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Integrating New Zealand Flax into Land Management Systems





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Introduction

SFF Project 03/153 *Integrating NZ Flax into landscape management systems* began late in 2003 with the objective of assessing the opportunities and practicalities of strengthening the role of flax in land management systems, for environmental and commercial returns.

Through the course of the project we have researched historic and recent literature; undertaken specific work on farming values with AgResearch; linked with multiple agencies undertaking work in environmental and economic arenas; met and corresponded with landowners and businesses throughout the country; and established a national network of landowners, scientists and businesses with a common interest in harakeke.

This report describes a range of opportunities for strengthening the role of NZ Flax in land management systems; noting areas where work is ongoing, or where further work may be of value. The focus has been summarising work to date, to serve as a platform for continued developments: further to this, we have made suggestions for initiatives in specific key areas to more securely link supply and demand – environmental and economic values – in a coherent value chain.

Acknowledgements

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Throughout the CRI/university sector, we have many enthusiasts, willing to share their expertise. Roger Newman (Scion) and Sue Scheele (Landcare Research) have been leading work with harakeke for many years; and, in the wider network, we have appreciated the impetus and support given by Chris Smith (Biopolymer Network), Marcus King and Stephen Tauwhare (IRL), Debra Carr (Otago Clothing and Textile Sciences), Clive Davies, David Harding and Zirsha Wharemate (Massey University), Peter Molan and Kim Pickering (Waikato University), David Bergin and Ian Nicholas (Ensis), Chris Tanner (NIWA), Mike Marden, Chris Phillips, Robyn Simcock and Bob Frame (Landcare Research), Allan McDermott (AgResearch), Mark Staiger (Canterbury), Krishnan Jayaraman (Auckland) and Leo Vanhanen and Geoff Savage (Lincoln).

In 2005, we co-convoked a Hui Harakeke in Rotorua, with our appreciation to Tupara Morrison (Scion) and Rau Hoskins and Kapa Morgan (Uku Sustainable Housing Project); followed by a Flax Field Day on the West Coast in 2006, with generous support from the West Coast Development Trust, and our appreciation to Val Moynihan (Coastwide Growers Association). We are indebted to the generosity of the speakers who travelled long distances to join us on those days, including Rangi Te Kanawa, Sue Scheele, Geoff Savage, Nick Tucker (Crop & Food) and Malcolm Miao (Canesis).

***we thank
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Many other individuals, organisations and businesses have been supportive, including John McKinnon (Canesis), Liz Francis (Textiles NZ), Liz Te Amo (NZTE), Glenn Vile (NZ Seed Oils), John Millward (GreatetasteNZ), David King (NZ Flax Hybridisers), Philip Smith (Taupo Native Plant Nursery), Mark Dean (Naturally Native), Robert Reid (CLAW), Rob McGowan (Bay of Plenty), Rene Babbington (Gisborne), Graeme Law (Taupo Lake Care), Kevin Snowdon and John Hepi (Taupo Development Company), Turi Te Hira (Te Rarawa), Geoff Copps (Go Wairarapa), Ken and Margaret Wyatt (Chatham Islands), John Ringer (Paradigm), Lynn Sheridan (Marton), Alex Drysdale (Christchurch), Rob Bargh (Featherston), Tom Williamson (Wellington), Jane Pollard (Australia), Palmerston North City Council Archives and Rural Women New Zealand. We record particular thanks to Lucy McLachlan, Baker and Associates, for maintaining financial records for the project.

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Executive summary

Harakeke/NZ Flax is an ancient, iconic species.

In most parts of lowland NZ today, harakeke is lost from the landscape.

Harakeke/wharariki express themselves most strongly in the transition zones between land and water, coast and sea. It is in these transition zones that we have the greatest need – and the greatest opportunity – to restore the mauri of our land and waterways.

Harakeke is robust, fast-growing, wind-tolerant, flood-tolerant, drought-tolerant, light-tolerant, frost-tolerant... all the attributes required of plants to take a lead in establishing a new indigenous/exotic farming matrix in lowland New Zealand.

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PART A: **NZ Flax in farmscapes and landscapes** explores the opportunities and practicalities of extended plantings of flax, within a broader landscape context:

- Connecting corridors: noting the strongest opportunity for re-integrating flax into land management systems is to return harakeke to its natural habitat alongside waterways, supporting the transition from willows to natives; and describing the value of flax as fast, low-growing, evergreen shelter
- Extended buffers: extending beyond riparian corridors into floodplain plantings, noting that, while flood protection systems are faltering, flax is a proven performer on the floodplain; developing more generous buffers around natural or constructed wetlands; and considering an expanded role for flax in coastal vegetation communities, as attention moves from the foredunes to the back dunes
- Block plantings: noting attributes as a nurse plant; describing opportunities in two-tier or mixed systems – restoration or indigenous forestry blocks; and noting the resurgence in traditional and contemporary crafts, with opportunities for specialty blocks supplying niche markets.

Recommendations are made for further work to support expanded plantings of flax:

- Assessment of the root morphology and stabilising characteristics of the 'flexible frontline' plants, including *p. tenax* and *p. cookianum*, from both trial plots and 'real life' situations
- Work to assess the resistance/susceptibility of NZ Flax to weed-killing chemicals, and development of concentration/application guidelines
- Assessment of the role of flax in intercepting overland sediment flows
- Assessment of water uptake and transpiration rates
- Assessment of growth/fibre quality of flax fertilised with nutrient-rich wastewater

- Assessment of the extent to which harakeke facilitates, or inhibits, growth of other plants in two-tier or mixed-tier systems

Along the river/road/fenceline corridors, flax can be established principally for environmental reasons, while recognising secondary opportunities for harvest. Of their nature, these corridor plantings will be accessible; and, particularly if linked to extended buffer plantings (floodplains, wetland buffers, coastal dunes), the scale could be substantial.

Small block plantings strengthen the indigenous corridor/patch matrix in the landscape. Again these may be established principally for environmental reasons (restoration projects), or for dual environmental/commercial return (eg. two-tier indigenous forestry), or principally for harvest (eg. supply of material for regional enterprises).

Small niche markets can be readily supplied from small blocks: these blocks can equally serve as stepping stones towards larger scale commercial plantations.

it is not too soon to begin considering opportunities and practicalities of re-establishing flax plantations

The future establishment of plantations critically turns on the pull-through from the market, and it is too soon at this time to recommend large-scale plantings for commercial return. Nevertheless, applications development is underway and it is not too soon to begin considering opportunities and practicalities of re-establishing flax plantations in NZ. Not least to support investor confidence in product/market development.

As a commercial crop, NZ Flax has none of the risks and costs associated with new introductions (exotic species or genetically modified organisms). All the attributes described for environmental plantings (cheap, robust, fast growing) apply equally to commercial plantings. Flax can 'fit' with existing farming systems. Most importantly, harakeke has a long history of traditional and industrial agronomy which can serve as a platform for future developments. The final sections of PART A review the history of managed plantations in NZ, suggest implications for future plantation scale management, and indicate areas where plantation developments could be integrated with other land use imperatives.

With a focus on the factors influencing fine-fibre production, key parameters are described as:

- Site selection: light, rich, free-draining soils (alluvial floodplains, rolling hills)
- Varietal selection: fine-fibre *p. cookianum*/*p. tenax* hybrid selections
- Harvest: selective annual harvest of mature leaves

Varietal selection is identified as a critical linker between growers and markets: currently hundreds of thousands of plants are going in the ground every year, none selected for their fibre values. Decades of publicly funded breeding work were undertaken on the Moutua Estate (breeding for yield, disease resistance and fine fibre forms); and work is currently underway at Landcare Research mapping morphological/genetic variations in phormium from throughout NZ. Further to this, it is recommended that work be undertaken to:

- Identify fine-fibre forms, and patterns in their distribution, arising from the morphological/ genetic work underway; assess Moutua lines for fine-fibre forms; identify selections for preliminary 'bulking up'.

While harakeke could potentially be grown as a plantation crop in all regions of NZ, there is considerable merit in developing initial capacity and critical mass in a selected area; particularly where other landuse imperatives compel new approaches to integrating farming activities within broader catchments. In this context, it is recommended that:

- a collaboration of interested parties scope a programme for the initial establishment of trial plantations in the Rotorua and/or Taupo lakes catchments.

Ideally, plantations of the future will synthesise ecology, traditional agronomy, industrial agronomy and current integrated crop management principles: specifically, it is proposed we have the opportunity to consider whether harakeke is managed as a 'monoculture', or as part of a more diverse, multi-use 'mosaic'. Considering landscape patterns and flows first; paddocks and plantations second. Further to this, it is recommended:

- A 'strategic landscape' perspective be engaged to map opportunities for commercial plantings of harakeke as part of multi-use landscape mosaics within the Rotorua/Taupo catchments
- Sustainable cropping guidelines be developed, synthesising ecology, traditional agronomy, industrial agronomy, and integrated crop management principles

Flax has been described as New Zealand's first processing/manufacturing industry; an industry that was still operating through to 1985. We have had a 20-year gap.

Within just the last five years – aligned to a fundamental international movement from the 'hydrocarbon to the carbohydrate economy' – the sum of government investments in exploration of harakeke properties and potential for new products and markets is significant. Most initiatives are currently at the prototype stage (with an element of uncertainty as to the scale and timing of future developments): nevertheless, NZ Flax is being positioned for re-establishment as a landbased industry for the 21st century.

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PART B: **A New Landbased Industry** briefly describes the history of the flax industry; discusses processing as a critical factor influencing fibre quality and market positioning; and updates on R&D, principally:

- Fibre: development of biocomposite prototypes and product concepts, led by the Biopolymer Network (Scion, Crop & Food, Canesis); development of sustainable earth/fibre housing, led by Auckland University; creation of muka fabric, led by Rangī Te Kanawa
- Gel: work by IRL supporting expanded application in the cosmetic market
- Seed oil: work underway at Lincoln assessing stability and nutritional profile

The industry of last century positioned flax as a coarse fibre, suited to low-end markets. Applications development now underway is looking less to traditional or industrial applications, more to new uses; less to traditional cultivars, more to new forms; less to traditional or industrial processing techniques, but demanding a new approach.

A key point is that harakeke/wharariki forms span the spectrum from the fineness of linen to the coarseness of sisal; and varietal selection – supported by agronomy and processing – is fundamental to whether NZ Flax fibre is positioned at the low end

of the market (with the hard fibres) or at the high end (with the soft fibres). In lower-end applications, the cost of fibre (relative to wool, fibre-glass, imported coir etc) is a primary consideration. In higher-end applications, branding – the prestige/rarity factor – becomes a primary value.

Alongside price and prestige comes performance: understanding the inherent properties of selected fibres, and matching these to specific end-use applications. The Biopolymer Network is leading work characterising the properties/performance of flax fibre for biocomposites: it is proposed that further work – ideally working alongside new processing initiatives – be undertaken to formally characterise the properties of NZ Flax fibre, for application into New Zealand textiles. Specifically, it is recommended that collaborations of interested parties invest in:

- Formal proof-of-concept for new primary processing platform, and assessment of fit with secondary forming and manufacturing technologies
- Assessment of the properties/performance of selected forms; and development of concept materials for NZ textile applications

PART C: **Industry Development** proposes that – recognising we have lost the resource, we have lost processing capability, we are unconstrained by requirements to retrofit – we have an outstanding opportunity to design the industry from the ground up.

In considering possible pathways forward, reference is made to the experiences of other land-based sectors, emphasising the importance of communication and collaboration: “the most critical challenge facing stakeholders in supply chains in 2010, should they wish to participate in high value differentiated product markets, will be the establishment of successful supply chain relationships and communication processes”.

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Across the many projects and initiatives that are currently underway around the country – in commercial, environmental and farming arenas – there is a high level of motivation and momentum and willingness to collaborate.

It is proposed that capitalising on the momentum, capturing the synergies, will best be achieved through ongoing and regular collaborative forums: initially for development of a preliminary value-chain model, for discussion with wider constituencies; and subsequently to help inform strategic research agendas. It is recommended:

- A collaborative forum be convened, tasked with creating a preliminary value-chain model for harakeke/NZ Flax, for discussion with wider constituencies; and development of strategic research agendas

A ‘pre-industry’ consortia of interested parties would serve to link growers and markets, supply and demand, economic and environmental values into a coherent value chain; preliminary to the establishment of a more formal industry grouping for the re-establishment of harakeke/NZ Flax as a cornerstone element in a new indigenous/exotic farming matrix.

PART A

New Zealand flax in farmscapes and landscapes

The following sections briefly describe the ecology of harakeke, and its loss from the landscape; before considering opportunities for strengthening the role of flax in land management systems.

Ancient species

Harakeke/NZ Flax is an ancient species; unique to NZ and Norfolk Island. Fossil pollen has been dated at 21 million years.

Phormium grows throughout the islands of NZ: most strongly in the transitional zones between land and water, coast and sea. In 1872, Buller reported that phormium is “most abundant near the coast, but is also found abundantly in the interior to an altitude of 2000 feet”. In 1940, the *NZ Yearbook* recorded “large areas in NZ are covered with phormium”; and Critchfield (1951) noted that “the largest natural areas were, and still are, in the North Island”.

Two species are commonly distinguished: ***phormium tenax*** (lowland or swamp flax) and ***phormium cookianum*** (coastal or mountain flax) with perhaps hundreds of varieties and hybrid forms between.

P. tenax (harakeke) is the larger plant, growing on deeper soils alongside streams, around wetland edges, and extending into lowland hills. It “luxuriates in rich, moist and well-drained ground, and reaches it’s greatest size on the banks of running streams” (Hector, 1872). It is also “abundant on coastal slopes and dune hollows, and on open hillsides in the coastal and montane belt” (Wardle, 1979).

P. cookianum (wharariki) is the smaller plant, growing on coastal and inland cliffs, and sub-alpine zones. Wardle (1979) describes two forms of *cookianum*: the southern mountain form (with stiff leaves and short, thick capsules) which grows along the southern alps, and extends south to Stewart Island, north to the Tararuas. The northern lowland form (with flaccid leaves and dangling capsules) is strongest from the Manawatu Gorge northwards, mainly on damp cliffs of soft mudstone. *P. cookianum* is abundant both sides of Cook Strait: Wardle describes these coastal populations as seeming to consist of mixtures of the two forms and their hybrids.

LandcareResearch (Peter Heenan and Rob Smissen) have recently begun a revision of phormium, with sample plants being collected from locations throughout NZ. Molecular analysis is being undertaken first, to provide a framework against which to examine differences in morphological characters. While this work is still in its very early stages, indications are that geographic patterns are emerging in the distribution of harakeke and wharariki forms.

The patterns of variation may relate in part to the reproductive biology of the plant. Phormium reproduces both sexually (pollinated seed) and asexually (with new fans retaining

Phormium tenax
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Phormium
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(wharariki) is the
smaller plant

parent characteristics). Results of controlled pollinations (Craig et al, 1988) show that phormium preferentially out-crosses, and readily hybridises (with ovules responding preferentially to out-crossed pollen, and nutrient resources preferentially allocated to out-crossed zygotes), and the light seeds then carried by wind and water to colonise new places. The ability to also reproduce vegetatively may give flax a competitive advantage. Esler (2004) notes that flax is not destroyed by fire; and new shoots may appear from the stout rhizomes before associated species have had time to establish new generations of seedlings (perhaps accounting in part for the abundance of flax on some offshore islands).

The basic unit of a flax bush is the fan, a sheath of up to 10 leaves. The youngest leaf – *awhi rito* – is sheathed in the centre of the fan; with each leaf taking 18-22 months to grow to maturity (before it starts to decay). Flax is relatively slow growing in the first two years, but will begin rapidly bulking up from the third year. A seedling plant three years old may have up to 15 fans. Fans will begin flowering, generally from about the fifth year. After flowering, that fan dies, with up to three new fans growing round the flower stalk. An older bush will tend to take on a ring form, with younger fans encircling an empty area in the centre (where older fans have died).

The root system may extend as wide and deep as the height of the bush (3+ metres), with perhaps the bulk of the roots in the top 50cm, and in a radius 1.5m approx from the centre of the bush. Stout orange roots extend parallel, diagonal and vertical to the surface; with the upper layers branching into networks of fine, white roots. Atkinson (1922) noted that the surface roots, particularly in dry situations, “have abundant root hairs through which they absorb water. Some of the roots however, descend more deeply; these are not provided with root hairs, but absorb water through the epidermis, which is very thin towards the apex of the root... the effect of drought is to kill the root hairs... stagnant water may have a precisely similar effect on a plant growing in a swamp, through destroying the water absorbing tissues of the deep roots”.

***a flax bush
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A flax bush is home to a community of insects and snails using it for shelter and food (McKenzie et al identified over 70 species of fungi alone). The seed was eaten in quantities by the grey duck/parera (Garry McLennan, Foxton, recalled crops full of flax seed in duck shooting season); and the spectacular flowering stalks yielded copious nectar for geckos, short-tailed bats, kaka and the honey-eating birds – hihi, bellbird and tui. Only the last of these – the tui – is holding on in any numbers on mainland NZ today.

Lost from the landscape

Despite its broad ecological niche, its former abundance, and its robust reproductive strategy, in most parts of NZ today, harakeke has been lost from the landscape. Throughout lowland NZ, wetlands have been drained, rivers channelled and native vegetation cleared: “in all but a few districts, only tiny and barely sustainable remnants of coastal sand country, and lowland wetland and alluvial environments remain” (DOC, 1994). The role of flax in the landscape has diminished to remnants and reserves: displaced by ryegrass and clover, willows and poplars, pampas and pine.

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Region by region, the Landcover Database (held by Regional Councils and others) can be used to map areas of flax down to 15m² grids. Indicative of the scale of loss... in the Wairarapa the LCDB pinpointed one site only. Where other remnants are still extant, they are very, very small (and predictably, most often in awkward and inaccessible locations).

It's a familiar story: the speed and scale with which exotic biota have displaced indigenous species in Aotearoa. Native flora (80% of which are endemic to NZ) have been marginalized into the mountains (where the conservation imperative prevails). The plains and lowlands and

hill country have been turned over to introduced species (in service of agri-business). In 2000, a Ministerial Advisory Committee led by John Kneebone was convened to consider biodiversity on private land, and concluded: “we find it difficult to deny that humans have turned a unique ecological site into an industrial estate... it is now widely acknowledged that plants and animals are in serious competition with humans for space and sustenance, and that they have legitimate claim and entitlements”.

In the same year, Meurk and Swaffield recorded their concerns about the retreat of nature from public view and experience: “with little to indicate the rich biogeographical history of the land... there is the risk that further reduction in visibility of native vegetation may be perpetuated by a growing familiarity and identification with ubiquitous exotic species... we can collectively decide to integrate indigenous nature into our productive landscapes, or we can allow reinforcement of the historical dichotomy of nature and culture, and continue the ambivalence and uneasy sense of misplaced identity it brings. There is no neutral ground in this... inaction is tacit support of the status quo – of the values and landscapes that have been purposefully or inadvertently created in the past”.

The Ministerial Advisory Committee described the “fragmentation of ecosystems into ‘islands’ surrounded by farmland... and severance of ecological connections”. The ‘islands’ and remnants have been the focus of much conservation work in recent years (fencing, pest control, covenants). Meurk and Swaffield went one step further, recommending that landscape restoration look beyond individual remnants and restoration projects. They propose a new indigenous matrix of corridors and habitat patches and resource-rich stepping stones: “It involves protecting native remnants, enhancing damaged or unbuffered remnants, and restoring connections between them... corridors and stepping stones link other more substantive patches... areas that can provide such linkages include roadside remnants, hedgerows, shelterbelts, woodlots, water races, rivers and streams... these provide almost endless scope for under-planting, and facilitating regeneration of indigenous plants to create the structural corridors for wildlife from the mountains to the city and ocean”.

Harakeke is an iconic species. It is also robust, fast-growing, wind-tolerant, flood-tolerant, drought-tolerant, light-tolerant, frost-tolerant... all the attributes required of plants to take a lead in re-establishing an indigenous matrix in lowland NZ. The following sections explore the opportunities and practicalities of re-establishing NZ Flax in corridor plantings, in extended buffer plantings, and in small block plantings.

we can collectively decide to integrate indigenous nature into our productive landscapes...

a new indigenous matrix of corridors and habitat patches and resource-rich stepping stones

Corridor Connections

WATERWAYS

The strongest opportunity for re-integrating flax into land management systems is to return harakeke to its natural habitat alongside waterways.

For many years, riparian plantings have been dominated by willows (and to a lesser extent, alders and poplars). Alternate species are now being sought (partly consequent to the arrival of the willow sawfly, and problems with willows blocking flood flows) with particular interest in utilising native species in mixed tier plantings. Landcare Research (1997) noted that: “properties with waterways offer special opportunities where the indigenous component of the landscape can be greatly enhanced. They are clogged with willows, whereas native species offer more valuable habitat... and are more controllable”. Similarly NIWA suggest: “the key to improving water quality and restoring ecological diversity is connection. We think that rehabilitation of streams is most likely to be successful when planting in riparian zones begins from the headwaters and progresses down through the catchment to produce a long, continuous buffer”. Marden et al (2005) continued this theme: “since the turn of the 20th

flax provides a good starting point because it is easy to establish, multiplies rapidly, and fits in with a tight planting budget...

century much of NZ's indigenous riparian vegetation has been cleared... the loss of buffering and ecosystem services provided by this riparian vegetation has led to the progressive degradation of waterways through increased sedimentation and nutrient pollution... channel widening by bank collapse is now a common occurrence along many kilometres of stream throughout NZ. The loss of primary agricultural land and physical property adjacent to eroding stream banks is very costly... historically, effective structural streambank protection has been expensive to install and maintain, and as riverbank protection using only willows is no longer practical, other options are needed".

Around the country, farmers are actively exploring other options: "Michael and Margaret Oliver are planting flax around fenced off gullies and waterways because it provides shelter for native species they have planted as part of EWs clean streams initiative... Oliver says the flax provides a good starting point because it is easy to establish, multiplies rapidly, and fits in with a tight planting budget... the poplars and pines that have been planted in the last 30 years are being gradually felled and replaced with natives. Oliver says he now realises that planting these trees was a mistake because they don't fit in with the farms natural history. Willows, which he now regards as weeds, have largely been removed already" (*Countrywide*, 2003). Or again: "one km of the creek has now been planted... four years on and the results are wonderful to see with flaxes and ribbonwoods 2-3m high... Palmer says he has made some mistakes along the way, the biggest fencing too close to the creek... I'm now moving the fence out at least 2-3m from the top of the bank... my bottom line has not been affected by the loss of some productive land, if anything its gone the other way... and he would now only plant natives along the banks of the creek, not eucalypts as they had first done... natives look better, simply because they belong". (*Rural News*, 2003)

our indigenous riparian vegetation is sufficiently diverse to meet most of the requirements for slope and bank restoration

To assist the transition from willows to natives, Landcare Research (Mike Marden and Chris Phillips) are undertaking research into the root structure/stabilising effects of native species. In 2005, Marden et al reported results from trial plots with 12 indigenous trees and shrubs (including manuka, kowhai, karamu), concluding that NZ's indigenous riparian vegetation is sufficiently diverse to meet most of the requirements for slope and bank restoration, and recommending that the selection of plant material take into account "ability to provide year-round protection, have the capacity to become established under adverse soil conditions, be long-lived, develop a root system that will withstand the drag of stream flow on the above ground portion, have multi-stem characteristics with many stems emerging from the boundary surface, have tough, resilient stems, and require minimum maintenance".

This research was followed by work assessing the root morphology of ti kouka (Czernin and Phillips, 2005): "in terms of parameters assessed against published information for willows, it appears that *C. australis* falls short on both growth rate and tree anchoring parameters for use as a riverbank protection plant in all rivers. However, when grown with other native riparian colonising plants such as flax, river bank protection may be comparable, especially in low-order streams... during flood events, flexible plants may form streamlined bodies in order to minimise the area subjected to the current. As the plant is bent down, it covers the soil surface thereby contributing to the protection of the river bank... in areas where river bank stability is a major issue, perhaps the way forward is a combination of natives such as cabbage trees, flax, toetoe and willows. This approach would maximise the stabilising functions of these plants, but also limit any possible future effects of pest outbreaks that might occur in single species plantings".

It will now be of great value to follow through with formal assessments of the root structure and stabilising effects of the 'flexible frontline' plants – flax (*tenax* and *cookianum*), toetoe and carex – in both trial plot and 'real life' situations. Over the last decade, regional councils have already begun the transition from willows to natives, and have built up significant experience in how flax performs across a range of soils, conditions and river systems.

Environment Bay of Plenty estimate plantings upwards of 250,000 flax in the last decade: at the Hui Harakeke (2005) John Douglas noted flax is robust for handling; tolerant of a wide range of sites/soils/conditions; herbicide tolerant; and pest animal tolerant. Flax is not palatable to possums or rabbits, and can tolerate a certain level of stock damage (except pukeko, where John recommends planting deeply, up to 25% of the way up the fan).

For bulk plantings, flax is easy to propagate (with most environmental plantings being seedling stock sourced from the nursery trade); and cheap (EBoP source plants at \$1 each). With previous experience in pine plantations, John Douglas applies the same efficiency to planting flax: after a pre-plant spot spray, a two man team can plant 5-600/day, using cut down drainage spades (pivoting the spade 45 degrees each way to open the planting space), and recording 100% plant survival (with well-grown stock able to push its way up through grass and weeds). Post-planting releasing (in the spring/autumn/spring following planting) gives the plants a good start: beyond that, flax is very low maintenance.

EBoP are planting on major rivers, in the 6-10m zone between the shingle and the pasture (trying to prevent gravel pushing out onto productive land), using tiered plantings: grasses/sedges/carex in the frontline (and on rivers with steep batters), flax in the second tier (comprising around 30-40% of plantings), then karamu/ti kouka etc.

In the wake of the devastating Manawatu floods, Horizons (*Countrywide*, 2005) recommend a similar approach: "on larger rivers, the way forward for us is structured, tiered plantings... in zone A only grassy type plants such as flax and toetoe, then shrubby plants such as manuka, koromiko, on the third tier, larger trees". On smaller waterways, Taranaki and Waikato tend to favour *cookianum*, in preference to the larger *tenax*. Maurice Murray (Murrays Nursery) also distinguishes between varieties for flood control, suggesting dwarf *cookianum* in the front-line (low to the ground, wide-spreading roots), then standard *cookianum* (which can handle dry conditions), then *p. tenax*.

Experience to date strongly indicates that flax performs well in floods. Beyond the first year or two when it's still establishing (planting fans parallel to flows may help), flax will lie down in a flood, then get back up again. It traps silt in the fans; and the fans push up again. It is not top heavy. Experience is indicating that widely spaced plants in single rows offer poor protection; and that, for flood control, flax be planted at closer spacings to create interlocking root systems. Various of the regional councils are trialling plant spacings (with Environment Canterbury trialling densities as close as 1.2m spacings).

In 1986, the National Water and Soil Conservation Authority described the wide habitat range and climatic tolerance of flax: "most forms are very tolerant of frost, drought, wind and salt spray"; noted that flax will grow and maintain roots below the water-table; and recommended flax as an excellent species for stabilising stream banks, and "suitable for planting in gully systems where there is seasonal waterlogging, and on seasonally dry, windswept hillsides". In lower estuarine areas (eg. in the Thames/Coromandel area where Environment Waikato have planted 50,000+ flax since the 2002 Coromandel floods) flax is confirmed as being tolerant of salt spray and tides (even where its feet may get wet for an hour or so). Flax is also a proven performer in the upper catchment areas. In the Taupo catchment, for example, flax is used as a staple in riparian planting, along with toetoe, carex and koromiko: plants which have demonstrated their ability to handle the cold and frosts in this area, as well as the summer dry.

In relation to frosts, flax is generally hardy, with *p. cookianum* seeming to be more frost resistant (-9C) than *p. tenax* (-7.5C). Having said that, flax varieties differ in their frost tolerance; and EWs experience in the Taupo catchment is that only locally sourced flax has exhibited the frost tolerance required. The species also differ in their drought-hardiness: *p. cookianum* is more drought tolerant than *p. tenax*.

**flax is robust
for handling;
tolerant of a
wide range of
sites/soils/
conditions;
herbicide tolerant;
and pest animal
tolerant**

planting is recommended as soon as the area is retired... flax is the easiest and cheapest option

Many riparian sites are inherently 'weedy', and weed control can be a major issue in riparian zones. In Taranaki, for example, while the Clean Streams Accord focuses on preventing stock access to waterways, the Fonterra field rep. recommends farmers plant fenced-off zones: "if waterways are fenced off but left unplanted, Vickers says that there is a risk that invasive weeds such as blackberry will cover a significant percentage of the riparian zone within three years. Planting is recommended as soon as an area is retired... flax is the easiest and cheapest option" (*Countrywide*, 2006). Planting density is also a factor here: Maurice Murray suggests that early riparian plantings made the mistake of planting too far apart (with too much blackberry and rubbish coming away in between): in some areas many kilometres of older riparian works are completely inundated with blackberry.

flax is susceptible to Glyphosate

In this context, the tolerance of flax to spray-over by various weed killing chemicals is a decided virtue. Importantly, flax is tolerant to the Triclopyr range of chemicals (Grazon, Scrubcutter, Brush Off, Renovate, Victory etc) commonly used for brushweeds (eg. blackberry, gorse), making these a good option for post-planting control: John Paterson (EBoP) notes that if the weeds resurge, you can spray close to or actually over the flax and rescue the situation (whereas if it was planted with other species these can be wiped out or suffer considerably from collateral damage from the spray). In respect of other weed control chemicals, more work on resistance/susceptibility is required: Richard Mallinson (EBoP) suspects flax has some susceptibility to the Metsulfuron-methyl range of weed killing chemicals (eg. Escort, Answer, Matrix, Meturon, Mustang etc) and more work would be useful on its tolerance at various strengths of this chemical. John Douglas confirms that Escort will knock flax back (and uses it only 3-4 months pre-planting). Flax is susceptible to Glyphosate (eg. Roundup, AGPRO Green, Glyphosate 510, Trounce etc): again more work would be of value on its tolerance at various strengths (to achieve 'clean up' of weeds, without damaging the flax). Maurice Murray uses Roundup in nursery beds for weed control, but emphasises without the sticking agent, so as not to damage the flax.

The scale of riparian zones may vary from 2 metres (on smaller streams) up to 20 metres on major rivers (in the zone between the river and the stopbank). One of the functions of riparian zones is helping absorb run-off from surrounding catchments, either surface run-off (particularly sediment, phosphate and pathogens) or subsurface (particularly nitrogen which is soluble in water and leaches into groundwater flows). For surface run-off, the mechanical function of the zone in slowing and holding the flow preliminary to absorption is critical (ie. suggesting diverse planting with pits and hollows and barriers).

For subsurface nitrate flows, the depth of roots relative to groundwater flows is the important factor, along with the level of organic matter in the soil (from decaying leaf litter etc) fuelling microbe de-nitrification (ie. again supporting diverse plantings). Around 90% of grass pasture roots are in the top 20-30cm: as noted earlier, the bulk of flax roots may be in the top 50cm, but roots can extend 3 metres in deep soils. In 1955, Moss, noting that the effect of nitrogenous manure was very small, queried whether flax can utilise soil nitrogen which is not available to grasses.

In recognition of the established role of flax in riparian plantings, work was initiated as part of this SFF project to help determine the role it may play in nutrient uptake alongside waterways, or in broader landscape plantings. Dr Grant Douglas, Agresearch, led work to assess biomass and leaf nutrient concentrations (N, P, K, S) from a range of sites: the results (Douglas, 2005) indicate highest concentrations of potassium, followed by variable concentrations of nitrogen; and low concentrations of phosphorous and sulphur (notably, a significant proportion of total biomass/nutrient content is allocated to the reproductive parts of the plant – the flowering stem and seed pods). The report cautions that, while biomass data is preliminary (and dependent on assumptions about planting densities and age of fans) results indicate nutrient accumulation rates considerably less than annual cut-and-carry crops (maize,

pasture), and less than or similar to short-rotation tree crops (willow, poplar, eucalypt). The nutrient removal benefits of all these systems critically depend on the link to regular harvest: this study suggests that, while nutrient removal will not be a driver for broad-scale flax cropping systems, regular harvest (of korari, seed, leaves) from riparian zones would make a modest contribution to removing nutrients. Further to this work, assessment of the mechanical role of flax in intercepting overland sediment flows – across slopes and in riparian zones – may be of value in supporting effective planting design.

SHELTERBELTS

Flax is excellent low shelter, evergreen, and with all the same attributes of being relatively cheap, relatively fast-growing, robust, and simultaneously creating habitat corridors to help link native plant remnants.

In 1948, Yeates described the use of flax in shelterbelts: “on the farm at Massey College it is used in four ways: firstly as an unfenced hedge on land where sheep alone are grazed; secondly, in conjunction with poplars as a break-wind for an orchard; thirdly, at the piggery as shade and shelter for pigs; and fourthly, as a double-fenced hedge on the dairy farm. In the last case the lowest wire is set at two feet six inches to allow sheep, which are occasionally grazed, to get in amongst the flax and eat out the grass”. He recommended flax as a good hedge on the edge of coastal cliffs (between the fence and the cliff edge); and as a roadside hedge, on the outer side of the boundary fence. He noted that planting flax too close to trees is a frequent cause of failure: “the shade, and on poor, dry soils, the root competition, usually result in a poor, thin stunted growth of the flax. In a moist, rich soil, flax can be grown perfectly well in the same row as poplars”. Alternatively, flax can be grown with multi-tiered natives: Colin Meurk (1997) suggested ideal shelterbelts may be multi-layered with large tussock plants (flax, toetoe) creating the intermediate layer, and podocarps (eg. totara) planted between.

Flax is used extensively in shelterbelts in Southland, and the regional council recommend it as one of the few plants that can grow in coastal situations. On dairy farms, flax can co-exist with pivot irrigators, and large-scale plantings are currently underway (plantings of up to 5000 at a time). On sheep farms, a recent report (Pollard, 2005) recommended flax as ideal shelter in a lambing paddock. On average in NZ, 10-25% of lambs die within 3 days of birth: flax (or tussock) offer dense wind shelter, together with overhang to keep the rain off and the ground dry.

On boundaries, where taller-growing trees create offset issues for roads and powerlines and neighbours (shading and overhang), flax is ideal low-growing shelter. Transit make extensive use of flax in highway revegetation programmes (and Landcare report flax as the standout performer in early hydro-seeding trials on moist sites on batters up to 37 degrees). Flax features strongly along West Coast roads; and District Councils are responsible for many thousands of km of road reserve in rural NZ, which could potentially support extended corridors of flax and other native plantings.

As with riparian plantings, most shelterbelt plantings are seedling stock sourced from the nursery trade; and local stock is likely to be more reliable in more exposed and rigorous conditions. For wind shelter, taller, erect varieties may be used: other varieties with drooping leaves may offer more overhang for shade and rain shelter. Flax needs protection from stock, particularly in the first couple of years while still establishing.

Cattle (and deer and goats) are well-known for eating flax leaves (or more accurately, stripping off the green matter, leaving the fibre dangling). In the severe winter in Southland in 2004, cattle were reported eating flax shelterbelts down to waist height; and anecdotes

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abound of cattle doing well on flax. In 1959, Hector McIntosh, SI Consulting Officer, was reported in the *Dairy Exporter* as saying that, in his travels about the South Island, he had found several instances of flax having a beneficial effect on the health of calves, and that the cleanest young stock were to be found in Western Southland where flax is grown as shelter, and stock have free access to it. He reported the 'flax cure' for scours, where leaves were attached to a fence for calves to suck. Other farmers report similar experiences: "when we were dairy farming, in the bloat season, in the paddocks that the cows had access to flax, we never had a bloat problem. The cows would all come in for milking, chewing their cuds like crazy, and belching like never before" (J Atwood, 2004). Others harvest flax as a supplementary feed, eg. feeding flax leaves to weaner cattle through winter: "ultimately they will graze it... at the moment I cut an armful each day, fire it out, and they clean it up". (C Palmer, 2004). Lance Reid has been feeding flax to stock on and off for nearly 50 years, and reports no problems with the fibre binding them up.

On the strength of these and other reports, work was initiated with Dr Annette Litherland, Agresearch as part of this SFF project to assess nutritional, and possible anthelmintic, values of flax. The first study (Litherland et al, 2005) concluded that the nutrition costs to the ruminant of digesting fibrous leaves were too high to warrant feeding to livestock. However, flax green strippings (a by-product of fibre processing) has nutritive potential as a supplement to pasture fed animals. Green strippings contain low (9%) levels of protein, and high (87% higher than in the clover used in the experiment) concentrations of soluble carbohydrates and starch (relative to late winter pastures which commonly contain high protein and low carbohydrate contents). The BestFeed model predicted that a 500 kg Friesian bull would grow 0.8 kg/d on a sole diet of strippings or at 1.0 kg/d on a 50:50 mix of poor quality pasture and strippings. Overall, due to the fibre content of the green strippings, they would be considered to be of medium quality (10.3 MJME/kgDM), akin to that of green pasture leaf growing in summer (by comparison, clover with its low fibre content, is a high quality feed with an energy content of more than 11 MJME/kgDM).

In the second study (Litherland et al, in press) chopped flax leaves were fed to parasitized young cattle to help determine if flax possesses anthelmintic properties. The cattle each ate on average 3.2 kg of wet flax: after seven days all flax-fed cattle scoured, but recovered quickly when taken off the flax. There was no appreciable reduction in faecal egg counts; and it therefore could not be concluded that flax kills adult parasites already established in the gut of cattle (it is not beyond the realms of possibility that flax could reduce the establishment of L3 larvae but a different trial design would be needed to test this hypothesis). In this context it is worth noting that very few plants possess anthelmintic properties: reported activity can more often be ascribed to browsing above contaminated pasture (and this may be a factor also with flax).

Extended Buffers

This section considers opportunities for flax in extended buffers: extending beyond riparian corridors into floodplain plantings, developing more generous buffers around natural or constructed wetlands, and extending indigenous vegetation in coastal dune systems.

FLOOD PLAIN

Flax is an excellent floodplain crop. In 1953, Boyce wrote: "winter flooding of a fifty acre trial area at Moutua in two successive years 1949 and 1950, has shown that phormium withstands inundation to a depth of three feet, for periods up to 4 weeks during the winter months, and benefits from the resulting suppression of much weed and insect infestation".

On the lower Ruamahanga floodplain, south of Martinborough, flax was grown as a floodplain crop for nearly 100 years. In 1968, the *Wairarapa Times Age* reported on the upcoming

closure of the Mahaki Mill: "The Wairarapa Catchment Board's \$40,000 flood control scheme on the lower reaches of the Ruamahanga River has spelt doom for an industry which has been worth thousands of dollars to the district... 800 acres of the Mahaki farm were liable to flood before the two gates were built... over the years the flax bushes have trapped the silt carried by the flood waters, and this has built up a deep layer of fertile soil". Frank Wall explained, "flax is a really good flood-land crop, but with the risk of flooding removed, there is more money in crops and farming".

Over the last 50 odd years, massive investments have been made in river engineering works around the country to protect the fertile alluvial plains from the risk of floods.

Fifty years on, flood protection systems are faltering.

In the Bay of Plenty: "receding floodwaters in the Eastern Bay of Plenty have left dairy farmers with some major feed issues this season... contractors have been busy replanting ruined pasture" (*Countrywide*, 2004).

At Gisborne: "the Waipaoa River, which flows through the 9700ha of Gisborne flats, is a real problem. The river berms are being built up with sediment, so as time goes on the flood control scheme is less likely to be able to cope with floods" (*Countrywide*, 2006).

In the Lower Waikato, the Waipa Flood Control Scheme, completed in the 1960s, covers 17,000ha of land protected from flooding by stopbanks, drains and pumping stations: "Buckley's attitude to the drainage scheme is one of accepting its contribution to his dairy farms success, as well as questioning its longterm viability... we have a contract to the government to maintain the drainage system, but I query how sustainable it is long-term. The stopbanks I build are getting higher...eventually the cost of building up stopbanks... may make the farm economically unfeasible" (*Straight Furrow*, 2006).

In the Manawatu: Horizons advise that long-term silt and gravel build-up in the lower 10-15km of the Rangitikei River has been confirmed at 25-30mm pa: "while it was not impossible to keep improving the scheme, the engineering involved would one day make it unrealistic... threatening the expensive dairy farming infrastructure, and also making cropping marginal". The alternatives include: "letting the river go back to its natural state so farmers would have to make a living on the unprotected flood plain". Roger Dalrymple, Rangitikei River Scheme liaison committee chairman: "if I was a Scots Ferry resident, I'd want one in 100-year flood protection too, but if it's the landowners who are paying for this, then maybe we have to accept that every 20-30 years their properties could be flooded... we cannot keep raising the stopbanks forever. In another 20 years the freeboard in the river will be gone again and the stopbank will need to be raised again" (*NZ Farmers Weekly*, 2005).

From the climate change front, forecasts are for more, rather than less, extreme weather events: Alan Porteous, NIWA agricultural climatologist: "climate change this century will result in wins and losses for NZ farmers... the largest impacts on business will be from extreme rainfall, storm surges and drought" (*Straight Furrow*, 2006).

The Ministry for the Environment are currently leading a two-year work programme to improve how NZ manages its flood risk and river control. The project is taking a wide brief, noting that: "current river management practice is highly reliant on physical works, and this may not be the most appropriate approach to mitigate flood risks in the future".

Within this broader context, it may be appropriate in the future to re-visit the economics of farming flax on the floodplain. The value of flax in riparian corridors is established (albeit these are sometimes a skinny line of plants wavering on the edge of an eroding bank): the economics of commercial floodplain plantations is yet to be established. Between the two, there is scope to consider generous riparian plantings on the floodplain: in part to buffer flood events, and in part to help build the resource for emerging applications.

***we cannot
keep raising the
stopbanks forever –
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in the river will
be gone***

WETLAND BUFFERS

Over 90% of NZs natural wetlands have been drained. Major wetland systems, which may have been hundreds of hectares in extent (and rich with eels and ducks) are in many areas reduced to pools and puddles. As noted earlier, these remnant patches are now a focus for fencing and protection.

**wetlands are the
cleansing 'kidneys'
of the ecosystem**

Wetlands are the cleansing 'kidneys' of the ecosystem, the natural buffers between land and waterbodies. Alongside initiatives to protect existing wetlands and freshwater bodies (eg. 150,000 harakeke planted around Lake Horowhenua), others are working to re-construct wetlands: initially for 'point source' water treatment, more recently as part of broader landscape flows. Nutrient-rich wastewater (from farms and cities) has in the past been dropped from oxidation ponds, directly into the nearest waterway: new models of land-based treatment now utilise multi-phase settling systems, constructed wetlands and broad-scale irrigation to land. In relation to wastewater irrigation, the hunt is on for 'nutrient-sucking' cash crops, ie. crops which can be regularly harvested for the removal of nutrients. Ideally timber/fibre crops (in preference to food-chain crops). And ideally, the hungrier the better (to minimise land areas required). This is relatively new work, and various of the CRIs are active in this arena (eg. Ian Nicholas, Ensis; Chris Tanner, NIWA; Ian McIvor, Hortresearch; Val Snow, AgResearch): indications to date are that no one crop will suit every soil/climate situation, and it may well be that a combination of crops deliver optimum results at any one site.

**flax didn't like
being continually
inundated with
wastewater,
and grew better
on the edge**

It is not proposed that flax form a primary element in either constructed wetlands, or in wastewater cropping systems. In relation to the first: 'swamp' flax is a mis-nomer. In 1872, Hector wrote that what are frequently termed flax swamps, more often comprise a (conspicuous) margin of flax round the edge, the greater part of the extent being covered by raupo. Similarly, in 1949, Poole and Boyce reported in detail on vegetation communities on the Moutua Estate and recorded that "the belt which phormium occupied in the primitive community lies between raupo and sedges on the wetter side, and scrub and forest on the drier side" Recent work by NIWA (Chris Tanner and Brian Sorrell) on the growth of plants in constructed wetlands confirms reduced growth and lower survival of *p. tenax* under deeper water treatments (consistent with poor internal aeration capacity related to low root porosity, and the absence of pressurised gas flow in their shoots). Flax didn't like being continually inundated with wastewater, and grew better on the edge (water 30cm above ground, flax didn't like; water at ground level, flax tended to sit; water 30cm below ground, flax was OK). Boyce (1946) wrote that "while mature flax can stand a fairly high water-table, seedlings must be well-drained for several years, and free from submergence for more than a few days at one time in the case of floods".

**seedlings must
be well-drained for
several years**

In relation to wastewater cropping systems, we have already noted above that nutrient accumulation rates in flax are modest (particularly phosphorous, the element of particular concern in waterway quality). Having said that, it is of interest to note that Fergus (1976) reported on work showing the best flax producing soils in NZ had a high soil P content; and on fertiliser trials in NZ, South Africa and Brazil, all showing marked growth response to phosphate applications. Similarly, Moss (1955) reported that *phormium tenax* grew well under a variety of cultural conditions provided phosphates were employed in its treatment; and that the chemical composition of *p tenax* grown on four different soils showed a good correlation between the phosphoric acid content and the status of this constituent in the four soils. There are some suggestions that fibre yield may increase: we are not aware of any work on implications for fibre quality. At the Hui Harakeke (2005) Grant Douglas suggested that future work may consider nutrient concentrations in 'high fertility' environments, including field comparisons of flax vis-à-vis other species; and developing appropriate companion planting systems for harakeke for nutrient and/or other objectives. NIWA (Brian Sorrell) have collected samples of flax and raupo from a range of high to low nutrient environments, but this data is yet to be analysed.

Nutrient loadings are an important parameter in wastewater cropping systems: hydraulic loadings (volumes of water) are also a key factor in selecting plants and designing irrigated areas (particularly in the context that many urban wastewater systems have ageing pipes and heavy infiltration of groundwater, ie. large volumes/dilute concentrations). Maurice Murray has observed that flax can take as much water as you give them; and Mackay et al (2002) describe flax as having “high water-absorbing, deep-rooting qualities”: specific future work on the water uptake and transpiration rates of flax would be of value.

The MfE *Flood Control Review* notes that about 100 NZ cities and towns are located on flood plains, alongside major rivers. As noted above, municipal wastewater systems have traditionally been piped to oxidation ponds, generally located as close as possible to the river or shore for convenient discharge, and investments made in flood control works alongside. Within this broader context, it may be appropriate in the future to consider a role for flax in land treatment systems, linked to riparian corridors: buffering constructed wetlands, buffering flood risks, and potentially part of more generously scaled multi-crop irrigation systems.

it may be appropriate in the future to consider a role for flax in land treatment systems

COASTAL DUNES

In 1872, Buller wrote that “in the south, *phormium* is never found far from the sea... in the North Island, *phormium* is also most abundant near the coast”.

As noted earlier, coastal sand country has been no exception to the broad-scale clearance of indigenous vegetation. In 1999, McKelvey recorded the vegetation on NZ dune systems as being patchy grass and sedges on the foredunes (50,000 ha); an intermediate area of lupins and shrubs (40,000 ha); and an extensive area of back dunes (200,000+ ha) comprising grass, gorse and pines.

The Manawatu sand country (79,000 ha) is the largest dune field in New Zealand; and Horizons MW note that, despite many recent changes, it is one of the most significant in the world. The original forest and scrub vegetation was almost completely cleared, resulting in widespread dune erosion. The soils are thin and fragile; and the combination of rabbits and stock on these dunes often results in small patches of bare sand. Strong winds, common in spring and autumn, can cause localised ‘blowouts’. Once eroded, the topsoil is gone, and the site will remain sensitive to wind erosion for years to come.

Last century, lupins, marram grass and pines were the staples of dune stabilization schemes. More recently, the Coastal Dune Vegetation Network (co-ordinated by David Bergin and Greg Steward of Ensis) was established to advocate for the restoration of the natural character of sand dunes and coastal forest communities. They have been particularly active and influential in promoting the use of indigenous sand-binding plants (spinifex, pingao) in the actively eroding coastal foredunes (as a footnote here, the Foxton Mill produces flax fibre rope “webbing” to help stabilise newly planted areas); and the National Water and Soil Conservation Authority (1986) recommended *p. cookianum* for secondary planting between coastal dunes, once initial stabilization has been achieved.

p. cookianum is recommended for secondary planting between coastal dunes, once initial stabilization has been achieved

In the past, flax was harvested in quantities from the Manawatu sand country; as recently as the 1980s, NZ Bonded Felts chartered a small plane to scout new supplies of flax leaf, and identified a belt of flax about a mile inland from the coast, extending between Foxton and Wanganui (through the Santoft Forest/Flock House/Scots Ferry area). In the future, as attention moves from the foredunes to the back dunes, it will be appropriate to consider an expanded role for flax in coastal vegetation communities, particularly if broader scale plantings could be linked to emerging commercial applications.

Block plantings

This next section considers opportunities for flax in 'block' plantings, including two-tier or mixed systems: woodlots and restoration blocks, and specialty blocks supplying regional enterprises and crafts.

WOODLOTS/RESTORATION BLOCKS

Around existing woodlots and reserves, flax is useful as an 'edge' plant: for shelter to help protect the interior; and, where there are concerns about weed control on high-light margins, as noted earlier, flax is resistant to the sprays commonly used for gorse and blackberry.

flax is useful as an 'edge' plant: for shelter to help protect the interior

For rehabilitating damaged environments, flax is a good primary coloniser; eg. Landcare Research (Robyn Simcock) utilises flax in the rehabilitation of mining sites; and Robyn is trialling hydroseeding (with harakeke, manuka, koromiko, karamu) as a direct establishment technique.

It would generally be presumed that direct seeding of flax into restoration sites would require bare earth: in a very interesting piece of work however, Reay and Norton (1999) recorded harakeke self-seeding and establishing itself into ungrazed and lightly grazed pasture in a Port Hills Reserve, and suggested "*p. tenax* invasion of grasslands is an ongoing process" (a process which David Norton has subsequently observed at other sites). Even more interesting... they recorded abundant regeneration of shrubs and trees in the heart of the harakeke, in the central cavity encircled by younger fans: "once established, *p. tenax* clumps start to expand, and gaps form... many seedlings and saplings were found in *p. tenax* clumps... a total of 22 native species were recorded from within 52 of the 78 clumps sampled... most commonly *griselinia*, *mapou*, *coprosma*, *pittosporum*, *five finger* and *olearia*". The report notes that nearly all the species were bird-dispersed, and that regeneration was limited solely to *p. tenax* clumps (no regeneration was recorded in grassland within the transects). The authors speculated that birds are attracted to *p. tenax* plants perhaps as perches (noting that several studies have illustrated the importance of perch sites in encouraging seed dispersal into restoration areas), and also containing insects. Related to this, Meurk and Swaffield suggest that where there are adequate resource-rich stepping stones, even if only one tree (or one flax bush!) in extent, then wildlife will use them; and as the range and quantity of food sources for indigenous wildlife increase, this in turn should improve the rate of dispersal of native tree species across depleted landscapes.

flax is a good primary coloniser

Reay and Norton's report *Phormium tenax: an unusual nurse plant* notes that flax is relatively fast growing, can successfully establish into grasslands, tolerates a wide range of environmental conditions, and has the ability to act as a nurse species facilitating succession to native forest. It would be of great interest to track native plant succession at this site in years to come: it would equally be of value to consider implications of this work for low-cost, longer-term restoration strategies.

One, very simple option may be to use harakeke (cheap, robust) as the base planting in revegetation areas, and leave nature to take its course (provided native seed sources are within striking distance). Alternatively, harakeke can be considered as a nursery crop in indigenous plantations. Tane's Tree Trust (established in 1999) promote the establishment of native trees (totara, kauri, beech etc) mimicking natural processes (ie. mixed species plantations, use of nurse species, continuous cover systems). Flax fits the characteristics of successful nurse plants, ie. colonising species, fast growing, will grow in the open, will grow in a variety of conditions; and it would be of interest to assess the extent to which flax facilitates, or inhibits, the growth of planted stands (vis-à-vis manuka, tree lucerne etc). Flax would be of particular interest in this context, if it could not only serve as a nurse crop, but as a commercial crop in its own right (harvestable five years from establishment). The difficulty with all forestry regimes

(be it *pinus radiata* or NZ totara) is the time to harvest: as a farmer at a forestry field day put it "forestry is longterm, and we need short-term cash-rich harvesting principles" (Countrywide, 2005). A key point here is that – notwithstanding the widespread dismissal of native trees on the basis of being far too slow – work at FRI (David Bergin et al) has clearly demonstrated "the excellent potential of many indigenous timber species... if good quality seedlings are planted on fertile sites". David notes, however, that planting on the optimum sites, on the fertile lowlands "is likely to be small-scale as such sites are in competition with other land uses" (Tane's Tree Trust, 2002). The economics of indigenous forestry blocks would be considerably more attractive if the 'nurse' crop could in fact be a cash crop.

harakeke can be considered as a nursery crop in indigenous plantations

Another factor which may influence the economics of forestry blocks in the future is climate change, and the new science of 'eco-nomics'. The Forestry Institute recently identified challenges for the future of the forestry sector, including development of a carbon market in NZ, and putting a monetary value on the non-extractive values of plants such as biodiversity, water and soil quality and carbon sequestration. The Kyoto Forestry Association suggests that any domestic policy that seeks to encourage Kyoto compliant behaviour must act to make the establishment of carbon sinks an attractive land use option. At the Forestry Institute seminar (2006) Ket Bradshaw didn't pull any punches: "Climate change is here and the Kyoto Protocol is here. We can either urgently invest in reducing carbon-emissions within New Zealand, or end up paying people overseas because we haven't the spine. To me, it really is a no-brainer". In a Radio NZ interview, Cath Wallace agreed with the need to look at sinks, "but making sure that we have biodiversity and native forests in mind rather than just carpeting the place with pine trees" (Morning Report, 2006).

In most areas of lowland NZ, indigenous remnants are small. Too small to support self-sustaining populations of our larger birds (kiwi, kokako, kereru, kaka): many large species are regionally extinct. And small areas require disproportionately more conservation effort per hectare than larger areas. DOCs response – to bring back the morning chorus – has been to establish an initial network of 'mainland islands' (islands of bush in a sea of pasture): in the future, these mainland islands may be more firmly embedded in a broader matrix of indigenous plantings, where intensively managed core areas (sacrosanct for the birds) are buffered with broader multi-species plantings, managed for sustainable use.

SPECIALTY BLOCKS

In recent years, there has been a resurgence of interest in traditional crafts; and artists and artisans utilising harakeke in contemporary designer products (hapene, designer lampshades, hand-crafted furniture, korari surfboards). Hand woven kete are used for gift baskets, and in point-of-sale packaging. Piupui are in demand, to the point where a market research report (Te Whanganui a Orotu Whare Wananga Inc, 2004) noted "piupiu makers reported they were unable to fulfil requests for orders (and) demand is projected to increase" (and we have latterly heard rumours of piupiu "Made in China"). Mark Lander is well-known for his large-scale flax paper installations; Marty Vreede makes hand-crafted flax paper for the art market; and Rhonda Rutherford-Dunn uses discarded leaves from Living Nature in her paper-making operation.

there has been a resurgence of interest in traditional crafts; and artists and artisans utilising harakeke

Living Nature was one of the first companies to utilise native plant extracts in cosmetics, and use flax gel extensively in their product range. Ocean Organics use flax extracts in salves and hand balms; Egmont Soaps market a flax soap. All parts of the plant are utilised in various applications: terracotta and brown dyes are extracted for hand-dyed wool ("chrome mordanted wool takes on a fine brown colour when steeped in the hot juice, and the colour is very fast to light" Easterfield, 1922); Maorifood.com market a flax seed bread in Rotorua; Maori Tourism Corporate Services produce "Te Harakeke ra-re", flax/manuka honey sweets; and

Phytomed use root extracts in laxatives, and for application in digestive conditions.

After many years languishing in the back corner of nurseries, flax is flourishing in floriculture and horticulture. A network of nurseries supply the growing demand for flax plants in gardens, in subdivision developments, in bio-engineering, and on farms. In landscaping, flax is valued for its range of colours and striking structural effect: the same qualities are equally appreciated in floristry.

Some of these businesses are export scale; others are niche: all are helping create visibility and momentum and market 'pull'. Small enterprises may begin with 'wild' harvest: as demand grows, opportunities open up for the establishment of small plantations, supplying specialist applications.

In many areas, traditional cultivars have been lost; and, alongside the resurgence in traditional crafts, many iwi groups are re-establishing *pa harakeke*, carefully tended plantations of special local varieties or traditional weaving cultivars, selected for properties such as strength, softness, durability and yield. The Orchiston Collection (held in the stewardship of Landcare Research) comprises 60 traditional weaving cultivars (supported by descriptions of their properties and applications, now available on-line on the Landcare website): over recent years, thousands of plants have been replicated to support new plantings by marae and community groups around NZ.

***pa harakeke are
carefully tended
plantations selected
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such as strength,
softness, durability
and yield***

Whereas broadscale environmental plantings are mostly seedling stock, specialty plantations are more likely to comprise selected varieties, propagated by fan division to retain parent properties; generously spaced (2-3 metre spacings) for optimum leaf growth, and ease of management and harvest; carefully tended and regularly groomed (to keep bushes clear, and minimise pests/disease); and material selectively harvested by hand. Site selection is important for fibre quality: Scheele and Walls (1994) note that "flax will grow in almost any soil type, but will produce better quality fibre if grown on rich, light, moist soil which is well-drained". And selection of varieties for particular sites/locations is important: *He Korero Korari* (2004) describes an eight year growing trial, with 12 cultivars grown at 11 locations around NZ, to test observations that weaving qualities of harakeke change when the plants are grown in different places. Harris et al (2005) concluded that "to a large extent, differences of varietal characters were distinct regardless of where the varieties were grown", but noted significant changes in different growth environments, suggesting these may mainly be in response to favourable (or less favourable, eg. cold and frosty) growth conditions.

Small plantations help develop confidence and knowledge in planting and tending harakeke; provide accessible, quality supplies for existing and developing niche markets, and supply of material for R&D; and may help serve as the nuclei for expanded commercial applications in the future. Harakeke holds a central role in Maori culture, and many iwi land authorities are actively exploring landuse options. The *Maori Landuse National Resource Kit* (SFF, 2003), noting that much land in Maori title is under-utilised, outlines a range of potential farming/cropping options suited to a variety of areas and land types: alongside consideration of a wide range of introduced crops (berry fruits, herbs, flowers, forestry etc) there is scope to establish harakeke (perhaps initially on a small scale) to link with existing demand for traditional and contemporary crafts. Or indeed, as outlined in earlier sections, to establish harakeke as a nurse crop for two-tier indigenous forestry; or as shelter for other crops (which may currently have a more established place in the market).

***small plantations
help develop
confidence and
knowledge in
planting and
tending harakeke***

Many new crops are developed initially as speculative ventures on small blocks (trailing varieties, developing value-added niche products etc) before production is stepped up to larger-scale plantations. Currently we have around 140,000 small holdings in NZ (growing by 7000 each year) with a mean size of around five hectares. Discussion as to the merits or otherwise of subdivisions are ongoing: notwithstanding this, MAF projections are for life-

style blocks to continue in popularity and compete for Class 1 and 2 land in all regions. For optimum production, harakeke does indeed appreciate Class 1 and Class 2 land; and, as a potential crop, it is of considerable interest to lifestylers, attracted by the relatively quick crop establishment timeframes, and by the potential dual environmental/economic returns.

Harakeke is not the only indigenous plant which may offer new economic/environmental win-wins in rural NZ. As noted above, Suzanne Hall was one of the first to utilise native plant extracts (manuka, flax gel) in her product range (with accolades due for creating significant employment, deep in Northland); and Living Nature is still at the forefront of this movement. In May 2006, FRST announced it is investing \$1.7m (being matched dollar for dollar by Living Nature) to create "the world's most natural and effective skincare ingredients using unique, native NZ flora". Living Nature CEO, John O'Toole says the project "reflects a changing trend towards natural products in place of synthetic alternatives"; FRST Business Manager, Tom McLeod says "we could be sitting on an untapped goldmine"; and NZTEs Lyn Bridger says the project leverages NZs innovation, technology and natural environment, with the "potential to become a truly global brand and a high value added product". FRST believe the project will enable knowledge of the unique properties of native plants to be gathered together and developed to produce commercial benefits for the whole country; and "harvest and manufacturing processes will be investigated to ensure commercial quantities of new ingredients are readily available on a sustainable basis". This last is a key point. 'Wild' harvest – tramping into the mountains or pillaging remnant reserves – is not practical on any longterm basis (or even legal). Sustainable production of native plant extracts is likely to require the establishment of plantations on flat to rolling country. One possibility – crop by crop – is plantation mono-culture: an alternative future would see the establishment of diverse, multi-crop systems, designed to replicate ecological communities, and managed for sustainable yield.

Plantations

Along the river/road/fenceline corridors, flax can be established principally for environmental reasons, while recognising secondary opportunities for harvest (and acknowledging implications for planting patterns: generally closer for riparian/shelter functions, and wider for harvest). Of their nature, these corridor plantings will be accessible; and, particularly if linked to extended buffer plantings (floodplains, wetland buffers, coastal dunes), the scale could be substantial.

In relation to environmental plantings, it is of particular note that flax benefits from grooming (and at least one regional council actively encourages regular harvest by iwi groups). Regular removal of mature leaves tends to reduce incidence of pests and disease; reduce fire risk (flax is classified as moderate-high flammability, which increases with age due to the buildup of dead material from accumulations of dry matter); and perhaps discourage possums from using it as habitat. Certainly the role of flax in absorbing nutrients would be enhanced with regular removal of mature material. In Southland, Des Templeton's mill was harvesting out of farm shelterbelts right through to the 1970s (with the added benefit of keeping the shelterbelt tidy). A key issue in linking farm/conservation plantings into potential harvest regimes is varietal selection (a topic we will return to later in this report): currently hundreds of thousands of plants are going in the ground every year, none selected for their fibre values.

Small block plantings strengthen the indigenous corridor/patch matrix in the landscape. Again these may be established principally for environmental reasons (restoration projects), or for dual environmental/commercial return (eg. two-tier indigenous forestry), or principally for harvest (eg. supply of material for regional enterprises). Small niche markets can be readily supplied from small blocks: these blocks can equally serve as stepping stones – not just for the birds – but also towards larger scale commercial plantations.

flax benefits from grooming... regular removal of mature leaves tends to reduce incidence of pests and disease; reduce fire risk

**the future
establishment of
plantations critically
turns on the
pull-through
from the market**

Clearly, the future establishment of plantations critically turns on the pull-through from the market, and it is too soon at this time to recommend large-scale plantings for commercial return. Nevertheless, applications development is underway (developments are discussed later in this report) and it is not too soon to begin considering opportunities and practicalities of re-establishing flax plantations in NZ. Not least to support investor confidence in product/market development.

As a commercial crop, NZ Flax has none of the risks and costs associated with new introductions (exotic species or genetically modified organisms). All of the attributes previously described for environmental plantings equally apply to commercial plantings: flax has broad environmental tolerance, grows from one end of NZ to the other, is easy to propagate, cheap to establish, and can be harvested five years from planting (or a little longer in the South Island). Flax is compatible with existing farming systems; the nursery trade has a great depth of experience; and many growers are already familiar with the plant. Flax has multiple values; and wide harvest windows. As a crop, it is easy entry; it is also relatively easy exit. And perhaps most importantly, harakeke has a long history of traditional and industrial agronomy which can serve as a platform for future developments.

**above all,
the quality of the
fibre must be
improved**

Poole and Boyce (1949) identified three phases in the harvest and cultivation of flax for industrial use: the first up to 1900, when leaf was obtained from naturally occurring stands which were widely distributed over the North and South Islands; the second from 1900 to 1920, when large areas of swampland were drained (particularly in the Manawatu) to induce the growth of flax; and the period post-1920, when large tracts of flax (particularly in the 'induced' areas in the Manawatu) succumbed to yellow-leaf disease, and attempts were made to develop managed plantations. In 1935 the *Evening Post* reported on plantation developments, saying "talk about the NZ flax industry in optimistic tones is useless if the haphazard methods of production of the past are to continue. Above all, the quality of the fibre must be improved. Every bale of NZ flax at present exported is produced from the mixed varieties, mostly of poor or mediocre quality, which occur in natural flax areas. By planting areas with fans of a good variety, uniformity, higher yield and higher quality can be readily obtained". In 1951, Critchfield reported that the largest plantations were at Kaiangaroa; in Southland (an area of about 1000 acres, situated largely on hilly land); and the Moutua Estate (5000 acres of combined planted and induced swamp on the floodplain of the Manawatu River).

This next section reviews the history of managed plantations in New Zealand, suggests implications for future plantation scale management, and indicates areas where plantation developments could be integrated with other land use imperatives.

SITE SELECTION

**the best
phormium areas
have a high soil
fertility and a low
water table**

Flax researchers all converge on the requirements of flax for fertile, well-drained soils; agree on the critical importance of the water-table; and describe the value of periodic floods in building up a mulch around the base of the plant, and in washing away insect pests. In 1938, Yeates reported on a soil survey of phormium areas: "in general it might be said that the best phormium areas have a high soil fertility and a low water table. The general relationship of high water table to unthriftiness in phormium has long been realised by many growers". Again in 1948, Yeates talked of the "misconception as to the need or preference of flax for wet land. In general it can be said that poor sub-soil drainage is one of the most frequent causes of poor growth and disease in flax".

The misconception is still so prevalent, as to bear further repetition: "although phormium tenax will grow on a great variety of soils it is recognised by millers that, for largescale operations the soil, whether on high country or low country, must be of good quality"

(Holt, 1929); "the more fertile the soil, the more vigorous and healthy is the flax. It may seem unnecessary to mention this but for the fact that the idea is prevalent among some that flax can be grown on soil too poor for other purposes" (Taylor, 1937);

"the land required for making a profitable flax plantation must be good land... not too wet and not too dry; subject to periodic flooding is an advantage" (Westport News, 1943); or, in short, "the better the soil, the better the flax" (Des Templeton, 2004).

In 1937, Taylor reported: "other soil factors being equal, the flax growth on groundwater soils is poorest where the water table approaches nearest the surface... where the water table approaches the surface, the amount of seasonal fluctuation affects flax growth; flax grew best where the evidence suggested wide fluctuations... a sharp change in the subsoil texture from light to heavy causes a perched water table and seems to be as deleterious to flax growth as it is to many other deep rooting plants... the strong growth of flax on the edge of running streams supports the suggestion that the type of groundwater (composition, aeration, movement) has a bearing on flax growth". Related to this point, Robinson (1947) reported on work in Argentina, indicating that plants growing near a river gave a higher yield than those growing further away (within 900 yards of the river, yield was reported as 48tons/acre; further away, the yield was 26-32 tons/acre). Brazilian and South African researchers have reported on the relationship between the depth of the soil, and growth of plants (the deeper the soil, the deeper the roots, the better the growth). Yeates (1948) stated that "the ideal conditions for growth of flax are a porous deep soil, with moving (not stagnant) water three feet or more below the surface. The roots can penetrate at least ten feet downwards".

**the more fertile
the soil, the more
vigorous and
healthy is
the flax**

While good well-drained land is clearly required to support healthy growth, a critical factor in site selection is not just the growth per se, but the quality of the fibre. And again, we have a clear convergence as to the relationship between drier land and finer fibre: "phormium that grows on high or dry ground, although smaller, is in general finer and more easily stripped than that found in swamps... the more suitable the soil, the finer the quality. It grows best in light, rich soil by the sides of rivers and streams, where sheltered from the wind... a rich, dry clay soil, with plenty of light and air, is very suitable...the greatest crops are reared on high volcanic ash" (Hector, 1872); and again, "while the leaves from drained swamp are larger and more abundant than those produced on higher land, the percentage of fibre to leaf is much less, and the fibre itself is neither so fine nor so strong. Thus in Southland and Marlborough, a shorter but finer quality fibre is produced, than in Auckland or Wellington districts where most of the fields are low-lying" (Holt, 1929). Gordon Burr of the Foxton Flax Mill has observed the fineness of fibre grown on pumice soils (relative to the same variety grown on heavier soils in the Manawatu). Charles Pearce (NZ Woolpack & Textiles) and Bill Hoskins (NZ Bonded Felts) recall fine-fibre flax from Gisborne/Poverty Bay, and from the Mahaki Mill, situated on free-draining land south of Martinborough.

It is relevant to note here a suggestion (Harris et al reporting on earlier work by Poole in 1940) that there may be dryland and wetland types of *p. tenax*; and that the dryland varieties, or their hybrids with *p. cookianum*, would be especially amenable to dryland cultivation. The taxonomic work currently underway at Landcare Research may assist in determining this question, to support the selection of varieties for 'dryland' agronomy for fine-fibre production.

VARIETAL SELECTION

In 1905, the Agricultural, Pastoral and Stock Committee heard representations that: "a collection be made of every variety grown in NZ.... I feel confident if this collection was made, and the different varieties tested, there would be a great many varieties which are now

milled which would be discarded, and others of greater value would be taken in hand and cultivated.... I think it must be patent to everyone that with a plant of this kind, where there are so many different varieties, there must be a vast difference in quality. That is the reason why I would urge that the government should make this collection, and then by careful selection and testing, find out the best varieties which could be cultivated". More recently, Harris et al (2005) similarly recommended that "systematic study of the variation throughout NZ of wild populations of phormium would be of value in conserving the genetic variation of the genus, and provide material for the selection of new varieties for fibre quality, and for growth in more difficult environments".

*three major
collections of
flax varieties have
been made*

Three major collections of flax varieties have been made. In 1927/28, Yeates (Massey Agricultural College) collected 2-300 varieties from travels around NZ; and conducted extensive breeding trials through the 1930s, selecting for disease resistance, yield and strength of fibre; including work to assess the stability of selected characteristics in seedling grown stock. He documented substantial improvements in yields achievable, particularly with hybrid selections, and under agronomic conditions suited to the ecology of the plant. From 1939, attention turned to fine fibre, with finer varieties of *p. tenax* being crossed with *p. cookianum*: "Because of the soft qualities of the fibre, *p. cookianum*, or its cross with *p. tenax*, will probably be used extensively in the future. There should be no trouble in establishing plantations of plants from this cross in dry conditions" (Poole, 1940).

*it is to be
regretted that much
of this work seems
to have been lost*

It is to be regretted that much of this work seems to have been lost: literature records the loss of years of breeding work when acres of selected flax laid out for planting were washed away in a flood in 1936, other records have been lost in various institutional restructurings, and knowledge of the location of selected varieties (and their parentage/properties) is now patchy at best. In 1955, Moss recorded that the DSIR Botany Division at Christchurch held SS, Ngaro, 56, SS x Ngaro and SS x 56; and literature records the export of seed, including 'SS' to Australia, Argentina, St Helena, Ireland and elsewhere. When the Moutua Estate closed down in the early 1970s, 10,000 'Seifert's Special' were transferred to Rotorua and Tokoroa (recent reports indicate there may still be plantings at Te Puia, the Maori Arts and Crafts Institute, and remnants on Rotorua roadsides). In 1976, Fergus (NZFP) recorded that "the fate of other promising varieties is not known at this stage" and noted that "in retrospect, Yeates efforts were outstanding and the challenge today would be to track down his pedigree plants".

Several Moutua lines are still extant (including a line recently assessed as a finer fibre variety) but an element of confusion arises with the name 'Seifert's Special' (a stronger fibre line) seemingly loosely applied to more than one Moutua selection. The location of Moutua plantings, as currently understood, is: the 45 ha Flax Reserve at Moutua, now administered by DOC; a separate 4 ha covenanted area on the Moutua, administered by Landcorp; shelterbelts at Flock House, now managed by AgResearch; a one acre remnant of the NZFP trials in Northland, owned by a farmer; small plantings on private/iwi land around Foxton; plantings in the Foxton Flax Walk, behind the stripping mill; the plantings at Te Puia; and the 'Moutua' flax sourced by Maurice Murray at the break-up of the Moutua Estate (seedling stock has been grown on for over 30 years now, and plants are supplied in bulk to EBoP and other regional councils). These Moutua plants – the progeny of decades of publicly funded breeding work – would merit further systematic attention.

In the 1960s, Rene Orchiston gathered a collection of 50+ special weaving cultivars, sourced mostly from the East Coast of the North Island (the Dunedin Botanic Gardens reportedly hold a collection of South Island weaving cultivars). Most of the recent work with harakeke varieties/properties has been undertaken with cultivars from the Orchiston Collection: the growing trials led by Landcare Research have been mentioned above; Otago University have recently published work analysing the fibre properties of three varieties (Carr et al, 2005); and IRL, in a FRST-funded project **Harakeke: Traditional Knowledge and New Uses** have been

reconstructing traditional knowledge of harakeke varieties, alongside lab analysis of muka linear densities to supplement traditional uses and promote new uses. Fifty varieties from the Orchiston Collection have been assessed, and used as the standard against which to compare a further 30 forms from around the country. Preliminary results were reported at an IRL workshop in 2005 (with further publication of results pending): linear densities were measured in tex (the weight, in grams, of 1km of fibre) with preliminary assessments of 15 cultivars indicating a wide range from finer to coarser fibres (from 12 to 28 tex, ie. at the low end, getting close to the fineness of linen; at the upper end, similar to the coarseness of sisal). Newman (IRL, 2005) further reported on the length of ultimate fibres (range 4.8mm to 8.2mm on 15 samples); and differences in guaiacyl lignin content (guaiacyl photodegrades in sunlight), an aspect of relevance in textiles, with highest levels found in *p. cookianum*. A point to note is that finer fibre varieties are not well represented in the Orchiston Collection (traditional cultivars were perhaps selected for other attributes, including yield as an important parameter).

fifty varieties from the Orchiston Collection have been assessed

The third major collection of varieties from around NZ is currently underway: as noted above, Landcare Research have begun work on a revision of phormium, with plants collected from 50+ sites around NZ to date. It will be of great interest, as the data comes in, to identify any patterns in fibre characteristics related to patterns in the distribution of phormium varieties and hybrid forms; and especially to identify the distribution of finer-fibre forms.

finer fibre varieties are not well represented in the Orchiston Collection

The NZ National Flax Collection was established in 1987, and is housed at Landcare Research, Lincoln (under the stewardship of Sue Scheele). It currently includes plants from all three of these collections, ie. 50+ wild varieties (*tenax* and *cookianum*); plus the 60 named cultivars of the Orchiston Collection; plus 3 or 4 Moutua selections. Outside the national collection, various regional collections have been made (eg. Rob McGowan has gathered a collection of harakeke from the Bay of Plenty; and Te Aitanga A Mahaki Trust has initiated work to identify Mahaki/Gisborne varieties).

A critical factor in future commercial developments will be selection of varieties suited to specific applications, and consistent supply within defined quality parameters. Indications from applications development underway – in both textile and biocomposite arenas – is that the finer fibre varieties are of most interest. Along the spectrum of *tenax* to *cookianum* (broadly moving from coarser to finer, higher yield to lower yield) it is likely that *tenax/cookianum* hybrids will be of particular interest (ie. ideally finer fibre varieties with good yield). As noted elsewhere, the finer-fibre *p. cookianum* forms are also generally more disease-resistant, more drought-tolerant and more frost-tolerant.

the finer-fibre p. cookianum forms are generally more disease-resistant, more drought-tolerant and more frost-tolerant

A number of individuals and agencies have skills and resources in identifying varieties likely to be of interest, and following through with formal assessments of their structure and chemistry, properties and performance. Key agencies include Landcare Research (Sue Scheele), the Biopolymer Network (Roger Newman et al), and Otago Clothing and Textile Sciences (Debra Carr). Roger and Debra both emphasise the importance of fundamental work into fibre properties and performance, to underpin applications development: ideally, a collaboration of interested parties would identify 'best-bet' selections for formal assessment (preliminary to future 'bulking-up' of selected lines).

Recognising a potential tension between 'best-bet' bulk lines (for commercial harvest), and respecting the boundaries of regional varieties (eco-sourcing), it should be noted that it is too soon to presume an inherent conflict. It may be that commercial plantations (based on one or two lines, eg. Moutua selections) can co-exist with other eco-sourced environmental plantings (remembering that harakeke, of all NZ plants, has already been extensively moved around the country). Alternatively, it may be that fine-fibre varieties are identified, region by region, for development principally within that region (assuming a level of tolerance of variation in fibre

characteristics for commercial application; or indeed to match different applications). It is also important to note that fine-fibre production will be governed only in part by varietal selection; and that other factors – agronomy, processing – may be equally important.

A final point in respect of varietal selection: Alec Muir (NZWP&T) recalls a bugbear he had that flax growers were paid irrespective of variety and quality, ie. with no incentive or reward for improvements: varietal selection will be significant only insofar as it is clearly linked to grading/payment structures, and market applications.

PROPAGATION AND PLANTING

On a small scale, harakeke can be replicated by fan division, with the advantage of retaining selected parent qualities.

On a larger scale, seedling propagation has significant volume/cost virtues; and the element of seedling diversity gives a level of adaptability and resilience to the population. In 1950, Boyce reported that, while plantations of clones are ideal because they combine high quality and uniformity, nevertheless “some of the clonal varieties throw lines of seedlings which are sufficiently uniform for practical purposes, (and) a greater degree of uniformity can be obtained by culling”. The point of being sufficiently uniform for practical purposes is a key one, especially when linked to processing techniques (discussed later in this report).

Harakeke seed matures in March: some growers sow it fresh, others cool store or stratify for varying periods. Mackay et al (2002) tested germination under a range of conditions, and reported: “there was some germination in all treatments (but) *phormium tenax* seed requires a period of chilling to overcome dormancy in the majority of the population... 8-10 weeks stratification is required as a pre-treatment to break dormancy... our data are in agreement with Metcalfe (1995) who reported that *phormium tenax* could be cool-moist stored for several months, and that seed stored for 5 months germinated within 12 days”. Seedlings may be grown on in either potting bags, or in open ground nursery beds; before being planted at between 18 months, or up to 4 years. In 1921, Seifert recommended that “in order to encourage farmers to grow flax, cheap and reliable plants must be readily obtainable... the seed from the best varieties should be sown in nurseries, and the plants sold to farmers at moderate prices after having been brought well forward”. The great majority of flax plants sold in NZ today are seedling plants grown by the nursery trade (generally available at between \$1-\$2.50 each). Currently, some are differentiated as being eco-sourced (for environmental plantings); in the future, there would be great value in nurserymen linking with the R&D underway in other sectors, to develop commercially available lines with known fibre properties. And, looking further into the future, NZ Flax can now be successfully replicated with tissue culture: if clonal consistency is required for new commercial applications, tissue culture offers the ability to replicate selected varieties on a large-scale. A point worth noting is the relatively quick propagation timeframes: new varietal selections could be made available for planting within a 2-3 year period.

there would be great value in nurserymen linking with the R&D underway to develop commercially available lines with known fibre properties

On a small-scale, hand planting into well-prepared holes is labour intensive work. On a larger scale, as noted earlier, the ‘pine planting’ technique is considerably more efficient. On a plantation scale, mechanised planting would be required. In 1950 the *Manawatu Herald* reported on a mechanised flax planter: “Officers were shown a mechanical flax planter, which reduces the back-breaking labour of 40 men to the work of four... a converted cabbage tree planter capable of dealing with nearly 10,000 plants/day, over an area of 6 acres... apart from the driver, only 3 men are needed to feed the digging apparatus... a small harrow cuts a furrow to a pre-determined depth, the plant is deposited in the incision, and 2 wheels force the earth around the base of the plant”. Peter Huff worked on the Moutua Estate for 25 years:

he describes a tractor (with a steel wheel clipped to the side making incisions), followed by men on a caterpillar sledge with the plants, and recalls planting 3000 flax per day. This is established technology, used in other cropping operations: clearly flax plantations of the future could be readily established with mechanised planting techniques.

*clearly
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ESTABLISHMENT AND MAINTENANCE

Establishment of a flax plantation, as with any perennial crop, includes the elements of ground preparation, plant spacings and inter-row management. In 1946, Boyce recommended that "to establish *phormium* seedlings successfully, the ground must be well-drained, clean, and generally in as good condition as would be required for any other fairly hardy crop plant... plant to mid-way up the fans and firm well... after planting the inter-row spaces are cultivated with rotary hoes for 18 months to give the seedlings a good start... sow down with pasture mixes, and lambs or young sheep can then control the growth until the plantation has developed sufficiently to shade the ground... old sheep have to be watched carefully as they take to chewing out the suckers".

*the ground must
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any other fairly
hardy crop plant*

Moss (1955) described a similar regime: "in Southland where plantations are in hilly country... in order to keep the yields up as far as possible Johnston Bros have carried out cultivation work between the rows. While I do not think they have any concrete facts or figures to substantiate their view, they are of the opinion that cultivation is beneficial... their flax is planted with 8 foot spacing between rows to enable a crawler tractor equipped with a rotary cultivator to work between the rows... in the case of new plantings, they cultivate during the first 2 years until the plants stool out... in the case of established plantings, they cultivate twice after cutting, after which time the growth prevents further work".

Alternatively, Peter Huff described the cycle on the Moutua Estate as being ploughing, discing, sowing grass seed, then planting, then grazing sheep. Moss (1955) noted that "the theory behind this was that grass kept down the weeds, and in turn, the sheep kept down the grass (and weeds). But in practice, of course, the sheep proved to be just as much the enemies of flax in NZ, as in St Helena".

Notwithstanding this last comment, sheep were extensively used to keep the grass down in flax plantations. In 1980, NZFP reported on two Southland plantations: on the Redan plantation, "sheep were grazed on the plantation during winter. These were owned by the adjoining farmer who grazed them for the rest of the year on his own property"; and, on the Neiderer plantation, "sheep were grazed through the summer, from September to early March, with up to 500 old ewes on the 500 acres at one time. Stock were bought and sold for this and not normally wintered on the property. No damage was done by the old stock, but hoggets were reported as damaging the growing tips... since grazing was started, the fire hazard was reduced to nil. Previously the rank grass growth died off in summer and was a significant fire risk". Ted Pratt, Mill Manager at Mahaki, recalled "we used to put mobs of wethers in to clean it up, good as gold". Peter Huff similarly recalled that the sheep never did much damage: "depends how hungry they are, they might have a go at the sucker when you first plant them... at times, pull some out, just replant... the main problem is they make the ground hard under heavy stocking, too hard for the roots... light stocking is OK". This last is a key point: flax roots run along very close to, or even on, the surface of the ground (ie. with implications not just for stocking, but also for the use of machinery in flax plantations).

In relation to spacings, Moss (1955) noted: "there are various views on this point and a number of different layouts have been tried in NZ. The following spacings are generally regarded as satisfactory – 6 ft x 4 ft 6 inches, 8 ft x 4 ft, and 6 ft x 6 ft. Mr Boyce said that in his experience, if plants are too close insufficient light reaches the base of the plant and new

conventional tillage of arable land is financially costly, damages soil structure and increases erosion risk...

shoots do not appear, and growth is confined to the old stock after cutting". Following through this last point, Harris et al (2005) describe the role of the butt (providing physical support for blades, and uplifting to avoid shading of blades by other leaves) and discuss partitioning of resources to the butt: "this response would be greater where plants are growing closely together, (and) emphasises the value of growing plants widely spaced, and regularly pruning out dead leaves to foster the growth of leaves with a high proportion of useful blade". In 1965, Morice recorded that: "at Moutua, the Department of Agriculture grows *p. tenax* in rows 6 ft apart, with the plants 4.5 ft distant in the rows, a spacing which gives about 1600 plants/acre".

The broad-scale cultivation techniques utilised in the industrial-era plantations have fallen from favour in recent years: "conventional tillage of arable land is financially costly, damages soil structure and increases erosion risk... minimum tillage minimises soil disturbance, thus reducing soil erosion. It also assists in maintaining good soil structure, reducing soil nutrient loss, and reducing water loss by evaporation" (Parliamentary Commissioner for the Environment, 2004). In the future, it may be that strip tillage – cultivating only about a third of the crop row width – is employed in the establishment of flax plantations. The experience of the past can be used as a guide to spacings: as a general guide, 2m spacings between plants in the rows would seem to be indicated (minimum 1.5m), with minimum 2m spacings between rows (or set at a width to accommodate light mowing or harvest equipment). For inter-row maintenance, it may be that mowing is an easy option to manage grass growth, particularly in the first year or two after planting; and then periodic grazing by sheep (noting the proviso about light stocking).

In relation to coppicing willow, Tom Barry has noted: "we are in the business of managing the grass and clover mix, as well as the trees" (*Countrywide*, 2002). The same comment equally applies to flax; and, in the context of utilising sheep for grass control (alongside earlier points re the value of flax as shelter in lambing paddocks, and the quality of fibre grown on hill plantations), flax farming could potentially offer a useful fit with sheep farming.

HEALTH AND DISEASE

'Yellow-leaf' is one of the most serious diseases of harakeke (similar to the 'sudden decline' in cabbage trees). It is characterised by abnormal yellowing of the leaves: Scheele (1997) describes how "growth of young leaves may be stunted and eventually the whole plant may collapse. Underground, the roots die off, the rhizome tissues collapse and rot spreads towards the crown of the plant". The causative agent has been established as being a phytoplasma (a bacterium), which is transmitted by the native flax plant hopper (which injects the bacterium into the leaf, while sucking the sap).

Yellow-leaf is much more prevalent in the North Island

Yellow-leaf is present in both the North Island and South Island, but is much more prevalent in the North Island (Boyce et al, 1951). The most serious outbreaks recorded were in the 'induced swamps', in the Manawatu, in the 1920s (with a devastating impact on production at that time). In 1934, Seifert recorded that the Makerua Swamp was the biggest single flax producing area, and "it is here the disease has done its greatest damage". In 1953, Boyce reported the "Moutua area alone in the Manawatu remained fairly free of the disease, but since 1944, a rapid deterioration has taken place in that area also". Reports of damage from other flax producing areas are more sporadic: "observations since 1945 have shown the disease is widespread throughout the North Island... at Dargaville and Featherston the disease has scarcely affected production" (Boyce, 1953). In Southland, Ray Johnson farmed 450 acres of planted flax on gently rolling country in the Redan Valley, and "although only swamp flax was grown, yellow-leaf was not considered a problem, or a significant threat" (NZFP, 1980). Ted Pratt spent 50 years in the industry, and did not recall that yellow-leaf was a

significant problem in Wairarapa plantations. Maurice Murray has been in the nursery trade 50 years, and has never had yellow-leaf at his Woodville nursery (in his experience, disease hits stressed plants). In the later years of flax production on the Moutua Estate (1950s to 1970s), Peter Reihana, a long serving cutter, recalled that yellow-leaf occurred where the flax was denied water, eg. where it was growing on mounds. Charles Pearce (Secretary of NZ Woolpack and Textiles for 20 years) recalls that yellow-leaf would build up every four years or so, especially if there hadn't been a decent flood; but also noted it wasn't a major problem: "yellow-leaf gave dud fibre, along with the good fibre, had to put it to one side" (and the "dud" fibre was used as traffic platforms on riverbanks and sand dunes).

While the direct causative agent is clear, the causative conditions have been the subject of much debate over the years. In 1953, Boyce noted: "observations over many years made it clear that epiphytotic of the disease followed extensive draining and protection from flooding". He went on to suggest: "most observations on the occurrence and spread of the disease have coincided with periods of more intense activity in the industry". The first outbreak was recorded in a localised area in the Manawatu in 1908; the next more widespread outbreaks occurred in 1914-16; by 1920, the disease was widespread in the Manawatu. In this context, it is worth noting that 1911/12/13 are recorded as boom years for the industry, tempting millers to cut right through winter: "by 1914 it was clear the plants were not recovering" (*Horowhenua County and its People*). In 1926, G. Craw, a miller of over 20 years wrote: "all flax swamps have gradually diminished in the growth of flax from one cutting to another, owing to the bleeding of the plants caused by cutting the whole of the flax plant as close to the ground as the cutters could conveniently cut it... the old plants have bled to death, or so near it, that they become an easy prey to the ravages of the yellow blight" (PNCC Archives). A writer to the *Foxton Herald* in 1955 perhaps sums it up best: "there are so many factors to consider when we endeavour to pinpoint the reasons for the deterioration of the Moutua flax areas... over-drainage, under-drainage, cutting during winter, cutting too low, stopbanks around the estate, lack of flooding, infestation by other plants, stocking, etc... man has changed the Moutua, changed the physical and mechanical structures of the soils, changed the levels, changed the natural water table, in one syllable, changed the environment".

man has changed the Moutua, changed the physical and mechanical structures of the soils, changed the levels, changed the natural water table; changed the environment

In 1976, B J Fergus (NZFP) noted that "the vigour of the plant, and its resistance to yellow-leaf disease, a root disease, depends to a marked extent on the vigour of root growth". Related to this, Easterfield (1918) noted: "it is evident that phormium with its rapid growth must remove very large quantities of potash from the soil... it is remarkable that a plant drawing such large stores of potash can continue to thrive without the use of fertilisers, and it is obvious that lack of plant food may be at any rate a contributing, if not the main, cause of the flax disease in the Tane and surrounding flax swamps. A liberal supply of phosphoric acid is known to greatly stimulate root growth in many plants, and thus to cause a vigorous growth of leaves". The work by Grant Douglas, AgResearch, confirms the high rates of accumulation of potassium in NZ Flax.

While yellow-leaf is perhaps the most serious disease, other insect pests can also compromise fibre production in plantations (particularly those protected from flooding). In 1922, Atkinson cautioned that: "it must be remembered that phormium growing under virgin conditions shows its greatest luxuriance in rich, well-drained alluvial flats (such as the mouths of rivers) and that its presence in a more or less stagnant swamp does not imply that the conditions most favourable to its full development are fulfilled there... great as are the advantages gained by the draining of the swamps, so decided an alteration in the natural conditions has introduced several highly undesirable factors, the most important of which has been the enormous increase of certain insect enemies of phormium, which previously were negligible". Further to this, Scheele (1997) notes that: "dryland cultivation of harakeke leads to more vigorous plants, of generally superior leaf and fibre quality. But without the benefit of flood-

phormium growing under virgin conditions shows its greatest luxuriance in rich, well-drained alluvial flats

ing, bushes are more vulnerable to insect damage... the most essential measure of control is to keep harakeke bushes trimmed of dead foliage, especially rolled leaf tubes... which provide a perfect home for the 'windower' and 'notcher' caterpillars... and to keep the surrounding area free of dead leaf material or other debris". The growing trials reported in *He Korari Korero* (2004) confirmed that: "brown spot, circular black mould and scale insects were widespread among plants, but much less so on plants that had been correctly harvested and pruned. Scale and moulds are encouraged by shady conditions, and moist and humid weather".

***insect control
in the past didn't
just depend on
floods, but also
on birds***

There is an obvious link here to harvest regimes, and indeed Craw (1926) wrote: "with side-leaf cutting, taking the outside leaves, cutting can be carried out all the year round without doing the slightest injury to the plant... one has only to study nature a little to know that if rubbish and half-dead leaves are cleaned away from any plant to give more daylight and air space, the better the plant will thrive".

The Landcare Research publication *Insect pests and diseases of harakeke* describes and illustrates insects and fungi that damage harakeke, along with natural control methods, and insecticides. Re insecticides, the chemical armoury employed in the past may be less appropriate in the future. For example, in days gone by, Neiderer's plantation in Southland (more low-lying than the Johnston's hill plantation, and more problems with insect damage) sprayed with DDT to control damage from the looper caterpillar and army worm (NZFP, 1980). Plantations of the future are more likely to employ principles of "integrated pest management", with the great advantage of being able to design systems from the outset (rather than retro-fitting existing systems): specific work developing 'IPM' guidelines would be of value (integrating ecology, site selection and crop management parameters). Ideally – and especially if harakeke is positioned in the natural products marketplace – production would be organic. A further point to note in this context is that insect control in the past didn't just depend on floods, but also on birds (and as noted earlier, many indigenous birds, and especially the ground dwelling birds, have been lost). Ted Pratt and others remember large flocks of tui in the plantations; other plantations have been reported as harbouring healthy populations of quail and wild bantams (future efforts to perhaps bring back weka, or other indigenous birds, would require a concomitant commitment to predator control).

An important factor in IPM is selection for disease resistance. *P. cookianum* is recognised as being more disease resistant than *p. tenax* (Boyce, 1953; and Maurice Murray, personal observation). Critchfield (1951) noted that "mountain flax... is of little commercial value at present. However qualities of disease resistance and softness of fibre in some varieties have been useful for crossing with *tenax*". Developing disease resistant strains was in fact a major focus for several decades (initially at the Massey Agricultural College, subsequently by DSIR), with new cultivars (eg. Seiferts Special) selected in part for this attribute.

YIELD AND FERTILISER

***plantation flax
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The calculation of optimal, or even average, flax yields from historical data is greatly confounded by the use of non-stated assumptions, non-comparable data, and the varying influences of varieties, climate, soils and harvest regimes. The range can be considerable: "from natural, uncultivated stands, output varies from 10-15 tons/acre... the Moutua experiments, which have been in train since 1940, have demonstrated that with proper cultivation, plantation flax can be expected to harvest at between 35-40 tons/acre, provided selected lines are used. Some lines have yielded up to 60 tons" (NZWP&T, 1951). In 1950, Boyce confirmed that "a well-established plantation yields 30-40 tons of leaf per acre". Moss (1955) suggested that "obviously there is no easy way round the question of maintaining and increasing yields of leaf... yields per acre in NZ vary between 30 and 40 tons, and in some

cases up to 50 tons. Most of the really out of the ordinary yields (eg. 60-70 tons) of which I have heard are exceptional. In some cases these have been from plants in the advanced nursery stage where they are in close spacing (one foot between plants and four feet between rows) on cultivated ground."

In 1976, Fergus (NZFP) undertook a comprehensive literature survey describing the influence of varieties, climate, soils and other factors (including soil preparation, planting densities, frequency/style of cutting, diseases and pests, weed control, and incorporating data from overseas plantations), noting that "part of the confusion over yields is undoubtedly due to a variety difference, but the relative proportions of blade and butt will also have an important bearing"; and concluding that "the best varieties of *phormium tenax*, grown under good dry-land growing conditions in NZ, could yield up to 75-90 tons of green leaf/ha/year, using a cutting cycle of 18-22 months". Subsequently, NZFP embarked on a series of growing trials. In 1981 they noted: "as in previous years, soil condition is again recorded as the major factor affecting flax yield. It is obvious from this year's measurements that Northland features as the best site so far, with the colder, pumice region of the lower Waikato being in the 'poor to average' site class"; and in 1990 concluded that "while we are in possession of historical information regarding the expected yield from flax plantations, it has become obvious that these are very dependent on soil type and ground preparation". Experience on the Neiderer plantation in Southland (where new areas needed 7-8 years until initial harvest, ie. significantly slower than North Island plantations) confirms the influence of soils: harvesting could be done every 4-5 years on silt, but only every 6 years on peat soils. It also became obvious that variety had an important bearing: "at Kaipaki, variety 'SS' at 37.3kg/bush yields more than twice that of 'swamp' variety at 15.7kg/bush". Recent work led by Landcare Research (Harris et al, 2005) confirms "marked differences of leaf length growth between sites and between varieties, and these effects inter-acted" and "the rate of new shoot formation differed significantly between sites and varieties".

soil condition is again recorded as the major factor affecting flax yield

In 1989 Rud Boyce advised extreme caution in projections for growth rates and fibre yield at the viability stage; and suggested figures of half-a-ton of fibre per acre per year.

good fibre yield (after processing) per ha is a more important figure than the tons/biomass/ha

Peter Carter was closely involved with the NZFP growing trials, and similarly counsels keeping expectations of yield on planet earth. Roger Newman has suggested working on a conservative value of 25 tons leaves/ha/pa, and conservative fibre yield at 10%, ie. 2.5 tons dry fibre/ha/pa. In relation to fibre crops, Kessler et al highlight this last point: "It is important to emphasise that the good fibre yield (after processing) per ha is a more important figure than the tons/biomass/ha". And further to this again: there is a strong relationship between fine fibre and low yield (ie. while yield is clearly an important parameter, it is not the only, or even the driving factor, in varietal selection).

After selection of varieties and sites for optimal fibre production, a more important matter may be maintaining yields under an ongoing harvest regime. *He Korero Korari* (2004) notes that "NZ native plants, in general, have lower soil nutrient requirements than introduced pasture and crop plants. This is because they are adapted to low soil fertility conditions and are mostly slower growing". Having said that: "no crop can be farmed successfully on a falling fertility, and even on the best soils the fertility must be maintained if consistently good results are to be expected" (Taylor, 1937). "After each cutting, the soil should be fertilised with some suitable manure" (Seifert, 1921).

native plants, in general, have lower soil nutrient requirements than introduced pasture and crop plants

Without replenishment of soil nutrients, crop yields suffer: "We never put anything back... mostly just the silt feeding it... the flax kept growing, but it was shorter, smaller" (Ted Pratt, 2004). "Concern is felt about planted stands, as they show a marked decline in yield after the third cut" (*Foxton Herald*, 1957). "The flax at Moutua is first cut 5 years after planting. Then every 4 years... the first cut produces 20 tons/acre; the second and third 30-45 tons/acre.

It is then reviewed, and if production is below an economic cut, the area is reworked and planted" (NZ Truth, 1962).

the refuse has considerable manurial value... compares favourably with stable manure

Clearly one option – consistent with traditional practice of returning discarded leaf material to the plant – is to return the green 'strippings' (the by-product of fibre processing) back to the crop. In 1918, Easterfield suggested: "the most obvious and simple method of utilising the strippings would be to return them direct to the ground, as manure for the growing flax. They would supply humus, nitrogen, phosphoric acid, and above all, potash". And again: "Experiments at three state farms have proved the refuse has considerable manurial value... compares favourably with stable manure, and possesses the very great advantage of being practically free from weed seeds" (Holt, 1929); "All green bark from the mill is put back on recently cut plants – which seems to "freshen up" the appearance of them" (Moss, 1955). A critical factor here is the location of the stripping facility (and 'green strippings' are discussed further later in this report).

high phormium yields are attainable on fertile soil, particularly a humus-rich soil, with a naturally high P content

A significant body of work has been undertaken, both here and overseas, into the effect of mineral fertilisers. As previously noted, flax accumulates significant quantities of potassium, variable quantities of nitrogen, and low levels of phosphorous. Manurial trials indicate strong growth response to phosphate applications; and variable responses to nitrogen and potassium. *He Korero Korari* (2004) reported on manurial experiments (by Rigg and Watson, 1945) on acid, pakihi soils near Westport: "with no fertiliser, 4000 pounds green weight of flax was obtained from an acre, applying phosphate gave 91,000 pounds, and a complete NPK fertiliser gave 118,000 pounds". Moss (1955) wrote: "when there is a soil deficiency of phosphate and/or potash, there is a definite response to such fertilisers... potassic manures, when used in conjunction with phosphate, give a definite increase in growth over phosphate alone". In the Neiderer plantation in Southland, fertilizer was applied after harvesting (potassic superphosphate at 500kg/ha), and this reduced the time to next harvest from 5 to 4 years (NZFP, 1980). In Russia, work by Nadareishvili et al (1977) indicated the optimal rate of N was 350-400kg/ha; increasing leaf yield by 52-64%. In sandy soils in Brazil, De Paiva Castro et al (1968) applied N at levels of 0, 50 or 100kg/ha; P at 0, 75 or 100 kg/ha; and K at 0, 60 or 120kg/ha: after 4 years, N and K were reported as having little or no effect on growth or fibre yield; P raised output 100% and fibre yield 120%. Fergus, in summarising manurial work from NZ, South Africa and South America, proposed that: "from these four studies it is possible to conclude that high phormium yields are attainable on fertile soil, particularly a humus-rich soil, with a naturally high P content. Low fertility soils can be augmented with fertilisers".

A third option is to consider recycling nutrient-rich wastewater to growing crops. Wang et al (2004) note that "NZ dairy and pig farms generate significant amounts of effluents that contain high concentrations of nutrients such as nitrogen, potassium and phosphorous... land application is a preferred option for farm effluent management". Having said that, research on the application of dairy wastewater to pasture (Houlbrooke et al, 2004) has found that "between 2 and 20% of the nitrogen and phosphorous applied is leached through the soil profile"; and regulations are now being imposed to limit the application of farm wastewater to pasture. At face value, there may be a fit here: as noted earlier, a number of dairy farms are undertaking large-scale plantings of flax in shelterbelts, flax is deeper-rooting than pasture grasses, and growth is particularly responsive to phosphorous. Specific field work – to test the proposition that dairy (or pig) farming wastewater could be usefully recycled to supply ongoing nutrient requirements of flax crops – would be of considerable interest.

GROWING TRIALS

Throughout the industrial era, flax millers around the country conducted growing trials with selected varieties; and from the 1930s, worked closely with researchers on the Moutua Estate. Literature records that in 1934, Yeates sent 15,000 two-year-old hybrid seedlings to flax-millers

“who will allow us later to select the best bushes from the mature flax”. In 1938, the Plant Research Bureau of DSIR (PRB Circular 133) recommended: “an intimate knowledge should be acquired of the growth, fibre qualities, habitat requirements, disease resistance, etc, of the selected varieties... the most satisfactory method of obtaining habitat requirements appears to be the distribution of varieties to several localities differing widely in climate and soil conditions”; and further recommended “studies connected with actual plantation establishment and management; such as spacing trials, yield trials, cutting trials, manurial trials, and cultivation experiments... particular attention should be paid to cultivation experiments from the aspect of reducing the cost”.

In the late 1970s, NZFP embarked on a project to assess the viability of producing specialty pulp and paper from NZ Flax. A series of growth assessment plots were set up (12 sites in Northland, central North Island and Southland; each site 0.5-2ha) comparing the performance through time of ‘SS’ and local swamp flax, and yielding data on various soils, conditions and cultivars. Trial results generally confirmed improved growth under favourable soil and climate conditions: “as in past years, soil condition and fertility is again recorded as the major factor affecting flax yield”; “as demonstrated at Pouakani South (flax planted in shallow cultivated pure pumice soil in a frost basin) and observed at other locations, flax growth appears to be better than average if the plants are ‘sheltered’ from winds and frost”; “where plants are exposed to cold winds and continual frost conditions, growth is severely checked” (NZFP, 1981).

where conditions are less favourable, varietal selection is confirmed as especially important

From 1994-2002, Landcare Research undertook work to assess the growth response and weaving qualities of selected traditional cultivars: as noted earlier, the study proposed that differences in leaf traits (length, width, thickness, weight) could be linked to improved growth conditions at different sites (Harris et al, 2005).

In sum, there is a considerable body of data available on growing trials with harakeke in NZ: all generally agreeing on the importance of varietal selection, and converging on the requirements for favourable (or less favourable) growing conditions. Where conditions are less favourable, varietal selection is confirmed as especially important (ie. selection of varieties adapted to more limiting or rigorous local environments).

It is worth noting that, by contrast with exotic species (which have to be deliberately introduced to each new area for growing trials), harakeke is already out there. In the event a particular line is identified as being of interest (be it a Moutua selection, or a naturally occurring hybrid form), it is very likely that initial assessment of its growing performance and fibre qualities can be based on existing stands.

HARVEST

A flax bush comprises multiple fans, each a sheath of 8-10 leaves, and each arising at different angles within the bush. New leaves arise from the centre of the fan, and take around 18-22 months to grow to maturity (with most leaf growth during spring and summer) before beginning to decay and die. Harris et al (2005) describe traditional practice: “when gathering leaves for weaving, the traditional practice of Maori weavers was to cut off and discard dead, dying and damaged leaves, and avoid cutting the three youngest leaves on fans... the two parent leaves are seen as protecting the ‘baby’ from harm, particularly cold... from the remaining leaves they selectively harvested those that provided the best material for the articles they wove”. Contrast this with the ‘clear-fell’ regime of the industrial era: “leaf is millable for about 8 months after maturity and then begins to perish... the flax which arrives at the mill is a mixture of mature, immature and semi-decayed leaves, of varying quality and length... with four years between cuts, a considerable quantity of outer leaves must perish.

traditional practice was to cut off and discard dead, dying and damaged leaves, and avoid cutting the three youngest leaves on fans

Reliable estimates place the waste during a period of years as at least equal to the leaf taken for milling purposes" (Holt, 1929).

There would immediately seem to be compelling arguments in favour of selective annual harvest, on the counts of both quality and yield. George Smerle (a Latvian botanist employed by the NZ Flaxmillers Association) believed "the full cut method of harvesting was harmful to the plant, and urged the adoption of side-leaf cutting... removing only the outside leaves and leaving the three centre ones, thus making annual harvest possible" (PNCC Archives). In the 1920s, many millers trialled side-leaf cutting, but subsequently discarded the practice: "in NZ, side-cutting has been found to be unsatisfactory as it affects the succeeding yields... after a 'full cut' new shoots appear, whereas after the side-cut new growth tends to be confined to the old stock" (Moss, 1955). Smerle challenged their reasons: "The owners admit that they have more than doubled their output by sideleaf cutting. But they are going back to the hook cutting because of the decreasing yields... it is an erroneous impression that the method of cutting has caused this decrease. By removing such a large yield in so short a time, a corresponding amount of plant food has been removed from the soil, and probably the trouble is caused by insufficient food supply... to anyone acquainted with the plants physiology, the benefits of sideleaf cutting are manifest" (Smerle, 1926). In 1923, Smerle went to the trouble of counting the dead leaves on four- and five-year-old blocks previously cut level, close to the ground: "for every 100 tons of good leaf recovered, there was about 120 tons lost in dead leaves". Clearly, in light of work done on nutrient accumulation in flax, the significant quantities of leaf lost to production under the four-year/full-cut regime, did serve a purpose in replenishing nutrient supplies (supplies that would need to be topped up under any more regular harvest regime).

there seem to be compelling arguments in favour of selective annual harvest, on the counts of both quality and yield

A third way of cutting was the 'A' cut, "cutting all the leaves with the exception of the centre sucker, which enabled the plant to be harvested every 2 years" (PNCC Archives). Ted Pratt recalls using the 'A' cut when he started in the industry: "we left the sucker, and it regrew quicker... but then there wasn't enough flax and the pressure was on to take the lot". In 1976, Fergus reviewed literature on all three cutting regimes, including work from South Africa (which determined highest yields from selective cutting annually), and work from Brazil (which similarly concluded that the side cut, with first harvest at three years and subsequent harvest annually, gave close to maximum yield).

no cutting should take place from the time of the first appearance of the flowering stalk until its death

The timing of harvest has been a much-debated question. In 1922, Atkinson wrote: "The Maoris had certain definite ideas in regard to the cutting of the leaves, the one most universally held being that no cutting should take place from the time of the first appearance of the flowering stalk until its death. In support of this they maintained that during this period, the fibre is brittle and red in colour... it has been observed that in certain seasons which have been notable for extremely prolific flowering, the fibre has been more difficult to extract than usual, owing to its being somewhat woody in character, the reason for this apparently lying in the removal of the sap from the leaves to the rapidly growing flower stalks". It may be of interest in this context that Kirby (1963) notes that pectin, which binds fibre cells together (in harakeke and other fibre plants) while soluble in water in young plants, becomes insoluble in flowering plants.

More recently, Harris et al (2005) reiterated: "weavers prefer to harvest leaves in summer (after pod set), autumn and early winter, when the leaves are regarded as easier to work and muka is more easily extracted... harvesting was done in dry weather, as moist conditions impair the extraction of fibre". It is interesting in this context to note that work assessing linear densities at IRL (reported at the Harakeke Hui, 2004) found that: "for most forms, our results indicate that muka harvested during spring has a lower linear density and is therefore finer than the muka harvested during autumn". Researchers speculated that "whilst this project was driven by a desire to characterise those forms that produced fine muka, Maori may have been more

interested in those forms that produced coarser and hardier muka, for use in harder wearing clothing for example". It is the fine fibres that are likely to be of most interest in future applications; and further work on linear densities and implications for timing of harvest would be of value.

While the merits of spring or autumn harvest may still be open to debate, there is general agreement about not harvesting in the middle of winter. Yeates (1947): "cutting may be done at any time of the year except in mid-winter in very frosty districts. Hard frosts on the tender young growth after cutting can give a severe check to the plants"; Matheson (PNCC Archives): "during winter the growth of the flax plants was severely restricted, and no cutting was done during May and June. If the plant had been fully cut, frost usually burst the root, or retarded the growth"; Craw (1926): "when the whole of the flax is cut off level with the crown in April and May, the crown is then left during the winter months while there is no growth and the sap in the plant is down; this allows the water to get in to the heart and the frost on top of that either kills the plant, or sickens it to such an extent that it has no chance of recovery. Whereas flax cut in September and October does not suffer in this way to anything like the same extent, as the sap is rising, which forces the heart to come away quickly". Having said that, economic exigencies often prevailed: as Ted Pratt recalled: "originally we were only harvesting 4-5 months... then the pressure came on, and we started harvesting second-grade flax, and cutting through winter... it was hard on the flax, the frosts, hard to start to grow again". Labour supply was a factor: in the Wairarapa, "Ben Couch's shearing gang did most of the cutting for us" (ie. outside the shearing season); and in Southland – with competition from the freezing works and other employers – on some plantations, harvesting carried on all year round to maintain employment for staff. A point worth noting – in relation to the realities of seasonal labour – is that the harvest window for flax is wide (much wider than for many other crops). And it may perhaps be easier to engage labour for harvest in spring, than in autumn (when many other crops are ripening and labour is at a premium).

hard frosts on the tender young growth after cutting can give a severe check to the plants

the harvest window for flax is wide, much wider than for many other crops

Literature from the early years of the industry emphasise the arduous working conditions, and heavy manual work of the flax cutters (knee deep in swamps, wet in winter, baking hot in summer): top cutters were one-ton-a-day men. Work on the plantations was a different ballgame: "One day, the other week, the 20 cutters banged out 72 tons. And boy, that's really cutting" (NZ Truth, 1962). Peter Reihana confirms that he could cut four ton a day in the plantations on the Moutua. The tool was a sickle (or in the South Island, a slightly different styled knife): keeping a sharp cutting edge was critical. The heaviest part of the job was shouldering bundles of flax, and carrying them to the pick-up point. Gordon Burr suggests that future plantations could be designed to minimise cartage and double-handling, eg. harvesting directly into a trailer, with 4WD pick-up.

Mechanised harvesting of flax was trialled in the latter stages of the industry. Peter Huff recalls a machine after the style of a hedge-clipper, with big arms encircling the bush, and was there for the prototype run: "it made a hell of a mess". It may be that mechanised cutting could still be developed for a 'full-cut' regime: it stretches the imagination to consider how mechanised cutting could work under a selective harvest regime. A further factor to consider here is the weight of machinery on the land (compacting the soil and roots); and of course, trading off labour costs against capital.

A final point re harvesting is cutting height. Early on, the full-cut was taken as close to the ground as possible. Not only was this damaging to the plant, but "a substantial proportion of the weight of the flax leaf is in the butt region of low fibre yield... not only was this leaf difficult to process, it also contributed to lower than expected yield results" (NZFP, 1982). In latter years, Peter Huff and other cutters describe taking higher cuts (18 inches above the ground): discussion re the different fibre qualities of different parts of the leaf will be picked up again in relation to processing.

FUTURE PLANTATIONS

The single, strongest imperative arising from the preceding discussion is that “flax owners should see that the flax is cut in such a manner as to leave the heart of the flax fans uninjured” (NZ Official Yearbook, 1892). Briefly recapping other points made in terms of shaping future plantations, with a focus on the factors influencing fine-fibre production:

- Site selection: light, rich, free-draining soils (alluvial floodplains, rolling hills)
- Varietal selection: fine-fibre *p. cookianum*/*p. tenax* hybrid selections
- Propagation: seedling stock (if sufficiently uniform), or tissue culture
- Planting: mechanised planting
- Establishment: strip tillage, spacings 2m x 2m approx
- Maintenance: inter-row mowing, or grazing with sheep
- Health and Disease: integrated pest management (ideally organic)
- Yield: assume 25 tons green leaves/ha/pa, 2.5 tons dry fibre/ha/pa.
- Fertiliser: regular replenishment of nutrients
- Harvest: selective annual harvest of mature leaves, in spring or autumn.

Ideally, plantations of the future will synthesise ecology, traditional agronomy, industrial agronomy and current integrated crop management principles; and the development of formal ‘sustainable cropping’ guidelines would be of great value. A number of agencies have expertise in this arena (Lincoln, Hortresearch, AgResearch, Crop & Food, Scion/Ensis). It is worth noting that both Crop & Food and Scion are already partners in the Biopolymer Network (along with Canesis, perhaps shortly to be linked with AgResearch).

the development of formal ‘sustainable cropping’ guidelines would be of great value

And – picking up on several themes briefly introduced above – we have the opportunity to consider whether harakeke is managed as a ‘monoculture’, or as part of a more diverse, multi-use ‘mosaic’. Deliberately engaging the ecologists, the ‘strategic landscape’ people (eg. Mike Dodd/AgResearch, David Bergin/Ensis, Colin Meurk/Landcare Research, Simon Swaffield/Lincoln, Doug Clover/PCE) to work alongside the farmers and the cropping specialists. Mapping landscape patterns and flows first; paddocks and plantations second.

we have the opportunity to consider whether harakeke is managed as a ‘monoculture’, or as part of a more diverse, multi-use ‘mosaic’

In 2002, the Parliamentary Commissioner for the Environment recommended: “management of native plants on working lands in NZ must be based on the principles of ecologically sustainable management”. Swaffield et al (2003) note: “sustainability is a contested term, but in most formulations includes a commitment to the distinctiveness and resilience of local communities, ecosystems and biodiversity... emphasising the need for rich, local connections between community, economy and ecosystems”. The authors contrast this approach with NZ plantation forestry: “NZ plantation forests are characterised by homogenous and exotic land cover. The commercial estate is dominated by *pinus radiata*, which is selectively bred and cloned, resulting in low genetic diversity. Commercial imperatives in forest management are expressed in short rotation, clear fell regimes, in which the forest is cropped to ground level every 25-30 years. Economically and ecologically, there is much in common between NZ plantation forestry, and intensive agricultural cropping regimes. Each stand is closely integrated with overseas markets and investors... and increasingly disconnected from local communities and ecology”. The alternate vision (articulated by Meurk and Swaffield, 2000) is: “a matrix of indigenous species in reserves, along riparian systems, within functional elements of shelter, drainage, boundaries and road verges; second, intensively managed, exotic production systems within this matrix; third, indigenous species, managed for productive purposes... further development of this vision into practical strategies will require a more

integrated approach than has been evident to date... current funding is largely focussed upon the functional needs of different economic sectors, rather than upon multiple objective opportunities across sectors”.

It is in areas where landowners in certain economic sectors are at the sharp end of imposed regulatory changes, that there may be most scope to consider new approaches. Notably the Taupo and Rotorua lakes catchments. Around Taupo, achieving the 20% nutrient reduction target, will require farmland to be reduced by around 13,000ha. Around Rotorua, ‘Rule 11’ has been signed off, setting limits on the amount of N and P leaving rural properties in the five most vulnerable lake catchments. Landcorp is reported as having decided to pull out of farming on its Taupo catchment farms; others cannot easily cash up: “there are a lot of Maori blocks down here and they cannot sell even if some wanted to because of the joint ownership. What’s more, much of this land is of huge ancestral value to them, so why should they sell up and go?” (*Farmers Weekly*, 2005). An \$80m public fund has been set aside to buy up land for conversion into less nitrogen intensive activities such as forestry: “Philips did not believe retiring land for forestry was necessarily a sound option... do we really want any more pines?”.

The hunt is on for alternate, low-nutrient farming systems, to protect the lakes, while maintaining returns for landowners (preferably including the current generation). Clearly new farming systems are likely to involve more plants, less animals. Ideally, native plants (managed for commercial return) will be part of the mix (alongside willows for biofuels, blueberries, ginseng or other exotic crops). The suite of options is perhaps wider in the Rotorua catchment; considerably narrower in the (cold and frosty) Taupo catchment. New collaborative agencies have been set up to explore new approaches: “the only way we can protect Lake Taupo is through a ‘partnership of innovation’. It requires not only finding new ways of doing things, but also finding new things to do... there is no single answer” (Environment Waikato, *Protecting Lake Taupo*).

In 2006, the Parliamentary Commissioner for the Environment proposed: “It may be appropriate in the future for the PCE to explore what integrated catchment management, redesign for farming or other alternative approaches might encompass in the context of a ‘real’ situation, drawing on the PCEs 2004 report *Growing for Good*” (PCE, 2006 *Restoring the Rotorua Lakes*). And drawing on the PCEs 2001 report, wherein he notes: “ongoing pressure on landowners to improve the ecological sustainability of landuses, but limited potential to do so in ways that could directly contribute to farm income... for a biotically based economy it seems somewhat ironic that we are investing so little in researching the qualities and attributes of our natural capital while we invest tens of millions in dollars in some exotic species (eg. *pinus radiata*) and millions on a quest for new species via genetic engineering!”; and the PCEs 2002 report, noting again that while working lands are a major source of economic wealth to NZ, “at present, this wealth creation relies heavily on exotic plant and animal species, (and) the focus of current research is towards the commercial utilisation of exotic species... there is limited research being undertaken on the sustainable use of native plants, the productive capacity of native plant ecosystems, and the role that they can play in increasing the sustainability and diversity of landuse choices on our working lands”. He called for creative thinking about the place of native plants as productive resources; and recommended greater investment in exploring the economic potentials and capabilities of native plants in NZ.

While harakeke could potentially be grown as a plantation crop in all regions of NZ, there is considerable merit in developing initial capacity and critical mass in a selected area (be it Rotorua and/or Taupo – recognising that varietal selection for Taupo would require particular attention to frost resistance). In 1980, NZFP undertook a land suitability/availability survey: “there are small patches of swamp flax in Wellington, Lake Wairarapa area, Foxton, Tongariro

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National Park, and Northland, with the largest existing resource believed to be 1000 acres in Westland... because the existing resource is small and scattered all over the country, it will be totally uneconomic to transport and process on a commercial scale". The approach taken by Taupo Development Company with willows for biofuel offers a useful model: growing trials have been underway for some time, varieties have been selected, calculations have been made of yields and potential returns, and it is now being proposed that farmers would fund the planting and management of the crop, ideally with a collective crop of 2500-3000 ha within 20-50 km of a bio-refinery (NZ *Farmers Weekly*, 2006). A variation on this theme is the concept for truffles developed by Graham Smellie of Crop & Food: "large truffieries, from 1000-1500 trees, are currently being developed to expand NZs commercial truffle industry... the aim is to give more critical mass and surety of production to the fledgling industry through the establishment of joint ventures (between landowners, and Crop and Food scientists)... the initiative is being led by Truffle Investment NZ Ltd, a wholly owned subsidiary of Crop and Food... TRINZ seeks 10 investors with 3-5 ha of land, we will supply the truffle infected trees, and give science and technology support" (*Crop & Food Digest*, 2005). If the crop comes in, TRINZ/landowners share the proceeds; if the crop doesn't, the landowners keep the trees.

investment by industry in new product facilities will only take place if supply of raw materials is assured

If all goes well under the truffle scenario, truffles can fetch \$2-4000/kg. Under the willow scenario, calculations have been made that "NI hill country farms average a return after all costs paid of \$180-230/ha... based on modelling the energy farming business... we believe it is realistic to return to a farmer in the range of \$250-290 per hectare per year" (NZ *Farmers Weekly*, 2006). Roseberg (1996) notes that "estimating the crops value or return to the farmer was difficult, and this difficulty increased the further away the crop was from commercialisation". While we have niche markets for flax products, we are still some way away from being able to confidently project returns. Perhaps as a very rough and conservative indication, we could take the current grower price for wool as a guide (around \$3/kg): assuming 2500 kg of fibre/ha/pa, then gross returns could be guesstimated at \$7500/ha (less establishment, maintenance, harvest and primary processing costs).

Jim Watson (Genesis/Biojoule) suggests: "It's hard to see, without another way of using our land and our climate to produce a new set of products with a big growth market, where we are actually going to get growth in the farming sector" (NZ *Farmers Weekly*, 2006). Especially where the lid is on. For flax, the "new set of products with the big growth markets" are still in the pipeline (and discussed further in the next section). The point of fundamental importance is that: "investment by industry in new product facilities will only take place if supply of raw materials is assured" (IENICA, 2000). In 1869, William Finnimore wrote: "enterprise does not consist in waiting until a thing is fully proved, but in venturing where there is a reasonable prospect of success, and such appears to us in the cultivation of flax". Such appears to us also today. It is recommended that a collaboration of interested parties (Lake Taupo Protection Trust and Rotorua Lakes and Land Trust, with the Biopolymer Network, SFF, NZTE, EBoP, the PCE and key individuals who have expertise in the landscape, environmental, farming and commercial values of harakeke) scope a work programme for the selection of varieties, assessment of growth/fibre quality, identification of sites, and establishment of trial plantations in the Rotorua and/or Taupo catchments.

PART B

A new land-based industry

The following sections briefly describe the history of the industry, and discuss processing; before updating on applications development currently underway.

History

For hundreds of years, since human settlement, flax has been esteemed as a fibre plant, and for its medicinal qualities. All parts of the plant have been valued and utilised: root extracts, leaf extracts, gel, nectar, korari, leaves and muka. Harakeke holds a central role in Maori culture; and European settlers were similarly struck by its properties and virtues. In 1770, Cook's journal records: "There is a plant that serves the inhabitants instead of hemp or linen, which excels all that are put to the same purposes in other countries... of the leaves they make their strings, line and cordage, which are so much stronger than anything we make with hemp that they will not bear a comparison. From the same plant, by another preparation, they draw long, slender fibres which shine like silk, and are as white as snow; of these, which are also surprisingly strong, the finest clothes are made... a plant, with such advantages, might be applied to so many useful and important purposes" (Atkinson, 1922)

Hector (1872) records that, as early as 1828, a very considerable trade existed (fifty thousand pounds worth of fibre was sold in Sydney between 1828 and 1832); particularly noteworthy in that all fibre processed and sold up to 1860 was dressed by hand. Hand processing yields high quality fibre, but the work is very laborious. In the 1860s, machine processing was developed. The drum/beater bar mechanism sacrificed quality, but enabled tonnages of flax to be processed, of a grade suitable for hard-wearing cordage and textile applications. The fluctuating fortunes of flax through ensuing years have been well-documented: first ropes, then binder twine, then woolpacks, then floor coverings: "flax seemed to have the potential to develop into a plantation crop, but was highly vulnerable to competing fibres and new technology. Being almost entirely an export product, it was vulnerable to world price fluctuations... and the local processing industry was too weak in capital and research, to challenge cheaper materials produced closer to the mass market" (*Horowhenua County and its people*). A recent video production (Williamson, 2006) clearly locates the boom and bust cycles within an international context of politics, world wars, overseas prices and technological advances.

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Tom Williamson describes flax as NZ's first true processing/manufacturing export industry. Between 1900 and 1920, annual exports of line fibre averaged 20,000 tons/pa, representing an annual harvest of about 200,000 tons of green leaf (Poole and Boyce, 1949). Exports ceased during the 1930s depression; but the domestic market continued, and right through to the 1960s and 70s, stripping mills were still operating in the Manawatu, Wairarapa, West Coast and Southland; with baled fibre sent to Donaghy's (for twine), NZ Woolpack & Textiles (long fibre) for manufacture into woven products (woolpacks, carpets, floor mats, bee mats, cricket pitch matting, press cloths for the freezing works) or to NZ Bonded Felts (the shorter 'tow') for manufacture into non-woven products (underfelt, upholstery, insulation wraps for hot water cylinders) with the 'stripper slips' (the fine tip of the leaf blade) utilised in plasterboard. The

industry was subject to varying levels of government subsidies and intervention, including wage/price controls (with flax millers squeezed between flat prices and rising wages), shortfalls in supply, competition with alternate and synthetic fibres, lack of investment in maintenance and capital upgrades, and old-fashioned labour-intensive methods; until in 1973, the government of the day sold out of NZ Woolpack and Textiles. NZ Bonded Felts continued as a profitable operation, supplied from the Moutua Estate, until the factory was destroyed in a fire in 1985.

The significance of Harakeke/NZ Flax in our history, culture, economy and environment is reflected in a substantial body of literature. Major bibliographies have been compiled by Boyce/DSIR (1949), McLennan (1970), Fergus/NZFP (1976), and the online People/Plants database managed by Landcare Research includes comprehensive references. Major collections of flax-related papers are held by Landcare Research (including MAF/DSIR research reports), Palmerston North City Archives (the Ian Matheson Collection, particularly strong on the industrial history of the mills), Charles Pearce (custodian of the archives of NZ Woolpack & Textiles, and NZ Bonded Felts), and a substantial body of papers have been gathered together as part of this SFF project (held by the project manager). Reports notable for their breadth and detail include Hector 1872 *Phormium tenax* as a fibrous plant, Atkinson 1922 *Phormium tenax: the NZ fibre industry* and the body of papers compiled by NZFP through the 1980s.

Processing

In 1846, the *NZ Spectator* reported: "Two gentlemen... lately returned from England... reported that a manufacturer of the name of Donallan had completely overcome the difficulties which have hitherto stood in the way of the application of the flax to those kinds of fabric... brought specimens 1) exceedingly strong cloth, waterproof, suitable for tarpaulin; 2) sail cloth, superior to navy canvas; 3) a beautiful white cloth, for which Mr Donallan has a very large order for cavalry trousers; 4) a piece of cambric, so exquisitely fine, that it has to be laid upon a piece of paper to render it clearly visible; 5) white sewing thread, of the size usually employed for sewing on buttons... not only has Mr Donallan sent out these specimens of what he can produce, but... he has sent back samples of the raw material in order to shew the conditions in which he requires it... the finest and most highly prized specimen was of well-dressed tihore, just as the maoris prepare it for their finest mats. The second specimen had indeed the epidermis entirely removed, but was not much dressed. The third was much coarser.... Regarding supply, on two points he particularly insists: first that the different qualities shall be kept perfectly distinct. And secondly, which is of greatest importance, that in packing, the fibres shall be kept perfectly straight, not bent or twisted about in an irregular fashion".

the finest and most highly prized specimen was of well-dressed tihore, just as the maoris prepare it for their finest mats

flax varieties span the spectrum from the fineness of linen to the coarseness of sisal

This description immediately defies the 'horse-hair' perception of flax fibre (as used in woolpacks and binder twine). It reflects the careful selection and preparation of hand-dressed muka, which has been subject to varying processes of scraping, beating and soaking, in the manufacture of different articles. A key point to note is that "the different qualities shall be kept perfectly distinct". As noted earlier, flax varieties span the spectrum from the fineness of linen to the coarseness of sisal. And a similar spectrum is mirrored in each leaf, from the coarseness of the butt, through the blade, to the fineness of the tip. Yeates (1935) noted: "At present we are comparing the fibre of different plants without an adequate understanding of the variations found in the fibre of any one plant. It is well-known that leaves of different ages on one bush produce fibres of different qualities... it is also commonly supposed that there is a variation in fibre quality according to the seasons. Finally, different parts of the same leaf produce fibre of very different qualities... the main object of the work would be to acquire a better understanding of the fundamental microscopic and physical characteristics of

phormium leaf and fibre". King and Vincent (1996) reported the mechanical and fracture properties of the leaf are dictated by its high content of stiff, strong fibres, which are orientated parallel along the leaf. Harris et al (2000) noted that "the content, length, strength and extension of fibres differed markedly among the varieties", and that these fibre characteristics also differed according to the part of the leaf blade from which the fibre was extracted. Recent work at Otago University (Cruthers et al, in press) shows differences between six cultivars in terms of microscopic structure, fibre bundle shape, and repeat unit of the fibre bundles. Carr et al (2005) noted: "several microscopy studies of NZ flax have been reported although... the specific cultivar is rarely identified... and there is disagreement as to the length, shape, packing and adhesion of the ultimate fibres... fibre aggregate characterisations necessary for developing and using processing machinery are rarely discussed in the literature".

The superiority of hand-dressed muka – the softness and silkiness – is unquestioned. But hand-dressing is very laborious work (yielding perhaps 1kg/day). And it was the advent of the mechanised stripper (Gordon Burr advises the Sutton stripper could process 2 tons/hour) that enabled NZ Flax fibre to compete over many years in export markets, albeit at the low end of the market (positioned as a commodity fibre, competing with jute, sisal and manila from India, Africa and the Philippines). As a commodity product – and in line with the modus operandi of the times – selective harvesting was abandoned in favour of 'clear-felling' wild stands to feed the mills. Many histories record stories of "under-capitalised, under-powered mills chugging away in the swamps... dubious fibre, variable quality, small margins" (*Horowhenua county and its people*).

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The Government grading inspectors were well aware of the problems. In 1936, the Department of Agriculture reported: "NZ flax is recognised as a reasonably good fibre, and it is generally admitted that most commercial lines contain a percentage of material which, if isolated, would compare favourably with the highest grade fibres produced anywhere in the world... lack of uniformity means that commercial lines contain fibre which exhibits a wide divergence in the basic quality factors of strength, colour, stripping and scutching.... This is due to natural variations in fibre which exists within the single leaf, and to inherent quality variations between leaves and between flax plants. These variations in the natural product are not counteracted or allowed for in the technique of fibre extraction and mill packing... the causes of faulty stripping are: the leaves taper from butt to tip and from keel to edge, some varieties are easier to strip than others, irregularity in tension of the stripper, and the stripper bar is subject to wear, which alters stripper clearance". Gordon Burr confirms that, where mixed varieties are being presented to the stripper, the bar setting will probably be a compromise.

Note this problem is not unique to NZ Flax fibre. In relation to hemp and linen flax, Kessler et al note: "a major aspect in technical and textile applications is the inhomogeneity of the material. All technological and morphological variations as well as the chemical composition shows a broad distribution within the plant, and within the hectare. This leads to difficulties in assessing fibre quality, and successively the raw material cannot be processed optimally. The result is a mixture of over and under processed materials with a lower proportion of best fibre quality". Kessler et al recommend development of multi-step "adaptive processing", ie. where each step is used to balance variation and optimise for target values. Alongside the renaissance of interest in hemp, linen and other plant fibres worldwide (touched on later in applications development), significant R&D is underway internationally into new mechanical/chemical processing treatments for plant fibres, particularly treatments to yield finer fibres.

significant R&D is underway internationally into new mechanical/chemical processing treatments for plant fibres

It is generally recognised that conventional mechanical processing compromises fibre quality. For example, in relation to coir fibre from coconut husks, the FAO report: "the traditional production of fibres from the husks is a laborious and time-consuming process... traditional

the shortcomings of the mechanised stripping process have been recognised for many years

practices of this kind yield the highest quality of (white) fibre for spinning and weaving... alternatively mechanical processing using decorticating equipment can be used... the quality of the fibre is greatly affected by these procedures". And in relation to linen flax: "the presently used fibre processing technologies are optimised for textile production (strength, fineness, refinability) and are far from optimal in respect to other applications. The effects of the mechanical treatments on the performance of the fibre, eg. in biocomposites, may be causing inferior performance. Much damage to the fibre structure is occurring because of the mechanical forces required to separate the different tissues" (Van Dam). Similarly, at an IENICA Natural Fibres Performance Forum, Dr Jamie Hague noted: "For the reinforcement of plastics, plant fibres are competing against synthetic fibres... increasing evidence suggests that success of plant fibres in these applications (or perhaps lack of it) is related to the incidence of damage induced in fibres during processing. It is evident that plant fibres such as linen flax and hemp are very susceptible to damage induced by mechanical processing; this can severely reduce their ability to impart good toughness properties to composites... processing and manufacturing strategies are required which minimise the incidence of damage in fibres".

In NZ, the shortcomings of the mechanised stripping process have been recognised for many years: "it is recognised in the industry that the machine leaves much to be desired, and that the principle employed for stripping probably injures the fibre, and thus reduces its original strength... the stripping weakens the fibre, and unfortunately beats out part of the fibre, as well as the extraneous matter in the leaf. There is still a need for a stripping machine which does not weaken the fibre" (Eggers, 1958); "I do not think we will ever produce a superior article until we get right away from the drum and beater bars. The green blade is stripped merely by subjecting it to a series of blows" (*Manawatu Herald*, 1938). Des Templeton (former President of the NZ Flax Millers Association) is adamant a new approach to stripping flax fibre is required.

Industry old-timers recall that, back in the 1920s, two women in Foxton developed a technique for stripping flax leaves using chemicals (but it seems they may have been stymied by the flax industry hierarchy of the day). More recently, Hortresearch have reportedly experimented with enzymatic treatment (widely used with hemp fibre). A particular issue with chemical/enzyme treatments – against the trend of 'clean tech' – is the waste stream. A more 'natural' mechanical/chemical treatment is the action of cows, whose long, smooth action on the leaf yields fibre which is of similar quality to that of hand-dressing: "cattle are very fond of it, and chew the leaf till the fibre is left hanging from the plant, cleaned of all vegetable tissue, and as bright as if prepared by hand" (Hector, 1872). Kim Pickering has supervised work at the University of Waikato, comparing machine-stripped and cow-stripped fibre, indicating the cows do a good job of removing lignin, and the fibre retains improved mechanical properties.

current machine stripped fibre is not of the fineness required for textile companies to be able to explore new applications

Current applications development underway in NZ is indebted to the good offices of Gordon Burr of the Foxton Flax Stripping Museum; and Des Templeton, who operates the Southland equivalent. Note however, that current machine stripped fibre is not of the fineness required for textile companies to be able to explore new applications. And in biocomposites, to the extent that processing technology influences fibre properties and performance, R&D will be influenced (compromised) to the same degree. Clearly, re-establishing processing capability is critical infrastructure for any revival of the NZ flax industry.

Several initiatives are currently underway. Rangi Te Kanawa is working with IRL to develop a 'steel mussel shell' technique (with a premium on the quality of the muka extracted); Auckland University are working alongside the 'Uku' sustainable housing team to develop a trailer-mounted stripper (modelled on the Foxton machine, but with the mobility to operate in rural areas); other groups (in Taranaki and Christchurch) are reportedly keen to develop

stripping capability in the regions. It is relevant to note here that: “the first essential of a phormium machine is of course the quality of the fibre it produces... next in importance comes the quantity of green leaves passed through in a given time” (Hector, 1872). Any new processing initiatives must consider both quality and quantity: if quality comes first, then output may be restricted to very high end niche markets; if quality is sacrificed, then markets will similarly be restricted. It is also relevant to note that stripping off the green matter is only the first step; that further processing is required for the manufacture of value-added products. And all the old secondary processing opening/carding/spinning machinery is gone (scrapped when NZ Woolpack and Textiles was sold; or lost in the Bonded Felts fire); currently only Canesis have odd pieces of old gilling/spinning equipment for the preparation of flax fibre pre-forms. If value-add opportunities are to be captured within NZ, then attention is also required to secondary processing.

stripping off the green matter is only the first step; further processing is required for the manufacture of value-added products

Traditional hand-preparation requires multiple processing steps. Similarly, industrial manufacture required multiple processing steps. In fact, in 1961 the *Dominion* reported: “the fibre was handled 112 times between harvest and completion... more labour was absorbed than the industry was worth”. Charles Pearce (NZWP&T) and Bill Hoskins (Bonded Felts) agree on the old-fashioned, labour-intensive methods employed: “lots of man-handling, double-handling, nothing innovative”. Clearly – recognising the limitations of both traditional and industrial techniques – we have the opportunity to consider a new approach to primary and secondary processing of NZ Flax fibre (unconstrained by any need to retrofit existing systems).

We can take a wide brief. In 1872, James Hector speculated as to a new class of manufacture: “the fact that phormium fibre can be reduced by a single process to the ‘half-stuff’ of the papermaker, but having the very unusual property of being composed of complete fibre cells, having an equal length of about half an inch, and possessing a pure colour and glossy lustre, may perhaps lead to the introduction of a totally new class of manufacture, by which a material will be obtained with even greater facility than ordinary paper of fine quality, and, at the same time, possessing an even texture, cohesive strength and body... after the proper form is given to the fibre, by taking advantage of its gelatinous condition when wet, there would be no difficulty in drying it with such a material as would prevent the fibres again absorbing water”. Further to this, it is of interest to consider: “if the final shape can be produced during the primary processing step, the secondary manufacturing profits can be realised by the primary composite producer” (IENICA). And, from another arena, consistent with suggestions above about adaptive processing: “I believe we need to start differentiating on farm... concomitant with this, I think we need to miniaturise processing or at least introduce higher levels of flexibility, batch runs and greater sophistication... we need to see more smaller plants producing low volume, high value products” (Andy West, Women in Dairying Conference, 2006). And, in this era of green-tech and clean-tech, *Rural News* (2002) notes: “huge political support throughout Europe to introduce the EU Integrated Product Policy which highlights the importance of eco-design and eco-manufacturing... stressing the importance of starting at the raw wool stage to meet criteria for the EU Eco-Label – clean fibre, clean processing”. Within this wide brief, a concept for ‘a new class of manufacture’ for NZ Flax fibre has been developed at Massey University; and funding is now being sought for formal proof of concept work.

the scale of investments in processing capabilities critically depends on whether products are positioned in commodity, or added-value markets

It is worth noting that the scale of investments in processing capabilities critically depends on whether products are positioned in commodity, or added-value markets. Having said that, it is patently obvious there is no future for flax in re-entering the commodity fibre market. As Paul Blomfield (then CEO of the Apparel and Textile Federation) suggested: “the direction for the industry is clear. There’s no point in trying to compete in the low-price, mass-produced trade – there are too many low-wage countries out there already. If our apparel and textile industry is to succeed and prosper it must offer products perceived to be special – whether

in raw material, innovative design, clever branding, or a combination of all. Products will be at the mid to high end of the quality/price range and will stand out in the crowd" (Venture, 2001).

Ideally, re-establishing processing capability in the regions will be as close to the grower as possible. In former times, the location of mills shared common factors: "ample leaf close to the mill; good supply of clean, running water; clear land nearby for bleaching paddocks; mill site on dry ground, above flood levels; and good transport facilities" (*The Centenary of Shannon*). The return of green strippings to the crop would obviously be facilitated if processing is close to the plantation; and green leaf (70%+ water) is heavy, with obvious implications for minimising transportation costs. It is worth noting that harvested leaves do not need to be immediately presented to the stripper: Atkinson (1922) reports, and Gordon Burr concurs: "leaves feed into the stripper more readily some days after they have been cut".

It is important to note that the quality fibre is in the leaf blade, whereas most of the weight is in the butt. As noted earlier, re the NZFP trials: "butts had high moisture and non-fibre content, and were thicker... and caused considerable problems in the feed unit and transfer systems". Note also that the gel (an alternate product stream) is contained in the butt region, and that 'clean' fibre should be free of gel. Clearly, there are implications here for cutting height; and for alternate processing/disposal pathways for the butt.

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of the weight
is in the butt***

Bleaching is another processing step; the image of paddocks full of flax fibre bleaching in the sun is a familiar one. Hector (1862) noted that: "if a pure, white fibre were required the sun bleaching might be dispensed with, as purity of colour can only be obtained by thoroughly washing out the bitter principle from the plant... the effect of the sun's light is to change the nature of the substance producing a yellow-red tinge... however washing to such an extreme degree is not desirable as it tends to entangle the bundles". Various chemical bleaches were trialled over the years; and Moss (1955) noted experimental work with artificial bleaching, "but I gather that it has been found that artificially dried fibre tends to dry green... thus it would be necessary to perfect the washing process to such a pitch that all green colouring and vegetable matter is removed before drying".

The desired output from processing is clean fibre bundles (ideally finer rather than thicker, ideally in alignment rather than entangled) for moving through into either textile (woven or non-woven) or biocomposite applications (discussed further in the next section). To briefly recap the preceding discussion before moving on:

***the desired output
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than entangled***

- processing critically influences fibre quality and market positioning
- the current gap in processing capability represents an opportunity to develop a new primary processing platform (delivering on both quality and throughput)
- capturing value-add in NZ requires investment in secondary processing
- processing should be sensitive (to minimise damage to fibre structure); and sensitive to variations in feedstock
- attention should be given to compressing multiple processing steps
- the butt should be partitioned from the blade; and
- processing design should proceed from an understanding of the structure and chemistry (packing and adhesion) of the ultimate fibres.

The concept under development at Massey University offers the potential of delivering on a new primary processing platform; and potentially a seamless movement through to secondary processing and finished forms: a collaboration of interested parties is now required to invest in formal proof of concept.

Applications Development

The principal product from flax has historically been the fibre; and it is most likely that it will be the fibre driving new applications in the future. Nevertheless, all parts of the plant have traditionally been valued and utilised; and there is considerable merit in developing secondary products, and utilising by-products, as part of a 'whole plant' management cycle. The following sections briefly describe traditional and industrial applications; indicate international trends; and update on applications development underway with fibre, gel, seed oil and other extractives.

all parts of the plant have traditionally been valued and utilised

FIBRE

The renaissance of interest in plant fibres internationally is signalling a fundamental shift from "the hydrocarbon economy to the carbohydrate economy" (*Biotech Unlimited*, 2004). Petro-chemical derivatives and synthetics are on their way out (nylon, plastic, fibreglass, epoxy resin): plant fibres and bio-based resins are on their way in.

The shift is being driven by both environmental and economic pressures: "The development of synthetic materials has caused the steady replacement of biobased products. As a result of this change in raw material utilisation, combined with an enormous increase in energy and chemical demand, the world is now facing an ecological crisis. This crisis will intensify with the expected growth in demand for industrial products in developed countries. Such predictions have led to a number of political initiatives, including support for enhanced industrial use of renewable resources (eg. biomass) at the expense of non-renewable resources (plastic, glass fibres etc). Plant fibres may therefore face a renaissance, not only for past uses, but also for the manufacture of three-dimensional products" (IENICA, 2000). The volatility of oil is a driving factor: in 2003, MEDs energy outlook assumed oil prices would continue at US\$20 until 2020: "MED have updated those predictions, with a dramatic change to an expected US\$60, with potential highs of US\$120" (Jez Weston, Royal Society, 2006). The growing solid waste problem is another driver; with 'biodegradability' increasingly a favoured attribute in industry and in agriculture. Health is a further factor, eg. "In hot climates, volatile hydrocarbons evaporate from plastics and textiles" (Volvo Cars, 2006). And climate change is a factor, ie. reducing carbon dioxide emissions. The 'natural products' marketplace is growing; science is developing new 'green chemistry' disciplines; industry is looking for 'clean technology'; agriculture is re-focussing on 'renewable crops', 'non-timber forest products' and 'multi-purpose tree species'.

interest in plant fibres internationally is signalling a fundamental shift from the hydrocarbon economy to the carbohydrate economy

A wide range of tropical and temperate fibre crops – yielding wood, stem or leaf fibre, short or long, hard or soft – are being re-assessed for their application into old or new industrial uses. It is of considerable interest to note that NZ Flax occupies a position intermediate between the lower-value 'hard' fibres (eg. sisal, manila) and the higher-value 'soft' fibres (eg. linen flax, hemp). On the one hand: "NZ flax is traditionally positioned as a 'hard' fibre, which may be classed with sisal and abaca in respect to it's uses, and it is the only commercial hard fibre plant which thrives in middle latitude climates" (Critchfield, 1951). On the other hand: "If phormium fibre could be placed on the market equal in softness, silkiness and whiteness to the Maori product it would doubtless enter into competition with some of the soft fibres... but at present it is known commercially only as a hard fibre, its chief rivals being manila and sisal" (Atkinson, 1922).

the 'natural products' marketplace is growing; industry is looking for 'clean technology'; agriculture is re-focussing on 'renewable crops'

We have earlier noted work by IRL, indicating a wide range from finer to coarser fibres (from 12 to 28 tex), with lengths of ultimate fibres ranging from 4.8mm to 8.2mm on 15 samples. Kirby (1963) similarly described a range in the length of ultimate fibres from 2.5-15mm; and a range in micron values from 5-25 microns. Harris et al (2000) reiterate: "a feature of

phormium fibre is the variability of the diameter of its ultimate fibres, which can be finer than those of the soft fibres of linen flax, hemp and jute". Clearly, varietal selection (supported by agronomy and processing) is fundamental to whether NZ Flax fibre is positioned at the low end of the market (with the hard fibres) or at the high end (with the soft fibres).

At the Flax Field Day (West Coast, 2006), Malcom Miao (Canesis/Biopolymer Network) noted that in the industrial era, NZ flax fibre was processed on sisal-type machinery into thick, twine-type yarn; and queried whether this was the way forward. In both textiles and biocomposites, it is the finer fibres which are of most interest. Finer fibres have a much larger total surface area: in textiles, they are able to withstand combing out into 'slivers' (Kirby, 1963); in biocomposites, they present a larger area for adhesion to the matrix. IENICA (2000) describe a spectrum of applications for plant fibres:

- textile products: coarse yarns/ropes/carpets through home textiles/clothing to finest yarns/fashion products (moving from coarse to fine and up the added value spectrum); and
- non-textile products: pulp/plant pots/geotextiles through packaging/car interiors/composites to filters/high tech composites (again moving from coarse to fine and up the added value spectrum).

At face value, it would seem sensible to reposition at the higher/finer end of the market.

As Kessler et al note "the basic dilemma of agricultural production is the low value of their products. Competition in the world on raw materials is mainly on price rather than quality. Thus, production in high wage countries can only be profitable when high added value products are sold". Andy West is critical of the commodity strategy: "In a nutshell, the prevailing dairying recipe is to produce commodities, iron out as much biological variability as possible on farm, farm to a nationwide formula, and ruthlessly focus on costs and efficiencies... this is a mass industrial strategy similar to that of forestry yet executed far better. How much longer can this commodity strategy work I keep asking myself?" (Women in Dairying Conference, 2006). On his recent visit to NZ, Gerald Celente, US Trends Research Institute, warned: "Don't let your quality down... NZ had to aim for the top 25% of the market, which wanted quality and had the money to pay, and not compete with China, India or other poor wage countries" (*Dominion Post*, 2006).

Having said that, it's not necessarily an either/or decision: "as every farmer knows, each breed or grade of wool has its own characteristics and applications" (*Straight Furrow*, 2004), and the same comment equally applies to flax. Poole and Boyce (1949) noted advantages in spanning a breadth of applications: "Phormium occupies an intermediate position in fibre quality between typical hard fibres, and soft fibres... and can cover a range of uses in both groups in both cordage and textile work. Hence, whereas in overseas cordage markets, phormium was at a disadvantage, it has because of its wide range of uses, marked advantages for the local market". Further to this, Nick Tucker, Crop & Food/Biopolymer Network (Flax Field Day, 2006), noted that in relation to market applications, biocomposites may only need to be "tough enough". And Alex Drysdale (Christchurch) has suggested that, in the early stages of getting the industry back up, a 'bread and butter' application (perhaps with wider quality/consistency parameters) would be a useful bridge.

Whichever strategy is selected, the point of critical importance – repeated over and over in international literature, and reiterated by Roger Newman and Debra Carr – is having the fundamental knowledge of the basic properties of selected plants – and selected varieties – with these inherent properties then matched to specific applications.

varietal selection is fundamental to whether flax fibre is positioned at the low end of the market or at the high end

in the early stages of getting the industry back up, a 'bread and butter' application would be a useful bridge

BIOCOMPOSITES

At the Flax Field Day (West Coast, 2006) Nick Tucker described the long industrial heritage of plant fibre reinforcing in clothing, housing and other articles. He charted the economic/technological factors which pushed natural fibres out of contention after WW2; and addressed the current environmental/economic imperatives (eg. end-of-life disposal regulations in Europe; fuel/transportation costs) which are now making it more appropriate for countries to grow their own local materials.

Plant fibres are lighter than glass fibres, and biocomposites were originally developed in the aerospace industry. Over the last decade or more, biocomposites have found broader applications due to their mechanical/physical properties (low weight, high strength and stiffness); in parallel with a strong push from the environmental agenda. In North America, the use of wood/fibre/plastic composites is rapidly growing in applications including house frame profiles, extruded decking and injection moulded parts; in Europe the growth is focussed on automotive parts (Forest Research, 2004).

Within NZ, Forest Research took an early lead in identifying the 'biomaterials future': "Forest Research recognises that the world needs, and is beginning to demand, new high performance materials based on renewable plant resources... the answer is in our own backyard." (FRI, 2002). Ford's Model 'U' points the way forward: corn-based tyre fillers, sunflower seed engine oil, soy-based seat foam, compostable fibre sun-roof!

And, "not content with building machines to harvest soybeans and corn, John Deere now turns the crops into machine parts... "HarvestFoam" made from soybean and corn polymers, is strong yet weighs 25% less than steel... JD50 series Combines contain as much as 2 bushels of soybeans and half a bushel of corn in the rear engine panels, the cab roof, and the front panels on each side of the cab". Closer to home: "a house made entirely of plant materials including flooring, insulation, acoustic padding, roofing and wall claddings. A house that is also warm at no cost, is less expensive to build, costs less to live in, looks good and feels comfortable. A pipe dream? Scion says not. It is the house of the future, and they are developing it now (with shareholding partners from Fletcher Building, NZ Steel, Building Research and Waitakere City Council)".

In 2004, Scion linked together with Crop & Food and Canesis to form the Biopolymer Network, a joint venture company whose goal is to replace fibreglass with plant fibres, petrochemicals with bio-based resins – all derived from domestic, biobased renewable resources. The Biopolymer Network has attracted FRST funding (from 2004) to address the science underpinning wider applications for biobased composite materials (ie. understanding natural fibre properties, both mechanical and chemical; and understanding variability in relation to biocomposite design and performance): research is currently concentrating on the properties/performance of *pinus radiata* (wood fibre) and harakeke (leaf fibre).

At the Hui Harakeke (Rotorua, 2005), and again at the Flax Field Day (West Coast, 2006) Roger Newman (Scion) and Nick Tucker (Crop & Food) presented prototypes of materials constructed from flax fibre pre-forms (made at Canesis) and bound with lignin or epoxy resin (noting that work is underway on a 100% bio-based resin). Nick explained the importance of fibre alignment in biocomposite performance: for the low end of the market, short/random fibres are weaker but more versatile (if you just want a moulded shape); for the high end of the market (where performance under load/stress is important) uni-directional fibre mats are stronger, and can be placed to hold the load. Having developed concept materials, the Biopolymer Network is now talking with industry (textile, plastics and composites companies) about marketing/performance opportunities for biocomposites in their product ranges. Work to date indicates harakeke fibre can compete with glass fibre on performance (with work still required on water resistance and drapeability); Nick Tucker suggested that the issue may be

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less the technology, more the economics (glass fibres cost \$3/kg, and fibre is the cheap component in biocomposites, relative to the resin which is the expensive bit). He emphasised the importance of managing the whole supply chain for these new crops, from farmers to the front-room.

The Hui Harakeke also show-cased the Uku Sustainable Earth-Fibre Housing Project, being led by Auckland University. This is another FRST funded project, creating a new housing solution based on earth, with harakeke fibre reinforcing (less than 1% of the mass, but a large proportion of the volume) to increase the tensile strength. Traditional rammed earth walls are 280mm thick; prototype panels were displayed, now down to a third of that thickness. Prototype buildings have been constructed at Otara, and in the Firth of Thames; with plans to undertake further trials of the technology this year, leading up to construction of a full-scale house late 2006/early 2007.

TEXTILES

As noted above, applications for textiles can be developed along a spectrum from coarse yarns/carpets through home textiles/clothing to finest yarns/fashion products.

To begin at the top: for many years, Rangī Te Kanawa has held the vision of creating a contemporary fashion fabric from harakeke muka. The challenge has been to develop modern methods to achieve the same high quality as traditional hand preparation. As noted earlier, Rangī has been working with IRL to develop a 'steel mussel shell'; and developing processes for softening and carding slivers ready for machine spinning, and weaving. Prototype samples of woven muka fabric have been created, with work continuing; and a key issue for the project is now securing sufficient quantities of harakeke of the quality required.

Harakeke does indeed have a history in apparel (albeit there's been a long gap): "The threads or filaments of this NZ plant are formed by nature with the most exquisite delicacy, and may be so minutely divided, as to be manufactured into the finest materials" (Lord Sydney, 1786); "the thick canvas mat is worn in the field of battle, worn as a coat of mail... before they put them on, they soak them, in order that they may resist the force of the spear more effectually. I recommend you to put the thick mat into water, and you will see an instantaneous effect produced, the canvas will be rendered stiffened and more like a board, which appears to be the peculiar quality of the NZ flax" (Samuel Marsden, 1815); "In West Africa, well over half a century ago, garments made from NZ flax fibre were commended as being of the only known material that would withstand the thorns of the tropical jungle" (Wairarapa Age, 1934); "the army outfitter in Woolwich sent hanks of flax to a factory in Dundee to be made into linen. The shirts lasted well, took colour well... all the NZ officers wore them. The reason the flax shirts were liked so much was, that when you had sweated a great deal the flax shirt did not give you a chill" (Canterbury Flax Association, 1871); "The warm shirts of 50 years ago were said to be NZ Flax, and I've not seen anything like them since for wear" (G. Smerle, 1926).

In NZ today, a number of textile/clothing companies are carving out niche positions based on both performance and branding, across the spectrum from outdoor equipment and apparel to high-end fashion. A number of companies are interested in principle in exploring NZ Flax fibre (branding doesn't come any easier than this): in practice, the current machine stripped fibre samples are too coarse to be of use to them. Developing a new processing platform is a critical precursor to exploring an expanded range of clothing and textile applications.

Within this sector, a general trend is towards lightweight, finer, softer clothing; another is development of blended fibres. NZ Flax fibre has been explored in a number of blends: with linen flax, "notwithstanding the contrary opinions that have been expressed, the fibre can be

the challenge has been to develop modern methods to achieve the same high quality as traditional hand preparation

developing a new processing platform is a critical precursor to exploring an expanded range of clothing and textile applications

prepared so as to mix advantageously with linum flax in the manufacture of textile fabrics" (Hector, 1872); with possum (George Sanford created a prototype flax/possum fabric several years ago); with wool (small-scale experiments indicate flax fibre cards relatively easily onto a wool web); with synthetics ("Brusella" carpet blended phormium fibre with 15% rayon); and in the 1970s/80s South Africa (SAWTRI) mixed NZ Flax and jute in woven sacks, trialled blending and spinning with cotton, and experimented with blending flax fibre with polypropylene in curtain fabric.

Kirby (1963) described phormium fibre as "lustrous, soft and flexible". Charles Pearce (NZWP&T) and Bill Hoskins (Bonded Felts) recall the "strength, durability and versatility" of flax fibre, particularly as it was applied in textiles and furnishings. NZ Flax mats and woven carpets were renowned for their hardwearing qualities (and Charles Pearce notes that flax is not attacked by moth, as wool is). Gordon Burr recalls that it was "the advent of the tufted carpet, which proved to be so cheap compared to the woven one, that pushed our floor coverings off the market" (and, at the time, synthetics were also making heavy inroads). It is worth noting that carpets may be coming full circle, with carpet manufacturers looking again to natural fibres to replace nylons (eg. experimenting with biodegradable corn/jute backings).

flax mats and woven carpets were renowned for their hardwearing qualities

Non-woven textiles have wide and growing applications: in 2003, WRONZ noted "non-wovens is the fastest growing area of textile production", particularly in industrial fabrics and principally due to the cost savings accruing from fewer processing steps; coupled with converging fabric/paper technologies, eg. non-woven technical textiles. NZ Flax has a long history in non-woven forms: right through to 1985, NZ Bonded Felts were producing seat padding, upholstery/mattress stuffing, gymnastics mats, insulation and underfelt. Bill Hoskins recalls they developed a machine which was able to create fine fibre (finer than the carding machine at NZWP&T); and a machine with an oscillating conveyor, able to layer 15-20 very fine webs; and describes experimenting with flax/wool blends. Today, the main application for non-woven flax fibre pre-forms is into biocomposite development (ie. bound with resin rather than needle-punching etc).

In insulation, Lindsay Newton (New Wool Products) emphasises the fibre must be fine; the finer the better for acoustic or thermal insulation performance. In this context, it is worth noting (P. Rooney, 2004): "I have been a builder for 25 years... the one job that no-one but no-one is willing to do is install the glass batts, they get in your eyes, nose, skin, clothing, you feel like you are contaminated with the glass by the time the job is finished... I am sure that if a product made from flax could be developed, and it was as near as to the price of glass batts, it would be readily accepted by the building industry".

I would like to see our fashion designers getting alongside our textile graduates, providing new fabrics, so we can come up with garments that are uniquely New Zealand

In these lower-end applications, the cost of fibre (relative to wool, fibre-glass or imported coir etc) is a primary consideration. In higher-end applications, Malcolm Miao (Canesis) notes that branding – the prestige/rarity factor – comes into play (as with Escorial/Saxon, Stansborough/Gotland etc). Related to this, Niki Gribble (Massey BDes, 2001) proposed: "I would like to see our fashion designers getting alongside our textile graduates, providing new fabrics, so we can come up with garments that are uniquely New Zealand. If we want to make a statement on the world stage about who we are, why would we do it with imported cloth?".

Alongside price and prestige comes performance: at the Flax Field Day, Malcolm Miao (Canesis) described attributes important in industrial textiles (weight, mechanical properties) and home textiles (softness, breatheability, durability); and emphasised the importance of functional properties relative to end use performance. In this context, it is of interest to note the approach being taken with merino: "instead of producing garments that look or feel nice and selling them for a range of uses, we want to understand consumer and participant requirements within a particular sector and have a range of test methods that allow us to

construct a fabric specifically to suit... to develop fabrics from NZ merino wool for specific, high performance sporting activities... University of Otago, the NZ Merino Company and Designer Textiles International are joint research partners in the project which is supported by Technology NZ" (*Technology Reports*, 2004). Alongside work by the Biopolymer Network characterising the properties/performance of flax fibre for biocomposites and developing concept materials, it would be of considerable interest – ideally working alongside new processing initiatives – to undertake work formally characterising the properties and performance of NZ Flax fibre, with inherent properties then matched to NZ textile applications

PULP, PAPER, PACKAGING

From the late 1970s, NZ Forest Products undertook a comprehensive assessment of the potential for a NZ flax pulping/papermaking industry. As part of this assessment, Fergus (1976) completed a literature review addressing botanical and silvicultural aspects; chemistry and pulping behaviour of the leaf; and value of the fibre in respect of its papermaking and export pulp potential (determining that principal uses were in the specialty pulp market including teabag papers, filter papers, condenser insulation paper, cigarette paper, currency paper, wall paper, high quality writing and art paper and sausage casings). In 1980, Reid (NZFP) noted: "it will help reduce the company's almost total dependence on fibre supplies from the radiata mono-culture; plantation and maturation times are less than for radiata; the flax pulp has outstanding strength properties which could enable us to sell it as a premium grade market pulp, or use it to improve the quality of existing grades, or manufacture new grades of paper". In 1990, Robertson (Cawthron Institute) noted: "the fibre length/diameter ratio is the key factor which enables flax pulp to generate paper with extremely high strength. Such properties are especially valued for very lightweight papers". Other work assessing strength properties determined that phormium pulp was superior to radiata in tear index, burst index, breaking length and stretch.

flax pulp has outstanding strength properties which could enable us to sell it as a premium grade market pulp

NZFP undertook extensive pulping trials, and pilot production runs to produce clean, bleached pulp of high quality; alongside work, as noted earlier, undertaking growing trials in selected regions. The final proposal involved establishment of 5-10,000ha of flax plantations on good land, together with a pulp mill capable of producing 30 tons/day bleached flax pulp, for the specialty pulp market. Although a number of promising customers were identified, the project was not approved by the NZFP Board on the basis of the substantial capital outlay required, with eight years before full mill capacity was reached, and uncertainties over the marketing of such large quantities (perhaps 30% of the total world market).

In the late 1980s/early1990s, a group of West Coasters (Patrick and John Pfahlert and partners) picked up where NZFP left off, with the objective of establishing a smaller-scale flax papermaking enterprise on the coast. NZ Export Pulp Ltd negotiated a licencing agreement with NZFP for use of their information/technology on the West Coast; and the partners followed through with considerable technical and economic analyses (all supported with meticulous records). Although the proposed operation was significantly scaled down, the capital costs (linked to ongoing market uncertainties) meant that this project also was not proceeded with.

she describes flax as one of the strongest, most tenacious plants for paper-making

Throughout this period, NZ Flax has maintained a niche position in hand-made papers; and, very recently, Scion have begun producing flax paper in small industrial quantities. Rhonda Rutherford-Dunn (master paper-maker) describes flax as one of the strongest, most tenacious plants for paper-making (and Peter Carter speculates whether there may still be a new world use for its strength properties). Dr Sydney Shep (VUW) is currently researching the development of flax paper-making in NZ: in respect of printing applications, she notes the jury is still out on the quality of flax fibre for making paper of print quality: partly due to the quality of

fibre preparation, but principally due to the acidity of the lignins/xylan bonding the fibres (it self-consumes them; and, as a footnote in this context, stripping machines had to be made of cast iron or steel because of these corrosive acids).

Over the last decade, a number of trends are evident in the pulp and paper sector. Recycling is a major theme (and a focus of the NZ Paper Accord). Having said that, recycling is expensive, and there is still a requirement for 'virgin' feedstock. In this context, increasing attention is being given to sustainable plantation management for renewable feedstocks, including attention to non-wood plant fibres.

In packaging, biodegradability is a key theme, eg; "new regulations re disposal of packaging, and consumer pressures, are creating new opportunities for natural fibres... low-grade moulded pulp products might displace polystyrene in some applications... increasing need for biodegradeable twine in agriculture and industry" (IENICA, 2000). A further point worth noting here is the importance of integrity of packaging (supporting product attributes) in the natural products marketplace.

In wallpaper (identified as a potential market sector by NZFP) the trends are similar to those in the carpet industry: alternatives are being sought to the current vinyl/petrochemical base. A new niche product is of interest – a non-woven grass cloth wallpaper fabric. As noted earlier, an emerging field is the convergence of non-woven and paper technologies, particularly in the arena of technical textiles.

an emerging field is the convergence of non-woven and paper technologies, particularly in the arena of technical textiles

GREEN STRIPPINGS

The by-product of fibre processing is the 'green strippings', comprising sugars, wax, and other constituents; and notably, a high proportion of water. From the inception of the industry, the disposal or utilisation of green strippings exercised mill owners attention.

Most simply, strippings were washed into the nearest waterway; or sometimes just left to rot on the land. Les Warrington recalls that, at the Pukio Mill "flounders would come up, eels, the biggest perch you've ever seen".

In 1922, Easterfield described the green refuse as "a sticky wet material. It commences to ferment at once... it has considerable manurial value (but) the large percentage of water would prevent the refuse from receiving application except as a local fertilizer. On the old refuse heaps of the Manawatu mills very fine crops of potatoes and pumpkins have been raised, and the well-rotted material is enthusiastically spoken of by expert bulb growers". Seifert (1918) noted: "the refuse contains a great deal of potash, which as you know is very valuable as a manure... to get the potash is a problem that has been engaging our attention... it contains so much water that it is difficult to burn. In fact, it will not burn unless it is first dried". As noted earlier, a first application for the green strippings would ideally be returning them to the crop, particularly if the stripper is mobile or located in reasonable proximity to the plantation.

green strippings may be of benefit to farmers in summer and autumn as a nutritive supplement to stock

A second area of application is in stock food. In 1872, Hector noted "in feeding his horses, he mixes the strippings with their oats, and they eat it greedily". Similarly, the *Rangitikei Advocate* (1889) recorded "scrapings off the green plant at the mills form excellent fodder for horses, who eat it readily and prefer it to ensilage". In 1922, Easterfield noted: "Cattle will eat it readily, but in its natural state, it is far too wet to form a satisfactory food. In times of drought, it might be used a supplementary cattle food". The work recently completed by AgResearch (Litherland et al, 2005) confirms that green strippings may be of benefit to farmers in summer and autumn as a nutritive supplement to stock to alleviate the effects of drought or poor quality pastures. Further to this, as noted earlier, late winter pastures

commonly contain high protein and low carbohydrate contents: feeding out green strippings may improve the nutrient mix (which could in turn improve digestion, and potentially reduce methane production) with a possible further advantage of being parasite and mycotoxin free. Litherland et al note that, should there be a resurgence in the flax industry then further studies (eg. paddock testing of palatability, testing for scouring effects, determining the presence of anti-nutritional factors and effects on rumen pH, impact of green strippings on methane production, and developing practical storage and feeding out systems) would be warranted: should there be favourable outcomes from such studies then the fibre processing industry would have a practical method for the disposal of the green strippings (and part of the return to the farmer could perhaps be return of the green strippings in a storable and feedable form).

Beyond its value as fertiliser or stock feed, Seifert (1918) commissioned work on its value for making ethanol: "Professor Easterfield has analysed a great number of samples for us. He stated that the refuse is not suitable for making alcohol, because it contains very little starch or sugar". Several decades later, NZFP commissioned work by the Cawthron Institute to analyse the 'green stream' waste liquor, and to assess its potential as a source of ethanol, methane, furfural and food yeasts. This work, inter alia: "identified organic solids, sugars and tannins... noted problems with inhibition of methanogenesis by green streams with a total solids content >4% w/v (and) suspected tannic acid was the inhibitor... it was suggested that flash hydrolysis would destroy the tannin in the waste, but this now seems unlikely – indeed, hydrolysis and high temperature/pressure treatment appear only to increase the polymerization and binding activities of the tannins". Flax green strippings may contain bio-actives of interest (exploratory work is currently underway at Waikato University); and other by-products of fibre processing, (eg. pectin, lignin, waxes – the natural binders) may be of interest in future.

GEL

Flax gel – pia harakeke – is an exudate found in the leaf butt (the discarded portion in fibre processing), sheathing the leaves, comprised mostly of sugars (with a long polysaccharide structure). Flax gel is an excellent glue; it is antiseptic, and has long been esteemed for burns, skin conditions including eczema, and wound healing (its anti-coagulant activity has been ascribed to its pectin content).

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IRL have published work on the chemistry of the gel, noting: "the polysaccharides exuded are acidic xylans... the side-chains are highly branched, placing them in a class with brea, sapote and yabo gums" (Sims and Newman, 2006); and have undertaken work assessing flax gel as a standardised thickener for cosmetics. Viscosity is a key parameter in cosmetic applications; and Tauwhare et al (2006) note that: "the viscosity of pia harakeke is due to a polysaccharide, identified as an acidic xylan". They tested xylose residues from 50+ varieties; and determined clear differences between *cookianum* forms (low xylose/low viscosity) and *tenax* forms (high xylose/high viscosity), with likely hybrid forms having a range of values between. The implication of this work is that *tenax* forms are likely to be of most interest in cosmetic applications for the gel.

As noted above, Living Nature incorporate flax gel in their product range; with significant interest from other natural product companies. Gel can be readily harvested on a small scale, as a by-product of harvesting the leaf. Wet gel mixes readily with water (but goes mouldy quite quickly); air-dried gel is light and easy to store, and can be reconstituted to its fresh weight (dissolve in distilled water, heated to 80 degrees for about 60 minutes; leave to cool and stand overnight, then filter through glass fibre filters or similar).

Ted Pratt recalls that in spring, the gel would rise, and he “used to be able to get handfuls of gum, clear gum”. At the Christmas clean up, 2-3 inches of gum would be cleaned off the stripping mill floor. Conservation workers on Mangere Island in the Chathams similarly report flax gel ‘oozing’ from the leaves. Notwithstanding these reports, the primary attribute of gel relative to commercial applications, is the very modest yield per leaf (varying across varieties, and perhaps with seasonal or other influences); and the practicalities of the harvest of gel being contingent on harvest of the mature leaves. The economics of gel harvesting will depend either on gel being a by-product of large-scale fibre processing; and/or, developing high value niche applications.

Exploratory work has been undertaken by several agencies (with no outstanding results to date): IRL/edible films (determined that flax gel films unsuitable due to high water permeability and medium-high oxygen permeability); Auckland University/humectant (determined not strong enough for intended food industry application); Crop & Food/colonic bulking (determined that flax gel has a mild faecal bulking effect); Massey University/hydrogels (MURF funding for work screening gel and other compounds for medical applications); and an HRC funded initiative exploring the use of gel in diabetes and sports injuries. It may be that further work on identification and characterisation of properties would be of value in identifying extracts for high value-added niches in cosmetic or nutraceutical applications.

At a practical level, however, the harvest of the gel depends on the harvest of mature leaves; and commercial scale operations will depend on the parallel development of markets for fibre products.

further work would be of value in identifying extracts for high value-added niches

SEED OIL

NZ flax seed oil is rich in linoleic acid/omega 6 (as distinct from linen flax seed oil which is rich in linolenic acid/omega 3). Linoleic acid is more stable than linolenic acid: both are essential fatty acids in human and animal nutrition.

Morice (DSIR) researched NZ flax seed oil in the 1960s and 70s, determining that seeds can yield up to 29% oil. In 1962, she analysed the fatty acid composition of four samples: *p. tenax* from Wellington, *p. cookianum* from Cook Strait, and two Moutua lines (fresh seed, and one year old seed): all were high in linoleic acid (range 76-81%, lowest *cookianum*), oleic acid (range 10.5-15.5%, highest *cookianum*), palmitic acid (range 6-11%, highest Moutua), stearic acid (range 1.3-2.5%, highest *cookianum*). In 1971, Morice tested the effects of the oil fed to rats: “although the number of animals used in the present experiments was not great, it is shown that rats ingesting unrefined *p. tenax* oil, grew better than controls. No toxic effect or dietary deficiency was revealed. The oil when refined is pale yellow and odour-less, and should be acceptable for edible purposes as sunflower, safflower and maize oils”.

seed oil could be a major by-product from a phormium plantation

NZFP picked up on this work (Fergus, 1976) noting that seed oil could be a major by-product from a phormium plantation; positioned as a premium, edible vegetable oil (comparable to sunflower and safflower, superior to rape seed and soya bean); with the seedmeal potentially suitable for stock feed.

More recently, Zirsha Wharemate (Massey University) surveyed the fatty acid profiles of 46 native plant seed oils; and also concluded that NZ flax seed oil has the potential to be grown as a premium oil seed crop. Zirsha determined that: “Most of the oil is in the form of sterols or free fatty acids; with smaller contributions from triacyl-glycerols or diacylglycerols; and even smaller proportion from monoacyl-glycerols or polar components (eg. pigments)”. Harakeke seed oil is high in polyunsaturated fatty acid (linoleic acid), has a reasonable level of mono-unsaturated fatty acid (oleic acid 10-17%), low saturated fatty acids (palmitic acid 6-11%, stearic acid 1-2%), minimum highly unsaturated fatty acids (linolenic 0.2%), and

harakeke
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food grade oil

minimum other fats: "this oleic-linoleic group is the most widely used and adaptable of all the fats and oils. They are considered the premium oils since in the edible foods industry, they have desirable antioxidant properties and do not undergo flavour reversion. They may also be hydrogenated to plastic fats with varying degrees of hardness. Non-edible applications of these premium oils are in the manufacture of soaps, cosmetics and lotions... native species that might be classed in this group, and hence have potential commercial significance, include NZ flax, wineberry, and kōhia".

In 2005, Andrej Jentsch undertook work at Canterbury University trialling super-critical extraction of harakeke seed oil. After preliminary grinding to expose the kernel, Andrej tested a range of temperature/pressure parameters: yields obtained in a 90-minute extraction were between 14-23% of the dried mass of the seeds, with maximum yield at the maximum of the investigated parameter range (450 bar and 69 degrees C). Several samples were tested – 2004 seed, 2005 seed, hand-podded seed, machine threshed seed – with no significant differences detected in quality, composition or yield. Andrej noted similarities with commercial sunflower oil (but including more components); described a rich yellow colour; and noticed a tea-like smell during the extraction process, which was considered unique and pleasant. Andrej also concluded harakeke has promise as a signature NZ food grade oil.

In 2005, Glenn Vile (NZ Seed Oils) determined that the yield from cold-pressing was 25.5% from fresh 2005 seed (2.55kg oil from 10kg seed); and 18% from one year old (2004) seed (0.36kg from 2kg seed).

Later in 2005, Leo Vanhanen (Lincoln Food Group) assessed oil from three Wairarapa *p. tenax* samples (6 months fridge stored, 6 months room stored, 18 months room stored), and one Manawatu Gorge *p. cookianum* sample (6 months room stored). He analysed dry matter (range 94.9-96.7%), ash (range 2.8-3%), protein (range 23.6-29%, highest *cookianum*), fat (range 26.6-32%, highest *cookianum*) and fibre content (ADF range 26.2-28.2%, NDF range 28.6-37.7%, lowest *cookianum*).

At the Flax Field Day (2006) Geoff Savage reported on further work at Lincoln, confirming the seeds contain up to 30% oil. Comparative levels of fatty acids in samples tested were linoleic acid (70.3% for *p. tenax*; 67.3% for *p. cookianum*), and oleic acid (14.9% for *p. tenax*; 19.8% for *p. cookianum*). Geoff noted that this profile suggests the oil is nutritionally well balanced and is likely to be reasonably stable during storage. Geoff further noted that preliminary work to assess the peroxide value of the two oils investigated so far were 3.9 meqO₂/kg oil and 4.0 meqO₂/kg oil for *p. tenax* and *p. cookianum* respectively (the peroxide value is a measure of oxidation of the oil and these values, for freshly extracted oils, are very low). On the strength of these results, work at Lincoln is continuing: analysing a range of cultivars to determine any significant differences in fatty acid composition and antioxidant contents; undertaking stability and storage tests with 2004, 2005 and 2006 seed; and evaluating phytosterols (for positive health benefits), and any anti-nutritive factors (eg. toxic fatty acids).

Flax seed ripens in autumn; with strong variations across varieties in production of korari; and strong variations in flowering/seed set across years. Bob Brockie has published work indicating that, over a ten year span, flowering will be exceptional in 2 years, good in 2, average in 3, and hardly evident in 3; and that a good flowering year may be linked to high temperatures the preceding autumn. Subsequent to this work being published, Bob continued to monitor flowering at selected Wellington sites; and with over 20 years data now in hand, indications are that *p. cookianum* flowers more heavily in all years, with less fluctuations; and *p. tenax* flowering is very modest at these sites, and possibly bi-ennial (flowering was negligible in 12 out of 24 years). Note here that selection of *tenax/cookianum* hybrids for fibre values, may influence higher production of korari (than straight *p. tenax* forms).

Morice (1965) suggested oil production could be of the order of 87kg oil/acre; but her methodology was tenuous ("a rough count in a swamp near Plimmerton gave an average of 3 flower stalks per plant... at 3 flower stalks per plant... and 1600 plants/acre... an acre could provide approx 300kg seed, yielding 87kg oil @ 29% yield). The project manager harvested 60kg seed from 250 odd bushes in 2006 (a good flowering year): at 1600 plants/acre, this would represent 384kg seed/acre (in 2004 and 2005, seed production was closer to 40kg). Suffice to say, we cannot confidently project oil seed yields at this time; and future calculations will be very sensitive to the varying influences of varietal selection and year-to-year fluctuations.

Having said that, the seeds are easy to harvest (by hand on a small scale, and probably amenable to machine harvesting on a larger scale); and, particularly if oil is blended for consistency of product, large-scale environmental/farm plantings (which have not been selected for fibre values) could nevertheless yield seed. Seed ripens in autumn; it should be harvested from ripe, dry pods. Hand-podding is laborious work: AgResearch have successfully trialled machine threshing. The seeds are small and dry; and oil is currently being extracted with a screw press (ie. as used with other small seeds such as blackcurrant). As with the fibre, ideally reasonable quantities of seed would be available in reasonable proximity to processing facilities. We have strong interest in harakeke seed oil as a potential niche branded product, in both culinary and cosmetic arenas: as a rough point of comparison, it would potentially be positioned in the cosmetic arena alongside cold-pressed, organic almond oil from China (@ around \$20/kg); or in the culinary arena, alongside NZ olive oil (current range approx \$30-\$60/kg).

World-wide, demand for vegetable oils is increasing, as mineral oils/petrochemicals are depleting; alongside growing interest in nutrition/health benefits. Linoleic acid is essential in poultry diet (especially young chicks and laying hens); the Alberta Beef Industry Development Fund assessed a number of feed additives to alter rumen microbial populations, with the aim of enabling higher feed efficiency, and "found that long-chain unsaturated fatty acids, in particular linoleic acid, had a distinct inhibitory effect on protozoa without negatively affecting ruminal fermentation"; similarly, AgResearch (2004) found better feed efficiency in lambs dosed with polyunsaturated vegetable oils.

The world's major oil seed crops (eg. soy, rapeseed, sunflower, cotton) are mostly grown as intensive, chemical, mono-cultures; with genetic modification increasingly employed as a tool to manipulate crop attributes. It is of interest to note work to alter the fatty acid composition of linen flax seed oil (to increase levels of linoleic acid): in Australia, for example, CSIRO (*Australian New Crops Newsletter*, 1995) note that "since the mid-1960s, the demand for edible oils has risen dramatically, but the low oxidative stability of linseed oil has rendered it unsuitable for use as an edible oil.... CSIRO initiated a research programme in 1979, treating seeds with chemical mutagens to create new genetic variants... as a consequence, the low linolenic mutants have greatly elevated levels of linoleic acid (65-76%)... in fatty acid composition, the new 'Linola' oil is now similar to the premium polyunsaturated oils, such as sunflower, safflower and corn". And harakeke.

A final point here, with possible implications for the seed: Gould et al (2006) surveyed anti-oxidant activities of selected native plants (relative to blueberry), and identified significant anti-oxidant values in the stamens of *p. tenax* flowers. It may be that this could also have implications for harakeke honey: the honey has not been formally analysed as yet, but, as noted by Atkinson (1922), "in those areas where phormium is abundant, it is not without importance to the beekeeper. The honey is very thick in consistency, and dark in colour".

harakeke seed oil has a potential niche in both culinary and cosmetic arenas

demand for vegetable oils is increasing, as mineral oils/petrochemicals are depleting; alongside growing interest in nutrition/health benefits

PHYTO-MEDICAL EXTRACTS

Harakeke has a long history in rongoa. Murdoch Riley (1994) describes multiple uses for harakeke extracts, including the powerful purgative action of root extracts, the efficacy of butt extracts in rheumatic and arthritic conditions, and the application of gel in skin conditions.

A number of researchers have followed through with exploration of bio-active properties, eg: Matsuo et al (1980) found musizin in hexane extraction of roots; Hindle (1998) isolated aromatic glycosides from aqueous extraction of roots, including one biologically active compound; Harvey and Waring (1987) isolated anti-fungal compounds from the roots; Kupchan et al (1978) reported on anti-leukaemia activity, attributed to two cucurbitans in ethanol leaf extracts; Calder et al (1986) showed a level of activity of leaf and seed extracts against gram-positive bacteria (staph. aureus and bacillus subtilis); Bloor (1995) assayed anti-viral and anti-microbial activity; anthraquinones are present in the orange bases of the leaves, and in the roots (perhaps accounting for the laxative activity); and the Malaghan Institute determined that butt extracts contained polyphenolics (known as having anti-inflammatory activity).

A key point to note here is that safety/regulatory hurdles in the phyto-medical arena are very high. Having said that, extraction of bio-actives from fibre processing 'waste' streams (ie. the butt, and possibly the green strippings) may be considered as part of future commercial-scale operations.

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PART C

Industry development

Jeff Grant (Meat & Wool NZ) was recently reported as stating, in respect of wool: "This is the most archaic industry I have seen beyond the farm gate. Does it need to collapse to change?". Flax did.

The industry of last century positioned flax as a coarse fibre, suited to low-end applications.

Maori know harakeke as a multiple value fibre (and a multiple value plant): selecting certain varieties, certain leaves, certain techniques for drawing out soft, silky muka for fine articles; and selecting others for stronger applications.

Science confirms that harakeke/wharariki forms span the spectrum from 'soft' fibres to 'hard' fibres. An outstanding attribute is the strength of the fibres.

Applications development is underway, looking less to traditional or industrial applications, more to new uses; looking less to traditional cultivars, more to new forms; looking less to traditional or industrial processing techniques, but demanding a new approach.

Traditional agronomy emphasised respect for the plant – keeping bushes clean, groomed, generously spaced, with nutrients returned to replenish the plant. Industrial agronomy learned that optimum conditions for harakeke are close to its ecological niche.

Harakeke is an ancient, iconic species; lost from the landscape. As Don Merton said, in respect of kakapo: "it too has land rights".

Harakeke/wharariki express themselves most strongly in the transition zones between land and water, coast and sea. It is in these transition zones that we have the greatest need – and the greatest opportunity – to re-establish harakeke/wharariki as part of resilient, diverse indigenous ecosystems.

The return of the NZ Flax industry would be a brilliant quadruple bottom-line package for rural New Zealand. We have the opportunity – respecting traditional knowledge, and industrial knowledge – to synthesise a new industry platform incorporating sustainability and regional development as core principles.

This final section briefly outlines a strategic framework and touches on the experience of other industry sectors, in indicating possible pathways forward.

Biotech For Life

In 2005, MORST published *Futurewatch: Biotechnologies to 2025*. Within this document, three global scenarios (originally developed by Navigatus Ltd for Forest Research) are outlined:

- "biotech for profit": the globalisation scenario, characterised by anxiety, security measures, bloc-politics, reduced information flows

an outstanding attribute of harakeke/wharariki is the strength of the fibres

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- “biotech for basics”: an extension of the globalisation/profit scenario, characterised by increasing mistrust, escalating conflict, the rise of nationalism and self-sufficiency, duplication of technology
- “biotech for life”: this scenario is based on a grassroots belief that the dominant globalisation/security model is not environmentally sustainable in the medium (or even short) term. The environment for science and technology is characterised by world-class science, open collaboration and information flows, technology sharing and collegiality. Multi-lateral agreements shift from trade and security to sustainability. In this scenario, ecological activities dominate, and economic activity is incentivised and regulated with environmental imperatives.

at both community and council levels there is a desire for a collective vision towards which people’s energy can be directed

We have clear environmental imperatives in NZ: the restoration of indigenous biodiversity as vigorous functioning elements of our productive landscapes, restoring the mauri of our waterways. Our choice is the extent to which economic activity is ‘regulated’ (eg. pricing externalities, setting ‘caps’) or ‘incentivised’ by environmental imperatives. Meurk and Swaffield (2000) suggest the former has prevailed: “the emphasis of policy has been on protecting “environmental bottom lines”... with forward planning, and creative visions for the future being undertaken individually, and through the market”. They go on to suggest, however, that there is “growing disenchantment with this laissez-faire approach, and at both community and council levels a desire for a collective vision towards which people’s energy can be directed”. Similarly, the Parliamentary Commissioner for the Environment (2004) recommended the farming sector look beyond remedy and mitigation (eg. riparian planting), and beyond system redesign (eg. nutrient budgetting) to “create a vision and direction for farming that is environmentally, socially and economically sustainable”.

creative thinking about the place of native plants as productive resources is lacking

In 2001, the PCE wrote: “Native plants have spent 80 million years adapting to Aotearoa and are a key – if not the key – to maintaining the ecological health of New Zealand’s lands and waters”. Further to this, he suggested (2002): “creative thinking about the place of native plants as productive resources is lacking”. The point of fundamental importance here is that 80% of our flora are unique to New Zealand; and, as noted above, FRST suggest we may be “sitting on an untapped goldmine”. In this context, it is proposed that native plants may be a key – if not the key – to building longterm sustainable competitive advantage for our land-based industries.

In 2003, the Biotechnology Taskforce identified areas where we have the opportunity to build competitive advantage, including:

- the unique biological base that NZ has in both its marine and terrestrial biodiversity
- environmental management, in which NZ has skills and expertise as a result of protecting and enhancing its unique biodiversity
- NZs capability in niche manufacturing

harakeke ideally fits within a convergence of sustainable competitive advantage with sustainable environmental development

Clearly, harakeke fits this profile: a convergence of sustainable competitive advantage with sustainable environmental development. Within this broad ‘biotech for life’ framework – and within just the last five years – the sum of government investments in exploration of harakeke properties and potential for new products and markets is significant.

Most initiatives are currently at the prototype stage (with an element of uncertainty as to the scale and timing of future developments): nevertheless, NZ Flax is being positioned for re-establishment as a landbased industry for the 21st century. From this point, there is more than one possible pathway forward.

Pathways Forward

Through the long history of harakeke management and utilisation, we have a rich body of knowledge and expertise in ecology, bio-chemistry, agronomy and industry. Within this SFF project, we have researched and summarised historic and recent literature noting implications and suggestions for synthesising a new industry platform. In the course of the project, we have developed a national network linking people working on both environmental and economic values: farmers, iwi land authorities, regional councils, nurserymen, scientists researching environmental values, other scientists exploring cutting-edge applications, regional economic development agencies, and businesses in the textiles and natural products sectors. NZ is privileged to have many individuals (many named in this report) with a high level of commitment, knowledge and perseverance, working for harakeke. Within this network, we have a high level of collaboration and sharing of information, and willingness to work together to build a solid platform for a future industry. At the Harakeke Hui (2005), and again at the Flax Field Day (2006) co-ordination was a key theme: creating the links, managing the costs, developing the infrastructure, capitalising on the opportunities.

we have a rich body of knowledge and expertise in ecology, bio-chemistry, agronomy and industry

In considering pathways forward, there are lessons we can learn from the past. There are also lessons we can learn from the experience of other industry sectors nationally and internationally. Looking to wool, for example: "When I sat down with wool industry leaders, the clear message was that fragmentation is one of the key issues in the industry. Too many components of the industry value chain have become dis-connected... we need to work together" (Jim Anderton, 2006); "We are trying to create dialogue... a strategy needs to be laid out, followed by analysis, and a forum around research and development" (Mark Jeffries, 2006); "It would be from the animals back to the finished product... we are interested in whether there are synergies in having all that research endeavour right across the value chain under the one roof" (Ian Boddy, 2006, re the mooted merger of Canesis into AgResearch).

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In horticulture, *Rural News* (2006) reported: "NZ has a new horticultural technology industry cluster... the sector includes pest and disease management, inventory and crop management, grading, supply chain management, engineering, R&D". In forestry, Bryce Heard "learnt that you started with 'future insight' work. Essentially you ask what the future will look like. You build scenarios. At Forest Research, our scenario told us there would be a need for more sustainable material. The next step was to define niches in which you wanted to be world-class, and work out who you needed to work with to get there. Collaboration required of us mature behaviour" (*Dominion Post*, 2005).

Alan McDermott (AgResearch) confirms the importance of mature, collaborative behaviour: "food supply chains are moving away from adversarial, commodity-focussed spot markets towards tightly aligned relationships supplying differentiated food products... success in these new supply chains requires stakeholders to develop a new set of competencies pivoting around communication: sharing knowledge and resources, sharing gains, turning the supply chain into the unit of strategy and management... without the communication process in place, objectives are not agreed upon and stakeholders continue working from opposing positions asking "what's in it for me?", rather than "how can we all benefit from this?"... the value of face-to-face interaction will increase... the most critical challenge facing stakeholders in supply chains in 2010, should they wish to participate in high value differentiated product markets, will be the establishment of successful supply chain relationships and communication processes" (McDermott et al, *Communication challenges in the 2010 supply chain*).

In Europe, IENICA (the Interactive European Network for industrial crops and their applications) is an over-arching network linking otherwise independent organisations and initiatives which are involved in the development of renewable materials from crops throughout Europe,

promoting positive interaction and collaboration at all stages in the production-supply-processing-market supply chain. IENICA emphasises the early co-ordination of all parties involved in growing and developing new bio-crops: “communication between the main participants in the fibre industry – farmers, seed vendors, research bodies, primary and secondary processors and industrial users – need improvement. Only by multi-path communication will the confidence and requirements of all parties be defined and understood” (IENICA, 2000).

Within this broad collaborative context, Van Dam notes: “the whole chain approach is necessary to be able to see where the most promising improvements can be made at the lowest cost. When, for example, fineness is an issue for the application of a fibre, genetic improvements may not yield the necessary results, when no adequate fibre extraction technology is available. On the other hand, if an efficient fibre processing technology can be developed, which substantially upgrades the fibre quality for a specific end-use, irrespective of the variable properties of the input raw material, all the efforts for crop improvement are in vain”. Recognising that fine-fibre production of NZ Flax will be governed in part by varietal selection, in part by agronomy, and in part by processing – and we have made recommendations to invest efforts in all three areas – it is instructive to consider an approach which prioritises where most gains can be made. Particularly in the context where Nick Tucker (as noted earlier) suggests critical success factors may have less to do with the technology, more to do with managing the costs of the whole supply chain.

*emerging
new industries can
develop by targeting
the attributes of
successful industries*

In 2000, Mayell and Fairweather (*Success factors in new land-based industries*) proposed that emerging new industries can develop by targeting the attributes of successful industries. Of 22 new industries selected for study, seven were judged as successful at that time. Their conclusions were very similar to Alan McDermott: they suggested literature to date has been overly reliant on marketing, production and agronomic factors in explaining success. “These are necessary but not sufficient factors... the main results of this study emphasise industry organisation, functions and interactions”. They referred to Australian research, illustrating that a whole system of production, processing, marketing and consumption had to be developed for a particular new crop, with close co-ordination and cooperation between the various groups involved in all facets of the new industry: “similar to the associations within the major, conventional farming sectors, actors within a new industry complex should be organised into a constituency group or a professional association (including not only research centres, but also actors from the commercial sectors such as growers, bankers, brokers, equipment manufacturers, and even chefs promoting the specific products for food”. They drew on American research, emphasising the importance of industry champions: “without leadership, vision and simple persistence from individuals dedicated to a new crop, and supported by the commitment of time from many individuals, new industry development is unlikely to be successful”. The report commends the desirability of a professional industry organisation led by an enthusiastic, dedicated and motivated industry champion(s) as the best way to advance a new industry; and recommended that government can play an important role in assisting development from loose associations to professional councils.

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For harakeke, one pathway forward is to continue progressing, project by project, (particularly recognising that multiple opportunity/multiple objective projects test the boundaries of most conventional funding streams); relying on informal networks, and perhaps waiting until one (or more) project sector(s) is sufficiently advanced to assume an industry umbrella role for future investments. One risk with this approach is that commercial developments may be dislocated from environmental opportunities.

An alternate pathway is to develop the value chain as “the unit of strategy and management”. In 1922, Easterfield suggested: “It is an industry with immense possibilities, but these possibilities can only be attained by united and systematic effort”.

Within the body of this report, we have noted that – while multiple agencies are researching properties, and prototyping new products and processes for flax fibre, gel, seed oil and other extractives – supply lines are not currently in place for expanded commercial applications. And – while hundreds of thousands of flax plants are being established annually in riparian, conservation and farm plantings – none are currently selected for their fibre values. We have identified key steps required to link environmental/farm plantings into an industry value chain (varietal selection, engaging the nursery trade, agronomic guidelines); we have identified a range of opportunities for extended plantings within a broader landscape context (for environmental and/or commercial return), and noted areas where further work would be of value; and we have emphasised the importance of processing as a critical value-chain linker. All aspects are inextricably connected.

Across the many projects and initiatives that are currently underway around the country, there is a high level of motivation and momentum and willingness to collaborate. Rather than continue as a loose association of independent projects, it is proposed real synergies and progress will best be delivered through regular, formal collaborative forums, and development of strategic research agendas. Following on from this SFF project, it is specifically recommended that a forum of invited participants – with expertise spanning the spectrum of values – be convened with a focus on creating an initial value-chain model for harakeke, for discussion with wider constituencies.

The outstanding opportunity that we have – recognising we have lost the resource, we have lost processing capability, we are unconstrained by requirements to retrofit – is to design the industry from the ground up. Engaging all participants in the value chain – and beyond – in the task of re-building the foundations for a sustainable industry, and re-establishing Harakeke/NZ Flax as a cornerstone element in a new indigenous/exotic farming matrix.

it is recommended that a forum of invited participants – with expertise spanning the spectrum of values – be convened

the outstanding opportunity that we have is to design the industry from the ground up

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