Chapter 29
Forestry interactions – New Zealand

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Description of geographic region

New Zealand is a small country (about 270,000 km^2) comprising an elongated archipelago with many offshore islands oriented northeasterly to southwesterly in the southwestern Pacific Ocean, with its main islands spanning a latitudinal range of about 34–47°S (Fig. 29.1). Approximately half of the country lies >300 m above sea level, with slopes often greater than 28° (Statistics New Zealand 1998). Mountain ranges dominate the landscape of the South Island, where there are large areas with permanent snowfields and glaciers. These mountains are quite recent (Pliocene age), having formed from the Indo-Australian continental plate pushing up over the Pacific plate. The North Island is hilly, and much of it is steep terrain. A small chain of volcanic mountains that are snow-covered in winter lies near the centre of the North Island; some of these volcanoes are still active. A succession of major volcanic explosions from Lake Taupo has spread pumiceous tephra over much of the centre of the island.

New Zealand's rainfall patterns are largely a result of its long and narrow land mass, its steep topography and its isolated oceanic position. The country's mountainous backbone lies directly across the path of eastward-moving anticyclones and low pressure troughs (Duncan 1992). Although the passage of these weather systems results in high and regular rainfall over much of the country, winter build-up of snow on the mountains holds back runoff that is released later as snowmelt in spring and summer (Fitzharris *et al.* 1992). The north of the country can be subject to tropical cyclonic weather in summer and autumn. Rainfall decreases from west (2000–10,000 mm/year) to east (600 mm/year), with evaporation exceeding rainfall in summer, particularly in the eastern areas and the inland basins of the South Island where droughts are common.

The central North Island area, where most of the major forest plantations are situated, has a rainfall of about 1300 mm/year (New Zealand Soil Bureau 1968a; Tomlinson 1992). In the North Island, snowfalls occur only at higher altitudes, and snow accumulates only on the highest peaks. New Zealand's temperate climate results in relatively cool water. The mean temperature of 256 rivers was 12.6°C, ranging from 5.1° to 21.8°C (Mosley 1982). The soils of the central North Island, formed from rhyolitic pumice that erupted about 1700 years ago, are deep, free-draining pumice, with sandy silt and loamy sand textures that developed under the previous natural podocarp forests.

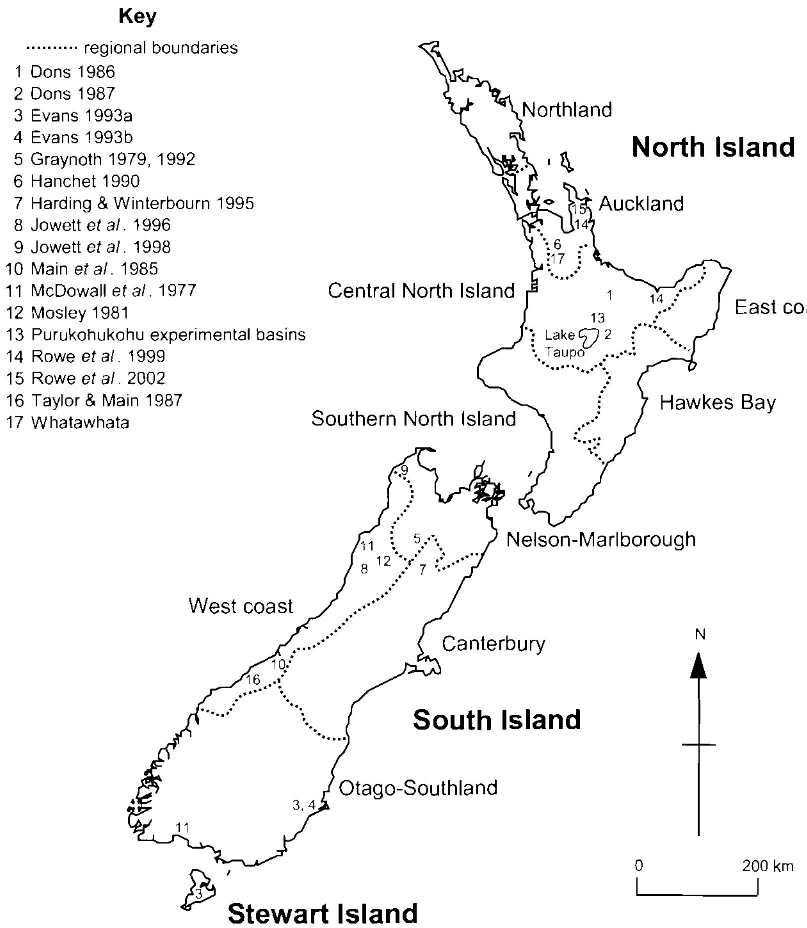

Fig. 29.1 The wood supply regions of New Zealand, showing the sites of selected watershed and aquatic ecological studies mentioned in the text.

The Nelson District of the South Island, where major forest plantations also exist, is predominantly rolling lands and hills, formed mainly from loess-covered, impervious Pleistocene gravels. Rainfall in the area ranges from 1100 to 1300 mm/year (New Zealand Soil Bureau 1968b). The soils are shallow and infertile with stony loam textures and drain slowly.

Major features of aquatic environments

Rivers

In general, the rivers in New Zealand are short, shallow and swift with gravel and boulder beds. The east coasts of both islands have braided rivers. Most rivers flow east or west from the northeast–southwest-lying mountain chains (Duncan 1987). The water is generally poorly buffered, and floods with high sediment loads are frequent. On average, New Zealand's rivers carry 400 million tonnes of sediment from the land to the ocean annually. The intermontane regions of Otago and Canterbury and the low rainfall regions of the North Island have sediment yields of 30–100 tonnes/km^2/year, whereas the other regions have yields of 200–30,000 tonnes/km^2/year (Hicks & Griffiths 1992).

The mountains in the South Island create a wet environment with high river flows on the west coast and a rain shadow with seasonal low flows in parts of the east coast (Tomlinson 1992). The drainages on the western slopes of the mountains of the North Island also periodically experience high flows.

Many of the streams and rivers of the central North Island region are partially spring-fed, with suppressed flood peaks and high, well-sustained base flows. Free-draining tephra soaks up the rainfall, releasing it slowly from springs to provide cool, clear, stable flows. In contrast, the streams draining the Nelson Pleistocene gravels are flashy and have long periods of low to no flow during summer and autumn. Replacement of remnant beech forest, scrub and pasture with plantation forests has reduced the flows in these streams by up to 70% (Duncan 1995).

Lakes

New Zealand has nearly 800 lakes, most of which are small (<5 km^2). They have diverse origins, including tectonism, vulcanism and damming by landslides, dunes and coastal bars (Lowe & Green 1987). Many of the lakes in the South Island have glacial origins, and in the North Island some of the largest lakes have volcanic origins. Lake Taupo (623 km^2), the largest lake in Australasia, is 163 m deep and is oligotrophic. The North Island also contains a diverse array of small lakes associated with sand dunes or floodplains. New Zealand lakes are generally polymictic, and very few ever freeze over in winter.

Wetlands and marshes

About 85% of New Zealand's original 670,000 ha of freshwater wetlands have been drained (Taylor & Smith 1997), mainly for conversion to pasture. The largest remaining wetlands in New Zealand are in the Waikato region where the Kopuatai Peat Dome and the Whangamarino wetland complex are of national significance. In the lower Waikato, wetlands were reduced from their original extent of nearly 200,000 ha to less than 34,000 ha by 1978 (Wardle 1991). Although the rate of loss throughout the country has slowed since this time, some wetland drainage continues with farm improvement.

Important for forestry are the wet heaths, which have ultra-infertile soils underlain by an impervious layer. In the west of the South Island, these wet heaths are known as 'pakihi', and in the north of the North Island as 'kauri gumlands', which formed following the removal of kauri (*Agathis australis*) forest (Wardle 1991).

Estuaries

There are about 300 estuaries around New Zealand (McLay 1976), covering a total area of about 100,000 ha (Taylor & Smith 1997). Most estuaries are short, and many are permanently protected from ocean waves by bars of sand or shingle. Some rivers and streams empty almost directly into the sea, and have no appreciable estuarine area. However, forests of the mangrove *Avicennia marina* var. *australasica* grow in harbours and estuaries of the North Island from about latitude 38° S northwards. Estuaries are sensitive to the accumulation of sediment from tributary streams, and this has been an issue for forestry.

General features of forests

Distribution of major vegetation types

Before human habitation, New Zealand's vegetation was principally evergreen temperate rainforest of conifers and broad-leaved trees. Indigenous forests once covered 23 million ha (85%) of New Zealand's land area; only 2.5 million ha (9%) of the land was above the tree line (Taylor & Smith 1997).

Of New Zealand's forest trees, the most important and widespread are the four endemic beech species (genus *Nothofagus*, family Fagaceae), and the 20 or so endemic species of conifers in the two families Podocarpaceae and Araucariaceae. Forests in the north were dominated by the giant kauri, of which little remains. The kauri is the sole New Zealand representative of the family Araucariaceae. It is the giant of the New Zealand forest, reaching a height of 60 m with a trunk diameter up to 7 m (Wardle 1991). Broad-leaved dominants, puketea (*Laurelia novae-zelandiae*), puriri (*Vitex lucens*), taraire (*Beilschmedia tarairi*), tawa (*B. tawa*) and towai (*Weinmannia silvicola*) also occur in the north. Throughout the country, depending on site characteristics, a variety of coniferous podocarps have become canopy trees (totara, *Podocarpus totara*; rimu, *Dacrydium cupressinum*; miro, *Prumnopitys ferruginea*; matai, *P. taxifolia*; kahikatea, *Dacrycarpus dacrydioides*), usually mixed with broad-leaved and beech species. Forests in the south are dominated by the southern beeches (*Nothofagus* spp.), the broad-leaved kamahi (*Weinmannia racemosa*) and southern rata (*Metrosideros umbellata*; Wardle 1991).

Most of the remaining native forest is in the South Island, and 40% of the total occurs in Southland and West Coast regions. After human habitation, beginning about 900 AD, fire destroyed most of the forest in the eastern half of the South Island and much of the central and eastern North Island (Wardle 1991). More forest was cleared for agriculture from about 1840, with the result that native vegetation was greatly modified in some places.

Ecological and forestry distinctiveness

The islands of New Zealand have been isolated from other land masses for about 70 million years, and successive glaciations created waves of extinctions that resulted in a depauperate flora and fauna with a high degree of endemism. Before the arrival of humans the only native land mammals were bats. With human habitation came rats, mustelids, browsing and grazing mammals such as deer, rabbits, Australian possums, goats, chamois and thar, as well as fish such as the salmonids and cyprinids (Wardle 1991). New Zealand also has numerous exotic land plants and aquatic weeds.

New Zealand's indigenous flora has some 2300 vascular species, about 85% of which are endemic. This flora has biogeographical affinities with southeastern Australia, Chile and South Africa. Genera of the Podocarpaceae with commercially harvestable trees are *Podocarpus*, *Dacrydium*, *Prumnopitys* and *Dacrycarpus*. However, the regeneration and growth rates of the native trees that attain commercial sizes are considered too slow to support commercially viable forestry; many individual trees are from several hundreds to a thousand or more years old. Kauri, for instance, has an annual increment of 4.5–7.5 m^3/ha, and rimu only 1.2–1.8 m^3/ha. The annual increment for the beech species is greater (5–17 m^3/ha), but does not match that of introduced radiata pine (*Pinus radiata*) in New Zealand, which has a normal annual increment of 23–36 m^3/ha, with a maximum of 50 m^3/ha (Wardle 1991). Radiata pine originated in Monterey, California. Although many other coniferous species have been tried as plantation forest species, none has matched the realized growth and wide range of site suitability of radiata pine. Some forestry species, such as lodgepole pine (*Pinus contorta*) now create environmental problems with their ability to spread by wind dispersal and invade sensitive habitats (Taylor & Smith 1997).

Distribution of logging

For administrative purposes, New Zealand is divided into 10 wood supply regions (Fig. 29.1). The land area in plantation forest is 1.8 million ha, 71% of which is in the North Island, with 33% in the Central North Island region alone (Table 29.1).

Major fish communities

Life history characteristics and ecological features

New Zealand's long isolation from other land masses, the severe cyclical effects of the geologically recent ice ages and vulcanism have limited the indigenous freshwater fish fauna. Up to 1995, New Zealand had 27 recognized species of truly freshwater fishes and 7 marine wanderers that occasionally frequent fresh waters (McDowall 1990). However, since 1995, several new species have been recognized following genetic examination, discoveries of new fish and reinstatement of species. There are 36 indigenous species (McDowall 2000), and there may still be more undescribed taxa (McDowall 2001).

Typically, the fish faunas of New Zealand streams and rivers are characterized by few species and variable abundance, with densities ranging from 4.5 to 362 fish/100 m^2 (Jowett & Richardson 1996; Rowe *et al.* 1999). In some small pastoral streams, fish

Table 29.1 Areas of plantation forest in New Zealand in 2000 by wood supply region (see Fig. 29.1)

Wood supply region	Land area in plantation forest (ha)
North Island	
Central North Island	575,607
Northland	203,458
Southern North Island	155,777
East Coast	149,722
Hawkes Bay	120,934
Auckland	54,720
South Island	
Otago-Southland	186,638
Nelson-Marlborough	173,606
Canterbury	114,244
West Coast	33,932

Source: Ministry of Agriculture and Forestry (2001), Table A8.

biomass comprising mainly eels can be very high (80–90 g/m^2; Hicks & McCaughan 1997; Rowe *et al.* 1999).

With the exception of eels and salmonids, the fish in New Zealand are relatively small. Eels (*Anguilla* spp.) dominate most fish communities by number and weight. Fish density and species richness in rivers tend to decrease with distance from the coast, reflecting the importance of passage for fish colonizing from the sea. Many riverine fish communities are structured by diadromy (i.e. the migration of fish between the sea and fresh water; McDowall 1993). About 50% of New Zealand's native fish fauna is diadromous, and three patterns of diadromy are common. Southern lampreys (*Geotria australis*) and many populations of the common smelt species (*Retropinna retropinna*) are anadromous, spawning in fresh water, but returning to the sea to rear to adulthood. Eels are long-lived and catadromous (i.e. spawn at sea and rear in fresh water), and occur in virtually all waterways draining to the sea. The bullies and galaxiids are amphidromous, migrating downstream to the sea as larvae and then back upstream some months later as larger juveniles. In lakes, the common smelt, and some bully and galaxiid species, can form populations that never go to sea.

There are 21 introduced freshwater fish species (McDowall 2000). With the exception of sea-run chinook salmon (*Oncorhynchus tshawytscha*) and some brown trout (*Salmo trutta*) populations, the salmonids in New Zealand are wholly freshwater resident; although rainbow trout (*O. mykiss*) can move from river to river by means of the sea, no anadromous stocks are known to exist.

Fish distributions in localized areas are quite well known because of fisheries surveys that have been conducted for a variety of reasons. For example, a scheme to log indigenous beech forests of the West Coast and Southland regions prompted extensive sampling of the fish populations in these regions (McDowall *et al.* 1977). The fish diversity recorded (16 native and 3 introduced species) was not high by world standards, but is typical for New Zealand streams. Similar fish species compositions have been reported by others, with a high proportion of large galaxiid species in forest streams of the West Coast of the South Island (Main *et al.* 1985; Taylor & Main 1987). Streams and rivers of the unmodified forest of the Kahurangi National Park had 12 species of native fish and brown trout, and a lower diversity and abundance of fish than at equivalent elevations in other areas of New Zealand (Jowett *et al.* 1998).

Eels, bullies, galaxiids and salmonids feed mainly on aquatic invertebrates, but also on terrestrial invertebrates, especially the large galaxiids in forest streams (e.g. Main & Lyon 1988). In small North Island streams, 44% of the diet of longfinned eels in native forest comprised terrestrial taxa, including cicadas, harvestmen, spiders and green beetles; 38% of the diet in plantation forest streams was terrestrial (Hicks 1997). Large eels and salmonids can be piscivorous, especially in lakes. There is generally a lack of herbivorous fish in New Zealand among the native fauna, although herbivores such as rudd (*Scardinius erythophthalmus*) have been introduced.

Fisheries values

Eels are highly valued by the native Maori people as a customary fishery and some localized fisheries for lampreys and whitebait (juvenile galaxiids) still remain. In addition, eels and whitebait support major commercial and recreational fisheries for all New Zealanders. The salmonids, principally rainbow trout, brown trout and chinook salmon, provide major recreational fisheries (McDowall 1990). The extensive lakes and their tributaries of the central North Island have world-renowned fisheries for rainbow trout (McDowall 1990), whereas brown trout form the majority of fisheries in the South Island.

Forestry practices in New Zealand

Historical background

The first commercial harvest from New Zealand's forests occurred in the late 1700s, following Captain James Cook's observations of the potential of the trees for mast building (Roche 1990). Young kauri trees (rickers) were cut for ships' spars for the British Royal Navy before 1820, and kauri logging reached a peak of 1 million $m^3/year^{-1}$ in 1907 (Roche 1990). Driving dams played a crucial part in transporting kauri logs down to tidal waters and harbours, where logs were loaded onto ships or made into rafts for transport to sawmills or for export (Halkett 1991). Drives of kauri logs were very destructive, sweeping everything before them, and tearing undergrowth and small trees from the stream banks (McDowall 1990; Halkett 1991). Kauri harvest declined between 1908 and 1922, and was partly replaced by harvest of rimu and kahikatea (or white pine).

Plantation forests were first established in New Zealand in the early 1900s with prison labour (Coker 1992). Following the imminent demise of the kauri harvest and reduction in the amount of merchantable timber from indigenous forests, there was

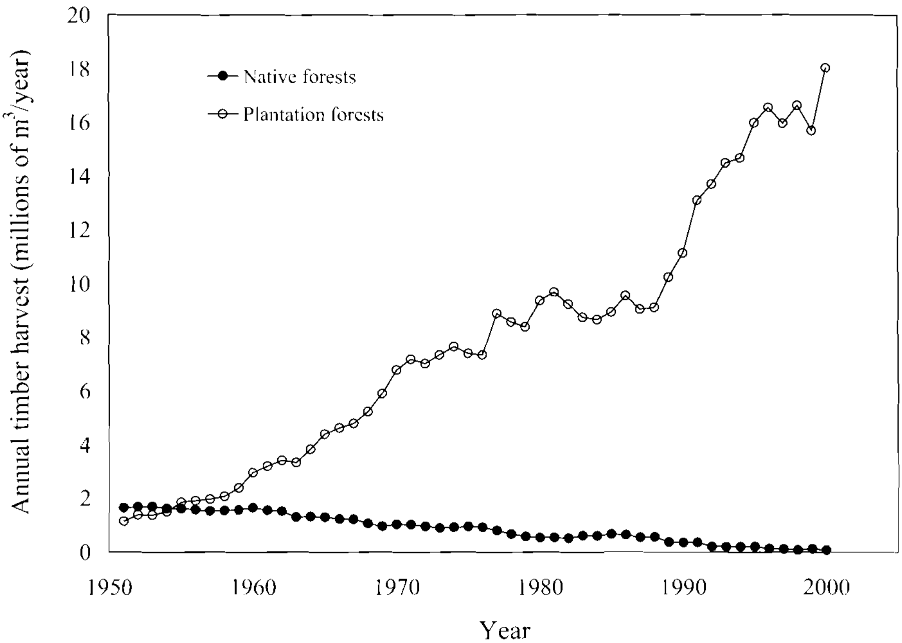

Fig. 29.2 Timber harvest as estimated by annual round wood removals from native and plantation forests in New Zealand between 1951 and 2000. Source: Ministry of Agriculture and Forestry (2001), Table A11.

major growth in afforestation with introduced tree species in the late 1920s to mid-1930s; by 1936, the total area of plantation forest had reached 317,000 ha (Coker 1992). Up until the mid-1970s, native forest was generally cleared to make way for plantation forest. This practice was phased out by the mid-1980s and any expansion of the plantation forest estate is now on marginal farmland. During the past four decades, the harvest from plantation forests has increased dramatically, while the harvest from native forests has fallen (Fig. 29.2). By 2000, the harvest from native forests had dropped to 76,000 m^3 while that from plantation forest had increased to 18 million m^3.

Extensive plantation forests have been developed in both islands of New Zealand, but development has been particularly extensive on the Central Plateau of the North Island. Free-draining volcanic soils and year-round rainfall provide ideal site conditions for the growth of radiata pine. Plantings in the North Island's central volcanic region occurred where 'bush sickness' (cobalt deficiency) in sheep and cattle prevented pastoral farming.

New Zealand's 10.7 million ha of forests and shrub land now cover about 40% of the land area. This area includes 6.3 million ha of indigenous forest in addition to the exotic plantation forests. Radiata pine comprises 90% of the total plantation forest estate, and Douglas fir (*Pseudotsuga menziesii*) about 5%. Hardwoods comprise about 3%, the most important being the Australian *Eucalyptus* species (Ministry of Agriculture and Forestry 2001).

Recent and current forestry practices

Once harvested, almost all areas of forest that are harvested in New Zealand are replanted. In addition, large areas of erosion-prone pasture have been recently afforested with radiata pine to control soil erosion and mass wasting. After intense cyclonic rainfall in 1988, land areas in established plantation forest in the East Coast wood supply region of the North Island had similar rates of landslides to undisturbed native forest (0.048–0.066 landslides/ha). Equivalent areas in pasture had an eight-fold greater rate of landsliding (0.564 landslides/ha; Maclaren 1996).

Preparation for planting

Very little preparation for planting is required on pastoral land, but herbicide treatment, burning, or windrowing has been used on sites that have gorse (*Ulex europeaus*) or other weeds. Sites with hard pan, such as pakihi, are sometimes ripped (deeply scored) to improve drainage and root penetration (Maclaren 1996).

Fire was considered a cheap form of site preparation as late as 1986, but is currently rare because of the costs of fire control, risks to surrounding forest, and environmental effects (Roberts 1994; Maclaren 1996). An alternative method of site preparation is windrowing, where slash left over from forest harvest is mechanically piled into rows or heaps (Maclaren 1996). Weed suppression by chemicals or oversowing with grasses and legumes is also used.

Optimal tree stocking densities for radiata pine depend on site quality, and general forestry practice is to plant more trees than are required for the final crop. Mature stands of radiata pine of ≥200 trees/ha will intercept most of the sunlight falling on a site, and the original stocking density may be about 400 trees/ha. In erosion-prone sites where the aim is to achieve closed canopy as fast as possible, densities of 1000 trees/ha may be planted (Maclaren 1993).

Forest maintenance

Radiata pine in New Zealand generally matures in 25–35 years (Maclaren 1996). During the growing cycle, thinning is usually carried out at least once a rotation to achieve canopy closure without stunting tree growth, and to ensure maximum production of knot-free wood. Early thinning to waste, in which the cut trees are left on the forest floor, usually occurs 3–6 years after planting. Production thinning at 10–16 years yields trees large enough to be merchantable. Pruning to maximize the amount of knot-free wood is often carried out twice a rotation, and is based on tree diameter. On sites with good tree growth, pruning can begin at 3 years of age. Weed control is essential to guarantee high seedling survival and uniform subsequent growth (Maclaren 1993).

Animal browsing can damage foliage and bark, especially during the establishment phase. Pest control to reduce browsing is important where rabbits, hares, possums, or deer are present. Trapping and 1080 poison (sodium monofluoroacetate) are often used to control possums (Maclaren 1993). Persistence of 1080 in the soil or waterways is short (Eason *et al.* 1992). For established trees, grazing can be used to control grass and weed growth, and at stocking rates of 200 trees/ha enough light penetrates the canopy to permit 'agroforestry' (i.e. a combination of grazing and tree growth; Maclaren 1993).

New Zealand is free from most diseases of forest trees, but fungal diseases such as needle blight (*Dothistroma pinii*) affect radiata pine. *Pinus ponderosa* and *P. nigra* are even more susceptible, but these species have now been almost completely replaced by radiata pine and Douglas fir. Regular spraying with low rates of fungicides is required to control *Dothistroma*, depending on season and locality (Coker 1992). The copper-based fungicides that are generally used have negligible effect on waterways (Fish 1968). Insect pests such as pinhole borer (*Platypus* spp.) and the wood wasp (*Sirex noctilio*) can be locally important, and biological control has been partially effective in the case of *Sirex* (Taylor & Smith 1997).

Road building

Road building was a prominent feature of logging in the 1970s, especially in steeper areas such as the northwest of the South Island. Unpaved skid tracks followed hill contours at intervals of 30–40 m during logging in the Golden Downs State Forest (Graynoth 1979).

Roads, tracks and landings (areas used for aggregation of logs during harvesting) that are permanently out of production can account for 3–8% of the total forest area (Coker 1992), and many are unpaved. Unpaved roads are an important source of sediment from forests, and sediment yield increases with use from 2 to 500 tonnes/km for lightly to heavily used roads (Maclaren 1996). Most sediment from roads is caused by traffic during storm events. Reducing tyre pressure from 90 to 30 psi decreases sediment production by as much as 84%.

Harvest methods

The most common harvest practice for plantation forest is clear felling in coupes (harvest blocks) of about 25 ha (Maclaren 1996). This form of harvest is considered the most economic and allows re-establishment of shade-intolerant species such as radiata pine. Ground-based logging operations (e.g. caterpillar tractors and rubber-tyred log skidders) generally work on slopes <25% (Coker 1992). These skidder logging and ground-based extraction systems were once used almost exclusively, and can result in considerable soil disturbance. As steeper slopes were planted and the forests reached maturity, there has been a move towards cable logging systems (O'Loughlin *et al.* 1980). Cable logging systems generally haul logs uphill along the ground to a prominent knob of land that commands a wide area within the economic hauling distance of the machine (generally about 400 m; Coker 1992). However, downhill cable systems where logs are lifted clear of the ground result in lower sediment yields than uphill systems. Sediment yields from downhill yardage systems can be similar to those of unlogged controls (O'Loughlin *et al.* 1980).

Transportation, storage and processing

Transportation of logs is mainly by truck, with some rail transport. During the harvest phase, truck traffic increases considerably, which can lead to increased sediment yields from unpaved roads (Maclaren 1996). There are several large mills in New Zealand, mostly in the North Island because of their proximity to the extensive forest estate in the centre of the island. These mills produce a variety of wood products, from pulp and paper to fibreboard and timber for construction. Effluent from some mills has been a long-standing source of environmental pollution, despite considerable improvements in effluent quality, e.g. the Tarawera River (Kanber *et al.* 2000).

Effects of forestry practices on fish and fisheries

The effects of forestry on fish may be divided into (1) the afforestation phase (including forest growth) and (2) the timber harvest phase. Our knowledge of the impacts of the afforestation phase is quite good, at least from the viewpoint of the physical effects on fish distribution. However, direct evidence of the effects of timber harvest on fish is limited, although inference can be made by considering effects on sediment yield, wood supply to streams, invertebrates and water quality.

Historical background

Growing concern over the effects of forestry practices on fish and fisheries in the mid-1970s prompted a review of the subject (Morgan & Graynoth 1978), and the effects of forestry practices and buffer strips on streams and their faunas were studied in the Golden Downs State Forest, Nelson District, South Island. A 30-m wide buffer strip of unlogged native forest may have protected the native fish fauna from the negative effects of timber harvest, especially the high concentrations of suspended sediment resulting from rainfall on exposed surfaces. Sediment concentrations were 13–860 g m^{-3} in logged reaches without buffer strips, compared with 7–124 g m^{-3} in the reach with buffer strips, and 2–22 g m^{-3} in unlogged stream reaches (Graynoth 1979). The buffer strips may also have protected the invertebrate fauna from the effects of logging, but did not prevent increased nitrate concentrations that occurred after timber harvest. A combination of greater fine and coarse sediment and warmer stream temperatures are thought to have substantially reduced the abundance of dwarf galaxias (*Galaxias divergens*) and eels in the logged reaches without buffer strips.

Several studies in the 1980s focused on basin hydrology and nutrient yield from plantation forests at the Purukohukohu experimental basins of the central North Island (e.g. Cooper *et al.* 1987; Cooper & Thomsen 1988; Fig. 29.1). The concentrations of total phosphorus and dissolved reactive phosphorus from plantation forest were intermediate between pasture and native forest, with more in the pasture stream than in the native forest stream. The median monthly concentration of nitrate over 14 years was, however, much greater in the native forest stream (805 mg m^{-3}) than in the plantation forest stream (176 mg m^{-3}), and was lower still in the pasture stream (13 mg m^{-3}; Cooper *et al.* 1987). The researchers ascribed the differences between land uses to different processing rates, concluding that the stream in plantation forest had a high capacity to remove nitrate from the stream waters (Cooper & Thomsen 1988). However, contrary results were observed in streams at Whatawhata (Fig. 29.1), where mean dissolved inorganic nitrogen concentrations were 180, 390 and 800 mg m^{-3} in native forest, plantation forest and pasture, respectively (Quinn *et al.* 1997). The cause of the difference between the Purukohukohu and Whatawhata studies has not been adequately explained, but streams draining native forest in the central North Island appear to have higher nitrate concentrations than native forest streams in other parts of the country.

In 1990, fishery biologists and resource managers met to discuss the impacts and remedies of forestry on physical and biological processes in rivers, mainly from studies in western North America (Hayes & Davis 1992). Since then, this subject has attracted considerable research in New Zealand, mainly on the effects of forestry practices on water quality and benthic invertebrate communities in streams.

Recent and current effects

Watershed hydrology and fluvial geomorphology

Forest harvest affects water yield and stream hydrology. The immediate response to land clearing in preparation for forest planting is an increase in water yield. In the first year after timber harvest, increases in annual water yield have ranged from 168 to 650 mm, depending on precipitation (Fahey & Rowe 1992). In these studies, annual precipitation ranged from 1069 to 2827 mm, and the original vegetation was manuka (*Leptospermum scoparium*), gorse or native forest.

Once a planted forest of radiata pine has become established, water yield is usually reduced significantly. A number of studies have shown that conversion of scrub and indigenous forest to plantation forest reduces stream flow (Fahey & Rowe 1992). Between 1964 and 1981, 28% of the Tarawera River drainage basin was afforested, principally with radiata pine. Tarawera River flows diminished following afforestation, and 13% of the decrease was attributed to the afforestation (Dons 1986); the decrease in flow continued into the early 1990s (Pang 1993).

Annual water yields after afforestation with radiata pine have tended to stabilize at about 150–200 mm below the previous yields from native vegetation (Fahey & Rowe 1992). The effect is greatest in small basins, where water yield from plantation forest is 50% less than the flow from pasture, and 25% less than the flow from native forest (Dons 1987). As the primary mechanism for reduced low flows appears to be interception of rainfall, flow reductions following afforestation with radiata pine are most severe in areas with low rainfall (Taylor & Smith 1997).

Water yields from established plantations of radiata pine 8–21 years of age were 230–290 mm lower than those from pasture, but flood flow was also reduced (Fahey & Rowe 1992). Thus the effect of reduced low flows may be offset somewhat by reduced flood severity.

Afforestation of pakihi wetlands is only possible after ripping or V-blading to break through the hard pan (Fahey & Rowe 1992; Maclaren 1996). This procedure disturbs about two-thirds of the land surface area in the plantation and can lead to higher and more frequent peak flows (Fahey & Rowe 1992). Also, runoff from roading works can increase a stream's drainage network and its peak discharge (Harding *et al.* 2000). During harvest, greater flow variability can be expected until the replanted forest grows.

The influence of forestry on sediment yield is generally much less than that caused by variations in rainfall around the country and, except during harvest phases, plantation forests generate only 20–60% of the sediment yield of pasture. However, in the high rainfall area of the West Coast, sediment yield increased up to 100-fold following clear-felling of native forest (Hicks & Griffiths 1992).

The role of woody debris in controlling channel morphology has not been widely studied in New Zealand, but can be important in small streams. Large woody debris (LWD) controlled channel morphology and bed-load transport in the west coast of the South Island (Mosley 1981), and LWD was retained even after a large flood in a second order stream on the east coast of the South Island (Evans *et al.* 1993b).

Quantitative studies of wood loadings in plantation forests are few, and radiata pine forests tend to have relatively small amounts of LWD compared with some of the higher loadings for streams in coniferous forests of North America. In New Zealand, however, streams in plantation forests >15 years old have similar wood loadings (mean 112–245 m^3/ha) to streams in ancient native forests (mean 101 m^3/ha; Evans *et al.* 1993a). Streams in younger radiata pine plantations (10 years old) have much less wood (mean 2.4 m^3/ha; Evans *et al.* 1993a). Radiata pine logs can remain intact in streams for over 20 years (Collier & Baillie 1999), so are likely to be important for stream structure, especially in the pumice-bed streams of the central North Island (Collier & Halliday 2000).

Streams and rivers

Studies by Graynoth (1979) in the Nelson District indicated that pine harvesting without buffer strips can reduce the abundance of fish in streams. In a re-evaluation of the effects of logging in the Nelson area 16 years later, stream flows appeared to be lower than in 1973–1974. While the most severe effects of sediment on the fish populations appear to have been short-lived, the lowered stream flows that occurred as the plantation forest grew to maturity lasted longer, and reduced some stream reaches to a series of disconnected pools. Brown trout, eels and upland bullies were less abundant in 1990 than in 1973–1974 (Graynoth 1992).

On the other hand, Harding *et al.* (2000) maintain that while headwater streams may become ephemeral or completely dry under plantation forest, the loss of habitat may be compensated to some extent by the greater width of stream channels in forest catchments downstream (Davies-Colley 1997) and improved habitat conditions provided by forest cover compared with pasture.

Recent studies indicate that the native fish faunas of streams in mature pine forests planted on pasture are similar to those in native forests, but not to those of pasture land (Hicks & McCaughan 1997; Rowe *et al.* 1999, 2002). Similarly, benthic invertebrate community composition in plantation forest streams more closely resembles that found in native forest streams than pasture streams (Quinn *et al.* 1997), although there are significant differences in relative abundance of some key species such as mayflies, stoneflies and caddisflies (Harding & Winterbourn 1995). Adult caddisflies caught by light trapping within 2 m of stream margins were lower in species diversity and overall abundance in pine forest than in native forest and pasture streams (Collier *et al.* 1997b).

The effect on fish and invertebrates of converting pasture land to plantation forests was investigated in a suite of studies conducted in hill country near Whatawhata, Waikato region, North Island. Physical habitat characteristics, algal productivity, and fish and invertebrate abundance were compared in Waikato River tributaries in native forest, 18-year-old plantation forest of radiata pine, and pasture. Fish were more abundant in pastoral streams than in forest streams, and therefore afforestation of pasture land is likely to reduce fish abundance. Native fish biomass (mainly eels) was four times greater (Table 29.2), and density was seven times greater, at pasture sites than in plantation sites. The likely cause of greater fish abundance in pasture streams than forested streams at Whatawhata is increased production due to greater light availability, higher mean and maximum water temperatures, and greater dissolved inorganic nitrogen concentrations. There were greater gross photosynthesis and invertebrate densities and biomass in the pasture streams (Quinn *et al.* 1997).

Fish abundance in plantation forest streams showed many similarities to native forest streams. The density and biomass of fish in plantation streams were similar to

Table 29.2 Fish biomass in North Island streams at 11 west coast sites at Whatawhata (Hicks & McCaughan 1997) and 19 east coast sites (Rowe *et al.* 1999)

	Fish biomass (g/m^2)		
Species	Native forest	Plantation forest	Pasture
North Island – Whatawhata			
Longfinned eel	11.10	18.50	60.00
Banded kokopu	1.32	0.07	0.00
Shortfinned eel	0.40	0.50	28.80
Cran's bully	0.00	0.23	0.29
Redfinned bully	0.00	0.02	0.00
Common smelt	0.00	0.00	0.70
Total	12.82	19.32	89.79
North Island – east coast sites			
Longfinned eel	9.24	16.50	47.60
Redfinned bully	1.60	1.42	1.22
Banded kokopu	1.22	0.56	0.01
Shortfinned eel	0.58	0.42	30.50
Common smelt	0.12	0.16	1.17
Inanga	0.00	0.60	0.86
Total	12.76	19.66	81.36

those of native forest, and east coast streams had very similar fish biomasses to west coast streams in the North Island (Table 29.2). Stable isotope analyses showed that leaf litter rather than epilithic diatoms was the primary source of carbon and nitrogen for the food webs in both native and plantation forests (Hicks 1997). However, the greater allochthonous inputs to forested streams (Quinn *et al.* 1997) failed to compensate for the reduced light availability. Dissolved inorganic nitrogen concentrations and gross photosynthesis in plantation forest streams were intermediate between pastoral and native forest streams. Light availability was, however, similar in plantation and native forests.

The number of fish species was low in Whatawhata streams (mean number of species 2.3–3.0), possibly because of barriers to the upstream migration of fish. In streams at 19 coastal sites in native forest, plantation forest, and pasture on the east coast of the North Island, there were more fish species (mean number of species 3.8–4.7) and fish densities were 2–10 times greater than at Whatawhata. Fish biomass in equivalent land uses was, however, almost identical (Table 29.2; Rowe *et al.* 1999). This suggests that light and nutrient availability caused by land use was similar in the different regions. In another study of Coromandel streams, the abundance of eels and redfinned bullies increased in the post-harvest period. Streams with undisturbed riparian forest had greater densities of native fish than those lacking such strips (Rowe *et al.* 2002).

Some differences between fish abundance in streams in native and plantation forest are contradictory. Banded kokopu, redfinned bullies and shortjawed kokopu were found at fewer sites in plantation forest compared with native forest sites in the Waikato region, whereas giant kokopu, shortfinned eels and Cran's bullies occurred more frequently in plantation forest (Hanchet 1990). Hanchet postulated that increased fine sediment loading in plantation forest streams was responsible for the differences in fish distribution. These plantation forests were planted on pasture land 18 years before the study, and stream channels had abundant fine sediment, possibly as a result of channel widening (Davies-Colley 1997). However, at the North Island east coast sites there was no significant difference in banded kokopu biomass between forest types (Rowe *et al.* 1999).

In tributaries of the Grey River on the west coast of the South Island, lamprey ammocoetes were more abundant in plantation forest than in adjacent native forest. As lamprey ammocoetes are generally found in silty backwaters, these plantation forest streams might have had more fine sediment than native forest streams, although this was not measured. Dwarf galaxias and bluegilled bullies were more abundant in native forest than in plantation forest sites (Jowett *et al.* 1996).

Forestry activities can have marked impacts on benthic invertebrate community composition, mainly through alteration of light availability, stream hydrology, morphology and water chemistry, especially where riparian buffers are not provided. Benthic invertebrate communities are resilient, however, and communities can resemble their pre-impact state within 10–15 years (Harding *et al.* 2000), or earlier, depending on the state of the riparian vegetation and proximity of sources of recolonists.

Wood in streams can be an important component of fish habitat, and slash overlying streams can reduce water temperature fluctuations (Collier *et al.* 1997a). However, where large amounts of slash (branches and tops) remain submersed following logging, dissolved oxygen can be lower than in reaches with slash removed (Collier *et al.* 1997a). Pine wood in streams can act as a substrate and food for stream invertebrates (Collier & Halliday 2000).

Wetlands

Information on forestry impacts on wetlands is sparse, although some exists for West Coast pakihi swamps. In preparation for planting with pine, these swampy areas are extensively channelized for drainage and the soils are enriched with phosphate fertilizers. Studies comparing modified with unmodified wetlands have shown that conversion to plantation forest has resulted in increased water temperature (Collier *et al.* 1989). The lower pHs and reduced number of invertebrate taxa found at sites that had been recently V-bladed and planted with radiata pines were attributed to the location of these sites in acidic wetlands rather than the effects of afforestation. However, these changes did not appear to be long-lived, and in one case, after 8 years, the species composition of the impacted invertebrate communities was similar to that of native forest streams (Valentine 1995).

Lakes

Nothing is known of the effects of forestry on fish populations in New Zealand lakes despite the extensive plantation forest in the drainage basins of some sand dune lakes and lakes in the central North Island. Forest planting may have reduced water levels in some northern dune lakes in the North Island with dwarf inanga (*Galaxias gracilis*), but there was no relationship between water level changes and dwarf inanga abundance (Rowe & Chisnall 1997).

Estuarine and coastal waters

Virtually no studies have been done on the effects of forestry on estuarine and coastal environments in New Zealand. For example, in the Marlborough Sounds situated at the north end of the South Island, steep hillsides with pine plantations have been logged close to sea level. Such activity almost certainly has considerable negative effect on water quality near-shore. However, coastal environments in New Zealand are reasonably well flushed and such impacts may not persist for extended periods.

Environmental effects from processing mills

Large pulp and paper mills in the central North Island have, in the past, discharged poorly treated effluent into waterways, especially from kraft processing and chemical pulping, which affected fish and invertebrate abundance and community composition (Scrimgeour 1989). More recently there has been a move towards thermomechanical pulping, which improves effluent quality.

Large amounts of pentachlorophenol (PCP) were used by the New Zealand timber industry as an anti-sapstain fungicide that was applied to the timber surface immediately after milling. Sawmills have also produced effluent discharges, and PCPs have built up in soils around treatment sites and in the sediment of Lake Rotorua in the central North Island. PCPs are toxic to a range of zooplankton (Hickey 1989; Willis *et al.* 1995). The technical grade of PCP used contained about 20% tetrachlorophenol and about 5% of other contaminants such as dibenzodioxins and dibenzofurans, and was more toxic than 'pure' PCP, which contained about 5% of these impurities (Willis *et al.* 1995). The larval stages of common smelt, inanga, koaro and common bullies are very sensitive to PCP, showing similar sensitivity to rainbow trout fry (Hannus 1998). Although the use of PCP as a timber treatment is no longer prevalent, many contaminated sites and waterways exist in localized areas (Taylor & Smith 1997).

Needs and recommendations for improvement of forestry practices and standards

The influence of forestry on New Zealand's environment, principally through the trend of conversion of steep pasture to plantation forest, is largely positive, but there are several areas in which improvements can still be made. A code of practice for forestry operations was developed to help forest managers to plan, manage and carry out forestry operations in a sustainable manner (Vaughan *et al.* 1993). Forest Research Ltd, the crown research institute responsible for research into forest management, has continued commitment to sustainable forest management, and current research initiatives include improvements in the treatment of mill effluent and the search for new tree species. Harvest of native forests on crown-owned land was recently halted (Griffiths 2002), but logging of native forests on privately owned land continues.

The timber processing industry in New Zealand has substantially reduced use of elemental chlorine for bleaching wood pulp, and now uses chlorine dioxide, which produces far fewer chlorinated hydrocarbons in the mill effluent. A series of anti-sap-staining chemicals has replaced PCP, and there is current research into biocontrol of sapstaining fungi.

Increased efficiency of wastewater recovery and water use within mills now occurs, so that less water is required. The performance of secondary treatment systems is being optimized by additional treatment systems within mills. In general, New Zealand mills are in the top 25% of mills worldwide for environmental performance. The quality of receiving waters has improved with modernization of pulp and paper mills, especially with improvements in the bleaching process, but a gradient in faunal composition associated with effluent discharge at some sites was still apparent in the early 1990s. There were fewer crayfish (*Paranephrops planifrons*) but more goldfish (*Carassius auratus*) at the site receiving mill effluent compared with more distant sites (Sharples & Evans 1998).

Roading

Barriers to upstream fish migration can be caused by dams, water intake weirs and road culverts. The timber harvest phase requires a well developed roading network that should minimize the number of stream crossings to reduce the potential for creating barriers to fish passage. Where stream crossings are unavoidable, guidelines for improved culvert design and a summary of the swimming and climbing ability of native and introduced fishes are available (Boubée *et al.* 1999). Fish passage is an area of ongoing research.

Sediment control during logging will always be a problem with ground-based harvest techniques. Paradoxically, improved protection of riparian buffers around headwater streams might require more roading and landings than harvest regimes without buffers, which is likely to increase sediment yield.

Planting

Preparation for planting

Burning has been largely phased out, partly to retain more nutrients in the soil between rotations. Chemical weed control is in many cases a better alternative for site preparation than burning. In addition, there has been a move away from systemic hormone-based chemicals to species-specific and spot treatments. Stream edges are an area of special concern during planting, and many first rotation stands were planted to the stream edge following land clearance. Streamside trees can lean out over the water and be difficult to fall back onto the land (Coker 1992). As early plantings are harvested, stream edges should not be replanted with the commercial crop. Most current practices avoid planting commercial trees in the riparian zone.

Tree species

Cypresses, acacias and some native species are being investigated as alternatives to radiata pine. Realistically, because of its fast growth and short rotation time, radiata pine will probably always be favoured by the forestry industry. Improvements in selecting genetic stocks for specific sites and cloning have the potential to maximize production and shorten rotation times. As rotation times are being reduced from 35 to 25 years on average by these methods, the fish fauna may spend a large proportion of the rotation recovering from the effects of timber harvest.

Riparian margins

Dense ground cover in the riparian strips has been demonstrated to reduce sediment ingress to streams during harvesting, and detailed guidelines have been prepared for management of riparian zones in agricultural settings in New Zealand (Collier *et al.* 1995a, 1995b). These guidelines suggest appropriate species for planting, and consider the role of riparian vegetation in providing bank stability, managing water temperatures, terrestrial carbon inputs and attenuating flood flows. In addition, a decision support system is under development by the National Institute of Water and Atmospheric Research and Forest Research to promote objective and effective riparian management to sustain in-stream environments within plantation forests (Murphy *et *al.* 1998; Collier 2001). Stream shade and nutrient inputs have also been considered (Rutherford *et al.* 1999). Sediment entry into streams during timber harvest is still a problem where suitable buffer strips are not provided, especially on erosion-prone sites. Sediment can bypass riparian zones by way of ephemeral channels, but slash left on slopes can help prevent sediment mobilization.

The shade provided by riparian forest lowers water temperature, minimizing temperature extremes. Where riparian forest is removed during timber harvest, water temperatures on summer afternoons can rise by 3–8°C in unshaded reaches, emphasizing the importance of maintaining riparian shade through the harvest phase of the forestry cycle (Maclaren 1996). The decrease in light caused by riparian shade under plantation forest is likely to result in lowered aquatic biomass compared with pasture streams, as demonstrated by the lower fish and invertebrate biomass in both native and plantation forest.

Timber harvesting

Harvest techniques

On steep ground, cable logging is an acceptable alternative to the ground-based skidder and tractor operations. Downhill hauling that keeps earthworks away from streams and avoids dragging logs along the ground is preferable to hauling by cable to an uphill landing. Where this is unavoidable, trimming of limbs should occur away from the landing so that an unstable 'bird's nest' of limbs and tops does not accumulate around the landing. Harvest operations should avoid suspending logs above riparian zones, and should instead haul away from streams by making them boundaries. Harvest method influences the volumes of small and large woody debris, with methods that haul across the stream contributing the most wood (Baillie *et al.* 1999). Helicopter logging has been used in some selective logging operations.

The amount of wood that remains in streams after harvest depends to a large extent on harvest method and riparian protection (Baillie *et al.* 1999), and the influence of wood in different settings has yet to be fully evaluated (e.g. Collier & Halliday 2000). Research continues into optimal post-harvest treatment of wood in streams to balance the needs of fish and invertebrates.

Conclusion

Plantation forestry is generally a benign land use in New Zealand. During the growing cycle, fragile hill slopes are protected from erosion, and sediment yields are lowered, especially compared with pasture. During the harvest cycle, however, some impacts on the aquatic environments are inevitable. Good management can reduce these effects, and speed recovery following logging and establishment of the new tree crop. One impact of the growing cycle cannot be mitigated: lowered water yield remains an unavoidable consequence of plantation forests of radiata pine in many areas of New Zealand.

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References

Baillie, B.R., Cummins, T.L. & Kimberley, M.O. (1999) Harvesting effects on woody debris and bank disturbance in stream channels. *New Zealand Journal of Forestry Science* **29**, 85–101.

Boubée, J., Jowett, I., Nichols, S. & Williams, E. (1999) *Fish Passage at Culverts: A Review, with Possible Solutions for New Zealand Indigenous Species*. Department of Conservation, Wellington. [63 pp. plus appendices and computer program.]

Coker, R. (1992) Forest management considerations in New Zealand. In: *Proceedings of the Fisheries/Forestry Conference, 28 February 1990, Christchurch*, (eds J.W. Hayes & S.F. Davis), pp. 35–44. New Zealand Freshwater Fisheries Report No. 136. MAF Fisheries, Christchurch.

Collier, K. (2001) A riparian DSS for plantation forests: update. *Water and Atmosphere*, **9**, 8.

Collier, K.J. & Baillie, B.R. (1999) Decay state and orientation of *Pinus radiata* wood in streams and riparian areas of the central North Island. *New Zealand Journal of Forestry Science*, **29**, 225–35.

Collier, K.J. & Halliday, J.N. (2000) Macroinvertebrate-wood associations during decay of plantation pine in New Zealand pumice-bed streams: stable habitat or trophic subsidy? *Journal of the North American Benthological Society*, **19**, 94–111.

Collier, K., Winterbourn, M.J. & Jackson, R.J. (1989) Impacts of wetland afforestation on the distribution of benthic invertebrates in acid streams of Westland, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, **23**, 479–90.

Collier, K.J., Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C., Smith, C.M. & Williamson, R.B. (1995a) *Managing Riparian Zones: A Contribution to Protecting New Zealand's Rivers and Streams. Vol. 1: Concepts*. Department of Conservation, Wellington.

Collier, K.J., Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C., Smith, C.M. & Williamson, R.B. (1995b) *Managing Riparian Zones: A Contribution to Protecting New Zealand's Rivers and Streams. Vol. 2: Guidelines*. Department of Conservation, Wellington.

Collier, K., Baillie, B., Bowman, E., Halliday, J., Quinn, J. & Smith, B. (1997a) Is wood in streams a dammed nuisance? *Water and Atmosphere*, **5**, 17–21.

Collier, K.J., Smith B.J. & Baillie, B.R. (1997b) Summer light-trap catches of adult Trichoptera in hill-country catchments of contrasting land use, Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, **31**, 623–34.

Cooper, A.B. & Thomsen, C.E. (1988) Nitrogen and phosphorus in streamwaters from adjacent pasture, pine, and native forest catchments. *New Zealand Journal of Marine and Freshwater Research*, **22**, 279–91.

Cooper, A.B., Hewitt, J.E., Cooper, A.B. & Thomsen, C.E. (1987) Land use impacts on streamwater nitrogen and phosphorus. *New Zealand Journal of Forestry Science*, **17**, 179–92.

Davies-Colley, R.J. (1997) Stream channels are narrower in pasture than in forest. *New Zealand Journal of Marine and Freshwater Research*, **31**, 599–608.

Dons, A. (1986) The effect of large-scale afforestation on Tarawera River flows. *Journal of Hydrology (NZ)*, **25**, 61–73.

Dons, A. (1987) Hydrology and sediment regime of a pasture, native forest, and pine forest catchment in the central North Island, New Zealand. *New Zealand Journal of Forestry Science*, 17, 161–78.

Duncan, M.J. (1987) River hydrology and sediment transport. In: *Inland Waters of New Zealand*, (ed. A.B. Viner), pp. 113–137. DSIR Bulletin 241. Science Information Publishing Center, Department of Scientific and Industrial Research, Wellington.

Duncan, M.J. (1992) Flow regimes of New Zealand rivers. In: *Waters of New Zealand*, (ed. M.P. Mosley), pp.13–27. New Zealand Hydrological Society, Wellington.

Duncan, M.J. (1995) Hydrological impacts of converting pasture and gorse to pine plantation, and forest harvesting, Nelson, New Zealand. *Journal of Hydrology (NZ)*, 34, 15–41.

Eason, C.T., Wright, A. & Fitzgerald, H. (1992) Sodium monofluoroacetate (1080) water residue analysis after large scale possum control. *New Zealand Journal of Ecology*, 16, 47–69.

Evans, B.F., Townsend, C.R. & Crowl, T.A. (1993a) Distribution and abundance of coarse woody debris in some southern New Zealand streams from contrasting forest catchments. *New Zealand Journal of Marine and Freshwater Research*, 27, 227–39.

Evans, B.F., Townsend, C.R. & Crowl, T.A. (1993b) The retention of woody debris structures in a small stream following a large flood. *New Zealand Natural Sciences*, 20, 35–9.

Fahey, B.D. & Rowe, L.K. (1992) Land use impacts. In: *Waters of New Zealand*, (ed. M.P. Mosley), pp. 265–84. New Zealand Hydrological Society, Wellington.

Fish, G.R. (1968) The hazard presented to freshwater life by aerial copper spraying. *New Zealand Journal of Forestry*, 13, 239–43.

Fitzharris, B., Owens, I. & Chinn, T. (1992) Snow, ice, and glacier hydrology. In: *Waters of New Zealand*, (ed. M.P. Mosley), pp. 75–93. New Zealand Hydrological Society, Wellington.

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

Graynoth, E. (1992) Long-term effects of logging practices in streams in Golden Downs State Forest, Nelson. In: *Proceedings of the Fisheries/Forestry Conference, 28 February 1990, Christchurch*, (eds J.W. Hayes & S.F. Davis), pp. 52–69. New Zealand Freshwater Fisheries Report No. 136. MAF Fisheries, Christchurch.

Griffiths, A.D. (2002) *Indigenous Forestry on Private Land: Present Trends and Future Potential*. MAF Technical Paper No. 01/6. Indigenous Forestry Unit, New Zealand Ministry of Agriculture and Forestry, Wellington.

Halkett, J. (1991) *The Native Forests of New Zealand*. GP Publications Ltd, Wellington.

Hanchet, S. (1990) Effect of land use on the distribution and abundance of native fish in tributaries of the Waikato River in the Hakarimata range, North Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 24, 159–71.

Hannus, I.M. (1998) *Native New Zealand fish: lethal sublethal effects of pentachlorophenol on early and adult life stages*. Unpublished doctoral thesis, University of Waikato, Hamilton, New Zealand.

Harding, J.S. & Winterbourn, M.J. (1995) Effects of contrasting land use on physico-chemical conditions and benthic assemblages of streams in a Canterbury (South Island, New Zealand) river system. *New Zealand Journal of Marine and Freshwater Research*, 29, 479–92.

Harding, J.S., Quinn, J.M. & Hickey, C.W. (2000) Effects of mining and production forestry. In: *New Zealand Stream Invertebrates: Ecology and Implications for Management*, (eds K.J. Collier & M.J. Winterbourn), pp. 230–59. Caxton Press, Christchurch, New Zealand.

Hayes, J.W. & Davis, S.F. (1992) *Proceedings of the Fisheries/Forestry Conference, 28 February 1990, Christchurch*. New Zealand Freshwater Fisheries Report No. 136. MAF Fisheries, Christchurch.

Hickey, C.W. (1989) Sensitivity of four New Zealand cladoceran species and *Daphnia magna* to aquatic toxicants. *New Zealand Journal of Marine and Freshwater Research*, 23, 131–7.

Hicks, B.J. (1997) Food webs in forest and pasture streams in the Waikato region: a study based on analyses of stable isotopes of carbon and nitrogen and fish gut contents. *New Zealand Journal of Marine and Freshwater Research*, 31, 651–64.

Hicks, B.J. & McCaughan, H.M.C. (1997) Land use, associated eel production, and abundance of fish and crayfish in streams in Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 31, 635–50.

Hicks, D.M. & Griffiths, G.A. (1992) Sediment load. In: *Waters of New Zealand*, (ed. M.P. Mosley), pp. 229–48. New Zealand Hydrological Society, Wellington.

Jowett, I.G. & Richardson, J. (1996) Distribution and abundance of freshwater fish in New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research*, 30, 239–55.

Jowett, I.G., Richardson, J. & McDowall, R.M. (1996) Relative effects of in-stream habitat and land use on fish distribution and abundance in tributaries of the Grey River, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 30, 463–75.

Jowett, I.G., Hayes, J.W., Deans, N. & Eldon, G.A. (1998) Comparison of fish communities and abundance in unmodified streams of Kahurangi National Park with other areas of New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 32, 307–22.

Kanber, S.A., Wilkins, A.L. & Langdon, A.G. (2000) Speciation of pulp mill derived resin acids in the Tarawera River, New Zealand. *Bulletin of Environmental Contamination and Toxicology*, 64, 622–9.

Lowe, D. & Green, J.D. (1987) Origins and development of the lakes. In: *Inland Waters of New Zealand*, (ed. A.B. Viner), pp. 1–64. DSIR Bulletin 241. Science Information Publishing Center, Department of Scientific and Industrial Research, Wellington.

McDowall, R.M. (1990) *New Zealand Freshwater Fish: A Natural History and Guide.* Heinemann-Reed, Auckland.

McDowall, R.M. (1993) Implications of diadromy for the structuring and modelling of riverine fish communities in New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 27, 453–62.

McDowall, R.M. (2000) *The Reed Field Guide to New Zealand Freshwater Fishes.* Reed Publishing, Auckland.

McDowall, R.M. (2001) Getting the measure of freshwater fish habitat in New Zealand. *Aquatic Ecosystem Health and Management*, 4, 343–55.

McDowall, R.M., Graynoth, E. & Eldon, G.A. (1977) The occurrence and distribution of fishes in streams draining the beech forest of the West Coast and Southland, South Island, New Zealand. *Journal of the Royal Society of New Zealand*, 7, 405–24.

Maclaren, J.P. (1993) *Radiata Pine Grower's Manual.* FRI Bulletin No. 184. New Zealand Forest Research Institute Ltd, Rotorua.

Maclaren, J.P. (1996) Environmental effects of planted forests in New Zealand. *FRI Bulletin No. 198.* New Zealand Forest Research Institute Ltd, Rotorua.

McLay, C.L. (1976) An inventory of the status and origin of New Zealand estuarine systems. *Proceedings of the New Zealand Ecological Society*, 23, 8–26.

Main, M.L. & Lyon, G.L. (1988) Contribution of terrestrial prey to the diet of banded kokopu (*Galaxias fasciatus* Gray) (Pisces: Galaxiidae) in South Westland, New Zealand. *Internationale Vereinigung für theoretische und angewandte Limnologie, Verhandlungen*, 23, 1785–9.

Main, M.R., Nicoll, G.J. & Eldon, G.A. (1985) *Distribution and Biology of Freshwater Fishes in the Cook River to Paringa River Area, South Westland.* Fisheries Environmental Report 60. Fisheries Research Division, New Zealand Ministry of Agriculture and Fisheries, Christchurch.

Ministry of Agriculture and Forestry (2001) *New Zealand Forestry Statistics 2000.* Ministry of Agriculture and Forests, Wellington.

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

Mosley, M.P. (1981) The influence of organic debris on channel morphology and bedload transport in a New Zealand forest stream. *Earth Surface Processes and Landforms*, **6**, 571–579.

Mosley, M.P. (1982) New Zealand river temperature regimes. *Water and Soil Miscellaneous Publication No. 36*. Ministry of Works and Development, Christchurch.

Murphy, G., Collier, K., Baillie, B., Boothroyd, I., Langer, L. & Quinn, J. (1998) Development of a riparian zone decision support system for production forest environments. *Water and Atmosphere* **6**, 26.

New Zealand Soil Bureau (1968a) *Soils of New Zealand. Part 3*. New Zealand Soil Bureau Bulletin, 26. New Zealand Department of Scientific and Industrial Research, Wellington.

New Zealand Soil Bureau (1968b) *Soils of South Island New Zealand*. New Zealand Soil Bureau Bulletin 27. New Zealand Department of Scientific and Industrial Research, Wellington.

O'Loughlin, C.L., Rowe, L.K. & Pearce, A.J. (1980) Sediment yield and water quality responses to clearfelling of evergreen mixed forests in western New Zealand. In: *The influence of man on the hydrological regime with special reference to representative and experimental basins. Proceedings of the Helsinki Symposium, June 1980*, pp. 285–92. IAHS Publication number 130.

Pang, L. (1993) *Tarawera River flow analysis*. Environmental Report 93–2. Unpublished report, Environment Bay of Plenty, Whakatane.

Quinn, J.M., Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C. & R.B. Williamson (1997) Land-use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research*, **31**, 579–7.

Roberts, N.J.V. (1994) Past, present, and future forest land management practices in New Zealand. *New Zealand Forestry*, **August**, 22–6.

Roche, M. (1990) *History of Forestry*. New Zealand Forestry Corporation Ltd in association with GP Books, Wellington.

Rowe, D.K. & Chisnall, B.L. (1997) Environmental factors associated with the decline of dwarf inanga *Galaxias gracilis* McDowall in New Zealand dune lakes. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 7, 277–86.

Rowe, D.K., Chisnall, B.L., Dean, T.L. & Richardson, J. (1999) Effects of land use on native fish communities in east coast streams of the North Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research*, **33**, 141–51.

Rowe, D.K., Smith, J., Quinn, J. & Boothroyd, I. (2002) Effects of logging with and without riparian strips on fish species abundance, mean size, and the structure of native fish assemblages in Coromandel, New Zealand, streams. *New Zealand Journal of Marine and Freshwater Research*, **36**, 67–79.

Rutherford, J.C., Davies-Colley, R.J., Quinn, J.M., Stroud, M.J. & Cooper, A.B. (1999) *Stream Shade: Towards a Restoration Strategy*. Department of Conservation, Wellington.

Scrimgeour, G.J. (1989) Effects of bleached kraft mill effluent on macroinvertebrate and fish populations in weedbeds in a New Zealand hydro-electric lake. *New Zealand Journal of Marine and Freshwater Research*, **23**, 373–9.

Sharples, A.D. & Evans, C.W. (1998) Impact of pulp and paper mill effluent on water quality and fauna in a New Zealand hydro-electric lake. *New Zealand Journal of Marine and Freshwater Research*, 32, 31–53.

Statistics New Zealand (1998) *New Zealand Official Yearbook. 101*. GP Publications, Wellington.

Taylor, M.J. & Main M.R. (1987) *Distribution of Freshwater Fishes in the Whakapohai River to Waita River Area, South Westland*. Fisheries Environmental Report 77. Fisheries Research Division, New Zealand Ministry of Agriculture and Fisheries, Christchurch.

Taylor, R. & Smith, I. (1997) *The State of New Zealand's Environment*. Ministry for the Environment, Wellington.

Tomlinson, A.I. (1992) Precipitation and atmosphere. In: *Waters of New Zealand*, (ed. M.P. Mosley), pp. 61–74. New Zealand Hydrological Society, Wellington.

Valentine, D.A. (1995) *The effects of forestry operations and catchment development on lotic ecosystems in North Westland.* Unpublished Master of Forestry Science thesis, University of Canterbury, Christchurch.
Vaughan, L., Visser, R. & Smith, M. (1993) *New Zealand Forest Code of Practice*, 2nd edn. New Zealand Logging Industry Research Organisation, Rotorua.
Wardle, P. (1991) *Vegetation of New Zealand.* Cambridge University Press, Cambridge.
Willis, K.J., Ling, N. & Chapman, M.A. (1995) Effects of temperature and chemical formulation on the acute toxicity of pentachlorophenol to *Simocephalus vetulus* (Schoedler, 1858) (Crustacea: Cladocera). *New Zealand Journal of Marine and Freshwater Research*, **29**, 289–94.

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