Plant Establishment following Debris Flows in Two Stream Valleys Matata, New Zealand

On May 18, 2005, powerful rain-triggered debris flows scoured Awatarariki and Waitepuru Stream Valleys, destroying 27 homes in their paths. Between the two valleys, the flows deposited 700,000 cubic meters of fine sand to large boulders that formed barren terraces upon which ensuing biological and physical processes could act. Within months, a suite of native and introduced plant species began to colonize these newly formed land surfaces. This project looks at the spatial and temporal pattern of succession along the two streams to gain a better understanding of the factors that determine the trajectory of plant community development, particularly the relative growth of native and introduced species.

Plant succession in context

Increasing human activities have disturbed land surfaces on a global scale, thereby creating plant communities characterized more than ever before by large-scale succession (Bazzaz 1996). Safe because of their isolation, New Zealand's native vegetative systems remained in their natural state until Polynesian settlement in the 13^{th} century (King 2003). These Maori settlers employed widespread fires to clear land for cultivation and to encourage growth of bracken fern, whose roots were staple food items (Esler 2004). Native grassland coverage increased five-fold and forest decreased by 30% as a result, and since then most New Zealand plant communities have changed in composition and shifted in distribution at an accelerating rate in response to a number of human-caused stresses to the environment (Craig et al. 2000, Atkinson and Cameron 1993). Today the most prevalent human disturbances are economically driven post-European land use changes: deforestation, conversion to dairy, pasture or pine plantation, and urbanization. Within these areas and particularly following their abandonment (e.g. after logging or following a reduction in grazing), succession dictates which plant species will thrive and which species will die out.

Although widespread human disturbances are novel, natural disturbances have always impacted ecosystems. From a fallen tree disrupting a few square meters to super volcanoes devastating thousands of square kilometers, natural events such as floods, fires, storms, landslides, earthquakes and volcanic eruptions all contribute to earth's dynamic systems. Indeed, these changing environments are fundamental to the biological diversity we see today; the intermediate disturbance hypothesis maintains that diversity peaks at intermediate levels of disturbance (Connell 1978). Many of New Zealand's light-demanding canopy trees only regenerated within these affected areas, and pre-human distribution of fauna and flora was greatly affected by periodic large-scale events (Craig et al. 2000). Today the distinction between natural and anthropogenic disturbances blurs as human impact on the earth (e.g. climate, floodplain topography) influences the frequency and intensity of natural events (e.g. storms, floods).

Regardless of its ultimate cause, each disturbance to the natural system creates disequilibrium and the opportunity for new plant associations to take over a piece of habitat. The conditions at hand determine the species that will colonize and ultimately prevail within the disturbed area. The physical factors of light, moisture, nutrients, temperature, wind and substrate are all interrelated with the surrounding flora and fauna, which additionally determine available herbivores, pollinators, and seed sources. Plants favored by one set of conditions may alter a site to favor their replacement by an entirely different community. A common example of this process of facultative succession is the early-successional fixation of nitrogen by mycorrhizal fungal and bacterial associations with root systems, preparing the soil for more nutrient-demanding species (Esler 2004).

Light availability is perhaps the most important difference between recently disturbed environments and mature vegetation. A dense forest canopy absorbs most of the red light, inhibiting seed germination and/or seedling growth in some light-demanding plants; more abundant radiation in early-successional environments raises the red : far-red ratio and permits these species to germinate and grow (Bazzaz 1996).

Many models can predict large-scale trends in vegetation with relatively simple parameters. Land Environments of New Zealand (LENZ) predicts original forest cover with reasonable accuracy using only climate, landscape, and soil (Leathwick in Harding et al. 2004). Still, on a smaller scale local variations in a plant's environment are quite complex. Even carbon dioxide, initially considered diffuse and well-mixed, varies sufficiently with time (diurnally and seasonally due to changing rates of plant photosynthesis) and height (in vegetated areas with little wind) that it affects the relative growth of plants possessing different mechanisms of carbon fixation; O^{13} isotope work has shown that in some cases plant respiration may be a more important source of CO_2 than diffusion or mixing (Bazzaz 1996).

At every stage of succession, an interconnected web of local physical and biological factors determines which plants will survive.

Volcanic succession

Most prior studies of plant succession near Matata look at the recovery of surfaces decimated by eruptions originating from the Taupo Volcanic Zone (TVZ), a geologically active region that covers much of the central North Island. In zones of major activity, rhyolitic magma has erupted here at a rate higher than anywhere else on the planet (Borella et al. 2008), so potential study sites are relatively common.

Mt. Tarawera's 1886 eruption is one of the most recent volcanic events in the TVZ. Historical records of vegetation before, immediately after, and periodically since (most notably in 1915, 1928, 1964, and 1979) the event create the opportunity to follow plant succession over reasonable time scales (Timmins 1983). In spite of differing immensely in scale, substrate, and climate, the sites affected by Mt Tarawera's 1886 eruption and the 2005 Matata debris flows share similar floristic compositions due to their geographic proximity. Thus the well-researched patterns of succession on Mt Tarawera provide a useful reference for studies upon debris flow deposits in nearby Matata.

In a matter of hours the Tarawera eruption of June 10, 1886 blanketed 6000 km^2 with more than 2.5 cm of scoria air fall deposits (Walker et al. 1984 in Borella et al. 2008). Much thicker deposits tens of meters thick are the result of intense activity within several hundred meters of active vents along the 7.5 km fissure (Borella et al. 2008).

Primary plant succession on the ash and lapilli substrate followed a pattern similar to several other post-European eruptions in New Zealand (Clarkson 1990). The bare surface was colonized first by spots of vegetative mats (dominated by *Muehlenbeckia axillaris*); next low grasses, herbs and mosses (*Racomitrium lanuginosum*) formed a growing ring over this stabilized ground; and finally hardwood scrub (manuka, kanuka) and native forest (kamahi) established within these hospitable circles of vegetation (Timmins 1983). Over this homogenous scoria-covered ground, plant succession was most rapid near the base of slopes, with vegetation lagging behind in harsher conditions found at elevation near the tree line (Timmins 1983). However, at the craters themselves large boulders trapped wind-blown seeds and organic substrate and also provided sufficient cover and water to permit immediate post-eruption colonization of some tree species (kamahi, broadleaf, *Coprosma* sp.), thus bypassing the traditional sequence of succession (Clarkson and Clarkson 1983).

On the northwest face of the Tarawera scoria deposits, a dense cover of the woody pioneer prickly hakea (*Hakea sericea*) at middle elevations is often smothered by lichen growth, an indicator of poor health (personal observation 2008; Esler 2004). Gaps within this degenerating canopy host frequent sapling pines, an introduced taxa sprouting from wind-blown seeds originating in areas of plantation pine forest and land occupied by their invasive progeny. These trees (mostly *Pinus radiatus*) are capable of colonizing high elevation sites with little trouble. Increasing populations of other introduced plants (e.g. ragwort) have been observed (Clarkson and Clarkson 1983). These new biota may compete with their native counterparts or alter the habitat to conditions native alpine plants cannot endure.

The abundance of nutrients released by weathering scoria upon Tarawera influence the suite of colonizing plants. The physiological requirements of each species limit potential habitats (Esler 2004). Often tree tutu (*Coriaria arborea*), koromiko (*Hebe stricta* var. *stricta*) and other nitrogen fixing plants facilitate the transition to late-successional tree species (Clarkson 1990, Timmins 1983). External inputs of nutrients can also play an important role: on Tarawera's Ruawahia and Wahanga domes, guano deposited by black-backed gull colonies (established between 1964 and 1980) permitted the growth of a locally unique nutrient-demanding grass and herb community dominated by the introduced sweet vernal (*Anthoxanthum odoratum*) (Clarkson and Clarkson 1983).

Tarawera's intense volcanism completely destroyed vegetation near the craters, but the impacts of the event predictably diminished with increasing distance. On the lower slopes some trees were able recover after being stripped of their leaves and bark, and in sheltered low-lying areas to the southeast some pockets of forest not only survived but even reproduced the following year (Aston 1916 in Timmins 1983). Such sources of seeds allowed forest species such as kamahi to quickly colonized suitable habitats on the topographically varied southeast face of the fissure (Timmins 1983). Meanwhile the more heavily impacted and less varied northwest face received fewer seeds because of Lakes Tarawera and Rotomahana, which isolate the region from potential parent plants. Species with long-distance seed dispersal mechanisms (e.g. manuka and kanuka, with light wind-borne seeds) (Esler 2004) were the most effective colonizers, while kamahi, a common element of succession on the southeast face, remains rare due to its limited dispersal range (Timmins 1983).

Debris Flows

Stream valleys in the Matata region of New Zealand are composed of loosely consolidated sedimentary and volcanic deposits. Significant annual precipitation mobilizes large amounts of sediment, contributing to slope instability by saturating the subsurface and increasing pore pressure. Plants' root structure may help stabilize sediments and absorb excess water, but large trees may also promote erosion events – their weight creates additional stress on slopes (McSaveney et al. 2005). Most forest in Awatarariki and Waitepuru Stream Valleys is relatively young, but slips and slides of the land surface are still common on steep valley walls. Where one or several of these erosion events flow into a confined channel, a debris flow may develop and create rapidly moving dense slurry of water and poorly sorted sediments. Such a flow may alternately pick up and deposit debris according to varying speed and topography before it drops most of the large clasts when it spreads out and slows after exiting the narrow box canyon.

The debris flows in Awatarariki and Waitepuru Stream Valleys on May 18, 2005 were caused by an intense burst of rain (13cm in less than 2 hours) following a day of steady precipitation (McSaveney et al. 2005). Though statistically a 500-year rainfall event (McSaveney et al. 2005), historic records indicate that major rain-triggered debris flows occur every few decades (Olsen, personal communication). This suggests that lesser rains must have been sufficient to mobilize debris flows in past conditions.

Only a few percent of the catchments' land surface was affected, but vegetation removal on these sites was complete (McSaveney et al. 2005). These areas contribute to the extremely high rates of sedimentation observed within the valleys since. It has been proposed that debris flows within the valleys may be clustered; several events may scour the canyon while sediment is quickly recharged before vegetation can stabilize the land surface and temporary equilibrium is once again reached (Frontiers Abroad coordinators, personal communication).

Debris flow deposits offer an environment for successional processes that differs significantly from the volcanic scoria domes of Tarawera. Most obviously, the scale of the event is far smaller. Seed sources are readily at hand along the narrow deposit (on the order of tens of meters), and the surrounding forest will also provide wind and sun protection along its perimeter. Deposited material in Awatarariki and Waitepuru Stream Valleys is sourced from both marine and volcanic sediments. Flooding and a consistently high water table near the stream may further alter these sandy soils. Abundant boulders up to 7m in diameter within these deposits create hospitable microhabitats for direct colonization, providing conditions more similar to the boulder-strewn Tarawera domes rather than the flanking homogenous scoria surfaces exposed to the elements. The moist, mild climate further encourages immediate establishment of less hardy plant species, both native and introduced. Significant variation in conditions (e.g. radiation, soil type, surrounding vegetation) between and along both streams also exists. Correlation between these factors and plant growth is crucial to defining mechanisms of succession.

Vegetation growing upon debris flow deposits at various sites around the world may share traits in common with those in Matata. Deposits in the Italian Central Alps follow successional stages and can often be roughly dated by looking at vegetation on their high ridge (lower areas are more likely to regress to early-successional communities because of post-debris flow disturbances such as floods) (Canone 2004). Short-lived species were the first to colonize debris flow deposits in the Grand Canyon, but in a few decades some of the established seedlings grew to tree status and attained dominance (Bowers et al. 1997). In the western Oregon Cascades, tree seedlings also colonized bare surfaces, but vegetative growth from surviving plants dominated, especially in less intensely scoured sections of the flow (Gecy and Wilson 1990). Thus one might expect to observe within Awatarariki and Waitepuru Stream Valleys a similar immediate colonization by seedlings, annuals, and vegetative growth from surviving plants followed by a transition to long-lived late-successional species.

New Zealand’s native and introduced biota

Following New Zealand’s separation from Gondwanaland in the early Cretaceous (~90 Ma), plants and animals evolved in relative isolation. Some natural introductions from westerly wind drift and island hopping occurred, but no mammals (other than 2 small resident bats) reached the archipelago (Craig et al. 2000). Under these unique conditions birds were the dominant macrofauna, although reptiles and amphibians have probably been underrepresented by past studies. Most notable in this country of birds were about 11 species of moa, large ratites that served important roles as herbivores. In response, many plants developed a divaricating stage to protect leaves valuable for photosynthesis with a network of tangled twiggy branches (Cave and Paddison 1999).

As is the case on many recently colonized isolated islands, New Zealand’s biota is seriously imperiled by competition from and predation by mainland species. The native plants of New Zealand evolved to successfully cope with prevailing pre-human conditions, but they could not be prepared for the sudden influx of plant and animal introductions that have occurred over the past millennium. Initial Polynesian introductions were sparse by today’s standards: six species of food plants (e.g. sweet potato – *Ipomoea batatas*; taro – *Colocasia esculenta*), the kiore (Pacific rat – *Rattus exulans*), and the dog (*Canis familiaris*) were most important (Craig et al. 2000). These introductions (particularly kiore) along with direct human exploitation caused the demise of 32% of New Zealand's native land birds, but virtually no plants became extinct (Atkinson and Cameron 1993).

The next surge of introductions, beginning with frequent European contact around 1840 and continuing into the present, was far greater. Some introductions were accidental, but many plants and animals from the Northern Hemisphere were introduced intentionally to provide food, sport, and familiar landscapes for homesick colonists. In total, 80 pest animals (including 34 mammals) were brought over (Craig et al. 2000). Control of these high-profile animal invaders (especially possums, rats, and mustelids) is of primary importance to most New Zealand conservation efforts.

Far greater in number are the 2400 naturalized introduced plants, and continued invasions add another 11 species per year (Atkinson and Cameron 1993). Established foreign plant species now outnumber those native to New Zealand (Craig et al. 2000). Introduced plants vary widely in their impact upon the environment, and indigenous flora often overcomes the competition. Closed forest systems are robust communities resistant to invasion (e.g. Atkinson and Cameron 1993, Esler 2004). Most successful invaders are weedy annuals that specialize in colonizing disturbed habitats, a niche exploited by comparatively few natives (Riis and Biggs 2001 in Harding et al. 2004). But even in the event of initial rapid colonization by non-native weeds it is likely that the mature community will be dominated by native flora (George Perry, personal communication). Some introduced species (e.g. gorse) can assist the rapid return of habitat to a developed native community, albeit by an altered pathway (Atkinson and Cameron 1993). Others, however, retard (e.g. pampas grass) or even prevent (e.g. kikuyu) the return of native plants (Esler 2004).

Awatarariki and Waitepuru Stream Valleys are open to colonization by introduced species from below by gardens and roads and from above by pastures, each habitat hosting an associated exotic plant assemblage. Within the stream valleys, natural disturbances (debris flows, floods, and slips) expose fresh surfaces to a flurry of competition between native and exotic flora. Tracking the relative growth of native and introduced plants in these naturally disturbed areas may help to understand the development of New Zealand plant communities given their exposure to seed dispersal from increasing numbers of invasive species. The knowledge gained may have applications to conservation and restoration ecology.

Methods

Fieldwork was carried out between February and April of 2008. After initial reconnaissance trips, five transect pairs were laid out: three in Awatarariki and two in Waitepuru. Each 1m wide transect ran from the stream's edge to the valley wall, with paired samples located across the stream from one another. Within it all plants over 20cm were recorded, including their identification, size (height or percent cover), and distance from water's edge. Plants under 20cm were noted as well, though numbers were estimated and identification of annuals was frequently not to species level. Significant topographic features (boulders, terrace levels, valley wall) were recorded, and the topography of the three Awatarariki transect pairs was measured precisely with a GPS total station.

During analysis major species along each transect were grouped according to their origin (introduced vs. native) and life history traits (trees vs. annuals, light tolerant vs. intolerant, etc.). The densities of the three or four groups selected to best highlight each case were graphed. Relative density was normalized such that each grouping had the same average density of 1 unit per meter. Densities were smoothed across 3m intervals to minimize distracting small-scale variability and reveal underlying trends.

Site descriptions were recorded along the lower sections of each valley. Locations were selected to be representative of vegetative communities, and efforts were made to contain each site to a single habitat type with characteristic environmental conditions and corresponding vegetation. Each species visible within 10m was identified, and its approximate abundance was recorded qualitatively (categories of increasing abundance: rare, infrequent, occasional, common, abundant, rampant). Outside of this immediate zone, additional nearby species were recorded separately if they appeared to be associated with the same community type. Details of soil type, surrounding mature vegetation, topography, shading, and other physical factors that may have influenced the plants were also noted, with the intention of linking these variables to plant distributions.

Much of this data was collected with the idea that vegetation surveys be repeated. Observed changes to communities will reveal characteristics of succession on debris flow terraces. This will prove valuable in assessing the behavior of various plant associations that frequently colonize disturbed habitats.

Overview of Major Colonizing Species

Native Flora

Cabbage tree (*Cordyline australis*)

The cabbage tree is actually a monocotyledon, with a “false trunk of vascular strands” (Esler 2004). It begins to branch after its first flowering and fruiting stages (Metcalf 2006). It is tolerant of sunny to moderately shaded conditions (Esler 2006). Flax and cabbage tree are common swamp species, and have probably been encouraged to outcompete other native wetland species by extensive Maori burning; both species are resistant to fire and recover quickly (Esler 2006). The roots and leaf buds of cabbage tree are edible, and its fruits are devoured and spread by native birds (Metcalf 2006). It is a common garden plant, and the few specimens visible at the outlet of Awatarariki may be planted for roadside aesthetics.

Coprosma (karamu – *Coprosma robusta*; taupata – *Coprosma repens*)
Coprosmas are one of the more common regenerating species along shaded margins of both stream valleys. The genus can be easily recognized by small domatia alternating about the midvein on the leaf's lower surface. *Coprosma repens* is a very hardy coastal specialist, while *Coprosma robusta* (probably the more abundant species in the valleys) often grows along forest margins and on hillsides (Salmon 1980). Birds readily eat the small orange to red translucent fruits and disperse their seeds (Esler 2004).

Hooked sedge (*Uncinia uncinata*)
Hooked sedge (*Uncinia uncinata*), also known by such varied names as bastard grass, hook grass, and kamu, is frequent in the upper Awatarariki catchment, latching its hooked seeds onto passerbies. Although this may be an effective dispersal mechanism, other sedges without this adaptation appear just as prevalent in many similar habitats (Esler 2004).

Kamahi (*Weinmannia racemosa*)
Kamahi's profuse flowering occurs between October and January, producing abundant nectar that is an important food source for birds, insects, and native lizards (Metcalf 2006). It is often common in regenerating lowland to montane forests, as observed on Mt Tarawera (Clarkson and Clarkson 1983). Although several mature kamahi were visible within the surrounding forest, seedlings were nearly absent from both debris flow deposits.

Kanuka (*Kunzea ericoides*)
Distinguished from manuka by its finer foliage, kanuka is longer-lived (100 years) and has a larger maximum size (15m) than its tea tree counterpart (Metcalf 2006, Esler 2004). Unlike manuka, fire destroys its seed capsules; in general it is less tolerant of harsh conditions and nutrient-poor soils (Esler 2004). Although still a pioneer, kanuka may prove more mid-successional in nature, and at times overtops and replaces initial manuka growth (EBoP, Esler 2004).

Karaka (Corynocarpus laevigatus)
Karaka forms a major component of coastal gully forests that divert winds over their canopy and protects delicate species within them; its large thick leaves heavily shade the forest floor, serve as effective wind-barriers, and decompose rapidly to add nutrients to the soil (Esler 2004). Up to 15m in height, the fruits (produced January to April) were collected and prepared for consumption by Maori cultivators (Metcalf 2006). Seeds are dispersed by fruit-loving native wood pigeons. Karaka saplings are frequent along shaded areas of Waitepuru debris flow deposits.

Kawakawa (*Macropiper excelsum*)
The heart-shaped leaves as well as the bark and fruits of kawakawa have traditional medicinal properties that treat cuts, stomachaches, and rheumatic pain (Salmon 1980). The tree, which grows in a jointed manner along swollen nodes, is an understory shrub that may approach the lower canopy (Esler 2004). It required shaded conditions, often in

gullies or on rocky outcrops (Salmon 1980). Along both streams it grows in the shelter of forest margins and steep valley walls.

Kiokio (*Blechnum novae-zelandiae*)
This robust native fern is tolerant of even full sunlight provided it has access to sufficient moisture (Esler 2004). It is the most abundant low-growing fern in the Awatarariki and Waitepuru Stream Valleys, colonizing open exposed debris flow deposits, crevices under boulders, and steep valley walls. In more shaded areas it is joined by other ground and cover ferns, particularly along forest margins.

Koromiko (*Hebe stricta*)
A native weedy pioneer, koromiko colonizes open space on stream banks (Esler 2004). Wind-dispersed, it is scattered in low to moderate densities along debris flow deposits in both Awatarariki and Waitepuru.

Mahoe (*Melicytus ramiflorus*)
Mahoe is a common native with easily-snapped white-colored wood (hence its alternative name, whiteywood). It is intolerant of wind and prefers shaded conditions; saplings were most common within very narrow, low-light regions of Waitepuru Stream Valley. Its "large ramifying surface roots" are capable of binding rocky soils, and sprouts from its trunk allow it to vegetatively recover and regenerate (Esler 2004). It is a frequent element of regenerating forest scrubland (Metcalf 2006). Fruits are small and violet to black in color; they are eaten and dispersed by a variety of native birds.

Manuka (*Leptospermum scoparium*)
Manuka and kanuka are often lumped together with the name tea tree; they are similar in appearance and are both woody pioneers (EBoP 2005). Manuka can be distinguished from kanuka by its coarser foliage, and some individuals have a soot-colored mold fungus on their bark (Metcalf 2006). Manuka seeds are wind-dispersed (often after fires), and germinate in large numbers across sun-lit nutrient-poor sandy soils (such as those on the debris flow deposits) (Esler 2004). Competition eventually whittles down the numbers and a thick canopy grows up to 8m in height, though being short-lived manuka groves senesce after about 30 years (Esler).

Pate (*Schefflera digitata*)
The bird-dispersed tree pate shows particular affinity for streamside zones on account of more readily available light, moisture, and shelter (Esler 2004). Its 3 to 9 leaflets, arranged like fingers on a hand, are relatively thin and delicate (Metcalf 2006). Appropriately, most individuals within the valleys were located along streamside cliffs sheltered from the elements.

Pepper tree / horopito (*Pseudowintera colorata*)
The pepper tree grows in scrub and forest through much of New Zealand (Salmon 1980). Its dull yellow-brown to green leaves may take on a brilliant red color in direct sunlight (Salmon). All pepper trees saplings and seedlings found within the valleys grew into

well-lit zones from underneath large volcanic boulders, which may provide valuable shelter and/or nutrients.

Pohutukawa (*Metrosideros excelsa*)
Pohutukawa is a dominant element of many coastal New Zealand forests, and its distribution has only increased with widespread planting for its brilliant red flowers and resistant sheltering canopy (Esler 2004). Pollinated by native birds and geckos, trees disperse their seeds by wind in April and May (Metcalf 2006). Seedlings readily colonize exposed habitats, using winter moisture to its fullest by storing water and nutrients (up to 90% by weight in the roots) to prepare for the coming dry season (Esler 2004). Young plants maintain a smooth shiny appearance until their fourth or fifth year, when dense protective tomentum first appears on the undersides of the leathery leaves (Metcalf 2006). Seedlings were abundant on sunny flats in both Awatarariki and Waitepuru, and overhanging mature trees were important shading elements along the debris flow deposits. Pohutukawa's extensive root system anchor it in unstable ground, but may also help to erode hillsides as they expand and break the soil apart (Esler 2004).

Rangiora (*Brachyglottis repanda*)
Rangiora's large (to 25cm x 20cm) leaves, shiny above and covered with soft light-colored tomentum below, make the plant highly visible (Salmon 1980). Seedlings are dispersed by the wind and establish in scrub and forest or along their margins, often along streams (Esler 2004, Salmon 1980). The plant is very tolerant of exposure (Esler 2004). It is found within both valleys along forest edges and in their understory.

Rewarewa (Knightia excelsa)
Rewarewa's tall erect growth form (to 30m) allow it to breach the forest canopy in its search for light (Metcalf 2006). It is a fairly adaptable species, colonizing on most well-drained soils given sufficient light (Esler 2004). It is bird-pollinated and wind-dispersed (Metcalf). It is extremely abundant on the exposed sandy surface of one recent slip near the top of Awatarariki, where groves of mature trees border nearby farmland and produce large numbers of seeds. Lower down similar habitat is mostly colonized by seedling manuka and kanuka, though occasional rewarewa still appear where seeding adults are at hand.

Toatoa (*Haloragis erecta*)
This weedy native shares a single-stemmed erect growth form wth koromiko, and colonizes similar habitats: forest edge, slopes, and streamsides (Crowe 1994). It is far more common in Waitepuru than in Awatarariki.

Totara (*Podocarpus totara*)
Totara is highly tolerant of light and general exposure and hence is a frequent colonizer of light gaps (Esler 2004). There is significant year-to-year variation in seed production, but fair numbers are usually widely dispersed by fruit-eating birds and establish best on well-drained soils including alluvium (Esler). In spite of its preference for these conditions, totara is not a significant colonizer of the debris flow deposits: only one

individual (~50cm in height) was found on the floodplain within Awatarariki Stream Valley.

Tree Tutu (*Coriaria arborea*)
Tree tutu is a common nitrogen-fixing colonizer of eroding stream banks, stabilizing them and enriching their nutrients (Esler 2004). Its seeds are bird-dispersed, though it also readily resprouts from its lignotuber, a "swollen base half meter or more wide that produces shoots freely" (Esler 2004). It is well known for its high concentrations of the poisonous tutin, a substance concentrated in young stems and leaves but also capable of affecting honey sourced from its nectar (Metcalf 2006). Tree tutu is often the dominant plant along sloping stream banks and also in a wide flat region of Awatarariki Stream Valley, and its modification of the habitat (e.g. by nitrogen fixation) may prove important to future vegetation.

Introduced Flora

Black nightshade (*Solanum nigrum*)
Black nightshade is a small bushy annual or perennial found frequently along open roadsides in Matata, and scattered plants disperse well into both stream valleys. The plant's green parts are poisonous, and it flowers between October and May (Bishop and Bishop 1994).

Blackberry (*Rubus fruticosus agg.*)
Blackberry is a common nuisance plant in poorly drained areas bordering water, often forming thorny tangles of vines if not controlled (Esler 2004). These dense thickets may harbor pest mammals including rabbits and possums (EBoP). It can easily disperse both vegetatively (whenever stems contact soil) and by seeds (dispersal of seeds within the edible berries often facilitated by their consumers) (EBoP). The odd strand can be found along forest margins and stream banks in both Waitepuru and Awatarariki, and blackberry thickets have taken hold adjacent to parts of the old quarry road in Awatarariki.

Blue morning glory (*Ipomea indica*)
The blue morning glory adds color to roadsides, disturbed soils, and forest margins with its deep blue flowers, but its harmful tendencies become clear as it overtops and smothers natives (EBoP). Seeds of this perennial vine are not commonly produced in New Zealand; instead it spreads from broken stem fragments (EBoP).

Buddleia (*Buddleja davidii*)
Woody purple-flowered buddleia reaching several meters in height are occasional on Awatarariki and frequent on Waitepuru debris flow deposits. Seeds of this deciduous shrub are spread by wind or water, helping it to invade wasteland, roadsides, and other disturbed habitats (EBoP).

Clovers (*Trifolium spp.*) (red clover **–** *T. pratense*; white clover **–** *T. repens*; haresfoot trefoil **–** *T. arvense*)
Clover is a valued pasture plant, providing both nutritious feed for stock and enriching poor soils with nitrogen-fixing bacteria living on their root nodules (Bishop and Bishop 1994). Various clovers are common in the valleys' lower reaches and occasionally extending down from the pastures above Awatarariki.

Cotoneaster (*Cotoneaster glaucophyllus* and *C. franchetii*)
Cotoneaster is an attractive bush with glossy leaves and bird-dispersed bright red berries. Dense stands to 4m in height may compete with surrounding natives where it invades forest margins, riparian zones, roadsides, and other disturbed land (EBoP 2005).

Ginger, wild (*Hedychium gardnerianum* and *H. flavescens*)
This herbaceous perennial was only occasional in the lower Waitepuru, but dense colonies have the potential to smother surrounding low-growing vegetation (EBoP 2005). It may spread by root fragmentation, and *H. gardnerianum* also produces seeds (EBoP).

Gorse (*Ulex spp.*)
Gorse, a native of western Europe, may actually assist native succession by protecting seedlings from herbivores, enriching the soil with nitrogen, and permitting sufficient radiation to reach plants below and within it (Atkinson and Cameron 1993). It can be a nuisance in lumber plantations where it competes with young pines and impedes their harvest (EBoP 2005). It also can provide cover for unwanted pest mammals (EBoP). Explosive seedpods can blast seeds up to six meters, and large numbers of them remain viable in the soil for up to thirty years (EBoP). It is common in exposed sun-lit areas of both valleys where it finds no trouble colonizing poor soils. A large field dominated by gorse lies just outside Waitepuru Stream Valley.

Houttuynia (*Houttuynia cordata*)
This Asian native was banned from New Zealand but inadvertently imported under the name "Chameleon plant" (EBoP 2004). The ornamental garden plant spread quickly both vegetatively and by seed, preferring loamy waterside ground (EBoP). Its creeping growth can smother large patches, posing a significant threat to native plants (EBoP). A single strand was found in Waitepuru below the garden area; continued monitoring will reveal its viability in this habitat.

Inkweed (*Phytolacca octandra*)
The South American inkweed is a perennial bush that flourishes on sheltered to exposed sites in both stream valleys, on eroding valley walls and flat sandy deposits. Its preferred habitat within New Zealand includes disturbed wasteland and cleared ground, where it flowers between November and August (Bishop and Bishop 1994).

Japanese honeysuckle (*Lonicera japonica*)
This woody vine frequently colonized disturbed forest gaps and margins, and is capable of invading surrounding closed forests (Atkinson and Cameron 1993). Because honeysuckle is a fast growing smothering climber, these invasive tendencies may

devastate low to mid-canopy natives (EBoP 2005). Its nectar-rich flowers are abundant on roadsides between September and May, and its seeds are bird dispersed, although it often spreads by fragmentation (Bishop and Bishop 1994). On the reforested wildlife refuge Tiritiri Matangi, Japanese honeysuckle was successfully controlled with liberal applications of chemical agents to localized patches that threatened to spread throughout the island (Mitchell, personal communication). Near Awatarariki and Waitepuru honeysuckle is common along the highway, and localized strands are occasional along both debris flow deposits. It grows in denser patches by the old quarry road in Awatarariki.

Jasmine (*Jasminium polyanthum*)
Jasmine is dense-growing evergreen climber that spreads by bird-dispersed fruit, plant fragmentation, and layering (layering is "producing new roots from stems or nodes, usually when the stems are touching the ground") (EBoP 2005). As such it poses a serious threat to plants up to the mid-canopy level, capable of smothering natives as it expands. Several patches to several meters in diameter thickly blanket parts of the garden slope in Awatarariki, and smaller plants are establishing further down and into the valley.

Jersey cudweed (*Pseudognaphalium luteoalbum*)
Jersey cudweed is possibly indigenous to New Zealand, but shares most characteristic traits with introduced annuals (Esler 2004). It is abundant along roadsides and disturbed areas, and extends its range quite successfully far into both valleys (particularly more sunlit areas of Awatarariki).

Kikuyu grass (*Pennisetum clandestinum*)
Kikuyu is valued on farms for its high summer growth rates, but away constant grazing pressure it quickly monopolizes the landscape (Esler 2004). A Kenyan import, it rapidly propagates both vegetatively (by runners and deep rhizomes) and by seed (Esler). It grows in thick mats that inundate surrounding plants, cutting them off from light and causing their demise. It is one of the biggest problems for conservation and restoration projects. Dense growth of kikuyu grass are thus far limited to the outlets of Awatarariki and Waitepuru Stream Valleys. Some remnant strands were found upon the debris flow deposits, but it remains to be seen if this will establish to threaten natives within the valleys.

Pampas (*Cortaderia jubata,* perhaps also *Cortaderia selloana*)
A deliberate South American introduction, the pampas grasses successfully grow on disturbed land throughout northern New Zealand (Atkinson and Cameron 1993). Its tall white, buff or purplish flowerheads disperse up to 100,000 wind-borne seeds in March to May, which quickly establish in most sun-lit areas (EBoP 2005). These may form "dense long-lived stands that retard re-establishment of forest" (Atkinson and Cameron 1993). Pampas grass is most abundant in wide areas of Awatarariki and at both stream mouths, but smaller individuals may be found far into the valleys. Pampas can be distinguished from native toetoe (also in the *Cortaderia* family) by its single prominent mid-vein (toetoe have "distinct secondary veins between the midrib and the leaf edge"), curling

dead leaves (dying toetoe leaves droop), and smooth to hairy leaf bases (toetoe leaf bases have a "white, waxy surface") (EBoP 2005).

Pink siris (*Albizia jubissium*)
A small erect tree to 10m with fern-like leaves that frequently colonizes flats, roadsides, and stream banks just outside each valley, though only by Awatarariki does it form large dense thickets of saplings (to 4m). In spite of this nearby abundance, it is virtually absent from the valleys themselves and the debris flow deposits within them.

Purple-top (*Verbena bonariensis*)
The perennial purple-top is easily recognized by its hairy square stem (up to 1.5m) and bright purple flowers that bloom between January and June (Bishop and Bishop 1994). Introduced from Buenos Aires, South America (hence *V. bonariensis*), it is common along roadsides, pastures, and other open disturbed land, including the debris flow deposits in Awatarariki and Waitepuru (Bishop and Bishop 1994).

Ragwort (*Senecio jacobaea*) and Australian fireweed (*Senecio bipinnatisectus*)
Both annuals are common on pasture, waste areas, roadsides, and other disturbed ground (Bishop and Bishop). The European ragwort poses a significant threat to stock, who may sustain liver damage they consume it (EBoP 2005). Sheep, however, show no ill effects. Large numbers of seeds are easily dispersed by natural wind and water movements and by human movement of hay and chaff (EBoP). These plants are common along roadsides in Matata and in pastures above the valleys, and penetrate along the entirety of the light-rich riparian zone.

Tree lupin (*Lupinus arboreus*)
Nitrogen-fixing tree lupin is frequently planted on dunes to enrich the soil in preparation for forest plantations or stabilizing vegetation. It spreads rapidly along sandy nutrient-poor soils (Bishop and Bishop 1994) and is common along debris flow deposits, particularly in Waitepuru.

Water pepper (*Polygonum hydropiper*)
Introduced water pepper is a common colonizer of wet streamside habitats within the two valleys. It is related to the willow weeds, including the native swamp willow weed, and the species can hybridize during its flowering period of November to June (Esler 2004, Bishop and Bishop 1994). Only water pepper has been positively identified in Awatarariki and Waitepuru.

Results

Surveys in both valleys began at their mouths, within meters of heavily trafficked paved roads and train tracks. High, steep banks of unconsolidated sediment led steeply up from the stream to a wide floodplain surfaced with poorly sorted sands and gravels. Upon these open flats grew a variety of weedy species. Black nightshade, Jersey cudweed, and purple top were very common along the roadside and extended their ranges up onto these exposed sites. Broad-leafed dock, buttercups, purple cudweed, clover and countless other introduced annuals also colonized these wastelands. Although present only in localized patches, dense mats of kikuyu appeared healthy and may expand to smother nearby vegetation. Pampas grass was frequent and noticeable because of its tall stature. Large thickets of sapling pink siris skirted Awatarariki in sunlit flats and banks but were less abundant near the Waitepuru outlet. All the aforementioned species are introduced, but in damp areas and along unstable steep stream banks there grew nitrogen-fixing natives tree tutu and koromiko in addition to umbrella sedge and introduced tree lupin, inkweed, and buddleia.

Thickets of sapling pink siris border the train tracks by the bridge that spans Awatarariki Stream. On nearby gravel flats, roadside specialists (primarily introduced annuals) provide sparse cover.

Along the debris flow deposits conditions changed frequently as the valleys narrowed and widened. Large broad pohutukawa trees proved important shading elements, especially lower in the valleys where they were associated with coastal five-finger, hardwood scrub (manuka, kanuka), coprosma, rangiora, and mamaku. In higher reaches there were hard beech, silver fern, rewarewa and mahoe. Rewarewa was especially abundant bordering farmland at the top of Awatarariki. In Waitepuru karaka, pigeonwood, and kamahi were also important elements of the coastal forest.

Left: Farmland gives way to tree ferns and rewarewa at the top of Awatarariki Stream Valley. Right: A large pohutukawa shades Awatarariki Stream near the valley's mouth.

Near to steep valley walls lay boundary zones in which eroding soils and falling leaves from the mature forest above maintained a thin layer of nutrient-rich material over the sands left by the debris flows. Sheltered by the adjacent steep slopes were sapling kawakawa, coprosmas, karaka, lacebark, mapou, and mahoe interspersed with hangehange and ground ferns (the robust kiokio as well as more delicate ladder, lace and kidney ferns) (Fig. 1). The invasive inkweed found no trouble establishing on these surfaces alongside this suite of natives; indeed it was found in a large variety of shaded to sunny but sufficiently moist habitats right down to the stream's edge.

Left: A dense thicket of coprosma saplings grows along the forest edge, collecting a thin nutrient-rich layer of decayed leaves and eroded soil. In the open grow specimens of pampas grass and tree tutu. **Right**: Rangiora, coprosma, pampas grass, and kiokio found suitable habitat in Awatarariki near a relatively exposed eroding valley wall.

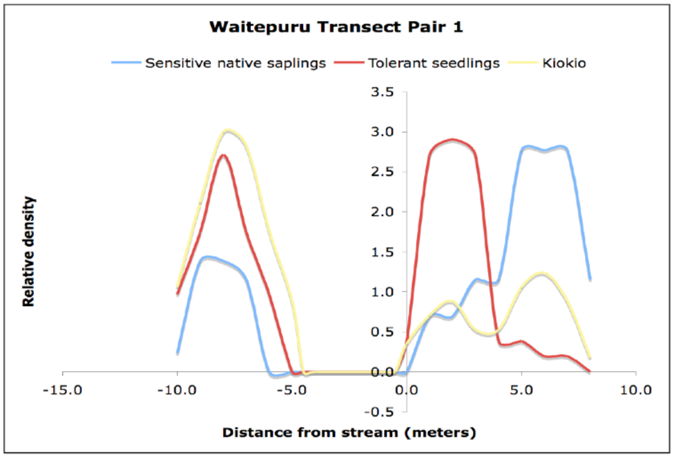

Fig. 1: The first transect in Waitepuru featured an exposed flat transitioning to a shaded north side (right bank, meters 5 to 10). For this (and all subsequent visual representations of transect densities), streams were placed between 0 and -5m, running into the diagram. Positive distances indicate locations to the true right and negative distances indicate locations to the true left. For this Waitepuru transect, plants groups were sensitive native saplings (coprosma, mahoe, kawakawa), tolerant seedlings (pohutukawa, manuka, kanuka), and kiokio (a hardy native fern). Kiokio was found across all environments, but pohutukawa and manuka seedlings were only found in sunny areas. In contrast, sensitive native saplings were mostly found under the heavily shaded right forest margin, although a few coprosma emerged from the cobbled south (left) bank.

On sandy terraces still in partial shade from surrounding cliffs or forest, sapling coprosma (joined by some karaka in Waitepuru) were common. Below them were seedling coastal five-finger, rewarewa, and occasional manuka. Ground ferns and sedges were also frequent colonizers. A *Carmichaelia* species was locally abundant on one shaded sand terrace by Awatararariki Stream, but only one small individual was found through the rest of the valley.

A short ways into Awatararariki Stream Valley there is a broad (~80m wide) open boulder-covered floodplain. The wide, sun-exposed terrace was dominated by pampas grass and tree tutu, both of which formed dense thickets up to 3m in height. Pampas in particular had thick bases that prevented smaller plants from springing up, but in the spaces between them manuka, kanuka, and pohutukawa seedlings were abundant (Fig. 2). A suite of other sun tolerant species were scattered across the flat. The hardy native fern kiokio grew low to the ground, while the spindly pioneer koromiko shot up from gullies and flats alike. Introduced annuals such as catsear, hawkbit, hawksbeard, dandelion and Jersey cudweed sprung up from gaps in taller vegetation. Larger bushes of inkweed, umbrella sedge, and gorse were infrequent but healthy.

Left: Awatarariki Stream flows through an open boulder-covered flat in the lower reaches of the valley. Here, a streamside inkweed and Jersey cudweed find room to grow amidst the abundant pampas grass and tree tutu.

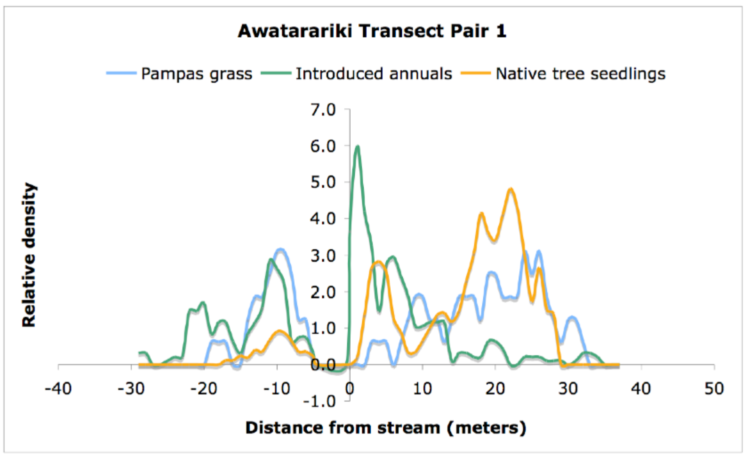

Fig. 2: A transect pair along Awatarariki in a broad exposed boulder-covered region. Plant groupings were pampas grass, introduced annuals (Jersey cudweed, purple top, and dandelion species), and sun-tolerant native tree seedlings (manuka, kanuka, pohutukawa, rewarewa). Highly variable densities (visible even on this smoothed graph) show the patchy distribution of plants that resulted from boulders occupying space on transects. The surfaces of the boulders were bare, but crevices beneath them often contained abundant native tree seedlings. Tea tree, pohutukawa, and rewarewa seedlings grew on the same areas as the introduced pampas grass, reaching maximum densities on the sun-lit floodplain. Introduced annuals were found across the valley but were particularly common along the stream's edge.

Waitepuru never broadens out as much as Awatarariki, so even sunlit terraces are more sheltered. Still, open areas shared many species and similar vegetative patterns with the aforementioned community (Fig. 3). The most striking difference was the absence of dense stands of pampas grass; this introduced sun-loving plant was only scattered in distribution. Rewarewa seedlings joined manuka, kanuka, and pohutukawa on sunny sand flats, showing their similar tolerance of exposure. Toatoa, a single-stalked colonizing native, was a very common addition to the community; in Awatarariki it was rare.

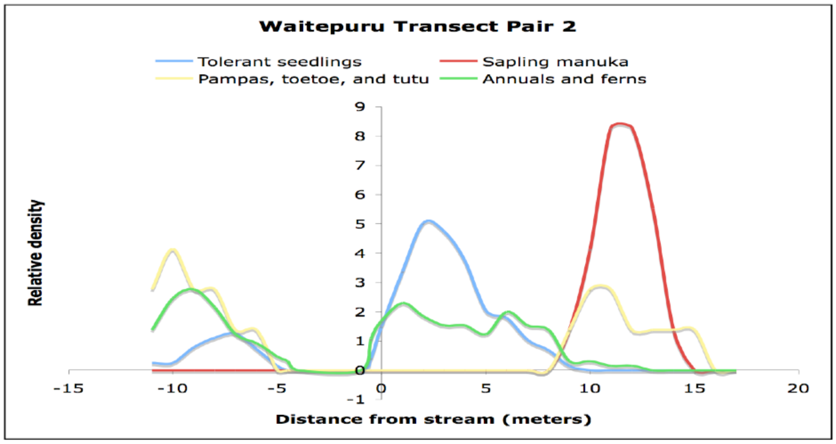

Fig. 3: Major colonizing plant groups were tolerant seedlings (manuka, kanuka, pohutukawa), sapling manuka (>60cm), light-loving grasses and shrubs (pampas, toetoe, and tree tutu), and annuals and ferns (Jersey cudweed, purple-top, and kiokio). Annuals and ferns preferred the same habitat as tea tree and pohutukawa seedlings, suggesting that interactions (competitive or mutual) between exotic weeds and native seedlings are likely. Immediately to the left and right of the stream were bouldery terraces approximately 1m above stream level. Plants perched on a higher elevation sandy flat (8m to 15m) were larger (manuka averaged 90cm, pampas and tutu averaged 1.2m) than those at lower elevations nearer to the stream (seedling manuka <15cm, pampas and tutu averaged 70cm). This probably reflects recent flooding which restarted the successional clock nearer to the stream but did not reach the upper terrace. Variations in streamside habitat are common along Waitepuru and Awatarariki, with gulleys and channels hosting vegetation of different ages.

Certain species showed particular affinities to streamside conditions. Tree tutu and inkweed were common along eroding banks, and water pepper and watercress were limited to wet conditions. Distribution of ragwort and fireweed traced the sandy soils adjacent to the waterway from the pastures above Awatarariki to the roadsides below it. Various sedges and reeds also shared this habitat.

Elements of shelter provided opportunities for species normally precluded from more exposed sites. Boulders up to 7m in diameter often hosted pepper tree (*Pseudowintera colorata*), karaka, and coprosma, while pate and hard beech favored streamside cliffs. Steeped in depressions against the valley walls there were also mahoe and wineberry. In all of these sheltered zones there were abundant ground and cover ferns.

At left, a large boulder perches atop the Awatarariki floodplain. Upon closer inspection, the shelter beneath it reveals an assortment of ferns and this seedling pepper tree (*Pseudowintera colorata*).

In Awatarariki an abandoned quarry road slopes up the north side of the lower valley (site 8). Many natives were scarce while introduced blackberry, Japanese honeysuckle, and gorse were abundant on this disturbed soil (Fig. 4).

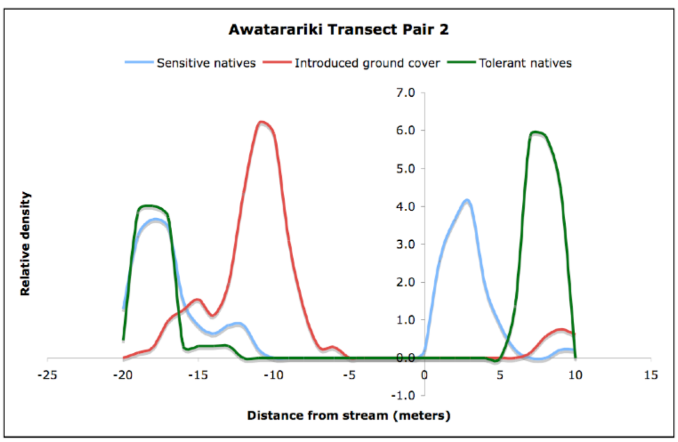

Fig. 4: A transect running across lower regions of Awatarariki near the old quarry road. Selected plant groups were sensitive natives (coprosma, kawakawa, wineberry), introduced ground cover (mat grasses and honeysuckle), and tolerant natives (kiokio, pohutukawa). Spikes in fern and pohutukawa density reflected their nearly exclusive growth from two boulder crevices. Natives were uncommon where introduced ground cover was high (0 to 5m).

Although introduced weeds initially appeared far less common in Waitepuru, a hill sloping down to the stream contained high numbers of naturalized garden plants. Jasmine formed thick ground cover capable of smothering low-growing surrounding vegetation. Cotoneaster grew in dense bushes, but had a more patchy distribution. Less frequent were houttuynia, wild ginger, and banana. Large eucalypts, privets, and macadamias soar overhead, and macadamia saplings indicate that this species is quite capable of reproduction in this environment. All of these plants appeared quite capable of dispersing themselves; several individuals of each species were found within several hundred meters of their source. Palms, grape, and variegated flax were found high on the slope but do not appear to have successfully dispersed downhill.

Discussion

While traditional conservation problems of terrestrial habitat loss and resource exploitation have been met with reasonable success through a network of parks covering 30% of the country, New Zealand's introduced pest plants and animals are the primary cause of unabated declines in species richness and ecosystem health (Craig et al. 2000). Feral possum, deer, goats, pigs, sheep, cattle and rabbits have altered the composition and prevented regeneration of coastal broad-leafed forests through intense grazing of highly palatable native species not adapted to large mammalian herbivores (e.g. Kviberg and Craig 2006). Possums, rats, mustelids and feral cats have decimated forest and coastal bird populations, which has in turn decreased dispersal of fruiting plants and reduced nutrient inputs of guano. Bees and wasps, mostly introduced to assist crop pollination, have impacted food sources of insectivorous birds and proven especially invasive in beech forests (*Nothofagus spp*.) (Atkinson and Cameron 1993). With exposure to ever-increasing numbers of competitive introduced species, forests are losing their ecological functionality as the species that inhabit them suffer from low densities and patchy distributions (Craig et al. 2000).

Only with their degradation have the services provided by native bush become appreciated. Such land cover sequesters carbon, filters water, reduces runoff, yields natural indigenous medicines, stabilizes slopes, and provides habitat for threatened animals. Efforts to conserve native bush must understand that in the modern context of invasive plants and animals, protection alone is no longer sufficient to maintain biological diversity. Effective management must include control of exotics; studies investigating species habits and the limits to their distribution are integral to the design of future conservation strategies (Atkinson and Cameron 1993).

Sandy deposits sorted by flowing water in Awatarariki and Waitepuru Stream Valleys may be nutrient poor, enhancing the need for nitrogen fixing plants to enrich the soil for future vegetation. Natives such as tutu and koromiko perform this task well, but in some cases invasives such as gorse and lupin may be more effective. Where these introduced species prepare the land for future natives, there is little point in suppressing them in the name of conservation. However, if certain species dominate an area and suppress native growth for extended periods of time their control is well warranted. Dense stands of pampas grass, for example, may crowd and suppress seedlings and thus delay succession for several decades. Where resources allow, thinning in these areas is probably a prudent decision.

Perhaps the most threatening to native plant species are vigorous introduced vines and ground cover plants. Kikuyu, honeysuckle, houttuynia, and jasmine have the potential to smother desirable species and prevent their regeneration. Their early control to prevent devastating large-scale outbreaks is especially important. Continued monitoring of these species on the debris flow deposits may shed light on the relative damage they cause to native communities.

Complementary to conservation is the growing field of restoration ecology, which focuses upon restoring vibrant native systems to degraded areas. Unfortunately, most deforested areas are replanted with invasive pines. Although this pattern is often attributed to the economic incentives of timber production (and now also carbon sequestration credits), native forests may be just as effective in this regard. Still, natives are rarely planted because landowners heavily favor established European and American methods over experimental cultivation of native bush (Salmon 1980).

With growing recognition of the values of native bush, there are increasing incentives to restore lands cleared in the past to their former forested state. There are now reasonable numbers of native planting efforts; those that take into account the growth patterns of native and invasive species are most likely to succeed.

Restoration may be tricky in dynamic stream valley systems: successes of one year may be wiped out the next (and certainly within a few decades) by a debris flow event. This is not to say that conservation is unimportant here. On the contrary, effective measures to maintain a native functioning ecosystem in the surrounding lands may assist the debris flow deposits to regenerate naturally. Still, restoration work is more practical in more stable locations. Deforested areas (especially degraded farmland and riparian corridors) near to the two stream valleys owned by DOC or locals eager to get in on the action are prime candidates for restoration works.

The debris flows offer a unique opportunity to witness the succession of disturbed lowland systems surrounded by native forests. Although introduced species play a role even within the deeply incised valleys, rates of native seed dispersal (especially for species with limited dispersal ranges) are far higher than more commonly observed succession on large open expanses of pastures or built environments. It may be possible to mimic the succession of debris flow deposits on nearby land that shares similar conditions (climate, soil, and exposure to various native and exotic species).

At the very least, characteristics of native and introduced plant behavior observed in the two stream valleys can be used to guide allocation of available resources for effective restoration. For instance, where natives fail to establish, physical conditions may need to be altered (compact soil loosened; logs or boulders added to create variable microhabitats). Where conditions are suitable for colonization but natural dispersal is insufficient, artificial seeding or planting may be the best option. Native species should be selected for the task at hand based upon their natural characteristics; for instance, ribbonwood and tree tutu can replace introduced willows and poplars in bank stabilization (Phillips et al. 2001 in Harding et al. 2004). Where introduced plants do not threaten the final community there is no need to eradicate them, but infestations of potentially damaging species should be rigorously controlled to prevent widespread invasion. In all these decisions, a working knowledge of both native and invasive species is critical to successful restoration.

The nature of colonizing communities varies along both Awatarariki and Waitepuru Stream Valleys according to shelter, seed sources, and soil type. Introduced and native species interact with one another and with the environment. The nature of this interaction determines their desirability: those that facilitate the final native community may be of use in restoration, while those that inhibit it should be controlled. Observation of succession on the Awatarariki and Waitepuru debris flow deposits may contribute to conservation and restoration ecology by explaining trends relating environmental factors to patterns of native and introduced plant establishment.

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