Consequences to threatened plants and insects of fragmentation of Southland floodplain forests

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CONTENTS

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ABSTRACT

The processes of ecosystem fragmentation and their effects on persistence of key plant and invertebrate groups were investigated within remnants of alluvial podocarp forests in Southland, New Zealand. Vegetation was sampled at 135 plots in floodplain vegetation covering a range of habitat units, plant communities, and fragmentation states. Special note was taken of six rare plant species. In addition, beetle assemblages were sampled intensively across local fragmentation and habitat gradients within a single catchment, and individual shrubs of *Coprosma* species and kowhai trees were sampled for key invertebrate groups across a landscape-scale fragmentation gradient. The distinctive floodplain forest communities and their rare plant species appeared to be maintained by conditions of reduced competition. Natural disturbance events (primarily periodic severe frost and waterlogging floods) impose periods of extreme stress within the floodplain ecosystem. The consequences of forest fragmentation for the plant community are tier simplification, loss of epiphytes, decreasing richness first in the ground layer and then in taller tiers, and invasion of ground and then lower forest tiers. Fragmentation also leads to reduced and patchy recruitment of the target rare plant species. Beetle assemblages showed significant compositional changes reflected in altered functional group proportions, particularly a marked increase in predators in the ground beetle fauna. Isolated *Coprosma* shrubs had significantly greater native invertebrate loadings than those in core fragment areas. However, Lepidoptera faunas were not significantly different between isolated and core kowhai trees. The ecological integrity of the floodplain ecosystem depends largely on the maintenance of natural hydrological regimes, and their alteration by drainage and flood control works is likely to have profound effects on community composition of remaining floodplain remnants, and adverse consequences for the persistence of its rare plant components. Remaining floodplain ecosystem remnants with intact hydrological regimes should be given very high priority for protection.

Keywords: ecosystem, fragmentation, podocarp forests, floodplain, hydrology, rare plants, beetle assemblages, moth assemblages, Southland, New Zealand

1. Introduction

1.1 HABITAT FRAGMENTATION

Habitat fragmentation occurs when the continuity of original vegetation is disrupted and reduced into a number of smaller patches (Collinge & Forman 1998). It is most often a consequence of human activities (e.g. road construction, clearing for agriculture, urbanisation), which have in the past and continue to dramatically alter the pattern, composition, and extent of global vegetation (Houghton 1994; Turner & Corlett 1998; Laurance et al. 2002). Fragmentation has also been described as the disruption of structural and spatial continuity (Lord & Norton 1990; Didham et al. 1996; Thomas et al. 1998; Laurance et al. 2002). Under this definition, the concept can be relevant to any ecosystem where continuity is important to ecosystem functions, regardless of scale.

Fragmentation affects ecosystems by altering the conditions within patches and the flow of resources (organisms, propagules, nutrients) among patches. Disruption and modification to environmental drivers by fragmentation include altered irradiance, increased wind exposure (windthrow, reduced understorey humidity), increased permeability of edges to alien plants and animals, disruptions to hydrological regimes, and wind- and water-borne nutrient inputs. Biological effects of fragmentation are also induced by the physical distances between habitat fragments and intact areas, reduced habitat area, and changes in fragment composition and structure, including changes in the surrounding matrix (Ricketts 2001). There are many references in the literature documenting the abiotic (environmental) and biotic (biological) consequences of fragmentation (Saunders et al. 1991; Forman 1995; Olff & Ritchie 2002; and for review see Harrison & Bruna 1999). A brief summary is given below.

1.1.1 Edge effects

Environmental conditions change along a gradient away from the boundary of a patch towards the interior. To account for this relationship, a patch is typically divided into 'core' and 'edge' areas (Morrison et al. 1992; Forman 1995). Core areas lie at least a certain distance from the edge and tend to have abiotic conditions similar to those found in the interior of larger patches. Edge areas receive the most influence from neighbouring patches and have a higher degree of alteration. Long and narrow patches may effectively have no core area despite being quite large.

By reducing habitat area, fragmentation increases the amount of edge habitat relative to core habitat (Hanski et al. 1995; Redpath 1995). New, more extensive edges created by fragmentation of a forest are often adjacent to patches with a more open physical structure such as pasture or urban areas. The edge areas tend to receive more solar radiation, which can produce higher temperatures and drier conditions, particularly when coupled with increased airflow from surrounding open areas. The same processes can also affect soil conditions through heating and drying. These 'edge effects' may alter

vegetation structure, composition, productivity and microclimate conditions (Davies-Colley et al. 2000), as well as forest leaf litter structure and nutrient cycling dynamics (Didham 1998).

As abiotic conditions change, growth rates will change (Rutledge 2003). As competitive interactions cause reshuffling to reflect changing abiotic conditions, plant species composition changes, and this affects faunal species composition through trophic interactions (i.e. different plant resources are available to herbivores, different herbivores available to predators, and detritivore recycling is also affected). Animals may alter behaviour or body size in response to dietary changes (Sumner et al. 1999), and individuals may have fewer resources and reserves for reproduction or combating parasites. Conversely, because edge areas tend to have attributes of both adjacent patches they may actually support more species (Berry 2001).

Forest edges that are created by fragmentation typically have simple, hard-edged structures, and may bear little resemblance to natural edges. Orientation and physiognomy are two factors that may modulate the intensity of a physical edge effect (Murcia 1995). Firstly, orientation determines the amount of solar radiation: the lower the exposure to solar radiation, the weaker are some of the physical edge effects. Secondly, edges with the least lateral protection from transition vegetation exhibit the greatest edge effects in several environmental variables.

1.1.2 Habitat isolation

Habitat isolation arises not only from physical distances between remaining intact areas and other fragments, but also from changes in habitat structure and composition, particularly through the invasion of exotic plants (Hobbs 2001). In addition, the nature of the environment in surrounding fragments, known as the matrix, can also render habitats more or less isolated for their occupants (Ricketts 2001).

Extensive habitat loss and the fragmentation of remaining habitat into isolated remnants affects the population dynamics of the biota. Subpopulations of species affected by habitat isolation will typically have disrupted individual and population behaviour. Individual species, and different stages of life history within the same species, will respond to degrees of habitat isolation variably. Their perceptions will depend primarily on their dispersal abilities (Gillespie & Roderick 2002) but also on how they spatially partition their habitat (Wiens 1990), their degree of tolerance or use of the matrix (Laurance 1991), and how specialised they are on fragment vegetation (Duelli 1990). Specific effects may include disrupted social structures and reduced opportunity for mating, more predation-vulnerable seeds or nests, or an overall increase in mortality rate implying a greater risk of extinction within the patch. Smaller patch sizes may increase mortality risk by reducing the total area required for a predator to search or by increasing visibility as individuals move between different patches. Conversely, habitat isolation may benefit certain species by providing a refuge if the predator or disease has difficulty moving among patches.

Individual plants can be considered as isolated habitat fragments, particularly for the smaller members of a community with restricted spatial requirements, such as plant-dwelling invertebrates (Lord & Norton 1990). Because plants may

act as hosts and/or places of refuge and resting periods, they have the potential to provide 'habitat islands' for multiple species and individuals isolated from source areas (Gillespie & Roderick 2002). If such 'islands' exist as remnant plants of a former type of vegetation, their contributions to native biodiversity in highly modified landscapes can be very significant indeed (Derraik et. al. 2001; Didham & Ewers 2002).

A considerable amount of research, both theoretical and empirical, has gone into understanding species dispersal among a network of isolated patches. However, Rutledge (2003) observes that the salient message is that the effects vary widely depending on the process or organism of interest.

1.1.3 Effects on biodiversity

Ecological models generally predict a decline in the diversity of resident species following fragmentation because of increasing disruptions to colonisation and extinction events in relation to decreasing habitat size and increasing spatial and temporal isolation (MacArthur & Wilson 1967; Hanski 1998). However, as emphasised above, the response of different species to habitat fragmentation will depend on the varying effects of isolation, reduced habitat area, and altered physical conditions, and each species' ability to cope with these changes. That is, species' individual habitat requirements and dispersal ability dictate the degree to which they are affected by habitat fragmentation (Turner & Corlett 1998; Vos et al. 2001).

The variability in species' characteristics needs to be considered when determining the appropriate geographic scale of habitat corridors or of connectivity between conservation areas. The differential responses of taxa to fragmentation also raises issues about the appropriate population size and interaction needed to ensure that sufficient genetic information is retained and expressed in a given population, in order to allow adaptation and natural selection processes to occur and hence to allow species to persist long-term in a changing environment. At small spatial scales, a single plant may represent a discrete habitat unit within a larger vegetation matrix (Gillespie & Roderick 2002). Therefore, individual remnant plants within landscapes of varying modification or degradation could act as refugia for indigenous biota such as invertebrates. However, other species may have much larger habitat requirements.

Beyond the effects on individual species such as population disruptions (Harrison & Bruna, 1999), increased likelihood of extinction (MacArthur & Wilson 1967; Hanski 1998), and altered gene exchange between populations (Sarre 1995), there is a concern that the effects of fragmentation could cascade into other ecological changes. For example, fragmentation may also threaten the provision of ecosystem services (Harris 1984; Lovejoy et al. 1986; Bierregaard et al. 1992; Laurance et al. 1997).

1.1.4 Fragmentation studies in New Zealand

Although negative impacts arising from the extensive loss of native vegetation are well known in New Zealand, few studies have investigated the effects of habitat fragmentation on native species. As with the majority of studies

worldwide (e.g. Holt et al. 1995; Basset et al. 1998), most of the New Zealand studies have focused on forest systems and defining fragmentation in terms of patch size and physical isolation (e.g. Harris & Burns 2000; Lövei & Cartellieri 2000; Watts & Larivière 2001). Others have examined pollination behaviour on forest edges and its consequences for Loranthaceous mistletoes (Kelly et al. 2000; Montgomery et al. 2003). There is also much scope to examine non-forest ecosystems, and to widen studies to include a greater variety of spatial scales and different taxonomic groups (Derraik et al. 2002; Leisnham & Jamieson 2002; Rufaut 2002). In the present study we recognise other modifiers that are important drivers of habitat fragmentation in New Zealand, for example, hydrological change (through the building of flood banks and retention dams as well as realignment and deepening), plantation forestry, weeds, and grazing.

1.2   SOUTHLAND PLAINS STUDY AREA

1.2.1   Geologic and geomorphic setting

Our study area stretches across Southland and Makarewa Ecological Regions from the eastern foothills of Fiordland (Te Anau, Takitimu and Tuatapere Ecological Districts), to the eastern Taringatura Ecological District, the southern foothills of Hokonui Ecological District, the Southland Plains Ecological District, and further east to Waituna Ecological District. The ecosystem we study is strongly associated with low-angle plains. Therefore, when referring to Southland Plains, we indicate the entire study area, rather than the Southland Plains Ecological District within it.

Southland has the second largest array of coastal or peripheral plains in New Zealand after Canterbury (Fitzharris et al. 1982). Because the surrounding hinterland represents an almost complete set of geological formations in New Zealand, Southland's geomorphic setting and suite of deposits is more complicated than the classical Pleistocene outwash surfaces of the Canterbury Plains. Geomorphically diverse remnants of former extensive lowland forest add to the diversity imparted by this physiography.

Southland's plains can be divided into seven distinct units, which are a function of the major rivers occupying large, fault-delineated valleys that follow the Median Tectonic Line, the Southland Syncline, and the Livingstone–Macpherson Fault. The Waiau River follows the fault depression of the Median Tectonic Line, while the middle reaches of the Oreti and Mataura rivers flow along the depression of the Livingstone-Macpherson Fault (Fitzharris et al. 1982).

The plains are underlain by mid-Tertiary sediments, mostly mudstones and sandstones. Associated lignite is important in the Mataura Valley, and limestone fringes the bordering hills and forms isolated hillocks on northern plains. Uplift during the Kaikoura Orogeny deposited coarse detritus as piedmont gravel fans and terraces forming the maturely weathered, higher-level surfaces of the Central Plains (Fitzharris et al. 1982).

Along the coast, complex interactions between fluctuating sea levels, changes in drainage patterns, and changes in sediment supply have produced an intricate series of marine cliffs and beaches, alluvial flats on old river deltas, old

and modern transgressive dunes, peat bogs, and lagoons (Fitzharris et al. 1982). Accordingly, the coast has diverse alluvial and aeolian geomorphology.

The major rivers—the Waiau, Aparima, Oreti, and Mataura—have produced flights of terraces that are incised in Pleistocene outwash gravel fans where they disgorge from their hinterland catchments. For that reason, greater relief is encountered approaching the rivers in their upper, terraced reaches (Fitzharris et al. 1982). Terraces can be traced both down-valley and towards the interfluves, gradually dying out to give a characteristic uniform surface, particularly on the Southland Plains themselves. Between the main rivers, shallow depressions form on the floodplain that have their own smaller streams such as the Makarewa, Hedgehope, Otapiri, Orauea, Waikiwi, and Waituna. Topogenous peat bogs (fed mainly by groundwater within depressions) have formed in the large interfluves on the lower floodplain. They can be contrasted with the 'pakihi' peat bogs on the headward terraces, which are ombrogenous bogs (products mainly of climate). In other words, climate and relief have combined in high-rainfall districts to develop iron pans at no great depth, leading to drainage problems and the development of pakihi clearings. While loess with an average thickness of 3–5 m mantles the higher terraces, downlands, and hill country, it is less influential as a soil parent material in the floodplain.

The lower reaches of floodplain-rivers are marked by abandoned river channels as rivers migrate across the alluvial plain. Old channel bars, point bars, and levees stand proud of the general surface, signalling past blocking or confinement of water flow. In general terms, the rivers and major streams have a dendritic pattern of tributaries in their upper reaches adjacent to the hill-country and deltoid fans as they near the sea. The flights of terraces on the upper sections of arterial rivers produced by active down-cutting or aggregation throughout the Holocene have little variation in sediment texture. Uniformly well-drained silts mantle the terraces.

Southland's floodplains have low relief but diverse physiography, comprising low-relief Tertiary sedimentary landforms interspersed with Pleistocene alluvial landforms. These diverse floodplain environments are reflected in a rich provincial lowland biota.

1.2.2 Loss of forest on the Southland Plains since the arrival of humans

Before human settlement, the forests of Southland showed a broad gradation from beech forests of the wet western mountains of Fiordland to podocarp forests on the plains. Most of the Southland Plains area (Fig. 1) is now farmland, with only remnants of the late Holocene podocarp forests. In 1997, it was estimated that a total of 35.6% of the area of Southland remained as indigenous forest, of which most is within Fiordland National Park (Ministry for the Environment 1997).

Our estimates of the percentage loss of forest in Southland since human settlement (Table 1) are based on the land cover database (LCDB1) and a recent estimate of potential prehuman forest (Leathwick et al. 2005) across 15 Southland ecological districts (Fig. 1). These sources indicate that although c. 47% of the original beech forest types that dominated the western plains and

Figure 1. Map of the Southland study area showing population centres, major rivers, and study areas mentioned in the text.

TABLE 1. LOSS OF FOREST IN 15 SOUTHLAND ECOLOGICAL DISTRICTS SHOWING THE PERCENTAGE OF THE AREA ORIGINALLY COVERED BY FOREST AND AT PRESENT.

CATEGORY	POTENTIAL FOREST TYPE*	ORIGINAL COVER (%)*	PRESENT (%)[†]
Beech	Silver beech	32	15
	Mountain beech	2	1
Podocarp	Matai-totara-kahikatea-rimu-broadleaf-fuchsia	28	1
	Rimu-miro-totara-kahikatea	20	3
	Matai-kahikatea-totara	7	0
	Kahikatea	<1	0
Mixed	Hall's totara-miro-rimu-kamahi-silver beech-southern rata	1	1

* Leathwick et al. (2005).
[†] LCDB1 category 'Indigenous forest'

Fiordland foothills remains, most of this is in the steeper terrain in the extreme west. A relatively small area of an original beech–totara forest type is mapped in the vicinity of the Longwood Range by Leathwick et al. (2005); 68% of this is estimated to remain. However, of the original podocarp forest that occupied the central and eastern portions of the Southland Plains, less than 8% is estimated to remain.

The precise extent of the prehuman and remaining floodplain forest ecosystem of the present study area is difficult to gauge precisely, since it is determined by subtle topographic factors that are not well represented in current GIS databases. However, alluvial floodplain and lowland forests across New Zealand have generally undergone greater degrees of clearance than forests on steeper, more leached colluvial landforms. This is because their relative accessibility, gentle topography and relative fertility make them desirable and economically viable for pastoral farming, particularly once flood prevention methods are imposed. Development and clearance trends in Southland have followed this general pattern (see a detailed treatment in Walls & Rance 2003), and we estimate that less than 1% of the original extent of the floodplain ecosystem remains today on the Southland Plains.

1.2.3 Current levels of protection of remaining forest

The largest remaining area of native forest on the Southland Plains is Forest Hill Scenic Reserve, which is 578.9 ha (Allan et al. 1989). There are fewer than 15 scenic reserves on the Southland Plains with an average size of 30 ha. Most remnant blocks of forest there are less than 5 ha, and most are on private land. A total of 1942 ha of private land is protected by the QEII National Trust open space covenants in Southland (based on covenant spatial data assembled by Rutledge et al. 2004).

1.3 SOUTHLAND'S FLOODPLAIN ECOSYSTEM

1.3.1 Floodplain ecosystem

The physiographic focus of this study is the dendritic upper sections of rivers. Here, meandering tributaries that are fed by sediment-laden stormwater from the adjacent hill-country flows across low-angle terraces in scroll channels. The imprint of stream migration across the floodplain is a series of cut-off meander channels or pronounced oxbows. This pattern is repeated in the coastal or peripheral sections of secondary streams such as the Makarewa and Hedgehope, adjacent to the Hokonui Hills.

1.3.2 Abiotic characteristics

Interactions among different climatic, geologic, geomorphic, and disturbance processes have produced a diversity of floodplain ecosystems in Southland (some examples are shown in Appendix 1). Firstly, the diverse geology of the hinterland has produced a wide variety of alluvial soil parent materials, with variable fertility. Coarser-grained sediments of the Otiran glacial advance that form the principal outwash fans of the plains are therefore variably overlain by Holocene alluvial sands and silts and periglacial loess.

Subtle changes in relief within the large lowland catchments also produce considerable variation in the distribution of cold-air inversion and intense winter frosts in hollows. The periodic extreme frosts resulting from such inversion events may be a principal driver of vegetation composition.

The rainshadow zones in the lee of Fiordland's mountains have steep rainfall gradients and corresponding gradients in rates of soil weathering. Wide variability in the size and relief of hinterland catchments also produces variation in the periodicity of flooding, which in turn drives the frequency of sedimentary rejuvenation of soil fertility.

1.3.3 Threatened plants

Our study targeted several shrubs and small trees that have discontinuous lowland distributions in New Zealand, namely *Coprosma wallii*, *C. pedicellata*, *C. obconica*, *Melicytus flexuosus*, *Pittosporum obcordatum*, and *Olearia hectorii*. These species were recently noted to all occur within alluvial floodplain habitats on the Southland Plains (Rogers et al. 1998 and Rance & Simpson 2000 first documented their Southland distributions in detail). All but *Olearia hectorii* are notoriously cryptic, small-leaved, divaricating plants.

de Lange et al. (2004) list *Pittosporum obcordatum* in Threat Category 2 (Nationally Endangered), *Olearia hectorii* in Threat Category 3 (Nationally Vulnerable) and *Coprosma obconica*, *C. pedicellata*, *C. wallii* and *Melicytus flexuosus* in Threat Category 5 (Gradual Decline). In addition to the target plants, several other threatened plants are present in the floodplain ecosystem in Southland. These include *Uncinia strictissima* (2, Nationally Endangered), *Ranunculus ternatifolius* (3, Nationally Vulnerable), *Deschampsia cespitosa*, *Peraxilla colensoi* and *Tupeia antarctica* (all Category 5, Gradual Decline). At-risk species include *Olearia lineata*, *O. fragrantissima* and *Pseudopanax ferox* (all Category 6, Sparse).

Because the native vegetation of valley floor, basin, and floodplain landforms has been comprehensively cleared across New Zealand, it is difficult to be certain that any of our target plants was originally absent from the region or has gone as a result of land clearance. *Pittosporum obcordatum* is known from Kaitaia and Wairua in Northland, but the remaining five target species are currently absent north of the Waikato region, despite ostensibly suitable lowland alluvial habitat. None of the six target species is recorded from the Horowhenua–Manawatu region. All of the target species occur exclusively or predominantly in eastern areas; only *C. wallii* and *M. flexuosus* occur west of the main axial ranges; these occurrences are in Westland, and about Taihape in inland North Island. Presently, of the six target species only *C. wallii* has been recorded from Rakiura (Stewart Island). Most target species show pronounced range disjunctions; *P. obcordatum* has the most conspicuous disjunction, from Wairarapa to the Catlins in South Otago and Southland (Raoul's record from near Akaroa on Banks Peninsula has not been re-located despite repeated searches; Clarkson & Clarkson 1994).

Coprosma pedicellata was described by Molloy et al. (1999). At that time, it was known from a few disjunct localities along the foothills of eastern New Zealand, where it is restricted to forests and forest margins. It is described as having a distinctive narrow cool winter-wet/warm summer-dry habitat, usually

on moderately fertile soils with impeded drainage, in overflow or flood channels, and beside small streams. It is described as usually erect in closed forest, but distinctively and typically leaning at an angle or with twisted stems in disturbed forest or clearings. It has distinctive yellow-orange cambium, and clear upper and lower leaf venation on delicate, widely spaced leaves, and a sparsely branched growth habit. Direct light is noted as not essential for growth to maturity, but regeneration is noted as absent in habitats exposed to grazing animals and to competition from introduced pasture grasses, rushes and herbs.

We know of no published studies that deal with the habitat and ecology of *C. obconica* and *C. wallii* in similar depth. Neither species is confined to the floodplain ecosystem, but both are recorded in upper montane broadleaved and conifer forests elsewhere in the South Island. Dopson et al. (1999) describe *C. wallii* as a 'divaricating tree, with glossy dark green thick leaves, twinned dark purple fruit, and wine-red underbark'. This underbark is an unmistakable, characteristic feature, as is its growth habit, with robust, twisted main stems with densely packed clusters of leaf-bearing branches at their tips. Its habitat is described as 'frost flats and temperature inversion colluvial toeslopes and alluvium. Occasionally on hillslopes with base-rich soils' (Dopson et al. 1999). Wilson & Galloway (1993) describe it as a shrub of 'lowland and montane shrubland, scrub and open forest, in the mountains favouring river terraces, but on Banks Peninsula favouring open broad ridge crests on fertile volcanic soils'. They describe the smaller bushy shrub *C. obconica* as a species of 'forest, scrub and shrubland on river terraces, on both poorly drained and sharply drained sites, including bluffs'.

Melicytus flexuosus was formally described by Molloy & Druce (1994). Its habitat was briefly noted as valley bottom alluvial terraces and floodplains. It was described as occurring mostly in full sunlight on forest edges and occasionally in forest gaps. Shade-tolerant seedlings and saplings were noted, but the species required direct light for growth to maturity. Regeneration was said to be dependent on periodic disturbance and a continued supply of seed, which was prevented by factors such as flood controls, removal of seed sources, competing pasture species, and animal grazing.

The ecology of *Olearia hectorii* was described by Rogers (1996), inclusive of the closely related *O. gardneri*, which was subsequently taxonomically distinguished as a North Island endemic. Floodplains are important habitat for *O. hectorii* throughout its eastern South Island distribution, particularly in Southland (Rogers 1996), although it was rarely recorded there in our study; Rogers (1996) reported that seven of its 10 Southland sites in 1996 were floodplain terraces (an updated assessment of its distribution is under way in the Department of Conservation); its Otago, Canterbury, and Nelson strongholds are also floodplains. It is suggested that in pre-settlement times, *O. hectorii* would have been predominantly a stream bank or levee species, by virtue of its disturbance-exploiting habit and apparent requirement for bright light for reproduction. *O. hectorii* develops multi-stemmed trunks with open-grown, lianoid branches that enable it to exploit local adjacent light-pockets within the competition of a tall floodplain forest. It also possesses life traits that enable clonal, multigenerational persistence in the absence of disturbance; it has the unusual habit of collapsing limbs and attached strips of trunk

adventitiously rooting on contact with the ground. Interpretation of the soils and substrates of its floodplain and hillslope habitats suggests that it favours moderate- to high-fertility soils, although, like *O. gardneri*, it can tolerate winter-waterlogged conditions.

Given (1981: 67) described the fate of *Pittosporum obcordatum* as 'one of the most spectacular examples of depletion of a New Zealand plant'. A detailed study of the ecology of *P. obcordatum* (Clarkson & Clarkson 1994) described it as one of New Zealand's most elusive plants. At that time, only one population was known in Southland (Back Valley, Morrison 1982; King 1986). Its habitat was described as 'distinctive, linear … bordering levees, back swamps, cut-off meanders, and oxbow lakes of lowland river flats in dryish climates … variously affected by flooding, waterlogging, drought and frost'. A limited ability to compete with broadleaved species is inferred from its absence from better-drained hill slope or alluvial landforms and from wetter, milder parts of New Zealand. Flooding is suggested as a mechanism that promoted the periodic establishment of new cohorts in pre-European times by creating canopy gaps; for example, in Back Valley, the habitat is frequently flooded to 10–20 cm depth following heavy rain (Morrison 1982). In its southern stronghold in Back Valley in Fiordland National Park, there is little evidence of mechanical damage from rapid flushing floods from an adjacent river or stream; instead, it appears that regeneration opportunities may be provided by water-ponding events that stimulate dieback of less-tolerant species. Clarkson & Clarkson (1994) suggested that *P. obcordatum* was extremely habitat-specific, and had evolved the physiological apparatus needed to use the resources of an extreme habitat (i.e. subject to intense flooding, waterlogging, drought and frost) at the cost of being able to compete in biologically more favourable habitats (after Drury 1974); and that this specificity conferred a degree of distribution discontinuity.

Five of these six target species are recorded from the Hautapu River catchment at Mataroa, near Taihape, on the western side of the North Island axial ranges; *Coprosma pedicellata* is the exception. Clarkson & Clarkson (1994) note that *Pittosporum obcordatum* often occurs in similar habitats to *C. pedicellata*, while Molloy et al. (1999) associate *C. pedicellata* with *C. obconica*, *C. wallii*, *Melicytus flexuosus*, *Olearia gardneri*, and *P. obcordatum*. Although these co-occurrences in Southland and elsewhere suggest broadly similar habitat requirements and ecologies, profound differences between species are also obvious; as noted above, several of the target plants are not confined to floodplain ecosystems, but have natural ranges that include a wider spectrum of landforms and habitats.

1.3.4 Habitat classification

The floodplain ecosystem contains several distinct habitats, based on physiographic differences (Table 2), which appear to support different plant communities and different rare plant species.

Paradoxically, the spatial arrangement of these units is more easily discerned in floodplains cleared of forest, especially when viewed from the air in low-angle sunlight, whereas in the rare instances where forest patterns remain intact (such as at Back Valley near Manapouri) the subtle relief of the floodplain makes these ecosystems difficult to differentiate and delineate.

In a floodplain cross-section, we differentiate 'levee', 'flood plain terrace' (hill-country and terrace interfluves of Table 2), 'backswamp' (a composite category embracing platform, flood channel, cut-off meander and oxbow, and depression or hollow of Table 2), and true 'swamp' (the peat bog of Table 2).

Stream banks are steep colluvial slopes usually composed of floodplain alluvium and unstable by virtue of flushing and undercutting from water flow. Stream bank instability is concentrated on the outside or concave bend of meander curves. Stream banks are scoured in floods, while tectonic uplift and catchment sediment supply regulate progradation or aggradation rates or corresponding adjustments in the base level of the riverbed. Because they are frequently disturbed, vegetation is commonly early successional.

Levees are linear hummocks of mostly coarse-grained sediment atop riverbank that accumulate when floods overflow the banks. Alternating layers of fine or coarse sediment result from floods being confined by or alternatively overtopping the levee.

Platforms are the narrow ridges on terrace surfaces formed between meander channels. As part of braided river channels, they may be underlain by coarse-grained sediment.

Flood channels are secondary meanders adjacent to the main river channel. They are flushed and veneered by mostly thin layers of sediment in flood events when rivers overtop the banks of their main channels. Their soils are consequently skeletal and, depending on the catchment bedrock, rich in some base elements.

Cut-off meanders and oxbows are the legacy of river braids migrating across the surface of terraces. Essentially isolated from flood events, cut-off meanders can have surface water in heavy rain, whereas oxbows are horseshoe-shaped channels subject to standing water for long periods. Seasonally fluctuating watertables produce gleyed soils.

TABLE 2. CLASSIFICATION OF PHYSIOGRAPHIC PROCESSES THAT DIFFERENTIATE THE VARIOUS HABITAT TYPES OF A SOUTHLAND FLOODPLAIN.

HABITAT TYPE	HYDROLOGY	SOIL PARENT MATERIAL	FROST INTENSITY	SOIL TYPE
Stream bank	Frequent scouring	Coarse and fine alluvium	Light	Skeletal gravel
Levee	Regular flooding	Coarse and fine alluvium	Intermediate	Skeletal silt
Platform	Flooding	Coarse and fine alluvium	Intermediate	Silt loam
Flood channel	Infrequent flooding, annual winter water ponding	Fine alluvium	Heavy	Skeletal silt
Cut-off meander and oxbow	Seldom flooded, but annual winter water ponding	Coarse and fine alluvium	Intermediate to heavy	Gleyed silt loam
Depression or hollow	Annual winter water ponding	Older outwash materials	Heavy	Gleyed silt loam
Terrace interfluve	Generally not flooded	Coarse and fine alluvium	Intermediate	Well-drained sand or silt loam
Peat bog	Not flooded, but seasonal water-table fluctuations	Organic	Intermediate	Organic
Hill-country interfluve	Not flooded	Colluvial	Light	Loam

Depressions or hollows are a post-depositional feature of terrace surfaces forming between the mantle of outwash colluvium bordering hill-slopes and the flood debris of overflowing rivers. As topographic hollows, they are subject to winter water-ponding and cold-air inversion and accordingly support trees, shrubs, or sedges tolerant of moist-to-wet, acidic, and humic soils. This vegetation may be transitional to peat formation.

Terraces, interfluves, or steps are flat erosional surfaces formed as rivers meander across the surface of the floodplain. A stepped sequence of interfluves forms when a river adjusts its bed level downward through a previous aggradational floodplain. The terrace steps are often scalloped by meander scars. Terrace interfluves are composed of well-drained alluvium, sometimes with a less well-drained loess veneer.

Peat bogs form in depressions on the terrace surface where impeded drainage maintains perpetually high watertables and anaerobic conditions lead to accumulating organic matter. Subsurface drainage may be impeded at the stratigraphic interface of layers of coarse and fine sediment. Stormwater from catchment hill-slopes means peat bogs often form at the rear of terraces in depressions bordering adjacent hill country. Extensive domed peat bogs also feature on Southland's coastal floodplain in depressions between the flooding environments and accumulating sediments of the major rivers.

Hill-country interfluves are the undulating to steep catchment slopes separating floodplains. They contribute downslope colluvium and stormwater to the adjacent floodplain surface that may be concentrated within shallowly incised gullies. Downslope disturbance processes maintain a young and often thin regolith.

1.4 FRAGMENTATION IN FLOODPLAIN FORESTS

1.4.1 Processes and symptoms of fragmentation

Fragmentation is multifaceted. In Southland, forest fragments are distinguished from intact forests by numerous factors, which include: small size, irregular shape, large edge (perimeter)-to-interior ratios, evolving edge communities, dewatered soils, elevated soil nutrient status around edges, and reduced flooding and sedimentation disturbance regimes. These attributes are the result of drainage and river straightening, removal of marketable emergent and canopy trees, dieback of canopy and emergent trees, and the presence of invasive alien plants and farm stock. Reduced native species richness, weed invasion, and reduced tier complexity are typically associated with these factors.

Although modified, a fragmented floodplain ecosystem may retain many threatened trees and shrubs that are apparently adapted to the seasonal extremes in soil moisture and frost inversion regulating them. Symptoms of fragmentation may also be reflected in the dynamics of the threatened biota; i.e. altered recruitment and turnover of rare plants.

1.4.2 Modification of the hydrological regime

Some key processes of the floodplain ecosystem have been considerably modified by human impacts in the last century. In particular, the hydrological regime has been severely altered, particularly its flooding component. The NZMS 260, 1:50 000 topographical map series reveals that virtually all the meander channels of the secondary streams in Southland have been straightened by drainage earthworks. The one exception is an upper section of the Makarewa Stream. In agricultural landscapes, the decapitated scrolls are conspicuous from the air in low-angle sunlight, as are the infilled remains of cut-off meanders or oxbows. Additional drainage earthworks have substantially lowered watertables across most low-lying depressions of the floodplain. Small sections of meandering streams remain water-filled but channel relocation and straightening has isolated them from stream flow except in instances of peak flow. Soil cultivation has subdued the relief by infilling depressions, truncating hillocks, and smoothing changes in slope angle.

1.5 SCOPE OF THIS REPORT

The objectives of this study of Southland's floodplain ecosystem are:

- Typify broad characteristics of fragmentation of the floodplain ecosystem by developing indices for size, shape, altered hydrology, the overall proportion of natural versus modified in the landscape setting, exterior-to-interior ratios, width and permeability of edge, edge-to-interior ratio, complexity of structural tiers, etc.

- Measure biological consequences of fragmentation: disrupted population structures, species richness indices, weed penetration in relation to edge intactness, changes in edge composition, etc.

- Determine impacts of fragmentation on persistence of key plant and invertebrate groups.

- Develop practical methods to assess the viability of forest fragments with respect to key floristic and insect groups. These methods are intended for application and testing.

We divided our study into two main parts, focused on vegetation and invertebrate associations; these parts are reported here in sections 2 and 3, respectively.

In the vegetation study, we sampled the physical and biotic characteristics of remaining floodplain forest communities across local and landscape-scale gradients of fragmentation using plot-based sampling techniques, and recorded plant community data and a range of simple environmental parameters. We explored relationships between a range of possible indicators of fragmentation and their biotic effects, including the consequences for their rare plant components, especially our six 'target' rare plants. In doing so, we examined the utility of some simple indices of fragmentation for predicting biotic consequences of fragmentation in this ecosystem (specifically, forest patch size and perimeter (edge)-to-area ratio, and the isolation of plots in pasture from nearest neighbouring fragments or forest tracts).

We limited the vegetation study in several ways: firstly, our approach was descriptive and not experimental (i.e. we did not experimentally manipulate plant communities to create a neatly replicated set of 'fragmented' and 'intact' sites). Instead we sampled (and attempt to interpret) the complex vegetation variation that arises from gradients in both environment and fragmentation. This correlative approach allowed us to expose patterns, to describe relationships among factors, and to suggest causes. However, it did not allow us to demonstrate the processes and mechanisms involved in the fragmentation of this ecosystem.

Secondly, we did not attempt to undertake detailed population studies or to precisely define the niches of the target rare species. We chose a region-wide, uniform-area (10×10 m) plot sampling design rather than a population-focused approach that would have required the location and measurement of entire populations of the different threatened plant species in variable area plots (cf. Rogers & Walker 2005). The latter approach would have provided detailed demographic data for select populations, but would have compromised the representativeness and coverage of our sampling. We expected, however, that trends in rare plant abundance, size and seedling presence/absence in representative plot samples would indicate general population responses of the target species to fragmentation. Analysis of the habitats and ecology of our six target plants outside the floodplain ecosystem in Southland was also beyond the scope of this report, although we draw on published and unpublished sources to expand our insights into their ecology.

Thirdly, the invertebrate part of the work (section 3) comprised three separate, exploratory pilot studies. Each study focused on a different component of invertebrate biodiversity, and took a different approach to examine the effects of ecosystem fragmentation. We made no attempt to comprehensively document the invertebrate fauna of the floodplain ecosystem, or to identify endangered or at-risk species within it.

Fourthly, it was not an aim of the report to identify and prioritise individual sites for management. Rather, our focus was to understand the ecosystem and the processes and consequences of fragmentation within it. From this understanding, we suggest general, practical guidelines and goals to assist managers in prioritisation.

A key objective of the study is to suggest practical methods to assess the viability of forest fragments. A formal analysis of the viability of fragments of this forest ecosystem would require spatial modelling of population viability for each key species (including common species), based on in-depth understanding of reproductive and dispersal parameters. This would be considerably beyond the bounds of the present study, and of limited value to conservation managers. Instead, in section 4, we suggest simple, practical indicators of forest viability, based on understanding arising from this study of the physical drivers and biotic characteristics of remaining floodplain forest communities. We suggest a structured framework of short and long-term conservation goals that might be applied in different situations.

2. Flora of Southland's floodplain ecosystem

2.1 INTRODUCTION

In this section, we describe the remaining indigenous flora and vegetation of the Southland alluvial floodplain forest ecosystem across the full range of fragmentation states that exist today. These range from relatively 'intact' sequences where continuous forest tracts extend down bordering hill slopes and across the floodplain, to single relict riparian trees and shrubs in developed pasture.

2.2 METHODS

2.2.1 Sampling design

The study depended on the local knowledge of Brian Rance and Geoff Rogers for information on the location of floodplain remnants in Southland. The vegetation of all known floodplain remnants on the Southland Plains was sampled between November 2002 and September 2003. All plots were sampled by Neill Simpson, assisted at times by Susan Walker or Barbara Simpson.

We attempted to sample a representative range of locations or fragments, different habitat types within these locations or fragments, and the full range of fragmentation states.

A few plots that contained threatened plants but that are located outside the target ecosystem were also sampled. These were included in our analyses since they provide some basis for comparison and gradient interpretation.

In total, 135 plots (of 10×10 m) were located in 19 locations in six major catchments (Table 3; Fig. 1). The 55 km-long Lower Waiau Valley and the central Southland Plains form the centre of our study area, solely because no remnants of our target vegetation remain in the Upper Mataura Valley or Waimea Plain. At each plot, the GPS location was recorded, one site corner was marked with tape to facilitate short- to medium-term re-location, and a photograph of the plot was taken from one corner. In follow-up to the study it may be desirable to undertake permanent marking of a selection of the plots for long-term monitoring in the future; however, this was not the purpose of this study.

2.2.2 Main study sites

Waiau catchment

The farm properties of the Mouat and Quinn families are situated northwest of Tuatapere along the Dean Burn. These properties adjoin the Dean Forest Scenic Reserve, which in turn is connected to Fiordland National Park. The Dean Burn (Mouat's) is described by Rance & Simpson (2000: 16). The privately owned

forests on these properties are at the most intact end of the fragmentation gradient and contain the largest tracts of floodplain forest ecosystem remaining on private land in Southland. This forest borders the Dean Burn itself and also part of one of its tributaries. Both properties offer a variety of fragmentation states for study, ranging from intact catenas adjacent to large continuous tracts of hill-slope forest, to riparian strips of forest, to scattered clumps and individual native trees in pasture. Although watertables have been lowered on terraces developed for farm pasture, stream courses have not been straightened as elsewhere in Southland. The soil type is unconsolidated sand, gravel and silt in modern flood plains, bordering slightly weathered gravel and sand in intermediate terraces (Turnbull & Allibone 2003). Farm stock accessed forest margins in many places.

Oreti catchment

Dunsdale Conservation Area (F45 705 445, Hedgehope) is a forest remnant of c. 190 ha that includes low riparian terraces either side of Dunsdale Stream, which flows south from the Hokonui Hills (described in Rance & Simpson 2000). Soils are Makarewa recent gley soils over outwash gravels, moraines, and till of the last glaciation. The west bank of the reserve is grazed, while stock are excluded from the east bank. Much of the catchment and adjacent catchments are planted in exotic forest.

TABLE 3. STUDY SITES CONTAINING FLOODPLAIN FOREST FRAGMENTS IN SOUTHLAND.

CATCHMENT	STUDY SITE: LOCATION OR FRAGMENT	GRID REFERENCE*	TOTAL STUDY PLOTS
Waiau	Back Valley	C44/871 992	12
	Broadlands–Motu Road	D45/975 595	2
	Mouat's (Dean Burn)	D45/941 627	31
	Quinn's (Dean Burn)	D45/929 661	21
	Swale Road	D45/001 551	2
	Taylor's/McLee's	D44/941 732	5
Oreti	Cowie Road	E45/555 463	3
	Dunsdale	F45/705 438	14
	Harris Road	E45/505 488	2
	Mabel Bush	E46/624 307	6
	Otapiri	E45/558 459	2
	Swale's Bush	E45/490 497	4
	Taringatura	E45/466 584	1
	Turnbull's	E46/613 303	22
Mataura	Glendenning	F47/818 010	2
	Gorge Road	F47/790 040	1
Toi	Titiroa	F47/848 997	1
Waihopai	Oreti	E47/485 096	1
Waituna	Cook Road	E47/680 026	3

*   Average of study plots within the location or fragment.

Turnbull's Bush (Rance & Simpson 2000: 6) is a privately owned smaller remnant of protected native forest of around 47 ha, within a wider agricultural landscape, located approximately 3 km southeast of Forest Hill Scenic Reserve (NZMS 260 E46 617306) approximately 27 m above sea level. It lies approximately 85 km from Mouat's Bush and is protected by a Queen Elizabeth II National Trust Open Space Covenant. It is a remnant of the Makarewa River riparian forest. The main flow of the river has been diverted into a straightened channel, altering the natural hydrological regime to reduce the frequency and intensity of floods. The soil type is unconsolidated sand, gravel and silt in modern floodplains (Turnbull & Allibone 2003). Although it retains some of the original forest structure, exotic species are prominent components of the plant communities. It is largely fenced, but some parts continue to be grazed. Severe frost damage in 1995 killed many of the mature canopy matai trees, altering the forest light environment, and probably encouraged a recent pulse in woody and herbaceous weed recruitment. Mabel Bush (RAP 30; Walls & Rance 2003) is an adjacent, smaller remnant.

Harris Road Bush is a smaller floodplain remnant that originally bordered the Makarewa River but now exists as a small forest patch in the plains surrounded by pasture. Although it is fenced, livestock still access the remnant forest, and lower vegetation tiers are considerably depleted, even though the canopy remains largely intact.

The Otapiri site (RAP 22; Walls & Rance 2003; which includes the study area referred to as Cowie Road) borders the Otapiri stream. Native plants along the meandering Otapiri riparian strip exist mainly as scattered individuals that retain little of the former forest structure. Many of the remnants at this site are small groups or isolated single trees or shrubs surrounded by pasture grass. This site represents one of the extremes of the fragmentation gradient, and there are no nearby core forest areas remaining. Nevertheless, several threatened trees and shrubs remain. Although entirely surrounded by farmed pasture, the strip of native vegetation along Otapiri stream was mostly fenced and protected from livestock. The soil type is unconsolidated sand, gravel and silt in modern floodplains (Turnbull & Allibone 2003). There are areas where stock has access to the riparian zone, and at these places there is trampling of the riverbanks and damage to mature trees.

The Taringatura study site is the Taringatura Camp (RAP 12) of Simpson (1998). Rance & Simpson (2000: 10) described the Broadlands Bush, and Taylor's/McLee's sites (Rance & Simpson 2000: 14–15).

Other catchments

We know of no published descriptions of the small fragments in the lower Mataura, Toi, Waihopai, and Waituna catchments, within which we placed sampling plots.

2.2.3   Vegetation and flora

Four woody plant tiers (emergent, canopy, subcanopy, and understorey) and ground, liane and epiphyte 'tiers' were distinguished. At each plot, the maximum and minimum height of emergent, canopy, subcanopy, and

understorey tiers (if present) were estimated by eye and recorded. The diameter at breast height of each woody stem above 1 m height was measured using a measuring tape and recorded within its tier. All plant species present in ground, liane and epiphyte tiers were also recorded. Seedlings of rare plants were noted where observed. The total percentage vegetation cover of each of the seven tiers was estimated by eye, together with percentage ground litter cover.

From the vegetation data, we calculated several characteristics of the community. These included the total number of rare plants present in the plot (i.e. the number of plants classified as endangered or at risk in the current New Zealand Threat Classification list). In addition to the target plants, these include *Uncinia strictissima*, *Ranunculus ternatifolius*, *Deschampsia cespitosa*, *Peraxilla colensoi*, *Tupeia antarctica*, *Olearia lineata*, *O. fragrantissima,* and *Pseudopanax ferox*. Other community characteristics were native and exotic vascular species richness of each plot, and of each vegetation tier within the plot. We calculated tier complexity as the number of tiers present (maximum of seven).

2.2.4   Habitat–environment parameters

We recorded the floodplain habitat type (levee, floodplain terrace, backswamp, or swamp), predominant substrate type (peat, loam, silt, sand or gravel) and soil properties (depth of organic layer, evidence of gleying < 30 cm depth; the latter are referred to hereafter as 'gleyed' soils).

From plot grid references, we obtained estimates of key climate variables for each site (Penman rainfall: potential evapotranspiration, October vapour pressure deficit, and Penman annual soil moisture deficit, as well as average ground frost temperature in July) from GIS climate surfaces (J.R. Leathwick, unpubl. data). We also determined the Level IV land environment (Leathwick et al. 2003) and the potential prehuman forest type (Leathwick et al. 2005) at each plot.

2.2.5   Indicators of fragmentation

We estimated the percentage catchment deforestation and local ecosystem loss (percentage forest loss or clearance of the local levee–platform–backswamp ecosystem sequence) in the field. We recorded whether the plot was in pasture, or located within a forest fragment (the latter was defined as vegetation with a forest tree canopy greater in area than the 10×10 m area of the plot). Where the plot was isolated in pasture, spatial isolation was also estimated in the field (i.e. the distance separating the forest fragment from the nearest neighbouring fragments or forest tract). At each plot, the distance from the plot to the stream channel and forest edge were estimated, and the nature of the nearest forest edge (natural, artificial, stream, pasture, or other) was recorded.

Other simple measures that are likely to indicate the degree of forest fragmentation were derived from the available land cover database (LCDB1; Terralink) in GIS. Using LCDB1, we estimated the deforestation of the six catchments represented in our plot-based sampling (i.e. Waiau, Oreti, Mataura, Toi, Waihopai, Waituna) to supplement our field estimates. We also determined the LCDB1 vegetation cover classification at each plot location (i.e. pasture, scrub, indigenous forest, plantation forest, or riparian willows). Next, to supplement our field estimates of the distance of plots to nearest forest edges,

we estimated the isolation of each plot mapped in a non-indigenous forest LCDB1 category from the nearest neighbouring indigenous forest fragment or tract. For each plot within indigenous forest, we determined patch size and perimeter (edge) to area ratios. On comparison with our records, we determined that several plots that were sampled within indigenous forest were classified as pasture by LCDB1, and vice versa. We therefore used our field estimates of pasture and indigenous forest in our analyses, rather than those derived from LCDB1. We note that the accuracy of our GIS-derived measures is low, and that results derived from them should be regarded with some caution.

2.2.6 Data analyses

Plant community

We used both multivariate and univariate methods to describe the present-day pattern of floodplain forest vegetation, and its relationship to the environment.

Detrended correspondence analysis (DCA) ordination was used to identify the principal floodplain forest vegetation gradients, and cluster analysis (an agglomerative classification technique) was used to classify the plots into eight broad forest types and 20 vegetation subtypes. In these multivariate analyses, species in different tiers were treated as separate species, and the summed stem area at breast height (cube-root transformed) was used as the measure of abundance.

Simple regressions were used to assist interpretation and description of the major vegetation types (from the classification) and gradients (from the DCA ordination) in terms of the habitat–environment parameters, and community characteristics (including aspects of vegetation structure, and rare-plant components).

Target rare plant species

We summarised the geographic distribution patterns, and the habitat and plant community associations of our target rare plants (*Coprosma wallii*, *C. pedicellata*, *C. obconica*, *Melicytus flexuosus*, *Pittosporum obcordatum*, and *Olearia hectorii*) within our sampled plots across the Southland Plains.

Effects of fragmentation on the plant community and rare plants

We used linear regression to explore relationships between the different forest types (from the classification) and gradients (from the DCA ordination) and our possible indicators of forest fragmentation. We also regressed community characteristics on our possible indicators of fragmentation. Those community characteristics that showed significant relationships with indicators of forest fragmentation were identified as likely biotic consequences of fragmentation. We used *t*-tests with unequal replication to compare indicators and biotic consequences of forest fragmentation between sites where the rare plant was present and absent across the whole dataset of 135 sites. To examine fragmentation effects on the occurrence of rare plant seedlings (an indicator of rare plant viability) we used *t*-tests with unequal replication to compare indicators and biotic consequences of forest fragmentation across only those sites where adult plants were recorded as present.

2.3 RESULTS

2.3.1 Floodplain forest communities

In total we collected c. 16 000 individual plant records at 135 sampling plots. Classification of the 135 plots identified eight types of floodplain forest community drawn from four habitat types (levee, floodplain terrace, backswamp, swamp). The structural dominant species of each type are shown in Table 4. Their distribution across the Southland Plains and across the different floodplain habitat types is given in Table 5. Their relationship to the major gradients identified by the ordination, and their characteristic features (in terms of environment, structural feature, species richness, rare plant components, and fragmentation) are shown in Table 6.

Some of the eight community types are diverse and include several subtypes (hereafter 'subcommunities'). Communities C (totara–matai terrace forest; sampled in 7 plots), E (Back Valley *Pittosporum obcordatum* forest; sampled in 6 plots) and F (mountain beech forest; sampled in 12 plots) are relatively uniform in composition (i.e. no distinctions were recognised at the 20-group level of the classification).

Community A (matai–kowhai–manatu levee forest) is the most widespread, diverse and (on average) the most fragmented forest type; 62 (46%) of the 135 sampled plots were sampled in this community. Five subcommunities were distinguished:

A1—These are typically shrubland communities, occasionally with emergent totara or kowhai. The rare shrubs *Coprosma obconica* (3 plots), *C. pedicellata* (7 plots), *C. wallii* (4 plots), and *Melicytus flexuosus* (3 plots) all occur here. The 13 plots are located in Turnbull's, Mouat's, Quinn's, Taylor's, and Cook Road forest fragments (Table 5).

A2—These ten plots represent relatively species-rich terrace forest fragments, often with manatu canopies, and occasionally with emergent manatu or totara. They typically contained a relatively high number of rare plants in the ground tier. The rare shrubs and small trees *Melicytus flexuosus* (14 plots), *Coprosma wallii* (4 plots), *Pittosporum obcordatum* (1 plot), and *Olearia hectorii* (1 plot), are recorded from these plots in forest fragments at Dunsdale, Swale's Bush, Taringatura, Turnbull's, Mouat's and Quinn's.

A3—These five plots have tall emergent matai, occasionally with kowhai and manatu remaining in the very sparse, species-poor canopy. There is very little ground cover, but *Coprosma obconica* (2 plots), *C. pedicellata* (1 plot), and *Melicytus flexuosus* (4 plots) were all recorded here. Principal sites are Mabel Bush, Turnbull's and Quinn's fragments.

A4—This group of 18 plots has a canopy of matai, and also occasionally canopy kowhai and manatu, but no emergents. The plots are particularly rich in exotic species, and occur predominantly in deforested eastern catchments where there has been a high degree of floodplain ecosystem loss. *Coprosma pedicellata* (7 plots), *C. wallii* (9 plots), *Melicytus flexuosus* (13 plots), *Pittosporum obcordatum* (1 plot) and *Olearia hectorii* (3 plots) were recorded. Plots with this composition were sampled in Mabel Bush, Swale's Bush, Turnbull's, Mouat's, and Taylor's forest fragments.

TABLE 4. STRUCTURAL DOMINANTS (EMERGENTS AND CANOPY TREES) OF THE EIGHT FOREST TYPES*.
Table entries are the percentage of plots in which the species was recorded as present in that tier. A–H are forest types, while Groups I–VII indicate ecologically similar canopy and emergent species (based on common co-occurrence).

GROUP	SPECIES	COMMON NAME	TIER	A 62	B 4	C 7	D 13	E 6	F 12	G 24	H 7
I	*Prumnopitys taxifolia*	matai	Canopy	37	25	71	15			17	43
II	*Sophora microphylla*	kowhai	Canopy	32	25				8		14
	Plagianthus regius	manatu	Canopy	39	25	14	23	33			
III	*Nothofagus solandri*	mountain beech	Canopy	3					92	4	43
IV	*Nothofagus menziesii*	silver beech	Canopy	3	75				8	17	71
	Elaeocarpus hookerianus	pokaka	Canopy	3	25				17	50	57
	Dacrycarpus dacrydioides	kahikatea	Canopy	8	25				17	46	43
	Dacrycarpus dacrydioides	kahikatea	Emergent	3						38	100
V	*Podocarpus totara*	totara	Canopy			100	8			4	
	Griselinia littoralis	broadleaf	Canopy	5			15			21	29
	Pennantia corymbosa	kaikomako	Canopy	15			38	17			
	Prumnopitys taxifolia	matai	Emergent	10			15				14
	Coprosma propinqua	mingimingi	Canopy	6			31	100		17	
	Plagianthus regius	manatu	Emergent				85	67			
VI	*Olearia fragrantissima*	fragrant tree daisy	Canopy			14	8				
	Sambucus nigra	elderberry	Canopy	3		29					
	Olearia hectorii	Hector's tree daisy	Canopy	5			8				
	Podocarpus totara	totara	Emergent			14	8				
	Coprosma pedicellata	mikimiki	Canopy	3						17	
	Pseudopanax colensoi	orihou	Canopy	2			8			13	
	Carpodetus serratus	putaputaweta	Canopy	3						17	14
	Cordyline australis	ti, cabbage tree	Canopy	3	25						14
	Weinmannia racemosa	kamahi	Canopy							17	
	Elaeocarpus hookerianus	pokaka	Emergent	2						17	
	Crataegus monogyna	hawthorn	Canopy	10						8	
	Coprosma rigida	mikimiki	Canopy	2			8	100		8	
	Melicytus flexuosus		Canopy	2			8	100			
	Pittosporum obcordatum	heart-leaved kohuhu	Canopy	3				100			
	Olearia lineata		Canopy				8	100			
	Podocarpus hallii	Hall's totara	Canopy	5		29	8			13	14
	Coprosma wallii	mikimiki	Canopy	3			54			4	
	Pseudopanax crassifolius	horoeka, lancewood	Canopy	2			23			13	14
	Sophora microphylla	kowhai	Emergent	2			23				
	Myrsine divaricata	weeping mapou	Canopy				31	17		13	
	Pittosporum tenuifolium	kohuhu	Canopy	11		14	38			17	
VII	*Coprosma 'taylorae'*	mikimiki	Canopy	3			8	17			
	Coprosma virescens	mikimiki	Canopy	2			23				
	Pittosporum tenuifolium	kohuhu	Emergent							8	
	Leptospermum scoparium	manuka	Canopy	2			8				14
	Coprosma rotundifolia	mikimiki	Canopy	5			8	33		8	
	Aristotelia fruticosa	mountain wineberry	Canopy	2				17			
	Corokia cotoneaster		Canopy	2				33			
	Prumnopitys ferruginea	miro	Canopy						8	4	
	Salix fragilis	crack willow	Canopy	3							
	Neomyrtus pedunculata	rohutu	Canopy							8	
	Ulex europaeus	gorse	Canopy							8	

* Forest types are: A = matai–kowhai–manatu levee forest; B = silver beech–pokaka terrace forest; C = totara–matai terrace forest; D = mixed manatu terrace forest; E = Back Valley *Pittosporum obcordatum* forest; F = mountain beech forest; G = kahikatea backswamp forest; H = kahikatea–silver beech levee/backswamp forest.

Table entries are the number of plots (numbers in parentheses are percentages in each vegetation type).

CATCHMENT/ LOCATION		HABITAT TYPES*							
		A	B	C	D	E	F	G	H
Waiau	Back Valley					6	5		1
	Broadlands-Motu Road			2					
	Mouats	12	3		3		4	8	1
	Quinn's	11		1			2	2	5
	Swale Road			2					
	Taylor's Bush/Mclees	2		2			1		
Oreti	Cowie Road	2						1	
	Dunsdale	1	1		10			2	
	Harris Road	2							
	Mabel Bush	6							
	Otapiri	2							
	Swale's Bush	4							
	Taringatua	1							
	Turnbull's	18						4	
Mataura	Glendenning							2	
	Gorge Road							1	
Toi	Titiroa							1	
Waihopai	Waihopai							1	
Waituna	Cook Road	1						2	
HABITAT TYPE									
Levee		28 (45)	1 (25)	1 (14)	4 (31)	0 (0)	3 (25)	0 (0)	4 (57)
Floodplain terrace		25 (40)	2 (50)	5 (71)	8 (62)	6 (100)	5 (42)	7 (29)	1 (14)
Backswamp		10 (16)	0 (0)	0 (0)	1 (8)	0 (0)	3 (25)	11 (46)	3 (43)
Swamp (i.e. peat)		2 (3)	1 (25)	0 (0)	0 (0)	1 (17)	1 (8)	4 (17)	1 (14)
Total (n =)		62	4	7	13	6	12	24	7

* Forest types are: A = matai-kowhai-manatu levee forest; B = silver beech-pokaka terrace forest; C = totara-matai terrace forest; D = mixed manatu terrace forest; E = Back Valley *Pittosporum obcordatum* forest; F = mountain beech forest; G = kahikatea backswamp forest; H = kahikatea-silver beech levee/backswamp forest.

A5—These 16 plots have kowhai canopies, often with manatu, matai and kaikomako also present. They typically occur in pasture and are spatially isolated. *Coprosma obconica* (2 plots), *C. wallii* (4 plots), *Melicytus flexuosus* (2 plots), *Pittosporum obcordatum* (2 plots) and *Olearia hectorii* (1 plot) are recorded. Examples occur in fragments at Cowie Road and Otapiri, Swale's Bush, Turnbull's, Mouat's and Quinn's (Table 5).

Only 4 plots were sampled in Community B (silver beech-pokaka terrace forest), but the classification distinguishes three subcommunities (B1, B2, and B3). Two of these have silver beech canopies (subcommunities B1 and B2; 3 plots in forest fragments at Mouat's) while B3 has a canopy of matai, kowhai, and manatu (this is represented by a single plot in a forest fragment at Dunsdale, where beech is absent). All Community B plots contain *Coprosma wallii*, while B2 and B3 also contain *Melicytus flexuosus*.

Community C (totara-matai terrace forest) comprises 7 plots, each with totara in the canopy. Only one of these plots (on Quinn's property adjacent to the Dean Burn) is within a remnant of a true meander floodplain ecosystem. The 6

plots that were sampled in Broadlands, Taylor's and Swale's forest fragments are on the higher terraces of the Waiau outside the floodplain ecosystem proper (Table 5; Appendix 2). Substrates at these six plots are therefore relatively older and therefore more leached, infrequently inundated, with relatively continuous litter layers. However, all of these contain *Melicytus flexuosus*, and four contain *Coprosma obconica*.

Ten of the 13 plots in Community D (Mixed manatu terrace forest; Table 6) were sampled in forest fragments along Dunsdale Creek, while the remainder were on Mouat's property in the Dean Burn. All but one plot contained *Coprosma wallii*, seven contained *Melicytus flexuosus,* and one had *Olearia hectorii* present. *C. obconica* and *C. pedicellata* were recorded in Dean Burn plots. The three subcommunities are D1 (2 plots dominated by *Pennantia corymbosa* and *Griselinia littoralis*), D2 (2 plots characterised by emergent manatu and kowhai), while D3 (9 plots) has emergent manatu.

Community E is the distinctive *Pittosporum obcordatum* forest sampled at 6 plots only in Back Valley (Appendix 2), in which *P. obcordatum*, *Melicytus flexuosus*, *Coprosma propinqua*, *C. rigida* and *Olearia lineata* are constant canopy components.

Community F is a mountain beech forest community covering levees, terraces, and backswamps at the more intact end of the Waiau catchment (11 plots in Back Valley, on Mouat's and Quinn's properties in the Dean Burn, and a single plot in Taylor's Bush). *Coprosma pedicellata* was the only one of our rare target plants recorded in this community.

Emergent kahikatea are constant in Communities G and H. A large number of plots (24) are classified within the backswamp and swamp forest type Community G, which is characterised by emergent kahikatea and gley soils, and is the typical habitat of *Coprosma pedicellata* (although *C. wallii* and to a lesser extent *C. obconica* and Melicytus flexuosus are also occasionally recorded). The community is species-rich, widely distributed geographically, and four main variants are distinguished at the lower (20-group) level of the classification, on the basis of different amounts of pokaka, silver beech, Coprosma rotundifolia, and broadleaf, and the presence or absence of emergent kahikatea.

Community H is a less fragmented kahikatea–silver beech forest type recorded at seven plots, mainly on Quinn's property and adjacent conservation land in the Dean Burn. It represents forest associations that grow on narrow transition zones between meandering streams and peat substrates, often including narrow backswamp zones. Species richness is high (apparently partly due to the high micro-topograpic variation associated with these ecotones) and *Coprosma obconica* and *C. pedicellata* were recorded there in similar numbers.

2.3.2 Floodplain forest vegetation gradients

Four major vegetation gradients were identified by DCA ordination (Fig. 2; Table 6). The first gradient does not correlate well with any of our measured environmental characteristics, but is almost certainly related to differences in forest composition caused by environmental factors, while the second to fourth gradients are all related to both environment and fragmentation.
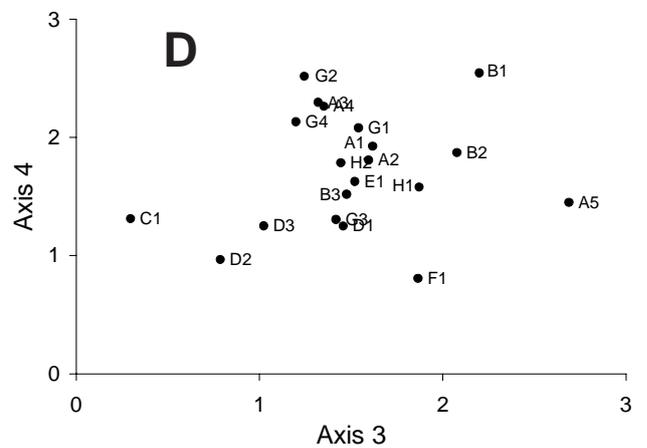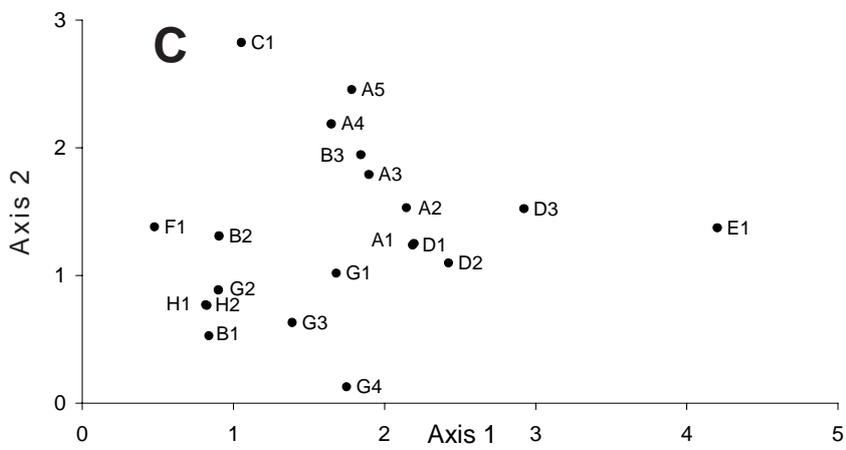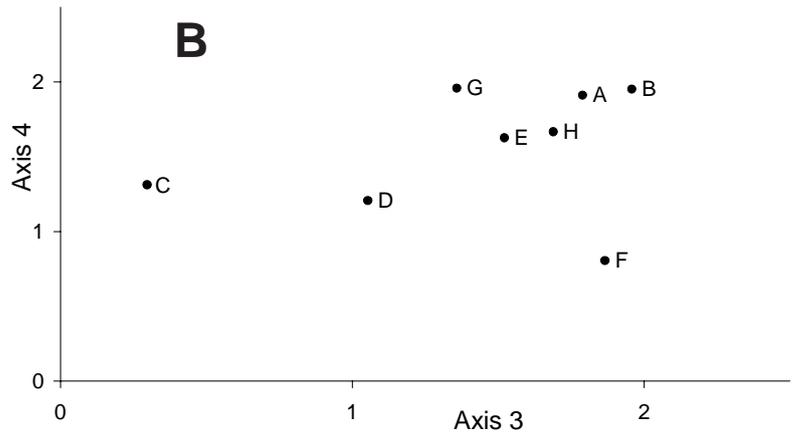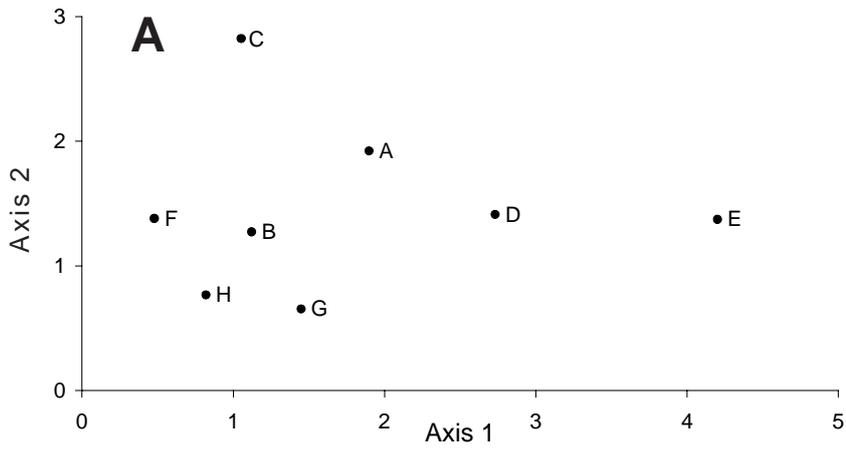
Figure 2. The first four axes (**A**, **C** = Axes 1 and 2; **B**, **D** = Axes 3 and 4) of the DCA ordination of sampling plots, showing the average scores of the eight communities (**A**, **B**) and the 20 subcommunities (**C**, **D**) on those axes.