waterways and avoiding aerial spray applications to the waterways. These policies complied with industry best practice guidelines and local government regulations to protect waterways from degradation during plantation harvest (New Zealand Forest Owners Association, 1995; 2005; Northland Regional Council, 2004; Forest Stewardship Council, 2005). These policies however, were unable to prevent the increase in waterway sedimentation at the clearcut sample sites and their degradation.

During the harvest of the Pipiwai forest, trees were harvested right up to the stream banks. This practice has been highlighted by research as contributing significantly to waterway sedimentation and one that should be avoided (Maclaren, 1996; Hicks, 2000). CHHFs management of this aspect of the harvest was determined by the planting policy employed when the plantation was established. Trees were planted right up to the stream banks and therefore during harvest they had to be removed. CHHF now employ a minimum five metre waterway set back policy for all tree planting. This new policy should not only largely eliminate disturbance close to the waterways but it should also make it possible for slash to be left at the edge of the harvested areas to serve as a run-off filter (Maclaren, 1996) (something that did not occur in the clearcut areas of the Pipiwai forest).

The results showed that plantation harvest brought about a change in the clearcut waterway energy inputs through increase solar radiation inputs, decreased tree debris inputs and likely decreased insect inputs. CHHF had no management policies to address these issues. Of the industry operating standards, only the National Standard for Certification of Plantation Forest Management specifically addresses any aspect of changing waterway energy inputs. Where tree planting had occurred within five metres of a waterway it required that management practices maintain water temperatures (New Zealand Forest Owners Association, 2005). This research did not monitor water temperatures after harvest, and spot temperatures taken at the time of sampling showed variable results that were likely linked to the time of day they were obtained. Research suggests however, that the exposed clearcut waterways would have experienced increased water temperatures stressful to aquatic invertebrates as a result of the increased solar radiation inputs (Quinn *et al,* 2001; Boothroyd *et al,* 2004). Removing the tree debris inputs would also have negatively impacted the aquatic invertebrates by removing habitat and food sources (Quinn and Scarsbrook, 2001; Boothroyd *et al,* 2004).

The results show that the management of the Pipiwai plantation harvest failed to prevent degradation of the clearcut waterways structure and function. Waterway structure was changed through a change in the habitat and fauna diversity and waterway function was changed when the energy dynamics and organism interactions were changed (Larsen, 1995). Blanco *et al*, 2005, stated that such impacts on a system are unsustainable. Larsen (1995) discussed them as system perturbations and related them to a system's resistance and resilience. When a perturbation is large enough to overcome a system's resistance, it causes a change or changes to occur within that system. Once that perturbation is removed the system's resilience will return it to its original state. When the Pipiwai forest was harvested, it imposed perturbations on the waterway systems which were of a large enough magnitude to overcome the system's resistance and therefore cause changes to occur in the waterways. However, the waterways have not been monitored for a sufficient length of time to determine if the system's resilience will return the waterways to their pre-harvest state. It is however, likely that the waterways were in a state of recovery at the time of sampling. Sediment levels were likely to have been at a lower level than immediately post-harvest, as a result of reduced inputs and high flows flushing sediment from the waterways (Maclaren, 1996; Hicks, 2000). Streamside vegetation had re-grown in some instances and was providing more waterway shade than the waterways would have experienced immediately post-harvest. To restore stream shade and a forest cover to smaller waterways takes 8-10 years when canopy closure of the new plantation occurs (Quinn *et al* 2004).

Conclusions and Recommendations

Chapter Seven

7.1 Conclusions

Following industry operating standards and the regional council regulations was not sufficient on their own to prevent the degradation of the clearcut waterways in the Pipiwai forest. The harvest management practices used could only minimise the negative impacts of harvest on the waterways. The retention of undisturbed buffer zones in conjunction with harvest management however, was able to mitigate the negative impacts of harvest. The buffer zones protected the waterways in the harvested areas from being degraded and maintained them in a condition similar to that of the standing mature pine reference sites.

Management practices that were used in the harvest of the clearcut waterway catchments were unable to prevent an increase in waterway sedimentation, solar radiation inputs, slash deposits, and a reduction in energy inputs supplied by the forest canopy. As such they also failed to meet the Forest Stewardship Council principle that requires that plantation forestry causes no adverse impacts on water quality, the Principles of Commercial Plantation Forest Management in New Zealand that have the objective of maintaining water quality and the National Standard for Certification of Plantation Forest Management in New Zealand that requires that water temperatures, sediment and nutrient levels are maintained.

Management practices were designed to minimise soil disturbance and prevent sediment reaching the waterways. However, where soil disturbance and exposure occurred up to the stream banks there was little opportunity to prevent sediment from entering the waterways. There was no possibility of using slash to filter surface run-off or drainage to trap sediments. Management failed to prevent loose soil from falling or being washed into the waterways during and after harvest. Where buffer zones were present they prevented the original disturbance and provided an ongoing filtration system for surface run-off from the rest of the catchment.

There were no management policies utilised to prevent or minimise the degradation of the clearcut waterways through increased solar radiation inputs. When all of the riparian vegetation was removed, and all the slash was cleared away, waterways were left almost fully exposed to the sun. No management practices were employed to remedy this situation and only the shade that will be provided by the second rotation crop will reverse this condition. Where buffer zones were present these impacts were avoided.

Clearcut waterway degradation caused by the mechanical disturbance of the streambed by slash and trees and increased nutrient inputs from slash were minimised or mitigated through management practices. Under ground-based harvest management, these impacts were mitigated through the use of an excavator to control tree extraction; on steep terrain, under cable hauler extraction, they were minimised through the use of directional felling and extracting trees across waterways in corridors. None of these activities occurred within the RBZs of the buffered waterways and they therefore did not suffer any of the potential negative impacts.

The first rotation harvest of the Pipiwai forest caused a change in the structure and function of the clearcut waterways and was therefore classed as unsustainable. This change was observed in the sort-term (24-30 months post harvest) though it could not be determined when and if waterways were able to recover to their pre-harvest levels. Nor could the effect that consecutive rotation harvests would have on the waterways be determined. Consideration also needs to be given to the change in management practices from the first to the second rotation and the benefits this could have. All waterways in the second rotation forest have minimum five metre planting setbacks. This may help to eliminate disturbances in the riparian management zone and reduce sediment inputs and maintain some riparian vegetation that could help to reduce solar inputs post-harvest. The second rotation harvest will also require less earthworks as all necessary infrastructures were already constructed for the first rotation harvest and will only require an upgrade for the second harvest. This may help to reduce sediment inputs to waterways and therefore reduce the negative impacts waterways experience as a result.

7.2 Recommendations

This study has found that buffer zones had protected waterways from degradation during plantation harvest, and that at 24-30 months post harvest, clearcut waterways were still in a degraded state comparatively. There are however, three areas related to riparian buffer zones that need further investigation as their inclusion in plantation forests will have financial ramifications for forestry owners. The first relates to the current level of sustainability. This study has shown that in the short term there are negative impacts from current harvest practices in Pipiwai. It is not known however, whether the clearcut waterways will recover to pre-harvest levels prior to the next rotation harvest. Quinn *et al* 2004 suggests a time of 8-10 years for waterway recovery, while Mosley *et al* (2004) suggests seven (for waterways up to 3m wide) which coincides with the re-growth of riparian vegetation and restoration of a forest regime. If this is accurate, then plantation waterways will have approximately 18-20 years in an undisturbed state equivalent to that of a native forest waterway. If this is the case, harvest practices may only be causing minor degradation. Therefore, investigations need to be carried out to determine when and if waterways recover to their pre-harvest state and if this can be maintained over consecutive rotations.

The second area of investigation is related to changes in the second rotation plantation management. Management of the Pipiwai forests second rotation is different from the first, due to the implementation of minimum five metre planting set backs from all waterways and the reduction in the need for infrastructure construction prior to the second rotation harvest. These two changes are likely to result in a drop in the waterway disturbances experienced during the second rotation harvest. Hicks (1998) identifies harvest activities adjacent to waterways as major contributors to waterway degradation and recommends that they be avoided. New planting set-backs may help to prevent streambed disturbance, slash inputs and nutrient enrichment, by helping to prevent trees entering waterways, as well as lowering sediment inputs by preventing soil disturbances close to the waterways. On the basis of the riparian vegetation that remained after the first rotation harvest when no set backs were employed, new set-backs may allow some riparian vegetation to grow and remain after harvest that can provide shade for some streams. When the second rotation trees are harvested, infrastructure will already be in place to facilitate this process. This may need an upgrade but the soil disturbance will only be a fraction of the first rotation constructions. As such, it is likely that the sediment that is generated and that is reaching the waterways will only be a fraction of that of the first rotation. Both of these changes may significantly lessen the negative impacts on the waterways and prevent the degradation observed during this study. The impacts of second rotation harvest of plantations with management regimes that have minimum five metre planting set-backs and require only an infrastructure upgrade need to be investigated to determine if these management changes significantly improve plantation sustainability.

The third area of investigation involves the possible negative impacts of increased infrastructure requirements associated with the inclusion of riparian buffer zones in plantation forests. A study by Quinn *et al* (2004) found a significant increase in infrastructural requirements when buffers were in place in a plantation in the Coromandel Peninsula. This study has found no increase in sedimentation of buffered waterways, which suggests any increase in infrastructure did not cause a corresponding increase in waterway sedimentation. Further investigation however, needs to be undertaken to specifically address whether the inclusion of RBZs causes an increase in forestry infrastructure and whether such an increase results in a corresponding increase in the sedimentation of waterways with RBZs.

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Appendices

Appendix 1 Regional Soil and Water Plan for Northland

Sections from the Northland Regional Soil and Water Plan relevant to forestry harvest.

32.1 GENERAL ENVIRONMENTAL STANDARDS

1. The short-term visual clarity of any permanently flowing river or wetland shall not be reduced by more than 40%, after reasonable mixing, due to sediment or sediment laden discharge originating from the site of the land disturbance activity.
2. The short-term visual clarity of any lake or coastal waters shall not be reduced by more than 20%, after reasonable mixing, due to sediment or sediment laden discharge originating from the site of the land disturbance activity.

Note: See Appendix 1 for explanation on the measurement of visual clarity.

3. No vegetation, slash, soil, earth, rock, or any other debris shall be allowed to enter or shall be placed in a position where it could readily enter, or be carried into, a river, lake or wetland, that may result in:
• Diversion or damming; and/or
• Bed or bank erosion; and/or
• Adverse effects on ecosystems that are more than minor.
4. No vegetation, slash, soil, earth, rock or any other debris shall be allowed to enter or shall be placed in a position where it could enter and have more than minor adverse effects within the Coastal Marine Area.
5. All practicable measures shall be taken to avoid creating erosion features such as sheet wash, slips, slumps, rills and gullies, wind erosion, blow outs and stream bank erosion and to mitigate the effects of existing erosion features.
6. The activity shall not interfere with or destroy any waahi tapu, as defined in the Definitions, urupa or any other sites known to the local iwi which are of spiritual or

cultural significance to Maori, which have been identified to the Council. Should archaeological remains or features be uncovered the activity shall cease and the Council notified as soon as practicable. Also as soon as practicable the Council will then notify the appropriate tangata whenua entity. The activity shall not be recommenced without the authority of the New Zealand Historic Places Trust.

7. To prevent erosion where vegetation clearance results in areas of exposed soil, these areas shall be re-vegetated as soon as practicable in the spring or autumn immediately following, to achieve an 80% ground cover within 24 months of the operation being completed.

8. No storage, mixing of fuels, oils, agrichemicals or other similar substances shall take place in the Riparian Management Zone.

9. All vegetation shall be felled away from any water body unless, for safety reasons, it is impractical to do so.

10. There are no more than minor adverse effects on aquatic life.

11. The activity shall not take place within any indigenous wetland and, where the activity involves the taking, use, drainage or diversion of water, the activity shall not cause any change to the seasonal or annual range in water level of any indigenous wetland to an extent that may adversely affect the wetland's natural ecosystem.

12. Any adverse effect on the ability of any downstream water users to take water to meet their authorised needs is minimised.

Vegetation clearance on erosion prone land that is not in the Riparian Management Zone is a permitted activity, provided that:

(a) The Council is notified at least 15 days prior to the vegetation clearance being undertaken;

(b) The Environmental Standards in Section 32 are complied with;

(c) The area of vegetation clearance is less than 5 hectares in any 12 month period unless the clearance is plantation forestry;

(d) Vegetation clearance by burning does not take place on peat soils; nor any contiguous area in excess of 5 hectares on other soils;

(e) The site of the activity will be re-established in woody vegetation within 24 months from the start of the vegetation clearance operation;

(f) Ground based methods of vegetation clearance are only undertaken during the period 1 October to 30 April inclusive, unless it is on sand country; and

(g) There are no more than minor adverse effects on soil conservation.

3. Any earthworks that are not in a Riparian Management Zone, are a permitted activity, provided that:

(a) The volume moved or disturbed is less than 5,000 m^3 in any 12 month period where the activity is not undertaken on erosion prone land;

(b) The volume moved or disturbed is less than 1,000 m^3 in any 12 month period and the surface area of the soil exposed is less than 1,000 square metres where the activity is undertaken on erosion prone land;

(c) There are no more than minor adverse effects on soil conservation beyond the property boundary; and

(d) The Environmental Standards in Section 32 are complied with.

4. Any land preparation that is not on erosion prone land, and that is not in a Riparian Management Zone, is a permitted activity, provided that;

(a) The Environmental Standards in Section 32 are complied with; and

(b) There are no more than minor adverse effects on soil conservation.

32.4 ENVIRONMENTAL STANDARDS FOR PLANTATION FORESTRY

1. Where practicable and safe to do so, all trees shall be directionally felled or pulled back from any river, lake, indigenous wetland or the Coastal Marine Area. The removal of any tree that has been felled into any river, lake or indigenous wetland shall be undertaken so as to minimise damage to the bed and/or banks.

Note: Where a tree has entered an indigenous wetland, it may be more appropriate to leave it in place rather than remove the tree if doing so will cause excessive damage.

2. During forest harvesting operations, all stem butts shall be raised above the ground when cable logging through the Riparian Management Zone. That is, when hauling the

operation shall be undertaken in such a manner so as to minimise damage to remaining riparian vegetation.

3. Machines from ground harvesting operations shall not operate within 5 metres of the bed of a river, lake, indigenous wetland or the Coastal Marine Area other than at a designated crossing or on existing roads or tracks or to assist with directional felling or to lift the stem butt out of any river, lake, indigenous wetland or the Coastal marine Area ('Turning' or 'screwing' of machines shall not occur within 5 metres of the bed of a river, lake, indigenous wetland, or the Coastal Marine Area).

4. Harvesting in or adjacent to the Riparian Management Zone shall be undertaken in such a way as to minimise disturbance of riparian edge vegetation (other than plantation forestry species being harvested that has formed part of the riparian vegetation).

5. Where soil disturbance within the Riparian Management Zone results from harvesting an 80% ground cover shall be achieved within 12 months of the operation being completed.

6. During the period 1 May to 30 September inclusive, the vegetation disturbance activity shall not result in more than 10% of the activity being disturbed to the extent that mineral subsoil (B3 Horizon or deeper) is exposed. Operations on sand soils are excluded.

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Note: A discretionary activity consent is required for the harvest of any trees planted after the date this Plan became operative6 where those trees are within 5 metres of a water body or the Coastal Marine Area. Consent may be refused for a discretionary activity, or it may be granted with or without conditions.

33. RULES FOR LAND DISTURBANCE ACTIVITIES

33.1 PERMITTED ACTIVITIES

The following land disturbance activities are permitted activities:

1. Vegetation clearance that is not on erosion prone land, and is not in a Riparian Management Zone, is a permitted activity, provided that:

(a) The Environmental Standards in Section 32 are complied with; and

(b) Vegetation clearance by burning does not take place on peat soils, nor on any contiguous area in excess of 5 hectares on other soils.

2. Vegetation clearance on erosion prone land that is not in the Riparian Management Zone, is a permitted activity, provided that:

(a) The Council is notified at least 15 days prior to the vegetation clearance being undertaken;

(b) The Environmental Standards in Section 32 are complied with;

(c) The area of vegetation clearance is less than 5 hectares in any 12 month period unless the clearance is plantation forestry;

(d) Vegetation clearance by burning does not take place on peat soils; nor any contiguous area in excess of 5 hectares on other soils;

(e) The site of the activity will be re-established in woody vegetation within 24 months from the start of the vegetation clearance operation;

(f) Ground based methods of vegetation clearance are only undertaken during the period 1 October to 30 April inclusive, unless it is on sand country; and

(g) There are no more than minor adverse effects on soil conservation.

3. Any earthworks that are not in a Riparian Management Zone, are a permitted activity, provided that:

(a) The volume moved or disturbed is less than 5,000 m^3 in any 12 month period where the activity is not undertaken on erosion prone land;

(b) The volume moved or disturbed is less than 1,000 m^3 in any 12 month period and the surface area of the soil exposed is less than 1,000 square metres where the activity is undertaken on erosion prone land;

(c) There are no more than minor adverse effects on soil conservation beyond the property boundary; and

(d) The Environmental Standards in Section 32 are complied with.

4. Any land preparation that is not on erosion prone land, and that is not in a Riparian Management Zone, is a permitted activity, provided that

(a) The Environmental Standards in Section 32 are complied with; and

(b) There are no more than minor adverse effects on soil conservation.

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Note: On land having a slope of greater than 15 degrees particular care needs to be taken to ensure there are no more than minor adverse effects, and reference should be made to the Council for guidance.

Explanation (For Rules 33.01.01 – 33.01.04): *Land use activities on non-erosion prone land should, as a general rule, be able to be undertaken with minimal adverse effects. There are however, certain combinations of geology, soils and slope which are more susceptible to erosion as a result of land disturbance activities, so environmental standards are required to be complied with in order to avoid or minimise potential adverse effects.*

33.2 CONTROLLED ACTIVITIES

The following land disturbance activities are controlled activities:

1. Any earthworks which are not located in the Riparian Management Zone; and

(1) Are not located on erosion prone land and the volume moved or disturbed is greater than 5,000 m^3 in any 12 month period; or

(2) The earthworks are associated with the harvest of plantation forestry on erosion prone land with a slope of less than 26 degrees or where the soils are sand soils; and the volume moved or disturbed is greater than 1,000 m^3 in any 12 month period and/or the surface area of the soil is exposed is greater than 1,000 m^2; are a controlled activity, provided that:

(a) The Environmental Standards in Section 32 are complied with; and

(b) There are no more than minor adverse effects on soil conservation beyond the property boundary.

Matters Subject to Control

The matters over which the Council will exercise control are:

(1) The adequacy of sediment and runoff control measures.

(2) The location and extent of any earthworks.

(3) The adequacy of site rehabilitation and re-vegetation measures to control sediment discharge and adverse effects on soil conservation.

(4) Information and monitoring requirements.

An application for a controlled activity under Rule 33.02.01 need not be notified in accordance with ss.94.1(c) of the Act if the written approvals of those who the Council considers to be adversely affected by the activity have been obtained unless:

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1. The Council considers it unreasonable in the circumstances to require every such approval to be obtained; or

2. The Council considers in accordance with Section 94(5) that special circumstances exist to require notification. In making a decision about whether for the purposes of s.94 of the Act any person is adversely affected by the granting of a resource consent, the Council may take into account effects on the following:

(a) Any landowner/occupier whose property may be adversely affected through any earth movement associated with the activity (refer also to Rule 22.02.01);

(b) The Department of Conservation where there is a known historical feature or area of significant indigenous vegetation or significant habitats of indigenous fauna as defined in Appendix 13B, at or near the site of the activity; and/or

(c) The local Iwi where there is a known site of spiritual or cultural significance.

33.3 DISCRETIONARY ACTIVITIES

The following land disturbance activities are discretionary activities:

1. Any earthworks, that are not located in the Riparian Management Zone that are not permitted, controlled or non-complying activities are discretionary activities.

2. Any vegetation clearance, that is not located in the Riparian Management Zone and is not a permitted, or non-complying activity is a discretionary activity.

3. Any land preparation, that is not located in the Riparian Management Zone which;

(a) is undertaken on erosion prone land; or

(b) does not comply with Rule 33.01.04,

is a discretionary activity.

33.4 NON-COMPLYING ACTIVITIES

The following land disturbance activity is a non-complying activity:

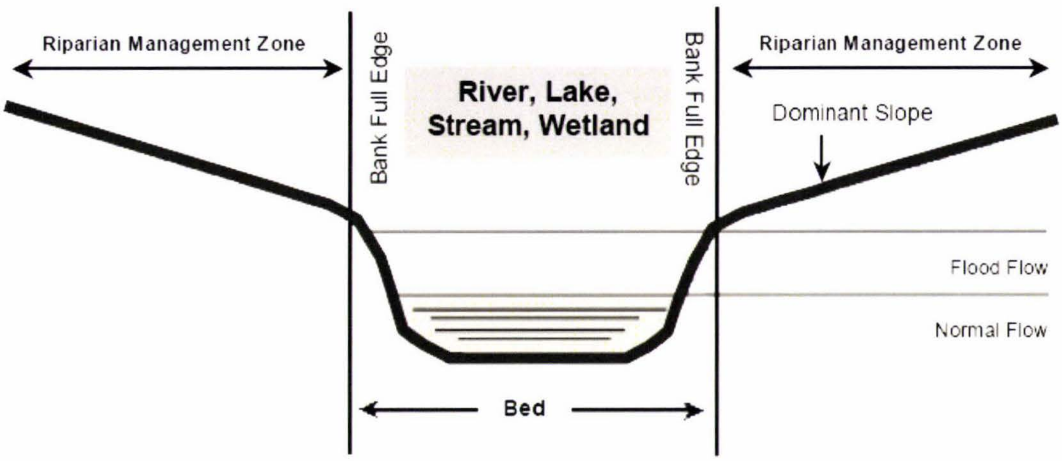
1. Any activity which takes place within a significant indigenous wetland identified in accordance with Appendix 13B is a non-complying activity.

33.5 PROHIBITED ACTIVITIES

There are no prohibited activities for land disturbance activities.

Appendix 2 Riparian Management Zone Definition

Taken from the Regional Soil and Water Plan for Northland.



Note: If the top of the bank cannot be identified it should be taken from the beginning of the vegetated area.

FIGURE 7A: RIPARIAN MANGEMENT ZONE

The Riparian Management Zone is the land between the bed of the river, lake, or indigenous wetland or the Coastal Marine Area and a distance measured inland from the bank full edge of the water body or from the top of the bank adjacent to the Coastal Marine Area of:

- 5 metres where the dominant slope is less than 8 degrees
- 10 metres where the dominant slope is between 8 – 15 degrees
- 20 metres where the dominant slope is greater than 15 degrees

Where the dominant slope is 0 degrees or less there shall be no Riparian Management Zone.

Appendix 3 SHMAK Monitoring Forms

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Stream monitoring forms

Date of survey: ....

Your name: ....

Farm name/address:...

Stream/site name: ....

Weather conditions: ....

Did you take a photograph from the photo reference point? YES / NO

A. Recent flow conditions

Which category most closely describes the flow in this stream over the past six weeks?

	Stable flow	Brief flooding (for less than 2 days)	Several brief floods	Prolonged flooding (more than 5 days)	Prolonged low flows (no rain and unusually low water level)	enter category:
Category	5	4	3	2	1	

If your answer to this question is anything other than "Stable flow" then it would be preferable to postpone this monitoring until there has been a lead-in period of 4 to 6 weeks to allow stream conditions to stabilise. If you continue with your survey now, remember that the effects of flow conditions may be the most important influence on the apparent health of the stream.

(*Note:* the four-to-six-week period of stable flows may be quite impractical for some regions or for certain times of the year. You may *have* to monitor in high-flow conditions. However, your monitoring results may indicate that the stream is healthier than it would have been following a period of stable flow. In low flow conditions, the result may be a less healthy stream. **The important thing is to take account of flow conditions when you interpret the results**. For more information refer to **Unit 4. Planning a stream monitoring programme** and **Unit 9. Explanations of categories and scores**.)

Optional: take stream width and depth measurements as described in **Unit 5. How to get started** (section 5.4, pages **5.3-5.4**).

	Stream width	Stream depth True left*	Centre	True right*	Average depth
at downstream site marker	______ m	______	______	______	______
at centre of site	______ m	______	______	______	______
at upstream site marker	______ m	______	______	______	______

*Note that the "True left" and "True right" banks are the left and right banks when you are looking downstream

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C. Habitat quality

Flow velocity

Measure the speed of the water flow by timing an object floating down the length of the site (or a part of the length) in the centre of the stream. Take the average of three measurements.

Distance travelled: ______ Time: 1 ______ 2 ______ 3 ______ Average time: ______

Average water velocity = Distance travelled/average time = ______ metres/sec

	Under 0.1 m/s	0.1 to 0.29	0.3 to 0.69	0.7 to 0.99	1.0 or more	enter score
score:	1	8	10	5	3	

Water pH

Use pH indicator strips to measure the pH of a sample of stream water from the main flow.

Measured pH: ______

	5 or less	5.5 to 6	6.5 to 7.5	8 to 9	9.5 or more	enter score
score:	-5	5	10	5	-5	

Water temperature

Measure water temperature in the main flow, in an undisturbed area.

Measured temperature: ______ °C Time of day: ______

	Under 5 °C	5 to 9.9	10 to 14.9	15 to 19.9	20 to 24.9	25 to 29.9	30 or more	enter score
score:	5	8	10	8	5	1	-5	

Water conductivity

Measure the conductivity of a water sample, from the main flow, using the meter provided.

Measured conductivity: ______ µSiemens/cm

	Under 50	50 to 149	150 to 249	250 to 399	400 or more	enter score
score:	20	16	10	6	1	

Water clarity

Measure the clarity of a water sample using the clarity tube (average of three readings).

Measured clarity: 1 ______ 2 ______ 3 ______ cm (from viewing end to disc surface) Average cm: ______

	Clear to bottom (=100)	70 to 99	55 to 69	35 to 54	under 35 cm	enter score
score:	10	8	5	3	1	

C. Habitat quality *(continued)*

Composition of the stream bed

Estimate by eye the percentages (to the nearest 10%) of cover of different types of material making up the stream bottom (see scale on ruler). (See page 6.15 for a more precise method.)

	Bed-rock	Boul-ders (> 25cm)	Large cobbles (12-25cm)	Small cobbles (6-12cm)	Gravels (0.2-6 cm)	Sand	Mud or silt	Man-made (eg, con-crete)	Woody debris	Water plants (rooted in the stream bed)	Total:
score:	-10	10	20	10	0	-10	-20	-20	0	0	
enter %											100
score x %											

enter total of (score x %)

overall score = total (score x %) / 100
(maximum score = 20)

enter score

Deposits

Note whether any loose deposited material is on the stream bed.

	None noticed	Fine (less than 1 mm thick), mainly in edge areas	Moderate (up to 3 mm), edge areas and elsewhere	Moderate to thick (3 mm or more) patchy, most of bed	Thick (over about 5 mm) on most horizon-tal surfaces
score:	10	5	0	-5	-10

enter score

Bank vegetation

For each bank along the 10 metre length of the site estimate the percentage (to the nearest 10%) covered by the listed vegetation types in a strip 5 metres wide parallel to the water's edge.

Note: the true left and true right are the left and right sides looking downstream.

	Native trees	Wet-land vegeta-tion	Tall tussock grass-land, not improved	Intro-duced trees (willow, poplar...)	Other intro-duced trees (conifers)	Scrub	Rock, gravels	Short tussock grass-land, improved	Pasture grasses and weeds	Bare ground, roads, build-ings	Total:
score:	10	10	8	8	5	5	5	3	-10	-10	
%, true left											100
%, true right											100
total % (L + R)											200
total % x score											

enter total of all (score x %)

overall score = total (score x %) / 100
(i.e., average L and R bank scores added)
(maximum possible score = 20)

enter score

Now add the scores for all questions and transfer to the *Monitoring record*. Also note any scores which are at the very low end of their range.

Total score:

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N.B. Complete *either* D1 *or* D2

D2 Stream-bed life: Level 2

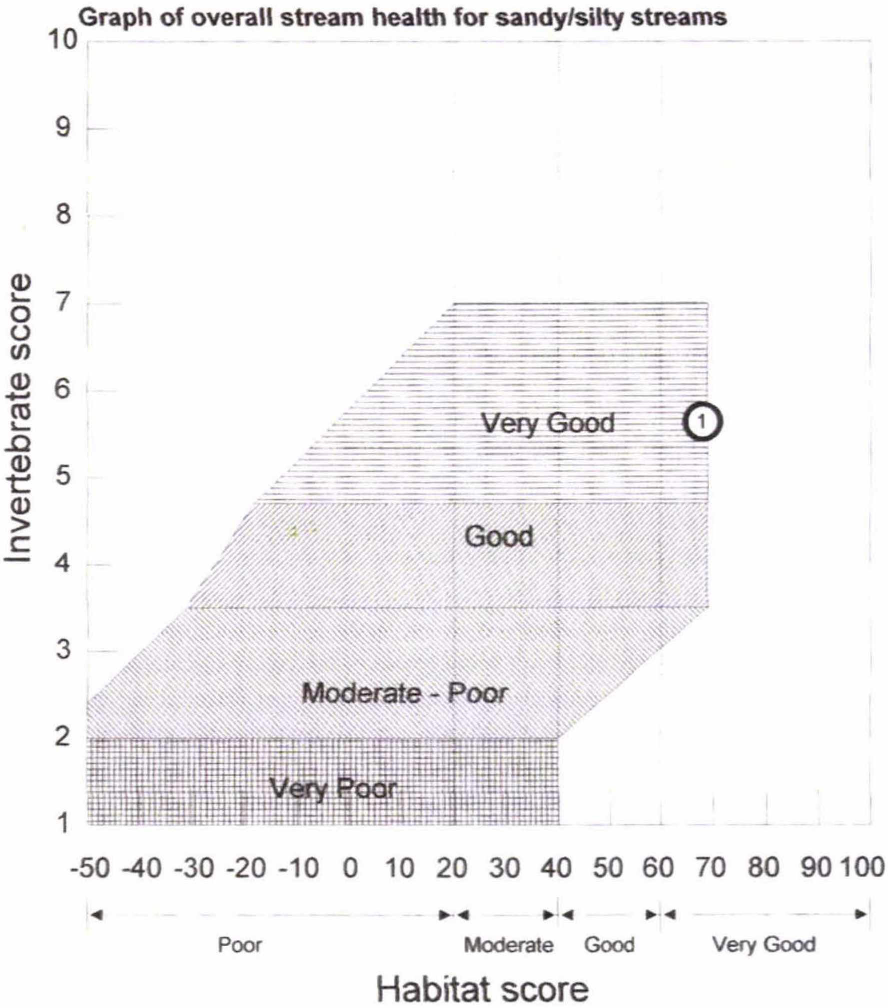
For each of 10 stones, sediment or water plant samples, record the number of "indicator" invertebrates for each category and then the estimated % coverage of the exposed part of the stone by each type of periphyton. (See over for calculating biological scores for this site.)

Invertebrates		Sample number:									
	Invert score	Transect 1 (if applicable)					Transect 2 (if applicable)				
		1	2	3	4	5	6	7	8	9	10
Enter type of sample (stone, gravel, silt, plant, etc.):											
Worms (e.g. thin brown/red)	1										
Flatworms, leeches	3										
Freshwater crustaceans (amphipods, water fleas)	5										
Small bivalves (up to 4 mm across)	3										
Snails (4–6 mm across, rounded)	3										
Snails (1–3 mm across, pointed end)	4										
Limpet-like molluscs (*Latia*, up to 8 mm wide)	7										
"Axehead" caddis (*Oxyethira*, 2–3 mm long)	3										
Midge larvae (3–7 mm long, white - red)	2										
Damselfly larvae	4										
Cranefly larvae	5										
Beetle larvae and adults	6										
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	6										
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	9										
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	10										
Mayfly larvae (2–15 mm long)	9										
Stonefly larvae (large species, up to 20 mm)	10										

Periphyton (on exposed surfaces)			Stone number:									
		Peri. score	Transect 1 (if applicable)					Transect 2 (if applicable)				
			1	2	3	4	5	6	7	8	9	10
Thin mat/film:	green	7										
(under 0.5 mm thick)	light brown	10										
	black/dark brown	10										
Medium mat:	green	5										
(0.5-3 mm thick)	light brown	7										
	black/dark brown	9										
Thick mat:	green/ light brown	4										
(over 3 mm thick)	black/dark brown	7										
Filaments, short	green	5										
(under 2 cm long)	brown/reddish	5										
Filaments, long	green	1										
(over 2 cm long)	brown/reddish	4										

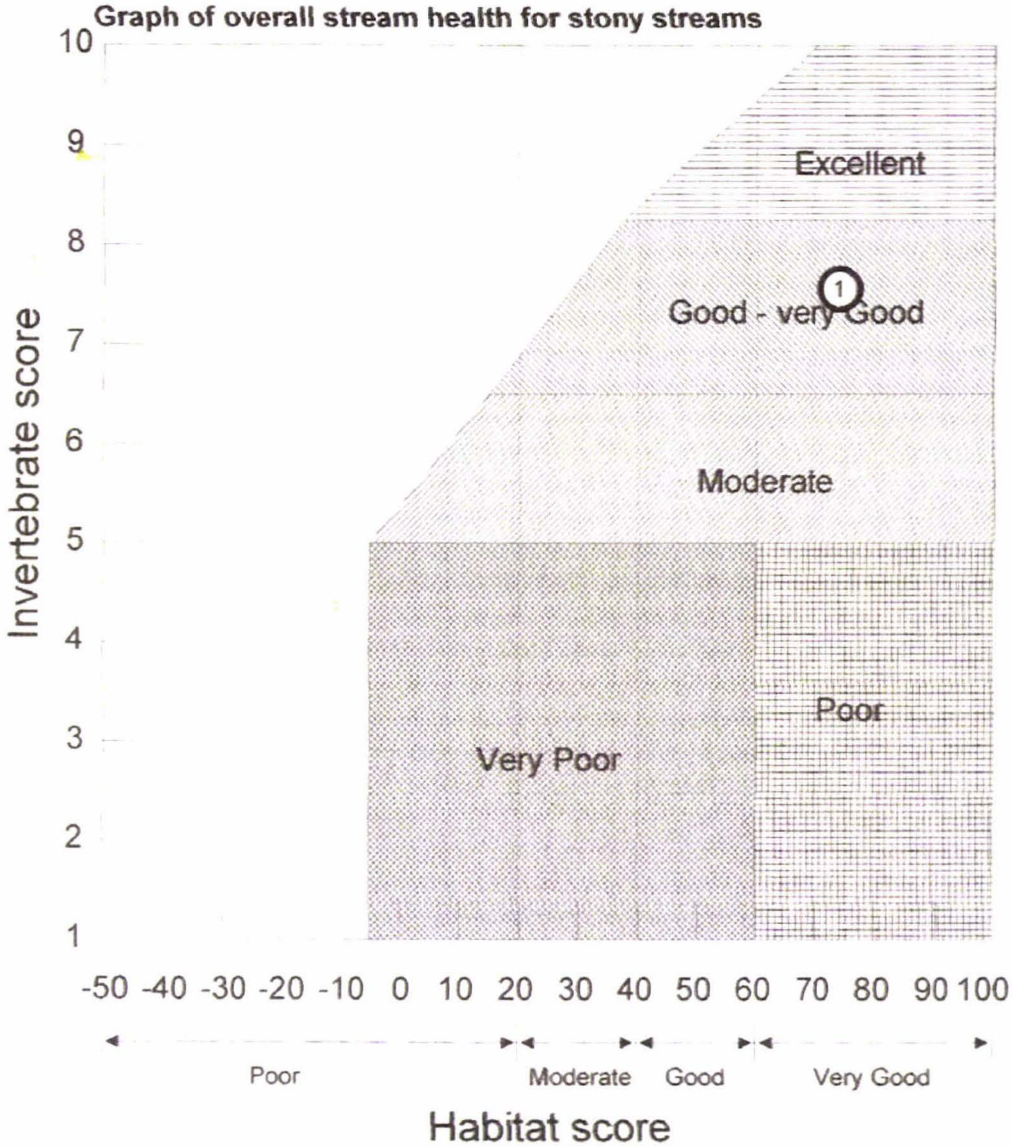
Appendix 4 SHMAK Stream Health Graphs

The following pages present the SHMAK graphs of the data showing the stream health ratings.



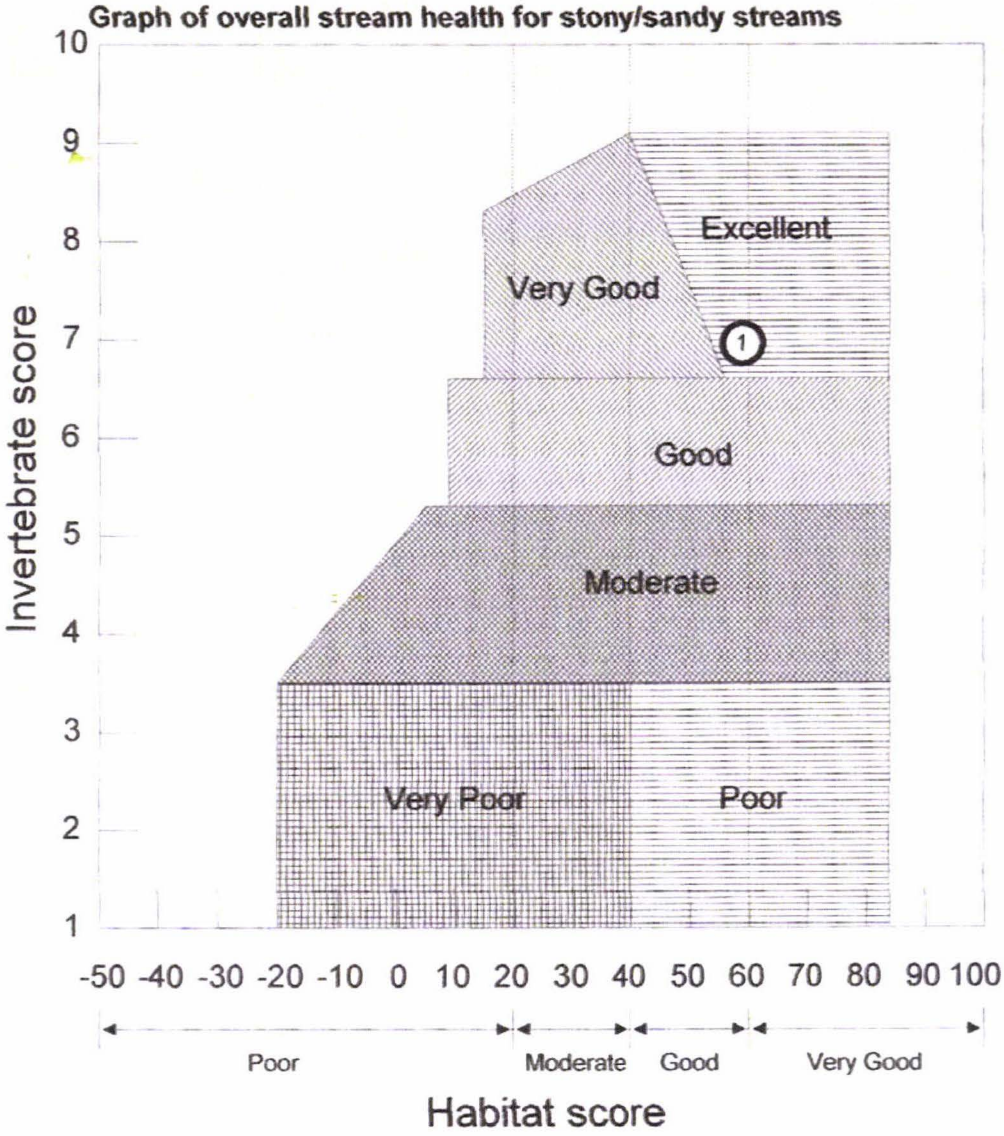
No.		File	Habitat	Invertebrate	Periphyton
1		RBZ 1	68	5.63	0.00
Score	Rating	Typical periphyton community	Typical conditions associated with this type of periphyton		
No score	No overall rating	No algae: clean stones. No hint of sliminess on stones.	There are several explanations for a lack of visible periphyton in streams • The stream bed is unsuitable. Periphyton does best on stable stony substrates. It's rarely seen on mobile sand and silt beds. • The water velocity is consistently too fast to allow periphton to colonise. • A recent flood scoured off most of the periphyton growth. • There is not enough light.		

Figure 5.21 SHMAK Stream Rating Results for RBZ Sample Site One



No.		File	Habitat	Invertebrate	Periphyton
	1	RBZ 2	74.	7.55	6.
Score	Rating	Typical periphyton community	Typical conditions associated with this type of periphyton		
6 to 7.9	Good	Thin but more noticeable 'mat' of of mostly brownish or black algae, easily scraped off rocks with a thumbnail, or a green film.	Clean streams with steady water flow but with slightly higher nutrient concentrations - possibly as a result of diffuse run-off. A wide range of invertebrates, often including many that need high quality water to survive, such as mayflies and stoneflies.		

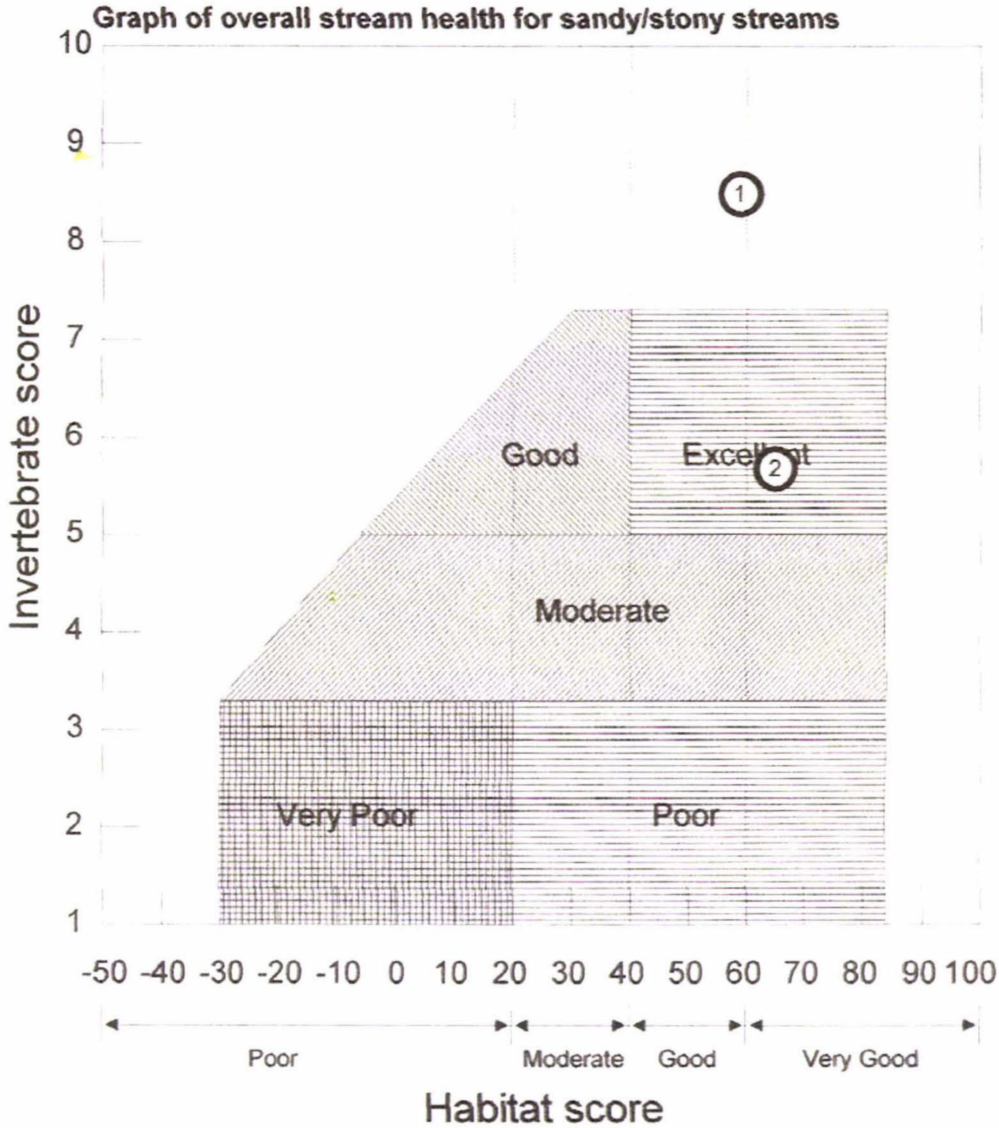
Figure 5.22 SHMAK Stream Rating Results for RBZ Sample Site Two



No.	File	Habitat	Invertebrate	Periphyton
1	RBZ 3	59.	6.95	6.78

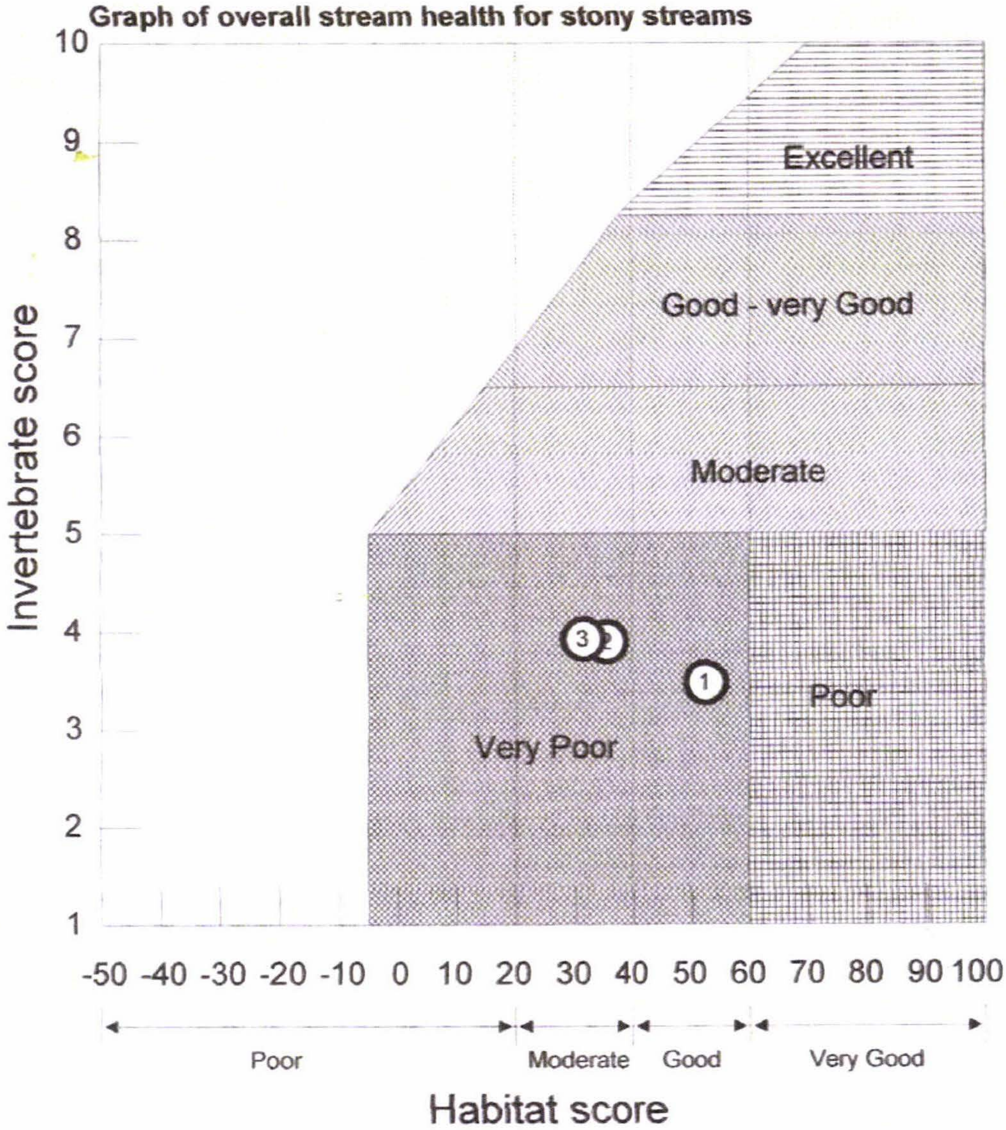
Score	Rating	Typical periphyton community	Typical conditions associated with this type of periphyton
6 to 7.9	Good	Thin but more noticeable 'mat' of of mostly brownish or black algae, easily scraped off rocks with a thumbnail, or a green film.	Clean streams with steady water flow but with slightly higher nutrient concentrations - possibly as a result of diffuse run-off. A wide range of invertebrates, often including many that need high quality water to survive, such as mayflies and stoneflies.

Figure 5.23 SHMAK Stream Rating Results for RBZ Sample Site Three



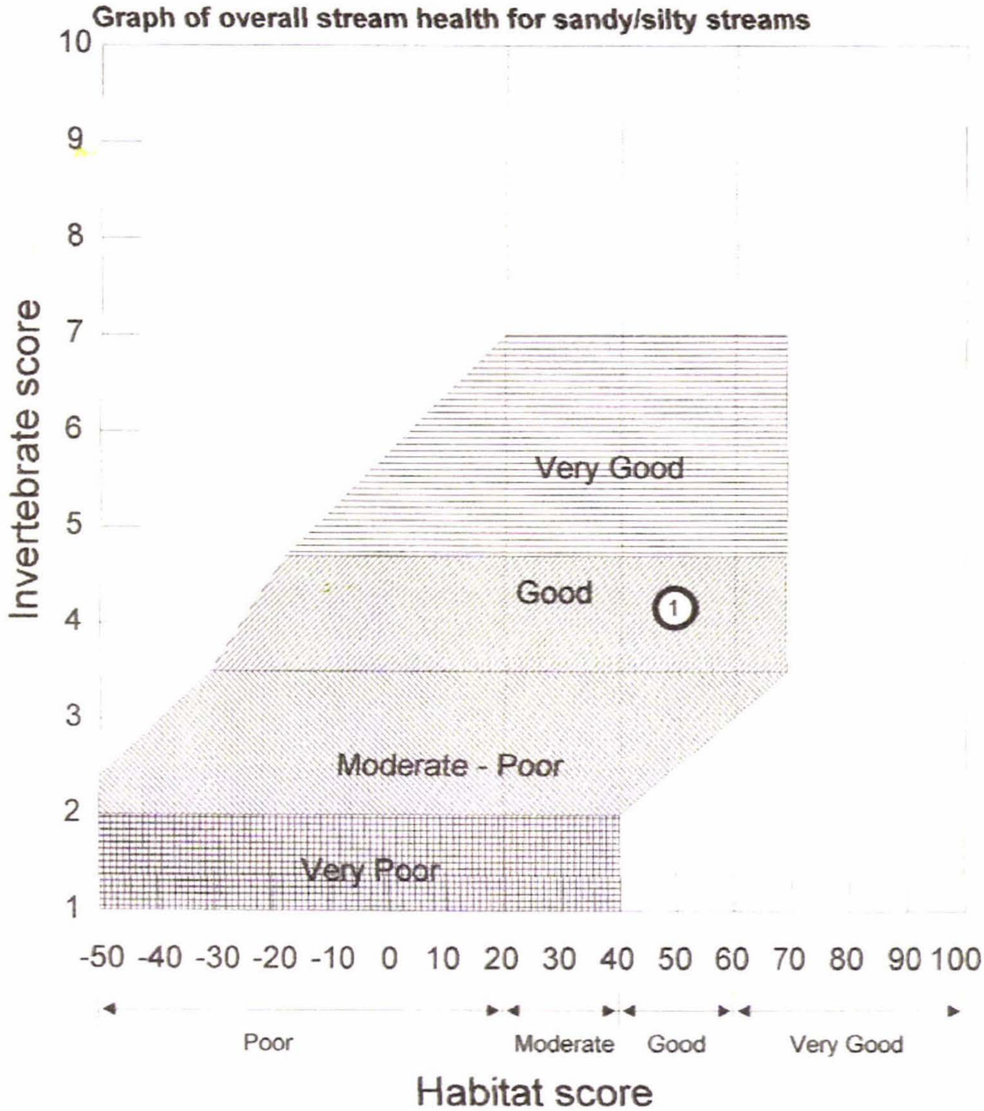
No.	File	Habitat	Invertebrate	Periphyton
1	RBZ 4	59.	8.48	0.00
2	RBZ 5	65.	5.67	0.00

Figure 5.24 SHMAK Stream Rating Results for RBZ Sample Sites Four and Five



No.	File	Habitat	Invertebrate	Periphyton
1	clear cut 1	52.5	3.47	5.
2	clear cut 4	35.5	3.89	5.
3	clear cut 5	31.5	3.92	6.

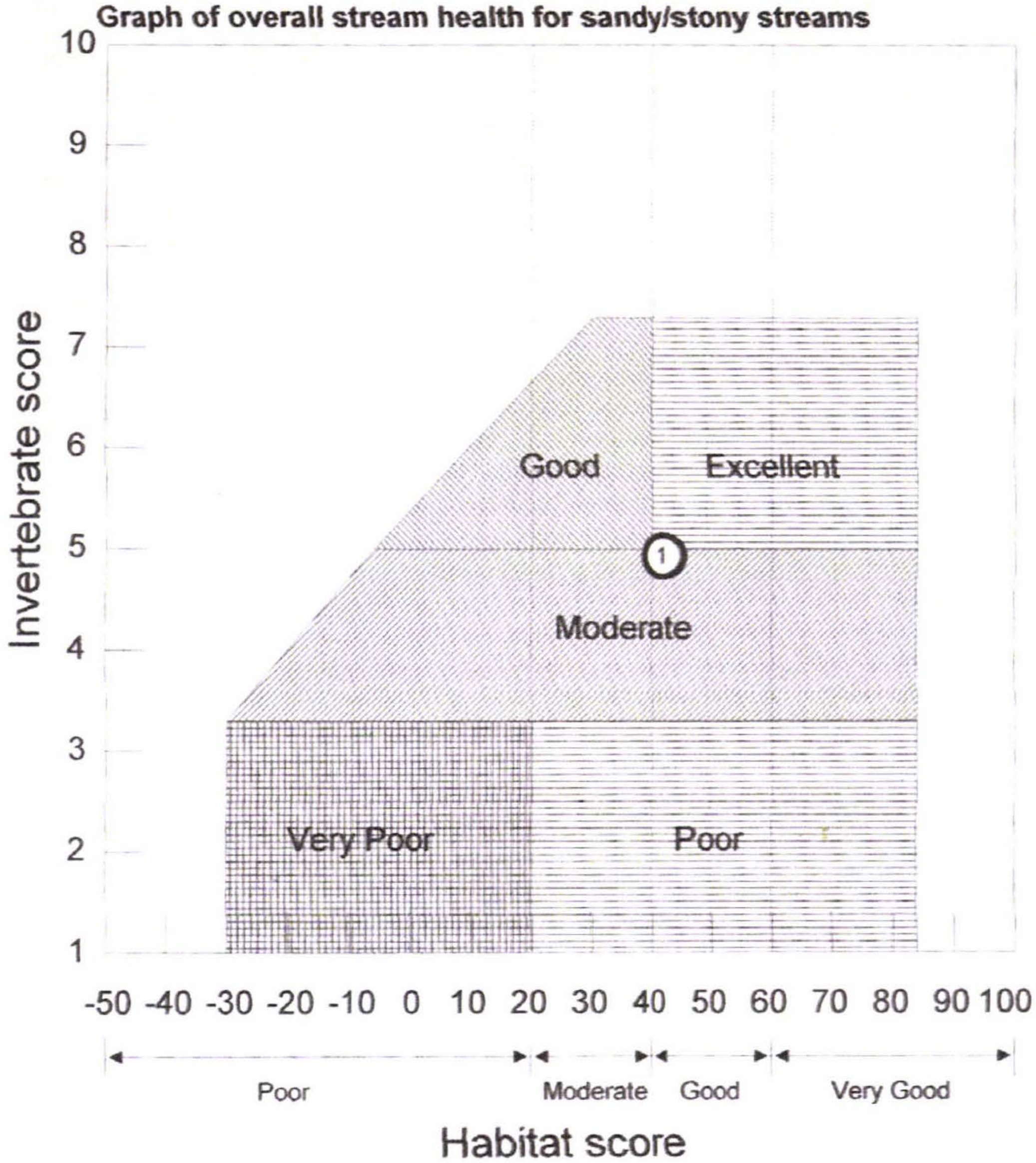
Figure 5.25 SHMAK Stream Rating Results for Clearcut Sample Sites One, Four and Five



No.	File	Habitat	Invertebrate	Periphyton
1	clear cut 2	49.5	4.16	0.00

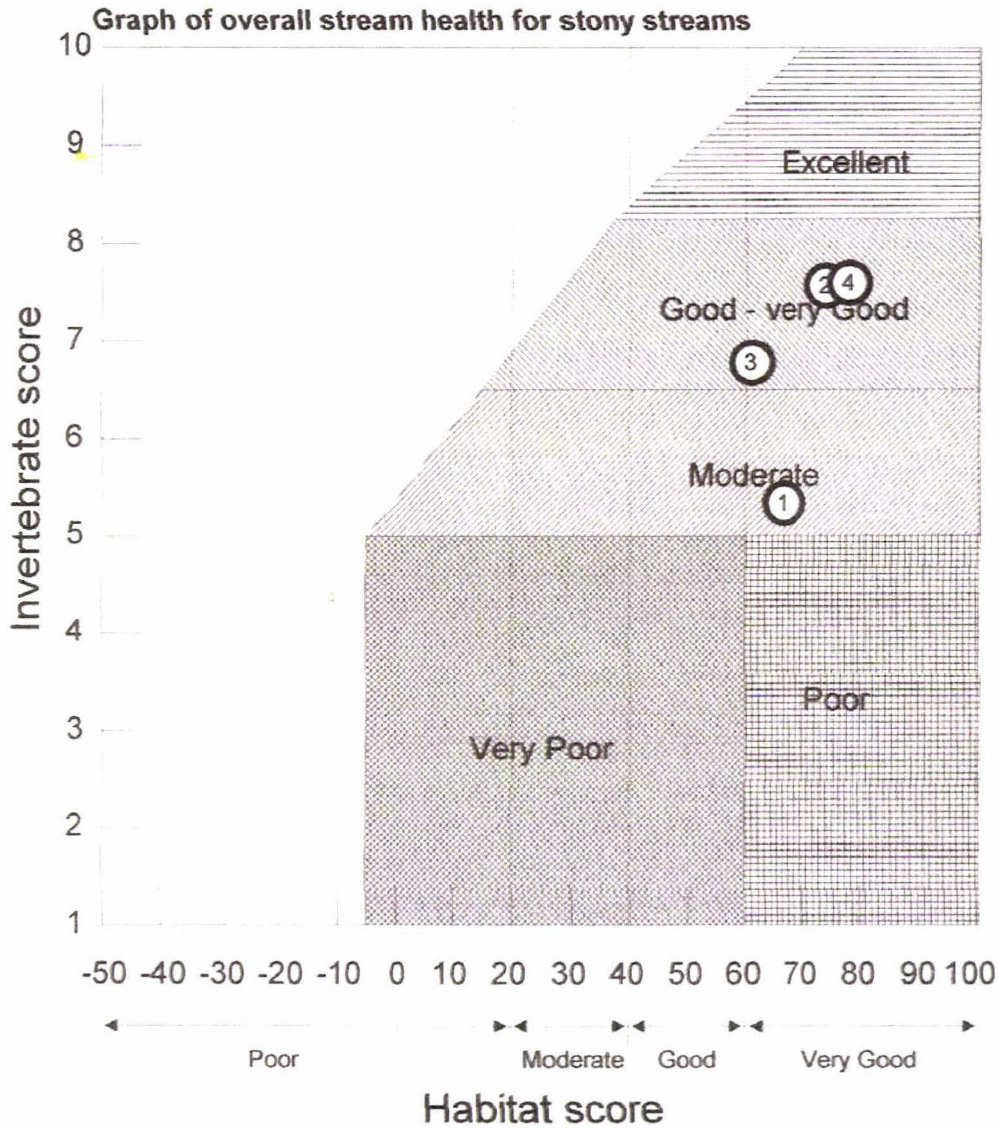
Score	Rating	Typical periphyton community	Typical conditions associated with this type of periphyton
No score	No overall rating	No algae: clean stones. No hint of sliminess on stones.	There are several explanations for a lack of visible periphyton in streams. • The stream bed is unsuitable. Periphyton does best on stable stony substrates. It's rarely seen on mobile sand and silt beds. • The water velocity is consistently too fast to allow periphton to colonise. • A recent flood scoured off most of the periphyton growth. • There is not enough light.

Figure 5.26 SHMAK Stream Rating Results for Clearcut Sample Site Two



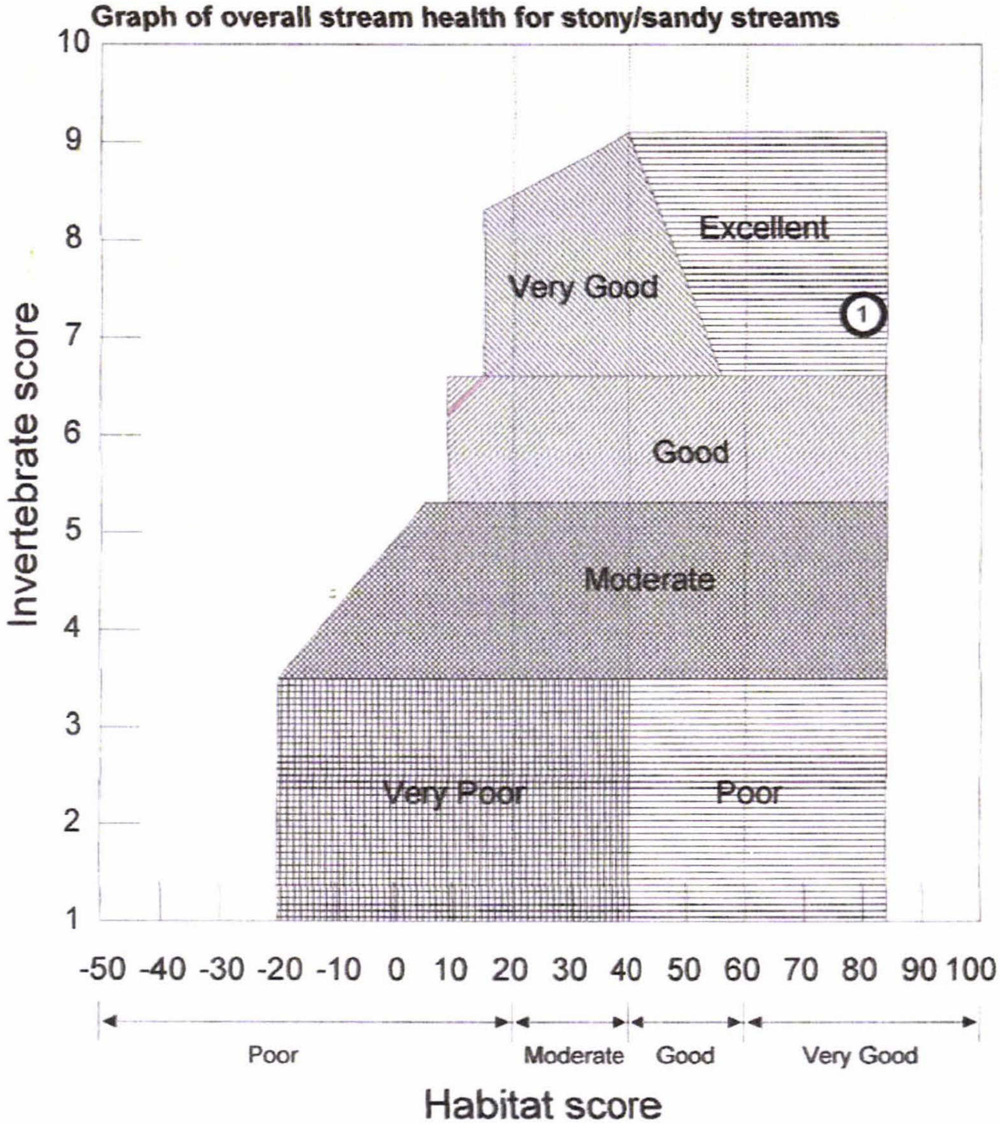
No.		File	Habitat	Invertebrate	Periphyton
	1	clear cut 3	42.	4.93	0.00
Score	Rating	Typical periphyton community	Typical conditions associated with this type of periphyton		
No score	No overall rating	No algae: clean stones. No hint of sliminess on stones.	There are several explanations for a lack of visible periphyton in streams. * The stream bed is unsuitable. Periphyton does best on stable stony substrates. It's rarely seen on mobile sand and silt beds. * The water velocity is consistently too fast to allow periphton to colonise. * A recent flood scoured off most of the periphyton growth. * There is not enough light		

Figure 5.27 SHMAK Stream Rating Results for Clearcut Sample Site Three



No.	File	Habitat	Invertebrate	Periphyton
1	Pine 1	66.5	5.33	9.17
2	Pine 2	74.	7.56	10.
3	Pine 3	61.	6.77	8.75
4	Pine 4	78.	7.59	5.

Figure 5.28 SHMAK Stream Rating Results for Pine Sample Sites One to Four



No.		File	Habitat	Invertebrate	Periphyton
1		Pine 5	80.	7.23	7.
Score	Rating	Typical periphyton community	Typical conditions associated with this type of periphyton		
6 to 7.9	Good	Thin but more noticeable 'mat' of of mostly brownish or black algae, easily scraped off rocks with a thumbnail, or a green film.	Clean streams with steady water flow but with slightly higher nutrient concentrations - possibly as a result of diffuse run-off. A wide range of invertebrates, often including many that need high quality water to survive, such as mayflies and stoneflies.		

Figure 5.29 SHMAK Stream Rating Results for Pine Sample Site Five

Appendix 5 SHMAK Stream Monitoring Data

Hard Rod Readings and Water Velocity

	1	2	3	4	5
RBZ	60/62 v = 0.14	28/30 v = 0.14	39/40 v = 0.099	25/26 v = 0.099	60/61 v = 0.099
	55/65 v = 0.313	23/25 v = 0.14	120/120 v =	43/48 v = 0.221	57/60 v = 0.171
	45/53 v = 0.28	38/48 v = 0.313	18/20 v = 0.14	90/90 v =	49/50 v = 0.099
Clearcut	50/55 v = 0.221	125/130 v = 0.221	38/43 v = 0.221	110/123 v = 0.357	65/80 v = 0.383
	165/167 v = 0.14	90/92 v = 0.14	40/65 v = 0.495	168/168 v =	109/113 v = 0.198
	23/35 v = 0.343	60/95 v = 0.586	84/85 v = 0.099	63/65 v =0.14	75/82 v = 0.262
Pine	48/49 v = 0.099	129/131 v = 0.14	30/35 v = 0.221	40/42 v = 0.14	10/20 v = 0.313
	140/140 v =	71/81 v = 0.313	110/110 v =	50/65 v = 0.383	40/41 v = 0.099
	20/23 v = 0.171	80/85 v = 0.221	10/15 v = 0.221	30/37 v = 0.262	80/80 v =

Average Water Velocity

	1	2	3	4	5
RBZ	0.244	0.151	0.080	0.107	0.123
Clearcut	0.235	0.316	0.272	0.166	0.281
Pine	0.090	0.225	0.147	0.262	0.137

Clarity Tube Readings (mm)

	1	2	3	4	5
RBZ	580/580	580/570	800/780	340/330	1000
	580/570	570/570	840/810	360/340	1000
	585/575	570/560	830/810	350/340	1000
Clearcut	800/770	750/730	430/410	800/785	840/825
	800/780	770/760	430/420	780/740	840/815
	780/760	760/750	435/410	780/740	850/830
Pine	700/760	840/830	530/510	640/630	750/750
	680/670	850/840	560/520	680/670	770/750
	680/660	850/840	550/520	680/670	770/75

Average Water Clarity (mm)

	1	2	3	4	5
RBZ	578	567	813	343	1000
Clearcut	782	753	423	771	832
Pine	678	842	532	662	757

Water pH

	1	2	3	4	5
RBZ	6.62	7.22	6.93	7.02	6.64
Clearcut	7.22	7.22	7.03	6.74	7.02
Pine	7.58	7.77	7.56	7.55	7.20

Water Conductivity (in µS/cm)

	1	2	3	4	5
RBZ	140	110	90	100	100
Clearcut	120	140	220	110	110
Pine	130	150	160	130	120

Stream Shade (%)

	1	2	3	4	5
RBZ	90	60	80	60	95
Clearcut	10	40	90	30	30
Pine	95	95	95	95	100

Streambed Sedimentation

	None	Fine (<1mm at edges)	Moderate (1-3mm at edges and elsewhere)	Moderate-Thick (3-5mm most of the bed)	Thick (5mm on most surfaces)
RBZ 1	x				
2		x			
3		x			
4		x			
5		x			
Clearcut 1			x		
2			x		
3			x		
4			x		
5			x		
Pine 1		x			
2	x				
3		x			
4		x			
5		x			

Streambed Composition (To the nearest 5%)

	Bed rock	Boulders >25cm	L. cob 12-25	S. cob 6-12	Gravel 0.2-6	Sand	Clay	Wood leaves	Plants In bed
RBZ1					5	80	15		
2				20	70	10			
3				10	30	30	20	10(L)	
4				10	20	70			
5					10	20	50	10(L)	
CC 1			5	15	70		10		
2							70		30
3					30	20	40	10(w)	
4	80			5	10			5 (w)	
5	80		5		10	5			
Pine 1			20	30	40		10		
2	40	10	20	20	10				
3				20	70			10	
4		30	20	30	10	10			
5			10	30	30	20			10 (r)

Bank Vegetation (%)

	Native Veg	Wetland Veg	Tall Tussock	Decid. trees	Conif-iers	Scrub	Rock gravel	Short grass	Bare ground
BZ 1	20	80							
2	30	60				10			
3	40	40					10		10
4	40	45				10			5
5	70	30							
CC 1	10	10				40			40*
2	5	10				85			
3			30			70			
4	5					20	10		65*
5	5	5				10			80*
Pine 1	60	35			5				
2	60	40							
3	40	40			20				
4	50	50							
5	50	50							

* These sites had slash on the ground.

Periphyton Growth (% cover of exposed surfaces) **and Colour** (g-green, lb-light brown, b-brown, bl-black)

	Thin film (<0.5mm)	Medium mat (0.5-3mm)	Thick mat (over 3mm)	Short filaments	Long filaments
RBZ 1					
2		45-lb, 45-g			
3	20-lb	40-g, 30lb			
4					
5					
Clear cut 1		5-g			
2					
3					
4		70-g			
5	25-g	25-g			
Pine 1	50-b	10-g			
2	80-b				
3	60-b	20-g			
4		80-g			
5		45-g, 45-b			

SHMAK Stream Classifications and Scores

	Stream Classification	Habitat Score /100	Invertebrate Score /10	Periphyton Score /10
RBZ 1	Sandy/silty	68	5.63	0
2	Stony	74	7.55	6
3	Stony/sandy	59	6.95	6.78
4	Sandy/stony	59	8.48	0
5	Sandy/stony	65	5.67	0
Clear cut 1	Stony	52.5	3.47	5
2	Sandy/silty	49.5	4.16	0
3	Sandy/stony	42	4.93	0
4	Stony	35.5	3.89	5
5	Stony	31.5	3.92	6
Pine 1	Stony	66.5	5.33	9.17
2	Stony	74	7.56	10
3	Stony	61	6.77	8.75
4	Stony	78	7.59	5
5	Stony/sandy	80	7.23	7

Average Invertebrate Numbers and Scores

The following tables contain the average invertebrate samples for each stream treatment. The MCI and the QMCI scores were not necessarily calculated from the scores shown for the SHMAK assessment. These were calculated using a more detailed list of invertebrates which separated invertebrates into species not just taxa. For example the SHMAK assigns a score of nine for all mayflies where as the list used for these assessment scores mayflies from seven to ten depending on the species.

RBZ

Average Number of Invertebrates per Sample per RBZ Site

Invertebrates	**Average Number per Sample per Site**				
	1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	0.6		0.2		0.4
Flatworms, leeches		2.8	1		
Freshwater crustaceans (amphipods, water fleas)	6.4	2	15.4		25.6
Small bivalves (up to 4 mm across)					
Snails (4.6 mm across, rounded)					
Snails (1.3 mm across, pointed end)		0.2			
Limpet-like molluscs (*Latia*, up to 8 mm wide)		0.2			
Axehead. caddis (*Oxyethira*, 2.3 mm long)					
Midge larvae (3.7 mm long, white - red)			0.4		
Damselfly larvae					
Cranefly larvae				0.2	
Beetle larvae and adults		0.4		0.2	
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	1.2	2.8	2.2		0.2
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)					
Mayfly larvae (2.15 mm long)	2.6	11	12.4	1.2	2.2
Stonefly larvae (large species, up to 20 mm)		0.2	0.8	0.2	
Number of Invertebrates	11.8	15.4	29.6	1.4	28.4
Number of species	3	3.2	4.6	0.8	2.2
MCI	105.6	85.5	116.3	92	119
QMCI	5.4	4.5	6.6	4.7	5.4

Clearcut

Average Number of Invertebrates per Sample per Clearcut Site

Invertebrates	**Average Number per Sample per Site**				
	1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	0.2		0.2		3.8
Flatworms, leeches	2.2		0.6	0.4	
Freshwater crustaceans (amphipods, water fleas)		8			
Small bivalves (up to 4 mm across)					
Snails (4.6 mm across, rounded)					
Snails (1.3 mm across, pointed end)		104.2	9.6	19	
Limpet-like molluscs (*Latia*, up to 8 mm wide)					0.8
Axehead. caddis (*Oxyethira*, 2.3 mm long)			0.8	20	0.6
Midge larvae (3.7 mm long, white - red)	60	0.8			0.6
Damselfly larvae					
Cranefly larvae					
Beetle larvae and adults	2.2			2.4	
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	11.2	0.6	3.4	2.2	1.4
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)					
Mayfly larvae (2.15 mm long)	3.2	0.8	1.4	3.6	1.6
Stonefly larvae (large species, up to 20 mm)					
Number of Invertebrate	79.2	114.8	16	47.4	8.8
Number of Species	4.2	1.8	2.8	3.4	1.8
MCI	104.3	85	96.9	83.2	60
QMCI	3.5	3.9	4.7	3.1	3.1

Pine

Average Number of Invertebrates per Sample per Pine Site

Invertebrates	Average Number per Sample per Site				
	1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)					
Flatworms, leeches	0.2			1.2	0.8
Freshwater crustaceans (amphipods, water fleas)	0.8		3		2.2
Small bivalves (up to 4 mm across)					
Snails (4.6 mm across, rounded)					
Snails (1.3 mm across, pointed end)		2.8			
Limpet-like molluscs (*Latia*, up to 8 mm wide)		4.2		8.4	
Axehead. caddis (*Oxyethira*, 2.3 mm long)					
Midge larvae (3.7 mm long, white - red)		0.2			
Damselfly larvae					
Cranefly larvae					
Beetle larvae and adults		0.2	0.4	0.8	
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)		1.4	0.2	1	2.2
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)		0.4			
Spiral caddis (*Helicopsyche*, up to 3 mm wide)					
Mayfly larvae (2.15 mm long)		12.8	2	9.8	7.2
Stonefly larvae (large species, up to 20 mm)					
Number of Invertebrate	1.	22.8	5.8	21.2	12.6
Number of Species	0.8	4.2	2.0	4.4	3.0
MCI	56	107.1	108	102.0	100.6
QMCI	2.8	6.4	5.2	5.4	5.6

The following tables contain the individual invertebrate sample data for each sample site.

RBZ Site One Invertebrate Sample Results

Invertebrates	**Score**	**Sample Number**				
		1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**	**1**				**2**
Freshwater crustaceans (amphipods, water fleas)	**5**	**14**	**1**	**6**	**9**	**4**
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**				**2**	**4**
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	**1**			**6**	**6**
Stonefly larvae (large species, up to 20 mm)	**10**					
Total Number of Invertebrates		**16**	**1**	**6**	**17**	**16**
Total Number of Species		**3**	**1**	**1**	**3**	**5**
MCI		**85**	**100**	**100**	**133.3**	**110**
QMCI		**4.8**	**5**	**5**	**6.3**	**5.8**

RBZ Site Two Invertebrate Sample Results

Invertebrates	**Score**	**Sample Number**				
		1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**	**11**	**1**			**2**
Freshwater crustaceans (amphipods, water fleas)	**5**	**3**		**1**		**1**
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					**1**
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**		**1**			
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**		**2**			
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**	**12**		**1**		**1**
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	**37**	**6**	**2**	**3**	**7**
Stonefly larvae (large species, up to 20 mm)	**10**					
Species outside of SHMAK						
Dobsonfly Larvae	**7**	**3**	**1**			
Total Number of Invertebrates		**66**	**11**	**4**	**3**	**12**
Total Number of Species		**8**	**5**	**3**	**1**	**5**
MCI		**122.5**	**90**	**120**	**160**	**95**
QMCI		**7.0**	**5.0**	**6.0**	**8**	**4.4**

RBZ Site Three Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	1			1		
Flatworms, leeches	3		1		3	1
Freshwater crustaceans (amphipods, water fleas)	5	1		2	74	
Small bivalves (up to 4 mm across)	3					
Snails (4.6 mm across, rounded)	3					
Snails (1.3 mm across, pointed end)	4					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	7					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	3					
Midge larvae (3.7 mm long, white - red)	2	2				
Damselfly larvae	4					
Cranefly larvae	5					
Beetle larvae and adults	6					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	6	2	1		3	5
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	9					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	10					
Mayfly larvae (2.15 mm long)	9	6	2	9	42	3
Stonefly larvae (large species, up to 20 mm)	10	1			3	
Species outside of SHMAK						
Dobsonfly larvae	7		1			
Total Number of Invertebrates		12	5	12	125	9
Total Number of Species		6	3	3	7	5
MCI		126.7	120	93.3	126.7	135
QMCI		6.7	6.4	6.9	5.9	7.1

RBZ Site Four Invertebrate Sample Results

Invertebrates	**Score**	**Sample Number**				
		1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**					
Freshwater crustaceans (amphipods, water fleas)	**5**					
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**		1			
Beetle larvae and adults	**6**	1				
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**					
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	4			1	1
Stonefly larvae (large species, up to 20 mm)	**10**		1			
Total Number of Invertebrates		**5**	**2**	**0**	**1**	**1**
Total Number of Species		**2**	**2**	**0**	**1**	**1**
MCI		**140**	**150**	**0**	**160**	**160**
QMCI		**7.6**	**7.5**	**0**	**8**	**8**

RBZ Site Five Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	1					2
Flatworms, leeches	3					
Freshwater crustaceans (amphipods, water fleas)	5	84	24	7	8	5
Small bivalves (up to 4 mm across)	3					
Snails (4.6 mm across, rounded)	3					
Snails (1.3 mm across, pointed end)	4					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	7					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	3					
Midge larvae (3.7 mm long, white - red)	2					
Damselfly larvae	4					
Cranefly larvae	5					
Beetle larvae and adults	6					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	6				1	
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	9					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	10					
Mayfly larvae (2.15 mm long)	9	1		2	3	5
Stonefly larvae (large species, up to 20 mm)	10					
Total Number of Invertebrates		**85**	**24**	**9**	**12**	**12**
Total Number of Species		**2**	**1**	**2**	**3**	**3**
MCI		**130**	**100**	**130**	**130**	**105**
QMCI		**5.0**	**5.0**	**5.7**	**5.8**	**5.7**

Clearcut Site One Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	**1**			1		
Flatworms, leeches	**3**	7	1		3	
Freshwater crustaceans (amphipods, water fleas)	**5**					
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**		147	89	42	22
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**	36	2		16	2
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	2	1	4	6	3
Stonefly larvae (large species, up to 20 mm)	**10**					
Species outside of SHMAK						
Dobsonfly larvae	**7**			1		
Total Number of Invertebrates		**45**	**151**	**95**	**74**	**31**
Total Number of Species		**4**	**5**	**3**	**7**	**5**
MCI		**66.7**	**133.3**	**90**	**116.7**	**115**
QMCI		**5.5**	**2.1**	**2.3**	**4**	**3.4**

Clearcut Site Two Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	1					
Flatworms, leeches	3					
Freshwater crustaceans (amphipods, water fleas)	5					40
Small bivalves (up to 4 mm across)	3					
Snails (4.6 mm across, rounded)	3					
Snails (1.3 mm across, pointed end)	4			76	410	35
Limpet-like molluscs (*Latia*, up to 8 mm wide)	7					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	3					
Midge larvae (3.7 mm long, white - red)	2	4				
Damselfly larvae	4					
Cranefly larvae	5					
Beetle larvae and adults	6					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	6		1	1		1
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	9					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	10					
Mayfly larvae (2.15 mm long)	9					4
Stonefly larvae (large species, up to 20 mm)	10					
Total Number of Invertebrates		**4**	**1**	**77**	**410**	**80**
Total Number of Species		**1**	**1**	**2**	**1**	**4**
MCI		**40**	**140**	**100**	**70**	**115**
QMCI		**2**	**7.0**	**4.0**	**4.0**	**4.7**

Clearcut Site Three Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	**1**	1				
Flatworms, leeches	**3**			1		2
Freshwater crustaceans (amphipods, water fleas)	**5**					
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**	13	10	24	1	
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**	4				
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**	11	4		2	
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	1	1	5		
Stonefly larvae (large species, up to 20 mm)	**10**					
Total Number of Invertebrates		**30**	**15**	**30**	**3**	**2**
Total Number of Species		**7**	**4**	**3**	**3**	**1**
MCI		**88**	**126.7**	**100**	**110**	**60**
QMCI		**4.9**	**5.1**	**4.6**	**6.0**	**3.0**

Clearcut Site Four Invertebrate Sample Results

Invertebrates	**Score**	**Sample Number**				
		1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**	1	1			
Freshwater crustaceans (amphipods, water fleas)	**5**					
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**	92	3			
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**	15	38	39	6	2
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**				1	
Beetle larvae and adults	**6**	12				
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**	9	1		1	
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	7	4	5	2	
Stonefly larvae (large species, up to 20 mm)	**10**					
Species outside of SHMAK						
Water boatman	**3**			1		
Total Number of Invertebrates		**136**	**47**	**45**	**10**	**2**
Total Number of Species		**8**	**5**	**3**	**4**	**1**
MCI		**100**	**96**	**100**	**106.7**	**40**
QMCI		**4.3**	**2.8**	**2.7**	**3.8**	**2**

Clearcut Site Five Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	**1**				18	1
Flatworms, leeches	**3**					
Freshwater crustaceans (amphipods, water fleas)	**5**					
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**		4			
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**		3			
Midge larvae (3.7 mm long, white - red)	**2**				1	2
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**	2	5			
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**		8			
Stonefly larvae (large species, up to 20 mm)	**10**					
Total Number of Invertebrates		**2**	**20**	**0**	**19**	**3**
Total Number of Species		**2**	**6**	**0**	**2**	**2**
MCI		**140**	**100**	**0**	**30**	**30**
QMCI		**7.0**	**5.9**	**0**	**1.1**	**1.7**

Pine Site One Invertebrate Sample Results

Invertebrates	**Score**	**Sample Number**				
		1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**	1				
Freshwater crustaceans (amphipods, water fleas)	**5**	1	1			2
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**					
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**					
Stonefly larvae (large species, up to 20 mm)	**10**					
Total Number of Invertebrates		**2**	**1**	**0**	**0**	**2**
Total Number of Species		**2**	**1**	**0**	**0**	**2**
MCI		**80**	**100**	**0**	**0**	**100**
QMCI		**4.0**	**5.0**	**0**	**0**	**5.0**

Pine Site Two Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	1					
Flatworms, leeches	3					
Freshwater crustaceans (amphipods, water fleas)	5					
Small bivalves (up to 4 mm across)	3					
Snails (4.6 mm across, rounded)	3					
Snails (1.3 mm across, pointed end)	4	2	4	1	3	4
Limpet-like molluscs (*Latia*, up to 8 mm wide)	7	1	5	4	5	6
Axehead. caddis (*Oxyethira*, 2.3 mm long)	3					
Midge larvae (3.7 mm long, white - red)	2		1			
Damselfly larvae	4					
Cranefly larvae	5					
Beetle larvae and adults	6	1				
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	6	3	1	1	1	1
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	9			2		
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	10					
Mayfly larvae (2.15 mm long)	9	4	21	20	6	13
Stonefly larvae (large species, up to 20 mm)	10					
Species outside of SHMAK						
Dobsonfly larvae	7	1				
Total Number of Invertebrates		**12**	**32**	**28**	**15**	**24**
Total Number of Species		**6**	**5**	**5**	**4**	**4**
MCI		**116.7**	**110**	**124**	**110**	**110**
QMCI		**6.4**	**6.8**	**7.2**	**5.5**	**6.0**

Pine Site Three Invertebrate Sample Results

Invertebrates	**Score**	**Sample Number**				
		1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**					
Freshwater crustaceans (amphipods, water fleas)	**5**	4	8			3
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**		2			
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**		1			
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	4	3	3		
Stonefly larvae (large species, up to 20 mm)	**10**					
Total Number of Invertebrates		**8**	**14**	**3**	**0**	**3**
Total Number of Species		**2**	**5**	**1**	**0**	**1**
MCI		**130**	**140**	**170**	**0**	**100**
QMCI		**6.5**	**6.0**	**8.3**	**0**	**5.0**

Pine Site Four Invertebrate Sample Results

Invertebrates	Score	Sample Number				
		1	2	3	4	5
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**	1	1	1	2	1
Freshwater crustaceans (amphipods, water fleas)	**5**					
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**	11	8	12	7	5
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**		1			3
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**		2		3	
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	5	21	11	9	3
Stonefly larvae (large species, up to 20 mm)	**10**					
Total Number of Invertebrates		**17**	**33**	**24**	**21**	**12**
Total Number of Species		**3**	**6**	**3**	**4**	**5**
MCI		**93.3**	**111.4**	**93.3**	**120**	**115**
QMCI		**4.5**	**6.6**	**5.3**	**5.8**	**4.9**

Pine Site Five Invertebrate Sample Results

Invertebrates	**Score**	**Sample Number**				
		1	**2**	**3**	**4**	**5**
Worms (e.g. thin brown/red)	**1**					
Flatworms, leeches	**3**	1			1	2
Freshwater crustaceans (amphipods, water fleas)	**5**	2			1	8
Small bivalves (up to 4 mm across)	**3**					
Snails (4.6 mm across, rounded)	**3**					
Snails (1.3 mm across, pointed end)	**4**					
Limpet-like molluscs (*Latia*, up to 8 mm wide)	**7**					
Axehead. caddis (*Oxyethira*, 2.3 mm long)	**3**					
Midge larvae (3.7 mm long, white - red)	**2**					
Damselfly larvae	**4**					
Cranefly larvae	**5**					
Beetle larvae and adults	**6**					
Caddisfly larvae (rough stony cases, or cases of sticks, etc. and free-living)	**6**	6			4	1
Smooth-cased caddisfly larvae (*Olinga*, up to 10 mm long, chestnut-brown colour)	**9**					
Spiral caddis (*Helicopsyche*, up to 3 mm wide)	**10**					
Mayfly larvae (2.15 mm long)	**9**	8		8		20
Stonefly larvae (large species, up to 20 mm)	**10**					
Total Number of Invertebrates		**17**	**0**	**8**	**6**	**31**
Total Number of Species		**5**	**0**	**2**	**4**	**6**
MCI		**128**	**0**	**160**	**100**	**115**
QMCI		**7.2**	**0**	**8.4**	**6.0**	**6.3**

Appendix 6 Sediment Generation Figures

To understand the impacts of plantation forestry sediment yields on waterways it is not only necessary to put them in the context of natural sediment yields but also yields of other land uses. The following data compares presents figures for other land disturbances that can be compared to the plantation figures above.

- Early stages of subdivision in the Auckland region – 30 to 160 t/km^2/year (Hicks 2000).
- Active subdivision – 970 to 2,370 t/km^2/year (Hicks 2000).
- Bare earthworks – 6,600 to 16,800 t/km^2/year (Hicks 2000).
- Cultivation of crop land – 1,100 to 5,300 t/km^2/year (Hicks 1998).
- Depleted pasture and tussock prior to and during pasture renewal – 80 to 1,000 t/km^2/year (Hicks 2000).

Hicks (1990) also presented the following figures for sediment yields from physically similar pasture and exotic forest basins at a Hydrological Society Symposium; unlogged plantation forests had sediment yields from 1.7 to 46.2 (mean 18.9) t/km^2/year and pasture had 4.3 to 94.6 (mean 47.7) t/km^2/year. These results are supported by Mosley *et al* (2004) who presents sediment yield figures for pasture sites that were over twice that of mature pine forest and Maclaren (1996) who quoted figures that showed pasture sites yielded up to 4.5 times more sediment. When the yields are compared for an entire plantation rotation including harvest and land preparation activities Mosley *et al* (2004) states that yields from plantation forests maybe less than from pasture, the above figures seem to support this though caution is needed as different site conditions can yield very different results and making such comparisons could yield erroneous results (Mosley *et al* (2004).

Appendix 7 Interview Guidelines

Environmental planner

Interview Objective: Determine how the waterways in the Pipiwai forest have been managed during plantation harvest.

- Does CHHF have environmental operating guidelines? If so, what are they?
- What specific steps are taken to protect waterways from degradation during plantation harvest?
- Are there specific operating standards for waterway crossings? If so, what are they?
- Can aerial applications of herbicides be applied over waterways?

Harvest Manager

Interview Objective: Determine how the harvest of the Pipiwai forest has been managed

- When was the Pipiwai forest harvested?
- Was a harvest plan completed and utilized for the harvest of the Pipiwai forest?
- What methods were used to harvest the Pipiwai Foest?
- Were trees felled and hauled across waterways?
- Was slash clearance carried out at the completion of harvest?
- When were the harvested areas replanted?
- What are the implications for plantation harvest when RBZ are included in a plantation?
- Can cabled haulers extracted trees under full suspension to a height that will clear the top of RBZs?

Forest Leader

Interview Objective: Determine how CHHF managed the first rotation of the Pipiwai forest.

- Has the plantation been fertilized? If so, when did this occur and what products were used?

- Has the plantation been sprayed with herbicide? If so, when did this occur, how was it applied, what products were used and what was the purpose of the application(s)?
- Has soil compaction been carried out? If so, how and when was this carried out?
- Has the plantation been pruned and thinned? If so, when did this occur?
- What is the geology of the plantation? What are the rock and soil types of the plantation? What is the height above sea level?
- From a management perspective, what are the implications of including RBZs in plantation forests?