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DOWNSTREAM IMPACTS OF PAKIHI DEVELOPMENT

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SUMMARY

Pakihi are isolated areas of mostly flat or gently sloping land where saturated and infertile soils support predominantly sedges, ferns, rushes, mosses and sometimes manuka. Recently, about half the exotic tree plantings in Westland have been on pakihi which has been drained by v-blading. In recently v-bladed catchments, peak stream flows (>10 l/s/ha) can be three times more frequent and sediment transport almost two orders of magnitude higher than in undeveloped pakihi catchments. These can cause downstream sedimentation and channel erosion whereas vegetation clearance typically results in substantial increases in water temperature which may detrimentally affect aquatic life.

Where undisturbed native forest is present immediately downstream, the effects of v-blading are likely to be most severe in the first kilometre of stream channel and for the first two years following development. Areas of undisturbed pakihi vegetation alongside the main drainage channel and at the heads of catchments could reduce the scale of impacts by detaining accelerated runoff and sediments, keeping water temperatures down and providing a habitat for aquatic life.

1. INTRODUCTION

"Pakihi" wetlands are characteristic of the west coast of the South Island and in recent years they have been subject to considerable economic development, particularly for exotic forestry. The effects of this type of development on catchment hydrology, land, and water uses and aquatic life have been investigated only recently. This report current knowledge of the impacts of development on environments downstream of pakihi wetlands, but first presents an overview of their features, history and conservation status.

1.1 What is "pakihi"?

Pakihi is a Maori word signifying a clearing free from forest and is now loosely applied to approximately 300,000 ha of discontinuous "swampy acidic barren type of land" between Golden Bay in northwest Nelson and Awarua Bay in Fiordland (Mew 1983; Hulme, 1984) (Fig. 1 & 2A). Similar types of land in other parts of New Zealand (e.g. mountain mires in west Taupo; Clarkson, 1984) are not referred to as pakihi. This appears to be primarily because of geographic location.

North of Ross, most pakihi sites occur on intermediate or high-terrace systems composed of glacial and postglacial material, although there are extensive areas of lowland pakihi near the coast around Westport (Rigg, 1962). In the south, many pakihi are found on estuarine and alluvial flats, moraine surfaces, swampy hollows behind and between dune systems, and on lakes and kettleholes (Mew, 1983). Few pakihi sites occur far inland except in valleys of some large rivers such as the Aorere, Buller and Grey-Inangahua systems (Fig. 1).

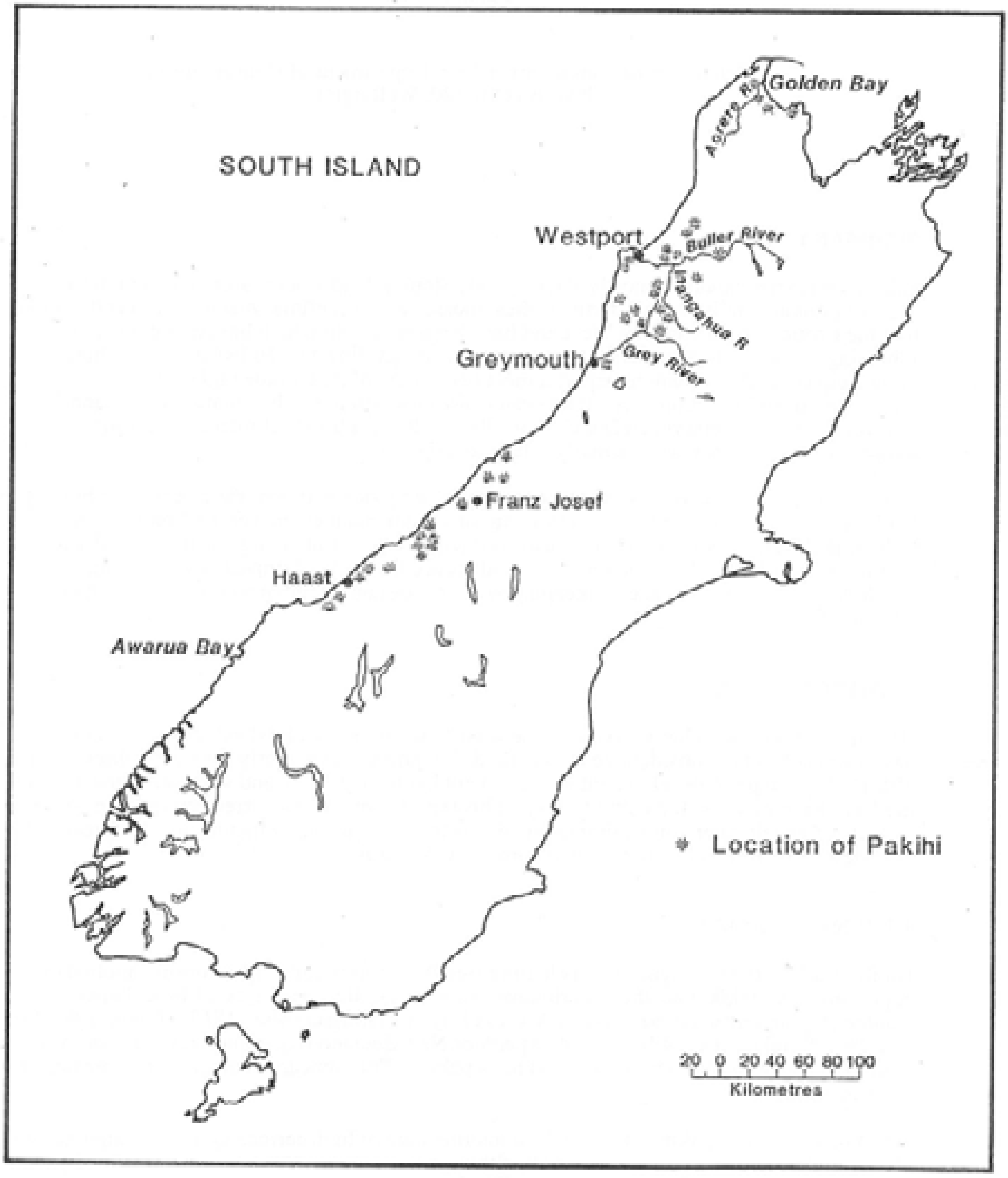

Fig. 1 : **Locations of pakihi currently Listed on the Department of Conservation's wetland inventory.**

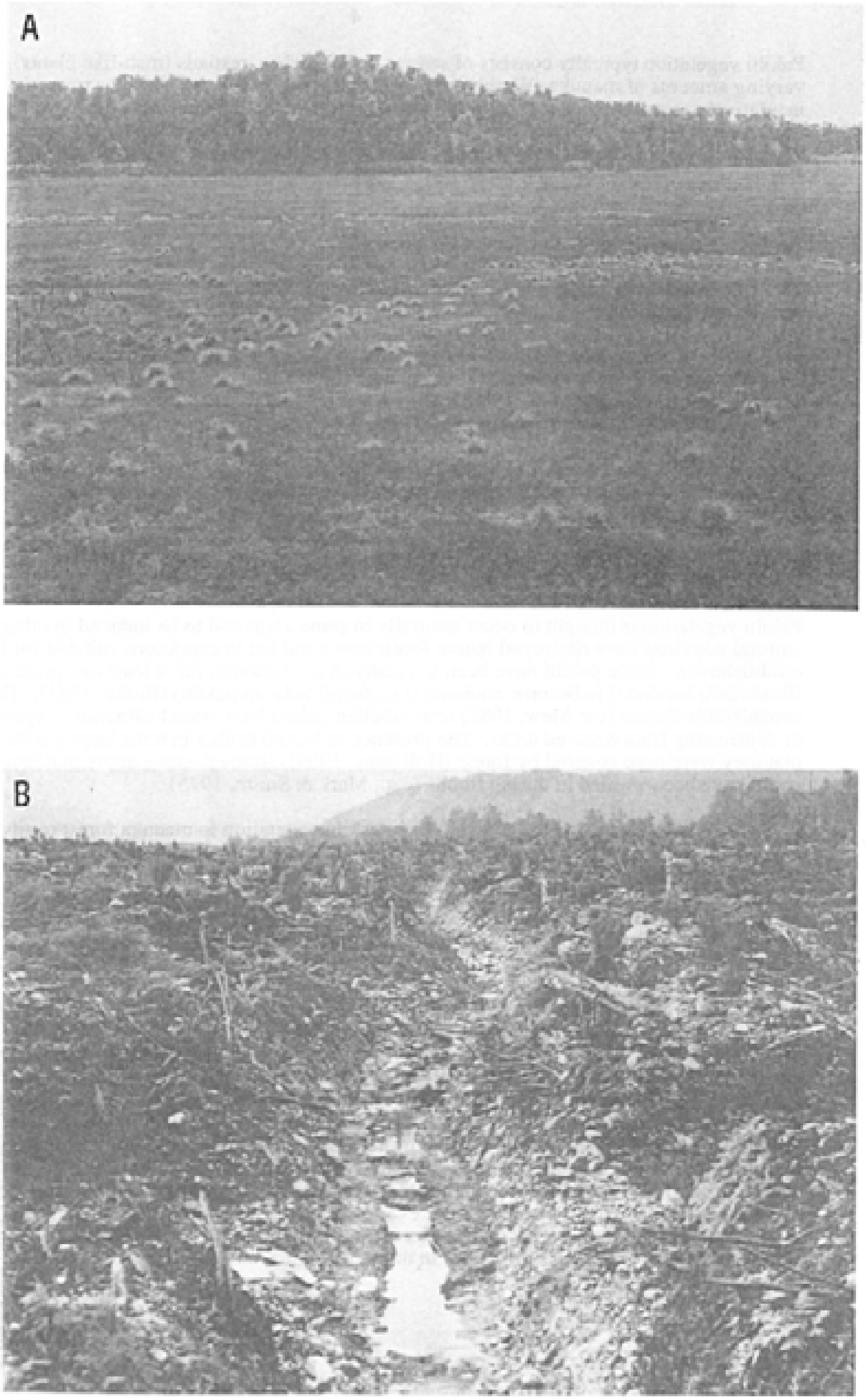

Fig. 2 : Undeveloped (A) and v-bladed (B) pakihi in Westland.

Pakihi vegetation typically consists of sedges, ferns, rushes, restiads (rush-like plants), moss and varying amounts of manuka (Washbourn, 1972; Jackson, 1987). Because the type of plant cover is relatively consistent between sites, it is often assumed that pakihi land is underlain by a uniform soil type. However, Mew (1983) described 22 soil classes found under pakihi vegetation, ranging from shallow stony soils of the Maimai series to relatively deep, fine-textured Okarito soils. Nevertheless, all pakihi soils have three features in common:

1. Natural infertility. Soils are typically low in phosphorus, calcium, magnesium, potassium, copper, cobalt and molybdenum (Walton, 1971).
2. Extreme acidity. Upper horizons usually have pH < 4.5 and this seldom rises above pH 5.4 in lower horizons.
3. Slow vertical or lateral movement of water. This is mainly a function of the low proportion of large soil pores and the presence of impermeable iron pans which are a feature of many (but not all) pakihi (Mew, 1983). Slow water movement and high annual rainfall (typically > 2,200 mm per annum) cause pakihi land to be saturated for a substantial part of the year.

Thus, "pakihi" can be defined as areas of flat or gently sloping wetland on the South Island's west coast which support a low, stunted vegetation community on wet, infertile soils (Mew Johnston, 1988).

1.2 Origin of pakihi

Pakihi vegetation is thought to occur naturally in some areas and to be induced in others where cultural activities have destroyed native forest cover and led to conditions suitable for its establishment. Some pakihi have been in existence long enough for at least one plant species (*Bulbinella modesta*) to become endemic (i.e. found only on pakihi) (Burke, 1981). There is considerable debate (see Mew, 1983) over whether pakihi have been historically expanding into or contracting from forested areas. The presence of buried timber in most large pakihi suggests that they were once covered by forest (Holloway, 1954), although some argue that much of this could have been washed in during floods (e.g. Mark & Smith, 1975).

In South Westland, zones of succession from pakihi vegetation to manuka forest to silver pine and fmally to rimu can be distinguished, and the presence of deep peat under successional forests suggests that some pakihi have been regressing for several centuries (Holloway, 1954; Chavasse, 1962; Wardle, 1979). Mew (1983) concluded that the present-day distribution of natural pakihi and forest in South Westland is best explained by regional or local variations in climate and localised topographic effects which control the amount of water at or near the surface.

According to Mew (1983), most pakihi in North Westland and Golden Bay have been culturally induced through deliberate burning and forest clearance. Fires were seen by Abel Tasman as he sailed along the Westland coast (Walsh, 1896), indicating that the first burnings may have been carried out by Maori, and Wardle (1979) suggested that some pakihi inland from Okarito were first cleared by Maori eeling parties heading for Lakes Wahapo and Mapourika. On terrace systems normally covered with native forest, most water drains laterally through the upper horizons and there is substantial leaching of nutrients (especially potassium, calcium, phosphate and sulphate) from the deep litter layer (N.Z. Soil Bureau, 1968; Washbourn, 1972; Gilbert, 1987). Removal of forest cover can alter surface water conditions by reducing lateral drainage, surface aeration and the amount of water evaporated from vegetation, thereby inhibiting the regeneration of seedlings. This can be accentuated by altered light regimes and destruction of the deep litter layer which is important in nutrient cycling.

Rigg (1962) described successional changes to induced pakihi on a terrace near the Totara River, North Westland. "Once the area had been cut over, podocarps failed to regenerate. Instead the broadleafs took over with an occasional *Nothofagus cliffortioides* (beech). The forest began to open out, with poor timber, low in stature. Over the floor of the forest pakihi species were making an appearance ..... A stage further where the area had been burnt at one time presented a typical pakihi character". Similar changes in vegetation were seen by Williams *et al.* (1987) in a survey of 32 pakihi sites in North Westland. They believe that, given time and the absence of fire, most induced pakihi will revert to native forest, possibly as soon as 60-70 years following colonisation by manuka.

1.3 Conservation status of pakihi

Wetlands are recognised as an important but diminishing part of the New Zealand environment and the protection of "representative important wetlands" is now considered "desirable" as government policy (N.Z. Commission for the Environment, 1986). An inventory of existing information on important remaining wetlands is currently being established by the Department of Conservation and this has identified many areas of pakihi as having ecological, economical, historical or recreational values. Some pakihi are closely associated with other wetland types such as swamps and lakes (e.g. Lake Kini pakihi and swamp, Karangarua; Topsy Lake complex, Paringa; Saltwater Ecological Area, Harihari) which have additional recreational and ecological values.

The wetland inventory recognises several pakihi as containing a notably diverse range of plant species, as displaying natural successional changes in vegetation type, or as being unique to, or particularly representative of certain ecological districts. In addition, many pakihi support large populations of the native South Island fern bird (*Bowdleria puctata punctata*) which is known to prefer structurally complex habitats such as that provided by forest (Williams *et al* 1987). Recreational values of pakihi tend to be limited to hunting (e.g. Bruce Bay pakihi, Karangarua; Coal Creek pakihi, Reefton; Dublin Terrace pakihi, Buller), whereas historical values reflect remains such as the old tram and mill on the Bruce Bay pakihi.

The main economical value of unmodified pakihi wetland is *Sphagnum* moss harvesting. Economical values of pakihi can be increased by drainage and development for pastoral farming or forestry. These, along with mining, agricultural pollution and fire, are listed by the inventory as immediate threats to pakihi wetlands.

1.4 History of economic development

Early attempts to reclaim pakihi land for forestry and pastoral farming were unsuccessful because of poor drainage and naturally low fertility. A land report commissioned in 1960 by the then Department of Lands and Survey stated that pakihi were unsuitable for pastoral development, but recommended that experimental and demonstration plots be developed (Washbourn, 1972). Subsequent trials near Westport showed that good pasture growth can result on some pakihi within one year if certain land management practices are adhered to (Walton, 1971). These include adequate topdressings of lime, super phosphate and essential trace elements, as well as mob stocking to limit regrowth of ferns and rushes, and to compact and dry out the soil. Gilbert (1987) found that intensive rotational stocking during winter months increased rates of nutrient cycling within the soil and elevated levels of phosphorus, sulphur, magnesium and potassium in plants. However, establishing pasture on pakihi can be expensive and many farmers are content to burn the vegetation once a year so that stock can feed on young regrowth (Rigg, 1962).

Initially, development of pakihi land for exotic forestry did not appear to be any more feasible than pastoral farming, but scattered plantings of Eucalyptus trees in 1953 on the Craigieburn pakihi, south of Reefton, (Washbourn, 1972). A series of trials subsequently established there, tested more than 20 tree species, various drainage techniques and different dosages and combinations of fertilisers. Early plantings of trees directly into the topsoil or onto mounds of up-ended earth were unsuccessful, but promising results were obtained when trees were planted on rows of soil heaped into mounds using a bulldozer blade. However, ponding of water between rows was a problem and this technique was later modified so that lateral drains followed contours of the land and connected with main drains which discharged runoff. This was the fore-runner of v-blading which is presently the most common method of developing pakihi wetlands for forestry.

Using this technique and with the application of fertilisers (particularly those containing phosphate) at rates up to 500 kg/ha, three tree species showed reasonably good growth: *Pinus contorta, P. radiata* and *P. muricata* (Washbourn, 1972). Best results were achieved with *P. radiata* (Fig. 3), although growth rates in these initial trials were only about half those of conifers growing elsewhere in New Zealand. Nevertheless, Washbourn (1972) expressed optimism that this could be improved as drainage techniques and management practices evolved.

By 1983, about half of exotic forest plantings (mostly *P. radiata*) in Westland were on pakihi land which had been developed by v-blading (N.Z. Forest Service, 1984). This technique draws its name from the shape of the bulldozer blade which is used to mound earth up in parallel rows at right angles to stream channels (Figs. 2B & 4). The v-blade typically removes a 2-3 m wide strip of soil to a depth of 0.3-0.4 m and rolls it outwards to form two continuous mounds which are 0.5-1.0 m high and 1.5-2.0 m wide at the base. Parallel runs with the blade are generally made 8-10 m apart, leaving a 2-3 m wide strip of undisturbed ground between adjacent ridges. The tracks excavated by the v-blade open directly into stream channels which are sometimes straightened and deepened with a ditch-digger.

Mounds formed in this way provide elevated, drier sites for trees, although the water table can remain high beneath and between the mounds (Jackson, 1987). The time interval between v-blading and planting is generally 3-6 months but can be as little as 6 days. Seedlings are planted at densities of around 1100 stems per ha and are hand fertilised with (80 grams per tree) of DAP fertiliser. Additional DAP fertiliser with potassium chloride (250 grams per tree) is usually applied three years after planting and this is repeated three years later. Plantations are thinned to 500 stems per ha at age three, and additional thinning is carried out 2-3 years later to achieve final densities of 250 stems per ha. It is anticipated that harvesting will be at age 30-40 years.

2. EFFECTS ON STREAMS

2.1 Recent research

Studies into the effects of v-blading on catchment hydrology, water quality and stream invertebrate communities have been stimulated recently by the concern of land-holders and the Catchment Board about increased peak flows and sedimentation downstream of drainage works. This led to the establishment in 1983 by Forest Research Institute of three experimental catchments on the highest level of the Larry River sequence, 14 km north of Reefton. At the start of the study, two catchments were covered in pakihi vegetation (mainly manuka and Sphagnum moss), whereas the third catchment had been v-bladed and

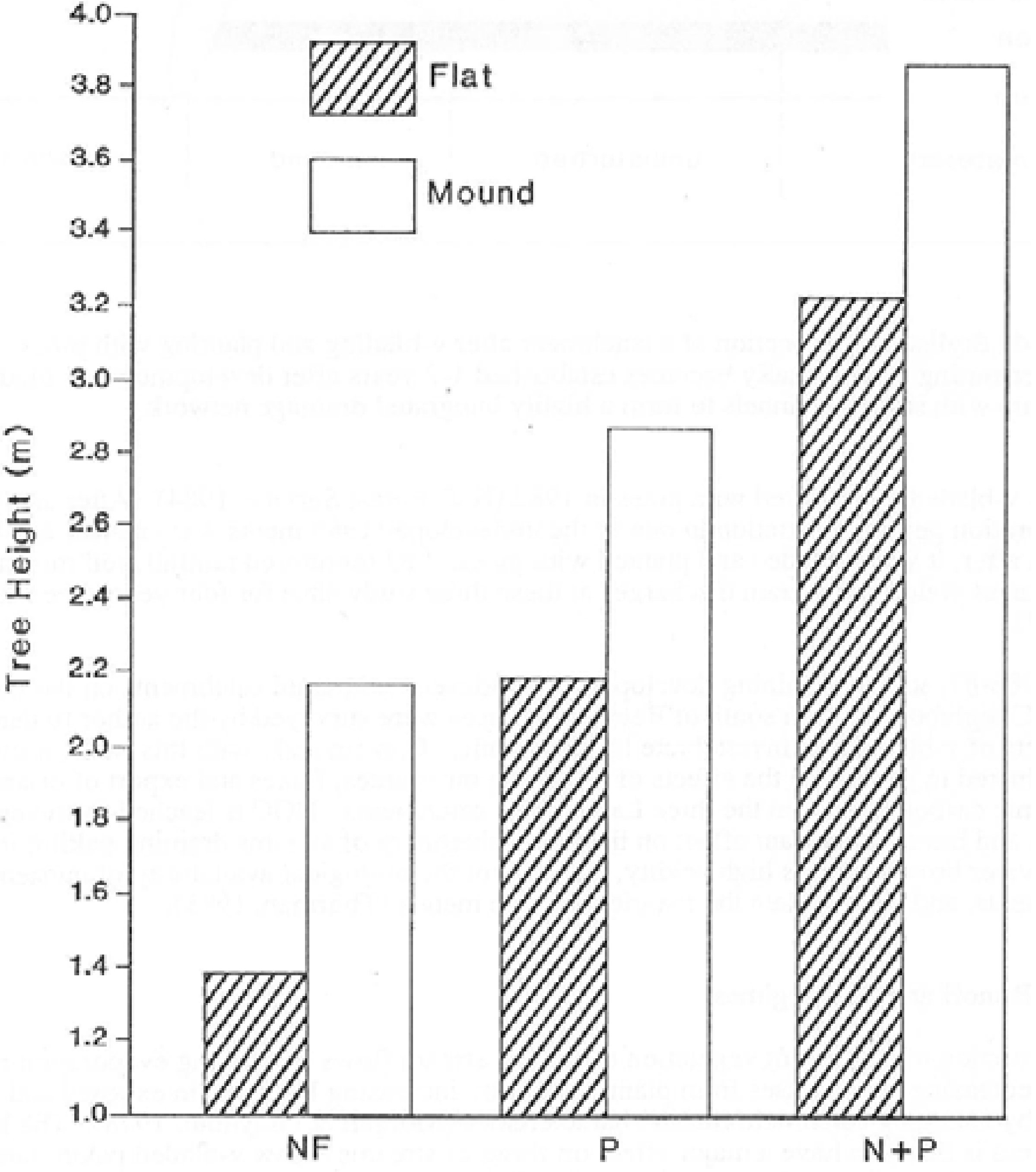

Fig. 3: Mean heights of *Pinus radiata* trees planted on flat and mounded earth and given different combinations of fertiliser. NF, no fertiliser applied, P, phosphate only; N+P, nitrogen and phosphate (from Washbourn, 1972).

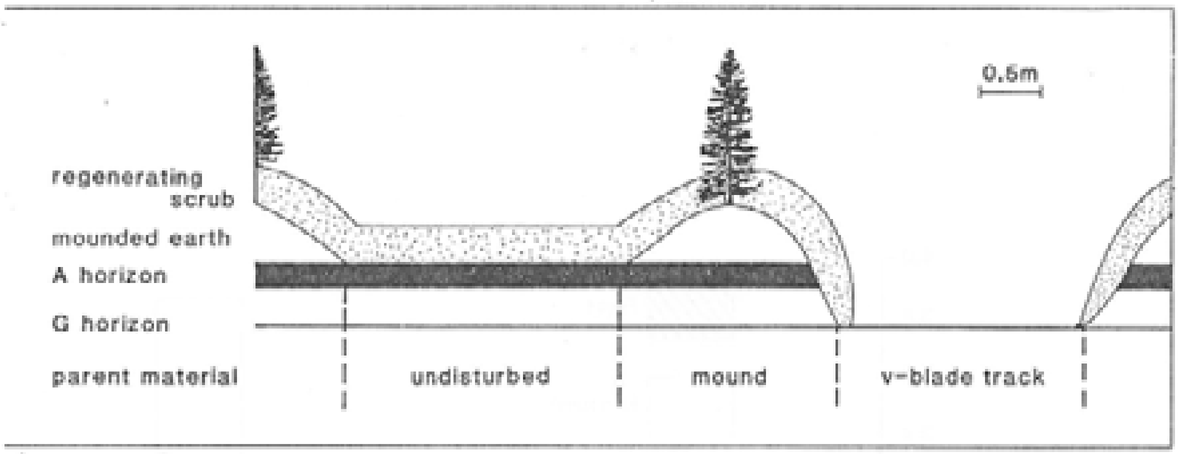

Fig. 4: Stylised cross section of a catchment after v-blading and planting with pines. Regenerating scrub usually becomes established 1-2 years after development. V-blade tacks link up with stream channels to form a highly integrated drainage network.

planted with pines in 1982 (N.Z. Forest Service, 1984). After an 18-month calibration period, vegetation in one of the undeveloped catchments was crushed and burnt, and soon after, it was v-bladed and planted with pines. FRI monitored rainfall, soil moisture, sediment yields and stream discharges at these three study sites for four years (see Jackson, 1987).

In 1986-87, streams draining developed and undeveloped pakihi catchments on the Larry River and Craigieburn (50 km south of Reefton) terraces were surveyed by the author to determine the effects of v-blading on invertebrate life in streams. Concurrently with this work, a study was conducted to determine the effects of v-blading on sources, fluxes and export of dissolved organic carbon (DOC) in the three Larry River catchments. DOC is leached from vegetation and soils and has an important effect on the water chemistry of streams draining it colours the water brown, causes high acidity, can control the biological availability of nutrients and trace elements, and can regulate the toxicity of some metals (Thurman, 1985).

2.2 Runoff and flow regimes

Destruction of catchment vegetation can affect stream flows by altering evaporation rates by decreasing water losses from plants and/or by increasing losses from exposed soil surfaces), and by changing catchment runoff characteristics (Morgan & Graynoth, 1978). The latter process is likely to have a major effect on flows of streams below v-bladed pakihi land where drainage channels are cut to accelerate runoff rates.

V-blading may cause slight increases (0-30%) in total volumes of water lost rapidly from catchments after storm events, but substantial increases in the frequency and magnitude of peak flows (Jackson, 1987). For example, the average peak stream flow of large flood events was over three times greater in a catchment v-bladed two years earlier compared with an undeveloped site (Fig. 5). Similarly, flows greater than 10 l/s/ha can be three times more frequent at v-bladed sites than at undeveloped sites, with short-duration, high-intensity rainfall giving the greatest contrasts (Jackson, 1987). In addition, the amount of time a

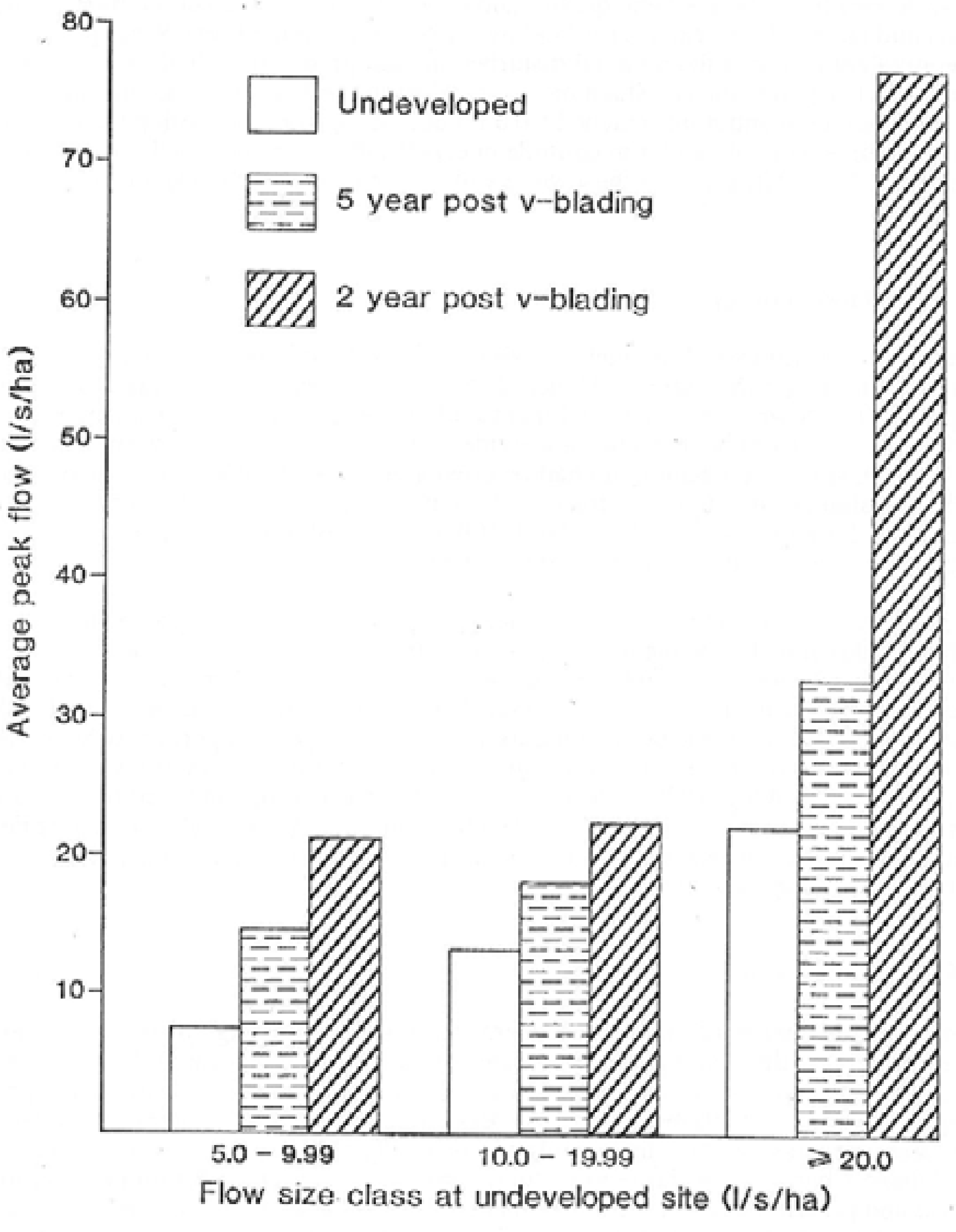

Fig. 5: Average peak flows in three flow size classes for three streams draining v-bladed or undeveloped catchments during 18 months from 1985-1986 (from Jackson, 1987).

stream spends at very low flows may be increased as a result of v-blading. For example, between August 1986 and July 1987, a stream draining an undeveloped catchment on the highest Larry River terrace spent 14% of its time at flows less than 0.2 l/s/ha, compared with 37% and 49%, respectively, at catchments developed five and two years previously (Collier, 1988).

2.3 Sediment loads

Catchment development can substantially increase sediment loads in drainage waters and thereby detract from the aesthetic quality and also detrimentally affect the biology of recipient streams and rivers. One year after v-blading a catchment on the Larry River pakihi, 100 m^3 of soil (equivalent to 1% of the material disturbed in land preparation) had been flushed downstream (Jackson, 1987). Much of this was lost in the first three months after v-blading when sediment concentrations reached 5-10 g/l during flood events with peak flows of 5-15 l/s/ha. During events of similar magnitude one year later, maximum sediment yields had dropped to 1.5-2.5 g/l, although these were still ten times higher than levels at the undeveloped site.

2.4 Channel morphology

Increases in peak flows and sediment yields can alter channel morphology by filling in pools, and undercutting and destabilising banks. Jackson (1987) noted that pools were filled in with silt up to 200 m downstream of a catchment v-bladed one year earlier. Channel erosion and stripping of moss from boulders became evident at that site after major storm events (peak flows 25-30 l/s/ha), and the escalation of channel erosion in subsequent storms is thought to have contributed significantly to downstream sediment movement. In the 1 km of stream bed between the drainage works and farmland, 100-1000 m^3 of coarse material was created by channel erosion during high peak flows (Jackson, 1987).

Increased peak flows could also alter channel morphology by washing away natural debris jams which slow down bed movement and help create the pool-riffle-pool sequences characteristic of many streams (Bisson *et al.,* 1982; Heifetz *et al.,* 1986). Debris jams can also provide important shelter for native fish such as kokopu (Main, 1987). Forested streams below undeveloped pakihi catchments may retain some organic inputs such as leaves and support growths of algae on stones, and these can be important food sources for stream invertebrates (Anderson & Cummins 1979; Cummins & Klug 1979). Changes in channel morphology induced by increased peak flows and sedimentation downstream of development may disrupt these food supplies by rapidly flushing out organic matter before it can be utilised by stream invertebrates, and by scouring or smothering algae on rock surfaces.

2.5 Water temperature

Removal of streamside vegetation and alteration of natural drainage patterns are known to have marked effects on thermal regimes of streams draining developed catchments. These changes usually involve increases in summer maxima and decreases in winter minima example, Graynoth (1979) recorded an increase in the summer maximum stream temperature of 6.5°C and a decrease in the winter minimum of 2.5°C after clear-cutting of a forested catchment near Nelson. Changes in water temperature, particularly increases in summer maxima, can affect survival and growth rates of invertebrates and fish, and change rates of stream processes such as algal productivity and microbial breakdown of organic matter (Winterbourn, 1986).

In a survey of streams in North Westland, Collier (1988) recorded summer water temperatures of 26-31°C in streams draining recently v-bladed pakihi catchments on the

Larry River terraces, compared with 13°C at a nearby undeveloped pakihi site. In one of the streams draining v-bladed pakihi, a drop of 12 °C (from 27 °C to 15 °C) was recorded after it had flowed for 1 km through native forest, indicating that water temperatures can return to normal levels within this distance if the bed is shaded by streamside vegetation.

2.6 Water chemistry

Burning and logging can cause the release of significant amounts of nutrients, especially nitrogen and phosphorus, into drainage waters by disrupting natural nutrient cycles within adjacent catchments and by increasing amounts of sediment released into streams (Morgan & Graynoth, 1978; Mosley & Rowe, 1981; Winterbourn, 1986). Elevated concentrations of nutrients in streams, along with other development-related factors (e.g. greater light levels and higher water temperatures) can contribute to increased algal growth if the scouring or smothering effects of elevated sediment loads are not too severe.

In streams draining clear-felled and burnt catchments in the Maimai Experimental Area, North Westland, concentrations of magnesium, calcium and soluble phosphorus were 1.5-2 times higher, potassium 3-4 times higher and nitrate 10 times higher than those found in streams draining undisturbed forested catchments (Mosley & Rowe, 1981). Because undeveloped pakihi soils are naturally low in nutrients (Walton, 1971; Mew, 1983), concentrations in drainage waters are also likely to be low. However, the effects of v-blading and the addition of fertilisers on nutrient fluxes in pakihi catchments are not known, although data on this topic are currently being collated by FRI.

The only other work on the effects of v-blading on the water chemistry of streams draining pakihi is that of Collier (1988), who investigated dissolved organic carbon (DOC) fluxes in developed and undeveloped catchments and streams. V-blading lowered DOC inputs into pakihi catchments by destruction of the natural plant cover (e.g. manuka) and by effectively removing one third of the soil (a major source of DOC) and dumping it in mounds. Consequently, the amount of DOC exported annually (per unit area of catchment), was 24% less in a stream draining a catchment v-bladed two years before the study, than in a stream flowing from an adjacent undeveloped catchment. Secondary regrowth of vegetation on v-bladed catchments can diminish some of the effects of v-blading on DOC dynamics as time progresses. DOC export from a catchment v-bladed five years before the study of Collier (1988), was only 12% less than that of the undisturbed site, with DOC leached from moss growing in the channel apparently accounting for a substantial proportion of this recovery.

2.7 Stream invertebrates

The main impacts of pakihi development on downstream aquatic life are likely to be increased sedimentation, elevated summer water temperatures, decreased availability of suitable habitat and alteration of the types of food available. The only study to specifically investigate the effects of v-blading on stream invertebrates is that of Collier (1988) who surveyed invertebrate populations in waters draining v-bladed and undeveloped (pakihi and native forest) catchments on the Larry River and Craigieburn terraces near Reefton. Streams surrounded by native forest contained, on average, about twice as many invertebrate species as v-bladed or undeveloped pakihi sites. Overall, fewest species were found in a very warm (summer water temperature 26 °C) stream on the Larry River terrace. Similar conditions in other streams draining developed catchments on the Larry River pakihi were apparently detrimental to a common genus of mayfly (*Deleatidium*) which was found at all the other sites sampled. Also absent from developed streams on the Larry River pakihi was the crustacean amphipod, *Paraleptamphopus caeruleus,* which was present at several cooler v-bladed sites on the Craigeburn terraces and was very abundant in cool, shaded streams draining undeveloped pakihi.

Although the upper temperature tolerances of New Zealand aquatic invertebrates are not known, it is possible that some invertebrate species were detrimentally affected by the high summer water temperatures recorded in developed streams draining the Larry River pakihi (26-31 ^{o}C). The thermal death point of most Northern Hemisphere stream invertebrates is between 30 and 40 ^{o}C, but sublethal effects on growth, reproduction and body functions are also likely to be important determinants of abundance and distribution (Pennak, 1978; Wiederholm, 1984). In addition, filling in of gravel interstices by fine sediments is likely to have reduced the habitat available to benthic invertebrates downstream of development, at least in the first few months after v-blading. Lemly (1982) found that the number of invertebrate species dropped in streams where fine sediments made up 12-43% of total bed composition.

2.8 Fish

The influence of forestry practices on freshwater fish in New Zealand has been reviewed by Morgan & Graynoth (1978). Although this review did not specifically deal with v-blading, effects such as reduced invertebrate food supplies (discussed in previous section), high summer water temperatures and increased sedimentation can be expected to result in similar faunal reductions.

Brown trout, eels and several species of bully and galaxiid occur in streams and rivers throughout Westland (McDowall & Richardson, 1986). Some of these (e.g. short and long finned eels, inanga, giant kokopu, banded kokopu and common bully) have been recorded in very acid, brown water typical of that draining pakihi catchments (Main *et al.,* 1985; Main, 1987). Migrating fry of inanga and kokopu make up most of the commercially and recreationally important whitebait catch which has shown a general decline in recent years (McDowall, 1984). This decline is thought to be due, in part, to loss of adult habitat through removal of forest cover, although other factors such as flood frequency and magnitude and water turbidity can affect whitebait migrations. Adult habitat may be lost downstream of v-blading works through alteration of channel morphology and increased flooding. For example, banded kokopu prefer slow flowing water (Main, 1987), and may be detrimentally affected by the increased frequency and magnitude of flooding of streams below v-blading works. This species lives mostly among woody debris and between boulders in pools (McDowall, 1980), but this habitat can be reduced by deposition of sediments derived from v-blading.

High sediment loads in streams and rivers can also affect fish directly by abrasion and by obstructing their respiration, or detrimentally affect them by increasing susceptibility to disease, reducing growth rates, modifying behaviour patterns and smothering spawning grounds and larval habitats (Morgan & Graynoth, 1978; Alabaster & Lloyd, 1980; Bruton, 1985). Wilber (1983) reported that suspended sediment concentrations of 1-6 g/l reduced some North American brown trout populations to one seventh the size of those at a clearwater reference site. This is in the range of sediment yields reported for a stream draining a recently v-bladed catchment on the Larry River terrace (Jackson, 1987). Longer term effects were reported by Graynoth (1979) in the Motueka River where numerous brown trout and other fishes died after logging of an area upstream, apparently due, in part, to low dissolved oxygen levels following extensive sedimentation of the river bed.

Main et al. (1985) recorded eels and inanga in waters with temperatures as high as 26 ^{o}C, although most other fish species were absent at temperatures above 18 ^{o}C. Nevertheless, in laboratory studies Main (1987) found that water temperatures did not become critical to the survival of koaro and kokopu (both members of the whitebait catch) until they reached 28-30 ^{o}C. He concluded that temperature was not a major factor affecting the distribution of these fishes in Westland streams. Frost & Brown (1967) reported that mortality of brown trout eggs increased significantly above 13 ^{o}C, although adult fish in a tributary of the Buller River were apparently unaffected by temperatures as high as 26^{o}C (Morgan & Graynoth, 1978). The effects of increased water temperatures on fish communities seems to depend on the species of fish, acclimation history and developmental stage (i.e. egg, fry or adult).

2.9 Spatial and temporal perspectives

Effects of pakihi v-blading on downstream environments are summarised in Fig. 6. This section addresses the questions of how far downstream these effects are likely to extend and how long they are likely to persist. The type of land use immediately below developed pakihi will have a major effect on the spatial and temporal recovery of downstream environments. For example, forest cover will help stabilise stream channels through the binding action of roots, and mitigate elevated water temperatures by providing shade. In addition, downstream effects of v-blading are likely to diminish with time after development as secondary regrowth of catchment vegetation stabilises soils and detains accelerated runoff.

Available evidence suggests that, if native forest is present immediately below v-blading works, impacts on channel morphology (i.e. increased sedimentation and channel erosion) will be most severe in the first kilometre downstream. This distance also appears sufficient for elevated water temperatures to drop to normal levels. Similarly, stream invertebrate communities as little as 1 km downstream of areas v-bladed as recently as 1-2 years before, contained a similar complement of species, overall, as some forested sites with no history of upstream development (Collier, 19880).

Downstream effects of v-blading are likely to become less severe with time after development (Fig. 7). This was the case for the amount of DOC carried annually by streams draining three Larry River catchments; DOC export from one catchment v-bladed two years previously was 76% that of an adjacent undeveloped catchment, but in another catchment v-bladed five years previously this had increased to 88% (Collier, 1988). Forthcoming work to be published by FRI should reveal whether other chemical parameters follow the same pattern. Mosley & Rowe (1981) found that concentrations of sodium, magnesium, potassium and calcium in streams draining afforested catchments in the Experimental Area approached levels in undisturbed forested catchments 2-3 years after development.

Peak flow frequency and magnitude also seem to decline with time after development (Fig. 7), although it is not clear how long it would take for flow regimes to return to pre-disturbance levels. Five years after development of a catchment on the Larry River terrace, peak flows measured after rainfall events of 5-10 mm were considerably less (mean = 14.3 l/s/ha), than those recorded two years after development (21.3 l/s/ha) but were still much greater than those at the undeveloped site (7.4 l/s/ha) (see Fig. 5). Even though increased peak discharges may persist in developed catchments for five years or more, sediment yields from v-bladed sites are likely to return to pre-disturbance levels within two years.

A major source of downstream sediment problems is thought to be channel instability induced by peak flows (Jackson, 1987). It is unclear how long after v-blading this instability is likely to persist or how long it would take for deposited fine sediments to be flushed out of the stream. Nevertheless, available evidence does suggest that, if there is at least 1 km of native forest below the v-bladed area, then effects on downstream environments will be most pernicious in the first two years following development. This may vary spatially depending on catchment geology and skill of the developer, and temporally depending on the climatic conditions prevailing in the first few years following development.

3. MEASURES TO DIMINISH DOWNSTREAM IMPACTS

The main downstream impacts of pakihi development appear to be altered flow regimes, increased sediment yields, changed water chemistry and elevated water temperatures. These are caused primarily by the removal of vegetation from the catchment, and the v-blade tracks which are fully linked with the natural stream channel and rapidly transport

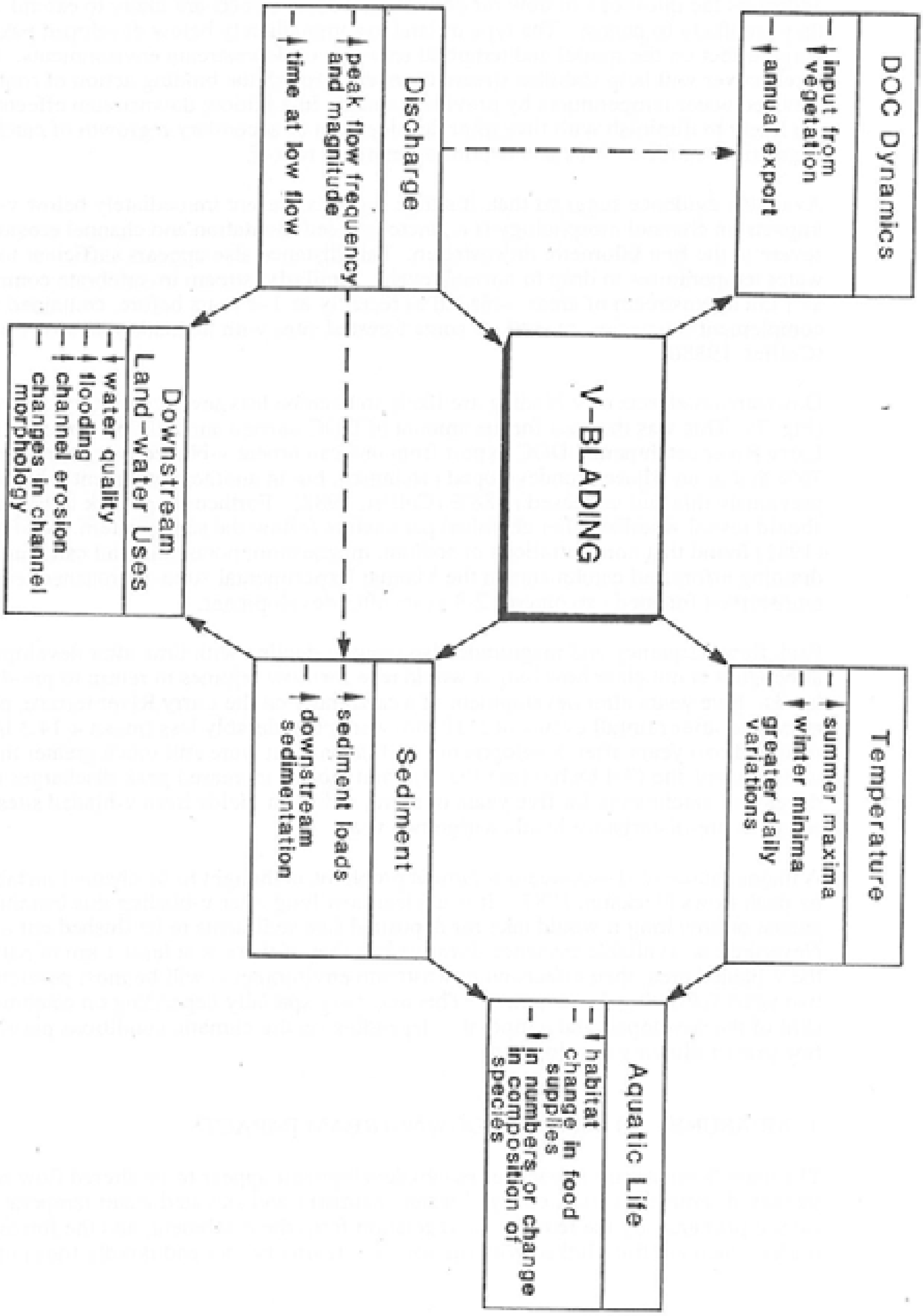

Fig. 6: Summary of the main effects of pakihi v-blading on downstream environments. DOC+ dissolved organic carbon

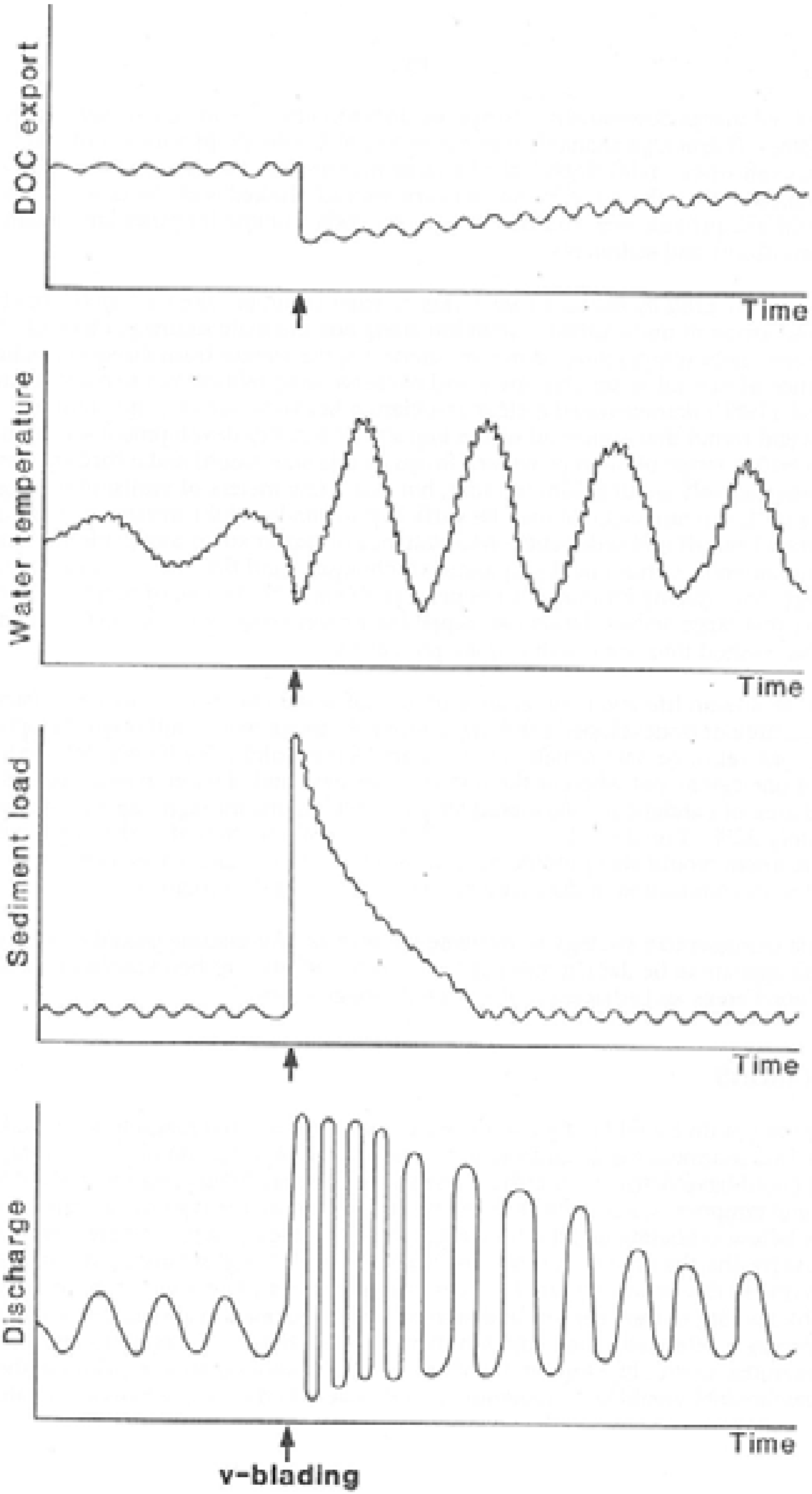

Fig. 7: **Model of temporal changes in stream discharge, sediment load, water temperature and dissolved organic carbon (DOC) export before and after v-blading of pakihi catchments.**

rainfall and mobilised downstream. However, Jackson (1987) concluded that a fully integrated system of drainage channels was not essential for the rapid removal of water from pakihi which, even when undeveloped, shed a large proportion of storm rainfall quickly. Thus, a drainage system in which the v-blade channels are not fully linked with the natural stream channel should still provide well-drained sites on mounds suitable for pines and detain much of the accelerated runoff and sediments.

Where pakihi are covered by manuka forest, this concept could be taken a step further by retaining buffer strips of undisturbed vegetation alongside the main drainage channel. These would help keep water temperatures down by sheltering the stream from direct sunlight, assist in the maintenance of natural water chemistry and conserve invertebrate and fish life in streams. Newbold *et al.* (1980) demonstrated a clear association between buffer strip width and effectiveness and found that almost all of the impacts of forestry development on streams were prevented by buffer strips of 30 m or wider. Strips of this size would make forestry development impractical on relatively small pakihi terraces, but just a few meters of undisturbed vegetation on either side of the stream channel may be sufficient to shade pakihi streams and detain much of the accelerated runoff and sediments. Maintenance of buffer strips alongside streams would involve modification of current land preparation techniques, and fire breaks would have to be built to protect strips during burning. A potential problem with the use of narrow buffer strips is the possibility that large accumulations of trapped sediment could build up on their fringes and these could be washed into streams during major storms.

Conservation of stream life and maintenance of natural water chemistry may be assisted by the retention of an area of undeveloped catchment above drainage works, although the optimal size of such areas has yet to be determined. On the Larry River pakihi, 3.2 ha was left undeveloped at the head of one catchment whereas the rest was v-bladed and planted in pines in 1982. The undeveloped area of catchment contributed 59% of DOC inputs through vegetation even though it occupied only 32% of total catchment area. Retention of a section of undisturbed pakihi at the head of a catchment would also provide habitat for invertebrates and act as a reservoir of animals for the recolonisation of downstream areas following development.

Thus, the best management strategy to mitigate the effects of v-blading pakihi on downstream environments appears to be the retention of buffer zones of undisturbed vegetation above and below developed areas and adjacent to the main drainage channel.

4. CONCLUSIONS

Development of pakihi by v-blading can increase the frequency and magnitude of peak stream flows, accelerate sediment yields and channel erosion, and elevate summer water temperatures, all of which could have detrimental effects on aquatic life and downstream water and land uses. The spatial and temporal scale of these impacts will depend on the type of catchment vegetation immediately below v-blading and the time elapsed since development. Where native forest is present below pakihi, the effects of v-blading are likely to be most severe in the first kilometre downstream and in the first two years following development. The scale of these impacts could be reduced by leaving buffer strips of undisturbed pakihi vegetation alongside the main drainage channel to detain accelerated runoff and sediments, and to shade the stream thereby keeping water temperatures down. In addition, retention of an undisturbed area of pakihi at the heads of developed catchments would help maintain natural water chemistry and provide a habitat for aquatic life.

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6. REFERENCES

Alabaster, J.S. & Lloyd, R. 1980: Water quality criteria for freshwater fish. Butterworths, London.

Anderson, N.H. & Cummins, K.W. 1979: Influences of diet on the life histories of aquatic insects. *Journal of the Fisheries Research Board of Canada 36:* 335-342.

Bisson, P.A., Nielsen, J.L., Palmason, R.A. & Grove, L.E. 1982: A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. *In:* Aquisition and utilization of aquatic habitat inventory information *(ed.* N.B. Armantrout). American Fisheries Society, Portland. p. 67-73.

Brunton, M.N. 1985: The effects of suspensoids on fish. *Hydrobiologia 125:* 221-241.

Burke, W.D. 1981: A botanical survey of the pakihi and vegetation of the Golden Bay region, Nelson. Unpubl. report, Department of Lands and Survey.

Chavasse, C.G.R. 1962: Forests, soils, and landforms of Westland. *N.Z. Forest Service Information Series No. 43.*

Clarkson, B.R. 1984: Vegetation of three mountain mires, west Taupo, New Zealand. *New Zealand Journal of Botany 22:* 361-375.

Collier, K.J. 1988: Ecology of acid brownwater streams in Westland, New Zealand. Unpubl, Ph.D. thesis, University of Canterbury.

Cummins, K.W. & Klug, M.J. 1979: Feeding ecology of stream invertebrates. *Annual Review of Ecology and Systematics 10:* 147-172.

Frost, W.E. & Brown, M.E. 1967: "The trout". Collins, London.

Gilbert, M.J.M. 1987: Nutrient studies on pakihi soils and pastures. Unpubl. M.Sc. thesis, University of Canterbury.

Graynoth, E. 1979: Effects of logging on stream environments and faunas in Nelson. *New Zealand Journal of Marine and Freshwater Research* 13: 79-109.

Heifetz, J., Murphy, M.L. & Koski, K.V. 1986: Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. *North American Journal of Fisheries Management 6:* 52-58.

Holloway, J.T. 1954: Forests and climates in the South Island of New Zealand. *Transactions of the Royal Society of NewZealand 82:* 329-410.

Hulme, K. 1984: The Bone People. Spiral Collective, New Zealand.

Jackson, R.J. 1987: Hydrology of an acid wetland before and after draining for afforestation, western New Zealand. In: Forest hydrology and watershed management (Proceedings of the Vancouver symposium, August, 1987). I.H.A.S. publ. No. 167. p. 465-574.

Lemly, D.A. 1982: Modification of benthic insect communities in polluted streams: combined effects of sedimentation and nutrient enrichment. *Hydrobiologia* 87: 229-245.

McDowall, R.M. 1980: Forest cover over streams is vital to some native freshwater fishes. *Forest and Bird 215 (13):* 22-24.

McDowall, R.M. 1984: The New Zealand Whitebait Book. A.H & A.W. Reed, Wellington.

McDowall, R.M. & Richardson, J. 1986: An atlas of New Zealand freshwater fish distributions. N.Z. Ministry of Agriculture and Fisheries, Fisheries Research Division, *Occasional Publication No. 26.*

Main, M.R. 1987: Factors influencing the distribution of kokopu and koaro *(Pisces: Galaxiidae).* Unpubl. M.Sc. thesis, University of Canterbury

Main, M.R., Nicoll, G.J. & Eldon, G.A. 1985: Distribution and biology of freshwater fishes in the Cook River to Piranga River area, South Westland. N.Z. Ministry of Agriculture and Fisheries, *Fisheries Environmental Report No. 60.*

Mark, A.F. & Smith, P.M.F. 1975: A lowland vegetation sequence in South Westland: Pakihi bog to mixed beech podocarp forest. Part 1: The principal strata. *Proceedings of the New Zealand Ecological Society 22:* 76-89.

Mew, G. 1983: Application of the term pakihi in New Zealand - an introduction to the literature. *Journal of the Royal Society of New Zealand 13:* 175-198.

Mew, G. & Johnston, M. 1988: The use of the word "pakihi" on the South Island west coast in the nineteenth century. *New Zealand Geographer* April 1988: 22-24.

Morgan, D.R. & Graynoth, E. 1978: The influence of forestry practices on the ecology of freshwater fish in New Zealand: an introduction to the literature. N.Z. Ministry of Agriculture and Fisheries, Fisheries Research Divison, *Occasional Publication No. 14.*

Mosley, M.P. & Rowe, L.K. 1981: Low flow water chemistry in forested and pasture catchments, Mawheraiti River, Westland. *New Zealand Journal of Marine and Freshwater Research 15:* 307-320.

N.Z. Commission for the Environment 1986: New Zealand wetlands management policy. N.Z. Commission for the Environment publ.

N.Z. Forest Service. 1984: Report of Forest Research Institute for 1 January to 31 December 1983. New Zealand Forest Service.

N.Z. Soil Bureau. 1968: Soils of New Zealand volume 1. *N.Z. Soil Bureau Bulletin 26(1).*

Newbold, J.D., Erman, D.C., & Roby, K.B. 1980: Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences 39:* 1383-1388.

Pennak, R.W. 1978: Freshwater invertebrates of the United States. J. Wiley & Sons, New York.

Rigg, H.H. 1962: The pakihi bogs of Westport, New Zealand. *Transactions of the Royal Society of New Zealand, Botany I:* 91-108.

Thurman, E.M. 1985: Organic geochemistry of natural waters. Martinus Nijhoff/Dr. W Junk, Dordrect.

Walsh, P. 1896: On the disappearance of the New Zealand bush. *Transactions of the New Zealand Institute 29:* 490-496.

Walton, T. 1971: Buller and the pakihi. *New Zealand Journal of Agriculture 123:* 40-43.

Wardle, P. 1979: Plants and landscape in Westland National Park. *National Park Series No.* 3. National Parks Authority.

Washbourn, R.W. 1972: The rehabilitation of induced pakihi sites in Westland. *New Zealand Journal of Forestry 17:* 232-248.

Wiederholm, T. 1984: Responses of aquatic insects to environmental pollution. *In:* The ecology of aquatic insects *(eds.* V.H. Resh & D.M. Rosenberg). Praeger Press, New York. P. 155-208.

Wilber, C.G. 1983: Turbidity in the aquatic environment: an environmental factor in fresh and oceanic waters. Charles C. Thomas, Springfield, Illinois.

Williams, P.A., Courtney, S., Glenny, D. & Hall, G. 1987: The diversity and status of pakihi and associated vegetation in North Westland. Unpubl. Report. Botany Division, DSIR.

Winterbourn, M.J. 1986: Forestry practices and stream communities with particular reference to New Zealand. *In:* Stream protection: the management of rivers for instream uses *(ed.* I.C.Campbell). Water Studies Centre, Chisholm Institute of Technology, Melbourne.