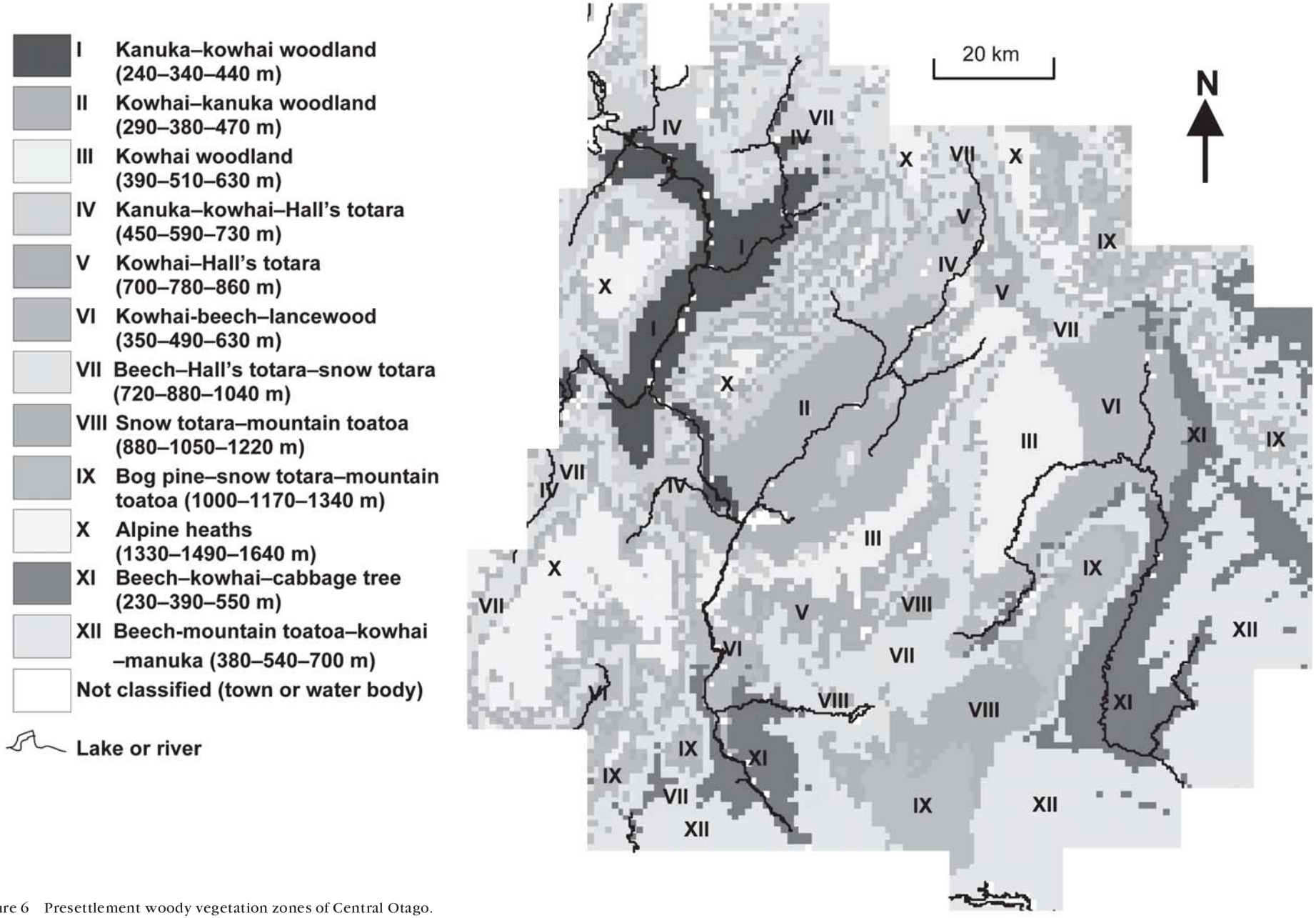

Figure 6 Presettlement woody vegetation zones of Central Otago.

Six of the pre-settlement woody vegetation zones are categorised as forest. On the basis of the distributions of existing remnants, the models predict that these zones were capable of supporting tall tree cover (including *Nothofagus* species) which we assume would have exceeded that of shrubs and herbaceous vegetation over most of their extent.

We categorised two of the remaining three high-elevation zones as shrubland. The principal canopy species predicted in this zone are *Podocarpus nivalis*, *Phyllocladus alpinus* and *Halocarpus bidwillii*, and we envisage that a tall shrub or low forest cover exceeded that of tall forest, subshrub and herbaceous vegetation here. We define the most high-elevation pre-settlement woody vegetation zone as tussock-shrubland (areas with tussocks accounting for >20% cover but less than shrubs; Atkinson 1985). Although the models suggest that environmental conditions here exceed the environmental tolerances of most tall woody species, and that subshrubs were the predominant woody growth form, remnant tall shrubs still occur in this zone and indicate that taller vegetation occupied Central Otago's alpine zone in pre-settlement times.

6.3.1 Environment and predicted composition from the models

The 12 pre-settlement woody vegetation zones were mapped in GIS ArcView (Fig. 6), and the average predicted percentage likelihood of a species occurring within each zone was tabulated for each of 74 common native species (Tables 6 and 7). We also tabulated the number of woody plant records within each pre-settlement woody vegetation zone that are too rare for models to be calculated, after we classified those species according to the zones in which they occurred (Table 8). We determined the average environmental characteristics of each pre-settlement woody vegetation zone (Table 9). We also tabulated the present woody vegetation associations recorded at study plots within each zone (Table 10) and their relationship with environmental domains (Table 11). In this section, we briefly describe the distribution of each pre-settlement woody vegetation zone, its pre-settlement composition as predicted by the generalised additive models based on current plant distributions, and its present-day woody species composition, noting both uncommon, rare and local woody plants, and present-day woody plant associations recorded in each zone.

Zone I—Kanuka-kowhai woodland

This vegetation zone is largely restricted to the Clutha Basin environmental domain (Table 11), and consequently experiences the highest mean annual temperatures and the greatest air and soil moisture deficits, and receives the highest mean annual solar radiation of all pre-settlement woody vegetation zones. Small portions of the kanuka-kowhai woodland zone (<5%) also extend into the Alexandra Basin rim, northern basin rims, recent Taieri soils and northern valley terraces domains.

The models predict that *Kunzea ericoides* (kanuka) may have been the principal canopy species, together with *Sophora microphylla* (kowhai) and *Leptospermum scoparium* (manuka). They indicate that the liane *Clematis marata*, and the subcanopy shrubs *Aristotelia fruticosa*, *Hebe salicifolia* and *Coprosma crassifolia* may have been common, while *Coprosma propinqua*, *Melicytus alpinus*, *Rubus schmidelioides*, *Discaria toumatou*, *Carmichaelia petriei*, *Olearia odorata*, *Muehlenbeckia australis*, *M. axillaris*, *M. complexa*,

TABLE 6 PREDICTED OCCURENCE (P_s) OF 15 POTENTIAL CANOPY SPECIES WITHIN 12 PRE-SETTLEMENT WOODY VEGETATION ZONES (I TO XII) FROM GENERALISED ADDITIVE MODELS OF SPECIES PRESENCE ON ENVIRONMENT ONTO A 1 × 1 KM GRID.

Eight groups of potential canopy species sharing similar environmental tolerances (Gp. *a* to *h*) were identified by the classification of pre-settlement woody vegetation zones. (TS = tussock-shrubland)

	STRUCTURAL CLASS	WOODLAND			FOREST				SHRUB-LAND		TS	FOREST	
	PRE-SETTLEMENT WOODY VEGETATION ZONE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
GP.	CANOPY SPECIES	KANUKA-KOWHAI	KOWHAI-KANUKA	KOWHAI	KANUKA-KOWHAI-HALL'S TOTARA	KOWHAI-HALL'S TOTARA	KOWHAI-BEECH-LANCEWOOD	BEECH-HALL'S TOTARA-SNOW TOTARA	SNOW TOTARA-MOUNTAIN TOATOA	BOG PINE-SNOW TOTARA-MOUNTAIN TOATOA	ALPINE	BEECH-KOWHAI-CABBAGE TREE	BEECH-MOUNTAIN TOATOA-KOWHAI-MANUKA
a	*Kunzea ericoides*	68	16	7	29	6	8	6	2	1		16	15
	Sophora microphylla	26	23	29	26	25	43	16	2			74	23
	Leptospermum scoparium	13	5	9	21	16	10	26	15	4	1	20	52
b	*Podocarpus hallii*	1		2	17	24	9	30	14	5	1	6	11
	Pseudopanax colensoi			1	1	12	8	18	10	5	4	3	10
c	*Podocarpus nivalis*		1	5	2	24	2	37	57	32	2	1	9
	Phyllocladus alpinus				2	3	2	16	40	33	4	3	21
d	*Halocarpus bidwillii*				1	2		5	12	18	1		5
e	*Griselinia littoralis*			2	2	4	9	12	7	4		23	15
	Nothofagus menziesii	1		1	6	5	28	29	15	6	1	41	17
f	*Carpodetus serratus*					1	12	14	5	1		21	6
	Cordyline australis	2			6		1	5	6	1		20	10
	Pseudopanax crassifolius		2	8		1	26	1				20	5
g	*Nothofagus solandri* var. *cliffortioides*			1	3	5	18	25	4			4	
h	*Nothofagus fusca*						8	6	1			1	

Pimelea aridula and *Hebe pimeleoides* var. *rupestris* might have occurred in canopy gaps. Species that are presently uncommon in the region, but which may have previously been more widespread, include *Carmichaelia compacta*, *Coprosma* aff. *pseudocuneata*, *Melicope simplex* and *Olearia avicenifolia.*

Matagouri-mingimingi (E: 38%), briar (D: 24%), and broom-gorse (C: 21%) and dry *Melicytus* (F: 10%) woody species associations are currently recorded at plots in this vegetation zone (Table 10). Less than 1% of plots are classified as forest relicts (woody plant association B).

Zone II—Kowhai-kanuka woodland

The kowhai-kanuka woodland zone incorporates Alexandra Basin rim, Maniototo Basin, Recent semiarid soils and Clutha Basin environmental domains on the gentle slopes of the Manuherikia and Ida valley floors. Mean annual

TABLE 7 PREDICTED OCCURRENCE (P_s) OF SUBSIDIARY WOODY PLANT SPECIES IN PRE-SETTLEMENT WOODY VEGETATION ZONES (I TO XII), CALCULATED AS FOR CANOPY SPECIES (TABLE 6).

Shade-tolerant species, which are associated with taller canopy species in the present day, are distinguished in the table from apparently shade-intolerant species that seldom occur beneath taller canopies. Predicted values for shade-intolerant species were revised downward in proportion to the maximum P_s for any potential canopy species at each point on the 1 × 1 km grid.

STRUCTURAL CLASS	WOODLAND			FOREST				SHRUB-LAND		TS	FOREST	
PRE-SETTLEMENT WOODY VEGETATION ZONE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
WOODY PLANT SPECIES	KANUKA-KOWHAI	KOWHAI-KANUKA	KOWHAI	KANUKA-KOWHAI-HALL'S TOTARA	KOWHAI-HALL'S TOTARA	KOWHAI-BEECH-LANCEWOOD	BEECH-HALL'S TOTARA-SNOW TOTARA	SNOW TOTARA-MOUNTAIN TOATOA	BOG PINE-SNOW TOTARA-MOUNTAIN TOATOA	ALPINE	BEECH-KOWHAI-CABBAGE TREE	BEECH-MOUNTAIN TOATOA-KOWHAI-MANUKA
Shade-tolerant species												
Shrubs												
Aristotelia fruticosa	15	8	7	55	44	10	39	12	4	1	12	10
Hebe salicifolia	12	9	12	29	13	14	17	6	2		26	41
Coprosma crassifolia	10		2	14	6	6	11	14	2		31	20
Coprosma 'taylorae'	3	4	7	19	34	14	44	31	17	3	11	36
Coprosma rugosa	2	4	10	10	24	15	34	15	4		19	32
Myrsine divaricata	1	2	9	4	11	26	21	3			9	
Dracophyllum longifolium		1	4	3	13	3	15	21	13		4	24
Coprosma colensoi			1		1	13	11	4			4	
Coprosma rhamnoides			1		2	14	11	3	1		6	1
Lianes												
Clematis marata	26	26	39	60	57	42	44	9	2		63	38
Helichrysum lanceolatum	2	1	5	7	10	7	5	1			10	4
Muehlenbeckia australis	10	6	4	12	4	10	7	3	1		41	25
Rubus cissoides		1	4	10	41	11	24	9	4		9	22
Shade-intolerant species												
Shrubs												
Coprosma propinqua	63	59	69	83	69	72	49	13	3	1	86	48
Melicytus alpinus	50	48	55	72	64	49	54	30	18	22	36	24
Discaria toumatou	39	47	50	67	69	53	40	12	3		53	33
Carmichaelia petriei	25	36	65	59	86	71	67	16	4	1	71	41
Olearia odorata	20	37	41	57	49	25	32	6	1		6	3
Pimelea aridula	17	8	2	21	6		8	3	1	1		
Hebe pimeleoides var. *rupestris*	12	2	1	13	3	1	6	3	2		1	1
Ozothamnus leptophyllus	6	7	8	12	16	9	28	50	57	24	17	37
Corokia cotoneaster	6	4	7	6	12	7	9	3	1		6	5
Olearia lineata	5	4	3	4	2	8	3	1			16	6
Helichrysum intermedium var. *selago*	3	3	2	10	14	3	20	16	13	15	2	3
Hebe subalpina	1	1	1	7	6		8	7	8	11	1	12
Coprosma ciliata	1	3	6	4	14	8	19	23	18	2	16	24

STRUCTURAL CLASS	WOODLAND			FOREST				SHRUB-LAND		TS	FOREST	
PRE-SETTLEMENT WOODY VEGETATION ZONE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
WOODY PLANT SPECIES	KANUKA-KOWHAI	KOWHAI-KANUKA	KOWHAI	KANUKA-KOWHAI-HALL'S TOTARA	KOWHAI-HALL'S TOTARA	KOWHAI-BEECH-LANCEWOOD	BEECH-HALL'S TOTARA-SNOW TOTARA	SNOW TOTARA-MOUNTAIN TOATOA	BOG PINE-SNOW TOTARA-MOUNTAIN TOATOA	ALPINE	BEECH-KOWHAI-CABBAGE TREE	BEECH-MOUNTAIN TOATOA-KOWHAI-MANUKA
Olearia bullata	1	7	16	13	25	21	25	12	6		21	39
Gaultheria antipoda	1	1	3	10	19	5	29	40	18	2	10	33
Coprosma intertexta		6	19	7	21	15	9	1			4	3
Hebe rakaiensis		1	3	2	8	4	12	16	12	1	8	15
Olearia nummularifolia		1	4	2	13	2	22	48	31	2	4	16
Carmichaelia crassicaule		1	7	2	28	5	25	15	4	1	1	1
Hebe odora			1		5		9	30	38	6	1	11
Hebe buchananii			1		2	1	7	14	16	39	1	2
Dracophyllum uniflorum				2	1	5	14	38	56	38	14	30
Hebe hectorii var. *hectorii*								1	3	17		
Hebe imbricata var. *poppelwellii*								1	8	5		
Brachyglottis revolutus								2	5	13		
Lianes												
Rubus schmidelioides	47	37	50	58	46	55	28	3	1		66	30
Muehlenbeckia axillaris	19	3	4	9	9	4	9	6	5	2	2	2
Muehlenbeckia complexa	15	23	26	27	34	27	22	12	5	1	36	31
Subshrubs												
Coprosma petriei	2	2	3	3	12	4	18	28	25	64	2	1
Pimelea oreophila	2	3	7	9	28	5	35	50	51	44	2	7
Leucopogon colensoi	1	1	3	12	26	11	51	55	33	5	9	30
Pimelea pseudolyallii		1	5	2	12	10	23	30	28	17	13	20
Carmichaelia vexillata		1	2	2	2	2	9	14	4	1		
Gaultheria depressa var. *depressa*			3	2	17	2	31	60	60	54	1	4
Pentachondra pumila			2	1	8	2	12	21	23	4	2	14
Coprosma cheesmanii			2		4	2	7	19	28	3	2	14
Myrsine nummularia			1	1	7	1	12	21	20	8	1	3
Gaultheria crassa			1	2	7	2	14	20	24	5	2	13
Gaultheria macrostigma			1		3	2	7	20	22	2	3	23
Pimelea traversii				5	9	1	11	9	9	4	1	2
Coprosma perpusilla								2	15	7		2
Gaultheria nubicola					4		5	9	11	17		1
Dracophyllum pronum					1		6	17	32	26		1
Dracophyllum muscoides							1	6	19	67		
Cyathodes pumila					3	1	3	8	14	7		2
Gaultheria depressa var. *novae-zelandiae*								2	12	2		6

TABLE 8 UNCOMMON, RARE AND LOCAL NATIVE WOODY SPECIES IN THE 12 POTENTIAL PRE-SETTLEMENT WOODY VEGETATION ZONES (I TO XII).
The cells show the number of recorded occurrences of each species within each pre-settlement vegetation zone. Seven of the eight groups of species (Gps. i to viii, based on the rare species classification) contain native species; rare species group v contains only exotic species.

GP.	UNCOMMON, LOCAL AND RARE NATIVE SPECIES	I KANUKA-KOWHAI	II KOWHAI-KANUKA	III KOWHAI	IV KANUKA-KOWHAI-HALL'S TOTARA	V KOWHAI-HALL'S TOTARA	VI KOWHAI-BEECH-LANCEWOOD	VII BEECH-HALL'S TOTARA-SNOW TOTARA	VIII SNOW TOTARA-MOUNTAIN TOATOA	IX BOG PINE-SNOW TOTARA-MOUNTAIN TOATOA	X ALPINE	XI BEECH-KOWHAI-CABBAGE TREE	XII BEECH-MOUNTAIN TOATOA-KOWHAI-MANUKA
i	*Aristotelia fruticosa* × *A. serrata*				1								
	Carmichaelia compacta	12	2		9	3		5			1	1	
	Carmichaelia kirkii		2	1	13	3		2				1	
	Coprosma aff. *pseudocuneata*	2											
	Parsonsia capsularis	2		2	4	1		8		1		5	
	Parsonsia heterophylla		1	2	1		1	2					2
	Pimelea pulvinaris	3			1								
	Pimelea sericeovillosa	7			2	1		6	5	4			
	Scandia geniculata		1		2	2	1	3				4	4
ii	*Coprosma virescens*	1	1		5			2				3	2
	Olearia aviceniifolia	3			7			10	1		1	4	5
iii	*Clematis quadribracteolata*											3	2
	Coprosma cuneata						3	4	5				1
	Coprosma linariifolia					1	3	4	1			4	3
	Coprosma rigida			1		1	1	3	2	13		6	6
	Coprosma rubra						2	5	4			4	
	Fuchsia excorticata				2		5	2	1			5	12
	Fuchsia perscandens						1					8	4
	Gaultheria depressa × *G. nubicola*							5				5	17
	Hebe pinguifolia			1				2	1	9			2
	Hoberia glabrata				3		3	3	3			1	2
	Hoberia lyallii				6		3	7				5	1
	Melicope simplex	4		2		3	6	6				5	2
	Melicytus ramiflorus											1	4
	Neomyrtus pedunculata			1									
	Olearia arborescens				1		2	4	3	2		2	12
	Olearia hectorii						2	1				2	
	Pittosporum divaricatum											1	
	Pittosporum tenuifolium			3			5	1				8	4
	Pseudopanax simplex						17	3	3				1
	Ripogonum scandens											1	
	Rubus australis											3	1
	Rubus squarrosus						1	4	1			1	1
	Solanum laciniatum											1	
	Teucridium parvifolium			1			1						2
	Urtica ferox											1	
iv	*Clematis paniculata*						2						
	Coprosma depressa				2		1	4		2	1		5
	Coprosma pseudocuneata						2	4	5	1	1		4
	Elaeocarpus hookerianus						2						

GP.	PRE-SETTLEMENT WOODY VEGETATION ZONE UNCOMMON, LOCAL AND RARE NATIVE SPECIES	I KANUKA-KOWHAI	II KOWHAI-KANUKA	III KOWHAI	IV KANUKA-KOWHAI-HALL'S TOTARA	V KOWHAI-HALL'S TOTARA	VI KOWHAI-BEECH-LANCEWOOD	VII BEECH-HALL'S TOTARA-SNOW TOTARA	VIII SNOW TOTARA-MOUNTAIN TOATOA	IX BOG PINE-SNOW TOTARA-MOUNTAIN TOATOA	X ALPINE	XI BEECH-KOWHAI-CABBAGE TREE	XII BEECH-MOUNTAIN TOATOA-KOWHAI-MANUKA
	Gaultheria parvula				1	2		8	2	6	7	2	2
	Hebe lycopodioides var. *lycopodioides*					2		4	6	3	16	1	2
	Hebe treadwellii						1						
	Olearia cymbifolia			1	3	5		19	3	2	1		1
	Olearia lineata dartonii				1								
	Pennantia corymbosa						1	2	1	1			
	Pimelea prostrata	4			5		1	6	3	1	4		
vi	*Aristotelia serrata*				2			1				3	
	Carmichaelia arborea				1			1					
	Carmichaelia corrugata							2					
	Coprosma antipoda												1
	Coprosma serrulata							1		1			
	Cyathodes empetrifolia							1					8
	Cyathodes juniperina												1
	Dracophyllum kirkii							1					
	Halocarpus biformis							1					
	Hoberia angustifolia							1				2	1
	Myrsine australis				2			1					4
	Olearia fimbriata						2	1					1
	Olearia ilicifolia							1					1
	Pittosporum eugenioides							1					2
	Pseudopanax arboreus												1
	Schefflera digitata							1					
vii	*Brachyglottis cassinioides*					1		6	3		1		
	Carmichaelia nana					1							
	Carmichaelia vexillata					1		2					
	Clematis paniculata					1	2	1					
	Hebe cupressoides					1							
viii	*Coprosma* alpina							3	2	4	6		
	Coprosma atropurpurea							2	3	12	7		
	Coprosma niphophila									2			
	Cyathodes dealbata									1			
	Dracophyllum politum									16			
	Dracophyllum prostratum									1	1		
	Dracophyllum prostratum × *D. uniflorum*								2				
	Exocarpus bidwillii								1				
	Hebe aff. *rakaiensis*									1			
	Hebe cockayneana										1		
	Hebe decora										1		
	Hebe epacridea							4	5	6	3		
	Hebe hectorii var. *demissa*								1	2			
	Hebe hectorii var. *subulata*								1	3	9		
	Hebe petriei										6		
	Hebe propinqua							5	3	21	6		
	Hebe tetrasticha								1		1		
	Pimelea poppelwellii							1	5	2	6		

TABLE 9 ENVIRONMENTAL ATTRIBUTES OF THE 12 PRE-SETTLEMENT WOODY VEGETATION ZONES OF CENTRAL OTAGO (I TO XII)

STRUCTURAL CLASS	ZONE NUMBER	PRE-SETTLEMENT WOODY VEGETATION ZONE	LOCATION	APPROXIMATE LAND AREA (km^2)	% OF LAND AREA	ELEVATION (m)	SLOPE (°)	MEAN ANNUAL TEMPERATURE (°C)	TEMPERATURE SEASONALITY (°C)	OCTOBER VAPOUR PRESSURE DEFICIT (kPa)	ANNUAL MOISTURE DEFICIT (mm)	RAINFALL TO PET RATIO	MEAN ANNUAL SOLAR RADIATION (MJ m^{-2} DAY^{-1})	SOLAR RADIATION SEASONALITY (MJ m^{-2} DAY^{-1})	AGE (1 = OLD, 3 = YOUNG)	PHOSPHATE (1 = LOW, 5 = HIGH)	CALCIUM (1 = LOW, 5 = HIGH)	PARTICLE SIZE (1 = SMALL, 5 = LARGE)	SALINITY (1 = LOW, 4 = HIGH)	DRAINAGE (1 = POOR, 5 = GOOD)
Woodland	I	Kanuka-kowhai	Upper Clutha Basin floors	739	5	340	6	9.98	-3.14	0.49	258	1.15	13.98	-0.78	2.56	2.96	2.06	3.21	1.41	4.53
	II	Kowhai-kanuka	Manuherikia and Ida basins	1011	7	380	3	9.10	-3.69	0.47	241	1.02	13.63	-0.57	2.20	3.07	2.06	3.01	1.98	4.25
	III	Kowhai	Maniototo Basin and basin fringe	827	5	510	10	8.36	-2.82	0.43	206	1.06	13.44	-0.37	2.19	3.19	2.09	3.04	1.88	4.12
Forest	IV	Kanuka-kowhai-Hall's totara	Northern basin fringes	1390	9	590	11	8.58	-2.58	0.43	137	1.69	13.83	-0.62	2.19	3.04	1.93	3.62	1.16	4.22
	V	Kowhai-Hall's totara	Maniototo and Ida Basin fringes	722	6	780	10	7.17	-2.37	0.38	96	1.74	13.48	-0.39	2.08	3.10	1.87	3.77	1.08	4.17
	VI	Kowhai-beech-lancewood	Montane hillslopes	948	17	490	6	8.56	-2.01	0.42	162	1.31	13.31	-0.25	2.32	3.19	1.94	2.95	1.50	4.15
	VII	Beech-Hall's totara-snow totara	Upper montane–lower subalpine	2612	7	880	11	6.81	-1.39	0.35	40	2.29	13.42	-0.31	2.05	3.01	1.84	3.74	1.04	4.19
Shrubland	VIII	Snow totara-mountain toatoa	Subalpine	1148	9	1050	10	5.83	-0.49	0.30	4	2.83	13.19	-0.15	1.99	2.97	1.83	3.96	1.01	4.17
	IX	Bog pine-snow totara-mountain toatoa	Upper subalpine–low alpine	1356	5	1170	7	5.26	0.19	0.27	0	3.21	13.05	-0.03	2.01	2.99	1.70	3.99	1.00	4.23
TS[1]	X	Alpine	Alpine ridge crests	977	6	1490	5	3.78	0.87	0.24	0	4.03	13.29	-0.19	1.99	2.99	1.78	3.98	1.00	3.98
Forest	XI	Beech-kowhai-cabbage tree	Southern valleys	1373	9	390	8	8.89	-1.24	0.39	112	1.47	12.95	-0.01	2.21	3.07	1.87	2.84	1.05	4.30
	XII	Beech-mountain toatoa-kowhai-manuka	South-eastern perimeter	2215	14	540	4	8.07	-0.17	0.35	52	1.98	12.74	0.12	2.31	3.03	1.84	3.03	1.00	4.20

[1] Tussock-shrubland.

TABLE 10 PERCENTAGE OF STUDY PLOTS WITHIN EACH PRE-SETTLEMENT WOODY VEGETATION ZONE (I TO XII) CLASSIFIED WITHIN THE 14 PRESENT-DAY WOODY PLANT ASSOCIATIONS.

ZONE NUMBER	PRE-SETTLEMENT WOODY VEGETATION ZONE	PRESENT-DAY WOODY PLANT ASSOCIATION A BEECH FOREST REMNANTS	B WIDESPREAD FOREST RELICTS	C BROOM-GORSE	D BRIAR	E DRY MATAGOURI-MINGIMINGI	F DRY *MELICYTUS*	G MATAGOURI-NATIVE BROOM	H HIGHLY MODIFIED SUBALPINE	I *OZOTHAMNUS* LOW ALPINE	J *DRACOPHYLLUM* LOW ALPINE	K *HEBE ODORA*-MOUNTAIN TOATOA SUBALPINE	L *BRACHYGLOTTIS REVOLUTUS* LOW ALPINE	M *DRACOPHYLLUM MUSCOIDES* HIGH ALPINE	N WIDESPREAD LOW ALPINE
I	Kanuka-kowhai		1	21	24	38	11	3	1						
II	Kowhai-kanuka		2	34	23	32	2	4	2	2					
III	Kowhai		3	19	3	67		5	2						
IV	Kanuka-kowhai-Hall's totara	1	3	8	6	61	11	5	3	< 1					1
V	Kowhai-Hall's totara		12	1	1	50	2	15	5	5		1		1	5
VI	Kowhai-beech-lancewood	26	3	28	2	34	2	4	1						
VII	Beech-Hall's totara-snow totara	2	15	4	1	30	6	15	11	9	1	3	< 1	< 1	1
VIII	Snow totara-mountain toatoa	< 1	13	< 1		1	3	4	22	21	7	13	1	6	8
IX	Bog pine-snow totara-mountain toatoa		7	1	1		< 1	1	10	19	12	35	2	5	6
X	Alpine		2	1			< 1	< 1	11	14	5	7	8	34	18
XI	Beech-kowhai-cabbage tree		6	32	5	43	1	11	1			2			
XII	Beech-mountain toatoa-kowhai-manuka	< 1	10	23	3	24	< 1	16	1	2	5	15			

TABLE 11 RELATIONSHIP BETWEEN PRE-SETTLEMENT WOODY VEGETATION ZONES AND ENVIRONMENTAL DOMAINS.

The table shows the percentage of the land area occupied by each pre-settlement woody vegetation zone (I to XII) that falls within the 18 environmental domains (Numbers 1 to 18) described earlier in the report.

ZONE NUMBER	PRE-SETTLEMENT WOODY VEGETATION ZONE	ENVIRONMENTAL DOMAIN NUMBER 1 CLUTHA BASIN	2 ALEXANDRA BASIN RIM	3 MANIOTOTO BASIN	4 RECENT SEMIARID SOILS	5 NORTHERN VALLEY TERRACES	6 UPPER MANIOTOTO	7 NORTHERN BASIN RIMS	8 LAKES RANGES	9 UPPER NEVIS VALLEY	10 NORTHERN RANGES	11 ROLLING RIDGE CRESTS	12 MANORBURN UPLANDS	13 LAMMERLAW	14 LAMMERLAW WETLANDS	15 RECENT TAIERI SOILS	16 SOUTH-EASTERN RANGES	17 SOUTH-EASTERN VALLEYS	18 COASTAL HILL COUNTRY
I	Kanuka-kowhai	86	4		3	4		3											
II	Kowhai-kanuka	11	37	33	15		3	1											
III	Kowhai	1	18	44	5		11	4					17						
IV	Kanuka-kowhai-Hall's totara	14	9	2		2	11	56	5										
V	Kowhai-Hall's totara						16	35			11		36						
VI	Kowhai-beech-lancewood		14	33	2		18	3					17			2	6	3	
VII	Beech-Hall's totara-snow totara						2	17	9	< 1	28	3	25	12	< 1		2		
VIII	Snow totara-mountain toatoa										42	11	3	42	< 1				
IX	Bog pine-snow totara-mountain toatoa										42	25		31	< 1				
X	Alpine										52	47			< 1				
XI	Beech-kowhai-cabbage tree						4						26			12	12	45	
XII	Beech-mountain toatoa-kowhai-manuka										5		18	4		2	12	14	46

temperatures and mean annual solar radiation are slightly lower than in the kanuka-kowhai woodland zone, but temperature seasonality is more negative, indicating severe winter frosts due to temperature inversions.

The models predict that the abundance of *Sophora microphylla* (kowhai) would have been similar to that in the kanuka-kowhai woodland zone in the Upper Clutha valley. However, they suggest that *Kunzea ericoides* (kanuka) and *Leptospermum scoparium* (manuka) may have been less common. The models suggest that native woody canopy may have largely comprised shade-intolerant tall shrubs of *Discaria toumatou*, *Olearia lineata* and *O. odorata*, with the lianes *Clematis marata* and *Muehlenbeckia complexa*. However, more moisture-demanding species such as *Aristotelia fruticosa*, *Corokia cotoneaster*, *Coprosma* taylorae, *C. rugosa*, *Hebe salicifolia*, and *Olearia bullata* are also predicted here. The models suggest that other common elements in this woody zone included *Carmichaelia petriei*, *Coprosma intertexta*, *C. propinqua*, *Melicytus alpinus*, *Rubus schmidelioides*, *Ozothamnus leptophyllus*, *Muehlenbeckia axillaris*, *M. australis*, *Pimelea aridula* and *Hebe pimeleoides* var. *rupestris*. The local species *Carmichaelia compacta* and the rare lianes *C. kirkii* and *Scandia geniculata* were recorded within this zone, and may have been more widespread in pre-settlement times.

Most plots in this zone are classified as broom-gorse or matagouri-mingimingi woody plant associations, and a small percentage are classified within the briar association (Table 10). Approximately 2% are classified as forest relicts (woody plant association B).

Zone III—Kowhai woodland

The Kowhai woodland zone covers the north-western segment of the Maniototo Plain and the Ida Valley, within the Maniototo Basin environmental domain. It also extends along the flanks of Rough Ridge and as far as the Clutha Valley south of Fruitlands, covering areas of the Alexandra Basin rim, Manorburn uplands, and upper Maniototo domains at higher elevations. Mean annual temperatures, water deficits, and mean annual solar radiation are correspondingly lower, and winter frosts are less severe, than in the kanuka-kowhai and kowhai-kanuka woodland zones.

Sophora microphylla (kowhai) is predicted to have been the principal canopy tree in this zone. The models suggest that *Kunzea ericoides* (kanuka) may have been scarce, but that *Leptospermum scoparium* (manuka) might have been more common than in the more arid kowhai-kanuka woodland zone. The models suggest that *Pseudopanax crassifolius* (lancewood), *Hebe salicifolia*, *Coprosma rugosa*, *Myrsine divaricata*, *Aristotelia fruticosa*, and *Coprosma* taylorae might have occurred locally, and that patches of *Podocarpus nivalis* (snow totara) may have been present. Drought-tolerant shrubs such as *Coprosma intertexta*, *C. propinqua*, *Carmichaelia petriei*, *Melicytus alpinus*, *Discaria toumatou*, *Olearia bullata*, *O. odorata*, and the lianes *Rubus schmidelioides* and *Muehlenbeckia complexa* are predicted to have been common. Presently uncommon species that may previously have been more widespread in this zone include *Pittosporum tenuifolium*, *Melicope simplex*, *Neomyrtus pedunculata*, *Teucridium parvifolium* and the lianes *Carmichaelia kirkii*, *Parsonsia capsularis* and *P. heterophylla.*

Two-thirds (66%) of present-day study plots in this zone were classified in the matagouri-mingimingi woody plant association (E; Table 10). A further 19% had been invaded by exotic woody species and are classified in the broom-gorse association (C), and the few remaining plots are classified within the matagouri-native broom (G: 5%) or briar (D: 3%) woody plant associations. Forest relicts are rare in this zone (woody plant association B, about 3%).

Zone IV—Kanuka-kowhai-Hall's totara forest

The kanuka-kowhai-Hall's totara forest zone covers the moderately steep lower slopes of the ranges fringing the Manuherikia, Upper Clutha, Lindis, Cardrona and lower Nevis valleys, in the sunny north-western quadrant of the Central Otago district. Most of it falls within the northern basin rims environmental domain, but it also extends downslope into the Clutha Basin, Alexandra Basin rim and Upper Maniototo domains. Although mean annual solar radiation is high, mean annual temperatures are lower than on the basin floors. Accordingly, droughts are less severe: rainfall:potential evapotranspiration ratios are higher, and annual soil moisture deficits are lower.

The models predict that *Kunzea ericoides* (kanuka), *Sophora microphylla* (kowhai), *Leptospermum scoparium* (manuka), and *Podocarpus hallii* (Hall's totara) would have been the principal species in this forest zone. They suggest that occasional stands of *Nothofagus menziesii* (silver beech) and *Nothofagus solandri* var. *cliffortioides* (mountain beech) and groves of *Cordyline australis* (cabbage trees) may also have occurred here. Understorey species predicted to have occurred here include the shrubs *Aristotelia fruticosa*, *Coprosma crassifolia*, *C. rugosa*, *C.* taylorae and *Hebe salicifolia*, and the lianes *Clematis marata* and *Rubus cissoides*. More drought-tolerant shrubs such as *Coprosma propinqua*, *Melicytus alpinus*, *Rubus schmidelioides*, *Discaria toumatou*, *Carmichaelia petriei*, *Olearia odorata*, *Pimelea aridula* and *Muehlenbeckia complexa* are also predicted here, and the models suggest that species such as *Hebe pimeleoides* var. *rupestris*, *Muehlenbeckia australis*, *Ozothamnus leptophyllus*, *Helichrysum intermedium* var. *selago*, *Olearia bullata*, and the subshrubs *Gaultheria antipoda*, and *Leucopogon colensoi* may also have occurred locally. Presently uncommon, local or rare species recorded in this vegetation zone include *Aristotelia serrata*, *Aristotelia fruticosa* × *A. serrata*, *Carmichaelia kirkii*, *C. compacta*, *Coprosma virescens*, *Fuchsia excorticata*, *Hoheria lyallii*, *H. glabrata*, *Myrsine australis*, *Olearia arborescens*, *O. avicenitifolia*, *O. cymbifolia*, *Parsonsia capsularis*, *P. heterophylla*, and the subshrub *Pimelea prostrata.*

Most present-day study plots within this zone are classified as the matagouri-mingimingi association (E, 61%), with the remainder being *Melicytus* (F: 11%), broom-gorse (C: 8%), briar (D: 6%) or matagouri-native broom (G: 5%) woody plant associations (Table 10). Although mountain beech forest remnants (woody plant association A) are known from this zone in the Lindis Ecological District, a very small percentage (c. 3%) of plots are classified as forest relicts.

Zone V—Kowhai-Hall's totara forest

The kowhai-Hall's totara zone occupies the elevation zone above the Kowhai woodland zone on the foothills of Rough Ridge (Manorburn uplands environmental domain). It also extends northward to the summits of Blackstone

Hill and Home Hills, and encompasses the lower foothills of the Hawkdun Range (upper Maniototo domain). A narrow band of this zone occurs immediately above the kanuka-kowhai-Hall's totara zone on the Dunstan Mountains, where it straddles the northern basin rims and northern ranges domains.

The models suggests a richer woody flora than on the lower-elevation valley floors. *Sophora microphylla* (kowhai), *Leptospermum scoparium* (manuka), *Podocarpus hallii* (Hall's totara), *Pseudopanax colensoi* (mountain threefinger) and *Podocarpus nivalis* (snow totara) are predicted to have occurred here, together with *Nothofagus menziesii* (silver beech), *N. solandri* var. *cliffortioides* (mountain beech), *Phyllocladus alpinus* (mountain toatoa) and *Griselinia littoralis* (broadleaf). Understorey species predicted in this zone include *Aristotelia fruticosa*, *Coprosma* 'taylorae', *C. rugosa*, *Hebe salicifolia*, *Dracophyllum longifolium* and *Myrsine divaricata* and lianes such as *Clematis marata*, *Rubus cissoides*, and *Helichrysum lanceolatum*. Shade-intolerant species such as *Pimelea oreophila*, *Carmichaelia crassicaule*, *Leucopogon colensoi*, *Olearia bullata*, *Coprosma intertexta*, *C. ciliata*, *C. petriei*, *Gaultheria antipoda*, *G. depressa* var. *depressa*, *Ozothamnus leptophyllus*, *Helichrysum intermedium* var. *selago*, *Olearia nummularifolia*, *Pimelea pseudolyallii* and *Corokia cotoneaster* are also predicted here, together with species that are presently more widespread in seral woody associations (*Coprosma propinqua*, *Melicytus alpinus*, *Rubus schmidelioides*, *Discaria toumatou*, *Carmichaelia petriei* and *Olearia odorata*). Species with restricted ranges that may previously have been more widespread in this zone include *Carmichaelia kirkii*, *C. compacta*, *Hebe cupressoides*, *H. lycopodioides* var. *lycopodioides*, *Melicope simplex*, *Olearia cymbifolia* and *Scandia geniculata*.

Half (50%) of the present-day study plots in this zone were classified within the matagouri-mingimingi woody plant association (E), and a further 15% in the matagouri-native broom association (G; Table 10). No intact forest fragments were recorded, but a relatively high proportion (12%) of study plots were classified as forest relicts (woody plant association B). Most remaining plots at higher elevations are classified within woody plant associations H (highly modified subalpine shrub and subshrub), I (*Ozothamnus* low alpine shrub and subshrub), and N (widespread low alpine subshrub).

Zone VI—Kowhai-beech-lancewood forest

This zone encompasses relatively moist montane areas on the southern and eastern fringes of the Central Otago basins. It includes the southern and eastern segments of the Maniototo Plain, within the Maniototo Basin, Upper Maniototo and Manorburn uplands environmental domains. It also occupies part of the Clutha Valley south of Fruitlands (Alexandra Basin rim domain), and the lower slopes of the Waikaia Valley in the south-west of the study area (Coastal hill country and South-eastern valleys domains). The latter areas presently contain fragments of closed-canopy *Nothofagus menziesii* and mixed beech forest.

Sophora microphylla (kowhai), *Nothofagus menziesii* (silver beech), *Pseudopanax crassifolius* (lancewood) and *N. solandri* var. *cliffortioides* (mountain beech) are predicted to have been the main canopy trees in this vegetation zone. The models also suggest that *Carpodetus serratus* (marbleleaf) and *Griselinia littoralis* (broadleaf) were once common throughout the zone, and

that *Podocarpus hallii*, *Pseudopanax colensoi*, *Leptospermum scoparium*, *Kunzea ericoides* and *Nothofagus fusca* (red beech) all occurred here. Understorey species predicted to have occurred here include *Myrsine divaricata*, *Coprosma colensoi*, *C. rugosa*, *C. rhamnoides*, *C.* 'taylorae', *Hebe salicifolia* and *Aristotelia fruticosa* and the lianes *Clematis marata*, *Muehlenbeckia australis*, *Rubus cissoides* and *Helichrysum lanceolatum.* Shade-intolerant species such as *Coprosma propinqua*, *Carmichaelia petriei*, *Rubus schmidelioides*, *Discaria toumatou* and *Melicytus alpinus* are predicted here, together with *Coprosma intertexta*, *C. ciliata*, *Corokia cotoneaster*, *Muehlenbeckia complexa*, *Olearia odorata*, *O. bullata*, *O. lineata*, *Ozothamnus leptophyllus* and the subshrubs *Leucopogon colensoi* and *Pimelea pseudolyallii*. Numerous species with restricted ranges presently occur within this zone, including *Raukaua simplex*, *Pittosporum tenuifolium*, *Fuchsia excorticata*, *F. perscandens*, *Hoheria glabrata*, *H. lyallii*, *Olearia fimbriata*, *O. hectorii*, *Scandia geniculata* and *Teucridium parvifolium*.

The present-day woody vegetation includes beech forest remnants in the Umbrella district (26% of plots, woody plant association A), and several shrub associations, including matagouri-mingimingi (E: 34%) and broom-gorse (C: 28%). Forest relicts (woody plant association B), and the matagouri-native broom (G), briar (D) and dry *Melicytus* (F) woody plant associations account for the remaining sites.

Zone VII—Beech-Hall's totara-snow totara forest

This zone covers the cool, elevated peneplain surfaces of North and South Rough Ridge in the Manorburn Ecological District, within the Manorburn uplands and Lammerlaw environmental domains. In the north-west of the district, it occupies a narrow elevation zone above the kanuka-kowhai-Hall's totara zone, while on the Dunstan Mountains and the Hawkdun Ranges, and on Rough Ridge, it occurs above the kowhai-Hall's totara zone. In the south-west of the region, including the Umbrella and eastern Manorburn ecological districts, it occupies the altitudinal zone above the kowhai-beech-lancewood forest zone.

The models predict a diverse forest zone, with *Podocarpus nivalis*, *P. hallii*, *Nothofagus menziesii* and *Nothofagus solandri* var. *cliffortioides* as the most abundant canopy trees, and *Leptospermum scoparium*, *Pseudopanax colensoi*, *Phyllocladus alpinus*, *Carpodetus serratus* and *Griselinia littoralis* as common subsidiary species. They suggest that *Halocarpus bidwillii* (bog pine) may have been present occasionally, but *Sophora microphylla* and *Kunzea ericoides* are predicted to have been less abundant than in lower-altitude zones. Many subcanopy species are predicted here, including *Aristotelia fruticosa*, *Coprosma* 'taylorae', *C. rhamnoides*, *C. colensoi*, *C. crassifolia*, *C. rugosa*, *Clematis marata*, *Rubus cissoides*, *Myrsine divaricata*, *Hebe salicifolia* and *Dracophyllum longifolium*. The models suggest that shade-intolerant species *Carmichaelia petriei*, *Melicytus alpinus*, *Coprosma propinqua* and *Discaria toumatou* may have been important light-gap species in this zone, together with other shrubs such as *Carmichaelia crassicaule*, *Coprosma ciliata*, *Dracophyllum uniflorum*, *Olearia odorata*, *O. bullata*, *O. nummularifolia*, *Ozothamnus leptophyllus*, *Helichrysum intermedium* var. *selago* and the subshrubs *Coprosma petriei*, *Gaultheria crassa*, *G. depressa* var. *depressa*, *Leucopogon colensoi*, *Myrsine nummularia*, *Pentachondra pumila*, *Pimelea*

oreophila and *P. traversii*. The zone now contains many species that are relatively restricted in the region, but which may have previously been more abundant and widespread, including *Brachyglottis cassinioides*, *Coprosma rubra*, *Fuchsia excorticata*, *Hebe lycopodioides* var. *lycopodioides*, *H. propinqua*, *Hoheria glabrata*, *H. lyallii*, *Olearia avicenifolia*, *O. arborescens*, *O. cymbifolia*, *Parsonsia capsularis*, *Pennantia corymbosa*, *Raukaua simplex* and *Rubus squarrosus*.

A wide range of woody plant associations presently occurs in this zone. About one-third (30%) of plots were classified in the matagouri-mingimingi woody plant association (E). Widespread forest relicts (woody plant association B) and the matagouri-native broom woody plant association (G) each account for about 15% of plots. Highly modified subalpine shrub and subshrub (H, 11%), *Ozothamnus leptophyllus* low alpine shrub and subshrub (I, 9%) and dry *Melicytus* shrub (F, 6%) associations are also recorded in this zone.

Zone VIII—Snow totara-mountain toatoa shrubland

The Beech-Hall's totara-snow totara forest zone is replaced by the snow totara-mountain toatoa zone above 900–1000 m elevation on the flanks of all of the major Central Otago mountain ranges. In the north and west, this zone occurs within the Northern ranges environmental domain, while in the south and east it occupies the Lammerlaw domain and extends into the lower regions of the Rolling ridge crests domain.

The models predict that the pre-settlement vegetation was dominated by *Podocarpus nivalis* (snow totara) and *Phyllocladus alpinus* (mountain toatoa), and that patches of *Halocarpus bidwillii* (bog pine) may have been common. They suggest that *Nothofagus menziesii* (silver beech) forest, containing *Podocarpus hallii*, *Carpodetus serratus*, *Cordyline australis*, *Griselinia littoralis*, *Leptospermum scoparium* and *Pseudopanax colensoi*, may have occurred locally. Understorey species predicted by the models include *Coprosma* 'taylorae', *C. rugosa*, *C. crassifolia* and *Aristotelia fruticosa*, and shade intolerant shrubs such as *Ozothamnus leptophyllus*, *Olearia nummularifolia*, *Dracophyllum uniflorum*, *Coprosma ciliata*, *Carmichaelia crassicaule*, *C. petriei*, *Hebe odora*, *Hebe rakaiensis* and *Melicytus alpinus*, and the subshrubs *Gaultheria antipoda*, *Gaultheria depressa* var. *depressa*, *Leucopogon colensoi*, *Pimelea oreophila* and *P. pseudolyallii* are also predicted here. Species with restricted ranges that occur within this zone include *Coprosma cuneata*, *C. pseudocuneata*, *C. rubra*, *Hebe epacridea*, *H. propinqua*, *H. lycopodioides* var. *lycopodioides*, *Hoheria glabrata*, *Olearia arborescens*, *Pimelea poppelwellii* and *Raukaua simplex.*

Forest relicts account for c. 13% of vegetation plots sampled in this potential forest vegetation zone. Associations I (*Ozothamnus* low alpine shrub and subshrub: 21%), H (highly modified subalpine shrub and subshrub: 22%), and K (*Hebe odora*-mountain toatoa subalpine shrub: 13%) are recorded in the south-east of the district. The matagouri-native broom association (G) was also recorded at lower elevations. Towards the upper altitudinal limits of the vegetation zone, woody plant asssociations include the *Dracophyllum uniflorum* low alpine shrub and subshrub association (J), and the *D. muscoides* high alpine subshrub association (M).

Zone IX—Bog pine-snow totara-mountain toatoa shrubland

This zone occupies large portions of the crests of the Lammerlaw and Rock and Pillar ranges in the Lammerlaw and rolling ridge crests environmental domains, adjacent to but at higher elevations than the snow totara-mountain toatoa and the manuka-mountain toatoa-kowhai-beech zones. The zone is more narrow on the slopes of the more northern Central Otago ranges, where it lies within the lower northern ranges and higher rolling ridge crests environmental domains. In the south-west of Central Otago, on mountain slopes in the Umbrella and Nokomai ecological districts, it is also restricted to a narrow altitudinal band, but here it covers three environmental domains (northern ranges and rolling ridge crests, and Lammerlaw). On the range slopes of Dansey Ecological District, this zone occurs largely within the northern ranges domain.

The models predict that *Podocarpus nivalis* (snow totara) and *Phyllocladus alpinus* (mountain toatoa) may have dominated the pre-settlement vegetation, with patches of *Halocarpus bidwillii* (bog pine) in what may have been low forest or shrubland canopies. The models suggest that the zone is only marginally suitable for *Leptospermum scoparium*, *Podocarpus hallii*, *Pseudopanax colensoi*, *Griselinia littoralis* and *Nothofagus menziesii*. Shade-intolerant shrubs predicted to have occurred here include *Coprosma* 'taylorae', *C. ciliata*, *Dracophyllum longifolium*, *D. uniflorum*, *Olearia nummularifolia*, *Ozothamnus leptophyllus*, *Hebe odora* and *Melicytus alpinus*, and subshrubs such as *Gaultheria depressa* var. *depressa*, *G. antipoda*, *Leucopogon colensoi*, *Pimelea oreophila*, *P. pseudolyallii*, and *Coprosma petriei*. The models suggest that several other cold-tolerant woody species might have extended into this zone, including *Carmichaelia crassicaule*, *C. petriei*, *C. rigida*, *Helichrysum intermedium* var. *selago*, *Hebe buchananii*, *H. pinguifolia*, *H. propinqua*, *H. rakaiensis*, and the subshrubs *Carmichaelia vexillata*, *Coprosma atropurpurea*, *C. cheesemanii*, *Dracophyllum politum*, *D. pronum*, *Gaultheria crassa*, *G. macrostigma*, *Myrsine nummularia* and *Pentachondra pumila*.

Much of the present-day woody vegetation in this potential low forest zone is classified within the southern *Hebe odora*-mountain toatoa subalpine (K: 35% of plots), *Ozothamnus* low alpine (I: 19%), *Dracophyllum uniflorum* low alpine (J: 12%) and highly modified subalpine (H: 10%) shrub and subshrub associations. Although this zone lies above the present upper altitudinal limit of beech forest remnants (woody plant association A), forest relicts (woody plant association B) are relatively common (recorded in about 7% of plots).

Zone X—Alpine tussock-shrubland

The alpine tussock-shrubland zone is restricted to the highest elevations in Central Otago, and occurs only within the northern ranges and rolling ridge crests environmental domains. It is most extensive on the summits of Old Man, Old Woman, and Pisa ranges and the Garvie Mountains. However, it also occurs on the crests of the St Bathans and Hawkdun ranges, and in smaller areas on the summits of the Dunstan and Kakanui mountains and the Rock and Pillar Range.

The models predict dominance by mat-forming and other low-statured woody plants, including *Dracophyllum muscoides*, *D. pronum*, *D. uniflorum*, *Coprosma petriei*, *Gaultheria depressa* var. *depressa*, *G. nubicola*, *Pimelea oreophila*, *P. pseudolyallii* and *Myrsine nummularia*. However, certain taller shrubs are also predicted here, including *Ozothamnus leptophyllus*, *Melicytus*

alpinus, *Brachyglottis revolutus*, *Hebe buchananii*, *H. hectorii* var. *hectorii*, *H. subalpina* and *Helichrysum intermedium* var. *selago*. Species that are presently uncommon, local or rare in Central Otago that were recorded in this vegetation zone include *Hebe hectorii* var. *subulata*, *H. lycopodioides* var. *lycopodioides*, *H. propinqua*, *H. petriei*, and subshrubs such as *Coprosma atropurpurea* and *Gaultheria parvula.*

Presently, about 34% of plots in the alpine tussock-shrubland zone support the *Dracophyllum muscoides* high alpine woody plant association (M). Most of the remainder of plots were classified as widespread low alpine (N: 18%), *Ozothamnus* low alpine (I: 14%), and highly modified subalpine (H: 11%) woody plant associations. At lower elevations in the south of the region, the *Brachyglottis revolutus* low alpine (L) and southern *Hebe odora*-mountain toatoa subalpine (K) woody plant associations presently occur here.

Zone XI—Beech-kowhai-cabbage tree forest

A diverse lowland forest composition is predicted on the valley floors and lower hillslopes of the Shag, Taieri and lower Clutha rivers, where the climate is warmer and drier than in adjacent areas of higher elevation. The zone is centred on the south-eastern valleys and recent Taieri soils environmental domains, but extends upslope into parts of the Manorburn uplands and south-eastern ranges domains.

The models suggest that the environment is optimal for both *Sophora microphylla* (kowhai) and *Nothofagus menziesii* (silver beech). A number of other relatively tall woody species, including *Cordyline australis*, *Griselinia littoralis*, *Carpodetus serratus*, *Leptospermum scoparium* and *Kunzea ericoides*, the subcanopy species *Hebe salicifolia* and *Coprosma crassifolia*, and the liane *Muehlenbeckia australis* are also predicted to have occurred more commonly here than in the kowhai-beech-lancewood zone that lies further inland. The models suggest that the environment is less suitable for several other species, including *Podocarpus hallii*, *Pseudopanax colensoi*, *P. crassifolius*, *Nothofagus solandri* var. *cliffortioides*, *N. fusca*, *Halocarpus bidwillii*, the subcanopy shrubs *Myrsine divaricata*, *Coprosma crassifolia* and *C. colensoi*, the liane *Rubus cissoides*, and some of the shade-intolerant shrubs that are currently characteristic of inland basins, such as *Olearia odorata* and *Coprosma intertexta*. However, some apparently shade-intolerant species such as *Coprosma propinqua*, *Carmichaelia petriei*, *Rubus schmidelioides*, *Discaria toumatou* and *Olearia bullata*, and the small tree *O. lineata*, are predicted to have been relatively common here. Several other woody species now occur in the beech-kowhai-cabbage tree forest zone, but were not included in our models because they are rare in the Central Otago region (e.g. *Aristotelia serrata*, *Coprosma virescens*, *Pittosporum tenuifolium*, *Fuchsia perscandens*, *F. excorticata*, *Hoheria lyallii*, *Melicope simplex*, *Olearia arborescens*, *O. avicenitifolia*, *O. hectorii*, *Rubus australis* and *Scandia geniculata*). These may have been more widespread here prior to human arrival.

The present woody vegetation is dominated by matagouri-mingimingi (E: 43% of plots) and broom-gorse (C: 32%) woody plant associations. The matagouri-native broom (G) association was recorded in about 11% of our study plots, and forest relicts (woody plant association B) were recorded in 6% of plots.

Zone XII—Beech-mountain toatoa-kowhai-manuka forest

This forest zone encompasses the southern and eastern perimeter of the region, including higher-elevation land in the Macraes ecological district, lower-altitude parts of the Waipori and Umbrella ecological districts, the foothills of the Kakanui Mountains, and a narrow zone along the eastern slopes of the Rock and Pillar Range. It encompasses all of the Coastal hill country environmental domain and parts of the Manorburn uplands, south-eastern valleys and south-eastern ranges domains. Relatively low mean annual temperatures and solar radiation inputs result from elevation above the floors of the southern valleys, predominantly southern latitude, and proximity to the coast. Evaporation rates and annual water deficits are also lower than in the beech-kowhai-cabbage tree forest zone (XI) on the lower range slopes and floors of the south-eastern valleys.

The models predict pre-settlement forests in which the principal species were *Nothofagus menziesii* (silver beech), *Sophora microphylla* (kowhai), and *Phyllocladus alpinus* (mountain toatoa). They suggest that the environment is optimal for *Leptospermum scoparium* (manuka), given its present distribution, and that *Kunzea ericoides* (kanuka), and *Podocarpus hallii* (Hall's totara), *P. nivalis* (snow totara) and *Halocarpus bidwillii* (bog pine) may been more common at these elevations than on adjacent valley floors, but that *Griselinia littoralis* (broadleaf), *Pseudopanax colensoi*, *P. crassifolius*, *Cordyline australis* and *Carpodetus serratus* may have been less so. Understorey species predicted here included *Hebe salicifolia*, *Coprosma* 'taylorae', *Coprosma rugosa* and *Dracophyllum longifolium*, and the models suggest that shade-intolerant species may have included *Olearia bullata*, *Ozothamnus leptophyllus* and *Dracophyllum uniflorum* and the subshrubs *Gaultheria antipoda* and *Leucopogon colensoi*. Trees and shrubs of *Fuchsia excorticata*, *Myrsine australis*, *Olearia arborescens*, *O. aviceniifolia*, *Olearia fimbriata*, *Olearia ilicifolia*, *Pittosporum eugenioides* and lianes such as *Fuchsia perscandens* and *Scandia geniculata* still occur within this zone and these species were probably common prior to the arrival of humans.

The present woody vegetation is similar to that found in the drier southern valleys zone, and matagouri-mingimingi (E) and broom-gorse (C) woody plant associations predominate (accounting for 24 and 23% of plots, respectively). Matagouri-native broom (G: 16% of plots), southern *Hebe odora*-mountain toatoa (K: 15%), and forest relict (woody plant association B, 10%) shrub and subshrub associations are also common.

6.3.2 Evidence from charcoal, subfossil wood and pollen

Subfossil charcoal and wood

Subfossil wood, charcoal, buried podzols and forest dimples indicating pre-settlement forests in eastern South Island were mapped by Molloy et al. (1963). More recently, Wardle (2001a) documented the distribution of charcoals in the Upper Clutha district of Central Otago, and the Landcare Research radiocarbon database holds further records. Although sparse, and requiring cautious interpretation (cf Section 5.5.6) these data provide some independent verification of the pre-settlement distributions of some canopy trees estimated by our models, and indicate where our estimates may be biased by the elimination of species from the more modified margins of their former ranges.

Wardle (2001b) notes that the fire-sensitive *Phyllocladus alpinus* is the most widespread charcoal type found in the Upper Clutha, occurring from treeline 'almost to the valley floor', especially in the Queensberry (eastern Pisa Range) and Bendigo (western Dunstan Mountains) areas. Our models, based on extant distributions, favour a predominantly higher-elevation distribution. They suggest that *P. alpinus* was absent or very rare on the Upper Clutha valley floors (kanuka-kowhai woodland zone) and a minor component of the kanuka-kowhai-Hall's totara zone (i.e. eastern Pisa Range and western Dunstan Mountains below 700 m), and the kowhai-Hall's totara-snow totara zones (slopes of the Dunstan Mountains between 700 and 900 m). They predict that *P. alpinus* increased above c. 800 m on the eastern slopes of the Pisa Range, and c. 900 m on the western Dunstan Mountains, and reached an environmental optimum between 1050 and 1150 m. As elsewhere in New Zealand, *Halocarpus* charcoals are less common than those of *Phyllocladus*, but they are recorded within the kanuka-kowhai-Hall's totara zone near Queensberry (Wardle 2001b). Taken together, the evidence suggests that the pre-settlement range of *P. alpinus* and *Halocarpus bidwillii* was likely to have extended to frosty fans and terraces below treeline, as in the Mackenzie Basin, but that these species were comprehensively eliminated from the lower parts of their former range in Central Otago by early human fires.

Records of logs and charcoals of *Podocarpus hallii* (Hall's totara), many of which have been dated to approximately the time of human arrival, are relatively common in the Upper Clutha (Wardle 2001b). These, and additional records from Molloy et al. (1963), suggest that *P. hallii* was widespread in the montane and subalpine zones in pre-settlement times, as estimated by our models.

The closest extant *Prumnopitys taxifolia* (matai) trees to our study region are at Diamond Lake and West Wanaka in the Matukituki Valley. Only two records of *P. taxifolia* charcoal are known from Central Otago: one from the southern shore of Lake Hawea (kanuka-kowhai-Hall's totara zone, undated, Wardle 2001b) and a tentative identification from c. 5 km south-east of Wanaka that is dated to the mid-Holocene (6650 ± 110 yr BP: M.L. Leamy and D.M. Leslie, unpublished radiocarbon Number 1953, GR F40 068 030). *Prumnopitys taxifolia* seed cases and charcoals (presumably undated) have been recovered from moraines in the Mackenzie Basin (Molloy et al. 1963), and Molloy (1969) records plentiful *P. taxifolia* charcoal both there, and on deep, well-drained Canterbury Plains soils, where it co-occurs with *Kunzea ericoides* (kanuka) charcoals. The Canterbury sites are relatively close climate analogues to lowland sites in Central Otago, but the geology there is better disposed to the preservation of charcoals. In its extant range, *P. taxifolia* is restricted to low elevations, and appears to tolerate severe frost and both soil and atmospheric water deficits (Leathwick & Whitehead 2001). A national estimate of its potential distribution, based on existing trees, predicts maxima on valley floors of inland basins across the eastern South Island (J.R. Leathwick, unpubl. data): in Central Otago, these coincide with our kanuka-kowhai woodland (I), kowhai-kanuka woodland (II), and kanuka-kowhai-Hall's totara forest (IV) pre-settlement woody vegetation zones.

Locations of *Nothofagus* (beech) charcoal in the Upper Clutha catchment (Wardle 2001b) do not extend beyond the arid, low-elevation limits of extant

trees in the kanuka-kowhai-Hall's totara woody zone. However, *Nothofagus* charcoals are seldom present, even in soils that are directly adjacent to extant stands with obvious fire-sharpened boundaries. Wells (1972) concluded that forests of *Podocarpus hallii* and *N. menziesii* (silver beech) and other species were extensive on the eastern slopes of the Pisa Range prior to human arrival. Our models lead to a similar conclusion. Records of *Nothofagus* charcoals and buried podzols within the kanuka-kowhai-Hall's totara and kowhai-Hall's totara pre-settlement woody vegetation zones in the upper Manuherikia Valley (Molloy et al. 1963), suggest that our models may in fact be too conservative (they predict only 3–6% presence for both *N. menziesii* and *N. solandri* var. *cliffortioides* there).

The pollen record

The pollen record is more generalised, and ambiguous, than *in situ* charcoal evidence (cf Section 5.5.6). Interpretations from most pollen sites conform broadly with our model's predictions and, in places, they provide some corroboration for our models of vegetation composition immediately prior to the arrival of humans. However, they also suggest the presence of various tree species that are now rare, and which may have been removed following the first fires soon after human arrival.

The interpretation of pollen from Idaburn Valley (kowhai-kanuka woodland zone II, but adjacent to zone IV) suggests pre-settlement vegetation comprising small-leaved shrubs of *Olearia*, *Coprosma*, and *Myrsine*, with taller vegetation of *Podocarpus hallii*, *Halocarpus* and *Phyllocladus* on nearby hillslopes. Poaceae are well represented, suggesting that some grassland was established in the vicinity. Nevertheless, grass pollen percentages increase several fold at the time of human settlement.

Earnscleugh Cave pollen (within the kanuka-kowhai-Hall's totara forest zone (IV) but adjacent to zones II, III, V, VI and VII) was interpreted to indicate that stands of tall podocarps *Prumnopitys taxifolia* (matai), *Podocarpus totara* (totara), and perhaps also *Dacrycarpus dacrydioides* (kahikatea) and *Dacrydium cupressinum* (rimu) may have grown in the vicinity, in more sheltered and damper environments on valley sides, from the mid-Holocene. Podocarp forest may have became more restricted in the period prior to human arrival, when *Sophora*, *Hoheria*, *Myrsine* and woody and herbaceous Asteraceae species may have formed a more open woodland, perhaps in response to infrequent, localised natural fires encouraged by drier conditions in the late Holocene. However, McGlone (2001) has argued more recently that deforestation by natural fire was probably relatively insignificant prior to human arrival.

The Clarks Junction pollen record suggests a rich pre-settlement woody vegetation in the vicinity, similar in composition to that predicted for the local Beech-mountain toatoa-kowhai-manuka (XII) and adjacent Beech-kowhai-cabbage tree (XI) zones. However, species that are now absent or rare in Central Otago are well represented in the pre-settlement pollen here, including *Prumnopitys taxifolia* (matai), *Libocedrus* (pahautea), and malvaceous (probably *Hoheria* and *Plagianthus*) trees.

The Kawarau pollen site is located on the steep southern slopes of the Pisa Range. Five zones of pre-settlement woody vegetation (I, IV, VII, VIII and IX)

TABLE 12 POLLEN SITES THAT HAVE BEEN DESCRIBED IN CENTRAL OTAGO PRE-SETTLEMENT WOODY VEGETATION ZONES (I TO XII), AND THE INTERPRETATIONS GIVEN OF THE PRE-SETTLEMENT WOODY VEGETATION.

NO.	PRE-SETTLEMENT WOODY VEGETATION ZONE	POLLEN SITE	ELEV. (m)	NZMS MAP	NZMS EASTING	NZMS NORTHING	INTERPRETATION OF VEGETATION (IMMEDIATELY PRE-SETTLEMENT)
I	Kanuka-kowhai woodland	–					
II	Kowhai-kanuka woodland	Idaburn Valley	420	H41	2250900	5561900	Shrub-grassland mosaic with *Coprosma* and *Olearia*, and *Phyllocladus*, *Podocarpus hallii* and *Halocarpus* on adjacent slopes. Asteraceae (e.g. *Taraxacum*) common (McGlone & Moar 1998).
III	Kowhai woodland	–					
IV	Kanuka-kowhai-Hall's totara	Earnscleugh Cave	540	G42	2219000	5538700	Open woodland of *Sophora*, *Hoheria*, *Kunzea* and small-leaved shrubland of *Muehlenbeckia*, *Coprosma* and *Myrsine*. Small lowland stands of tall podocarp forest (esp. *Prumnopitys*) grading into *Podocarpus hallii* on upper hillslopes, then *Phyllocladus* and silver beech to tree line (Clark et al. 1996).
V	Kowhai-Hall's totara	–					
VI	Kowhai-beech-lancewood	–					
VII	Beech-Hall's totara-snow totara	Kawarau Gorge	800	F41	2202600	5571100	*Phyllocladus*, *Podocarpus hallii* and *Halocarpus* with some beech pollen, *Coprosma, Myrsine* and tall tussock grassland (McGlone et al. 1995)
VIII	Snow totara-mountain toatoa	–					
IX	Bog pine-snow totara-mountain toatoa	Teviot Swamp	980	G43	2247800	5502500	Unpublished
X	Alpine	Waikaia Bush Road, Old Man Range	1400	G43	2212700	5522700	Pollen rain. Interpreted to indicate tall *Podocarpus*/*Prumnopitys* forest on lower range flanks, with *Nothofagus menziesii*, *Phyllocladus alpinus* and *Halocarpus bidwillii* at timberline (McGlone et al. 1997).
		Garvie Mountains	1400	F43	2185000	5520000	Similar to above (McGlone et al. 1995).
XI	Beech-kowhai-cabbage tree	–					
XII	Beech-mountain toatoa-kowhai-manuka	Clarks Junction	520	H44	2280000	5493700	Widely spaced podocarp dominants over low variable mixed angiosperm and gymnosperm canopies (*Prumnopitys, Podocarpus, Halocarpus, Phyllocladus, Hoheria, Plagianthus, Muehlenbeckia, Coprosma, Myrsine*: McGlone 2001)

form an elevation sequence within 2.5 km of the site, and most of the species that our models predict to have occurred here prior to human arrival are represented in the pollen record.

Prumnopitys taxifolia pollen is abundant (approx. 20% of the pollen sum) in all Central Otago pollen sites, which may represent either scattered stands of *P. taxifolia* (e.g. along the fringes of the Central Otago basins; M.S. McGlone, pers. comm.) or pollen rain entirely from distant sources such as the Southland Plains (McGlone 2001). *Dacrycarpus dacrydioides*, *Dacrydium cupressinum* and *P. ferruginea* pollens are also recorded at low percentages in most inland Central Otago pollen cores. As with *P. taxifolia*, no subfossil evidence for the local presence of these gymnosperms has been recovered to date.

6.3.3 Changes in extent of woody vegetation in Central Otago

The estimated extent of pre-settlement forest zones totals 77% of our Central Otago study area (Table 13) while woodland zones account for a further 17%. Non-forest alpine tussock shrubland are estimated to have covered 6% of the

TABLE 13 COMPARISON OF PRE-SETTLEMENT WOODY VEGETATION COVER IN CENTRAL OTAGO WITH PRESENT WOODY VEGETATION.
The table shows estimated areas of forest and shrubland in each of the 12 zones of pre-settlement woody vegetation at the time of human settlement (assumptions of percentage cover of forest, shrubland and non forest herbaceous cover for each zone are described in the text), and the present areas of forest and shrubland estimated in New Zealand Land Cover Database (LCDB1). The last two columns indicate the percentages of the estimated potential pre-settlement forest that has been converted to non-forest (i.e. shrubland or herbaceous vegetation), and the percentage of woody vegetation that has been converted to herbaceous non-woody vegetation since human settlement.

NUMBER	PRE-SETTLEMENT WOODY VEGETATION ZONE	ESTIMATED AREA OF POTENTIAL PRE-SETTLEMENT FOREST (km^2)	ESTIMATED AREA OF POTENTIAL PRE-SETTLEMENT SHRUBLAND (km^2)	AREA IN km^2 (AND %) LCDB1 INDIGENOUS FOREST CATEGORY	AREA IN km^2 (AND %) IN LCDB1 SCRUB INCL. EXOTIC SPECIES CATEGORY	ESTIMATED FOREST LOSS (%)	ESTIMATED % WOODY VEGETATION CONVERTED TO HERBACEOUS NON-FOREST VEGETATION
I	Kanuka-kowhai woodland	185	185	0 (0.0)	58 (7.8)	100.0	84.4
II	Kowhai-kanuka woodland	253	253	0 (0.0)	9 (0.9)	100.0	98.2
III	Kowhai woodland	207	207	0 (0.0)	16 (2.0)	100.0	96.0
IV	Kanuka-kowhai-Hall's totara	1321	0	14 (1.0)	108 (7.8)	98.9	90.7
V	Kowhai-Hall's totara	901	0	0 (0.0)	20 (2.1)	100.0	97.8
VI	Kowhai-beech-lancewood	2481	0	56 (2.1)	32 (1.2)	97.8	96.5
VII	Beech-Hall's totara-snow totara	1091	0	67 (5.9)	91 (7.9)	93.8	85.5
VIII	Snow totara-mountain toatoa	1288	0	9 (0.7)	7 (0.5)	99.3	98.7
IX	Bog pine-snow totara-mountain toatoa	686	0	0 (0.0)	23 (3.1)	100.0	96.7
X	Alpine tussock-shrublands	n/a	n/a	0 (0.0)	3 (0.3)	n/a	n/a
XI	Beech-kowhai-cabbage tree	1304	0	6 (0.5)	73 (5.3)	99.5	93.9
XII	Beech-mountain toatoa-kowhai-manuka	2104	0	13 (0.6)	49 (2.2)	99.4	97.0
	Total	11820	644	166 (1.1)	486 (3.2)	98.7	87.1

land area. We excluded this zone from our estimates of change in woody vegetation cover.

Analysis of the first New Zealand Land Cover Database (LCDB1) reveals that native forest is estimated to cover 1.1% of the study area, which is equivalent to a 98.7% loss of the potential forest cover across the whole non-alpine region. Scrub (native and exotic) is estimated to cover 3.2% of the land area. From these figures, we calculated that 94.8% of the potential woody vegetation of non-alpine areas (both shrubland and forest) in the Central Otago region has been converted from woody to herbaceous woody plant associations since human settlement.

No forest vegetation is mapped in LCDB1 within five zones of pre-settlement woody vegetation: the lowland woodland zones I, II and III, the kowhai-Hall's totara forest zone (V), and the bog pine-snow totara-mountain toatoa shrubland zone (IX). Forest loss is ≥98.9% complete in a further four zones: the kanuka-kowhai-Hall's totara (IV), beech-kowhai-cabbage tree (XI) and beech-mountain toatoa-kowhai-manuka (XII) forest zones, and the snow totara-mountain toatoa (VIII) shrubland zone. The largest areas and proportions of pre-settlement forest vegetation are retained in the beech-Hall's totara-snow totara (VII) and kowhai-beech-lancewood (VI) forest zones, due to the survival of tracts of beech forest on the south-west and north-west fringes of the region.

We estimated proportions of total woody vegetation loss based on the assumption that each of the three lowland pre-settlement woody vegetation zones (the woodland zones I, II and III) comprised 25% tall or low forest, 25% shrubland, and 50% herbaceous non-forest vegetation and that the six forest zones (IV, V, VI, VII, XI, XII) and the two shrubland zones (VIII, IX) included 5% cover of herbaceous non-woody vegetation, bare rock, or bare soil. Of the 12 pre-settlement woody vegetation zones, we estimated that proportions of total woody vegetation loss were lowest (c. 85%) in the kanuka-kowhai woodland (I) and the beech-Hall's totara-snow totara (VII) forest zones. Indigenous and exotic scrub, as classified in the LCDB, is most extensive in the kanuka-kowhai woodland (I), kanuka-kowhai-Hall's totara (IV), and beech-kowhai-cabbage tree (XI) zones, where it is estimated to cover 5–8% of the land area. Our classification of present woody vegetation suggests that broom-gorse, briar, and matagouri-mingimingi woody plant associations predominate in these areas mapped as scrub vegetation.

6.4 POTENTIAL DISTRIBUTIONS OF EXOTIC WOODY SPECIES

Elevation is the primary determinant of the present distribution of woody weeds in Central Otago: most weeds are confined to low elevation zones of pre-settlement woody vegetation (< 600 m: zones I, II, III, VI, XI and XII) and only *Pinus* spp. (pines) and occasionally *Rosa rubiginosa* (briar) extend to the range tops (Tables 14 and 15). Lowland environments in Central Otago may be particularly suitable for the establishment of ruderal species, both in terms of climatic characteristics, and because disturbed, nutrient-enriched microsites are available as a result of human and animal activities. However, the pattern we see may be largely attributable to the fact that most exotic woody species are relatively recent arrivals (i.e. < 150 years) and are therefore still expanding their ranges from points of introduction in the lowlands. Therefore, our estimates of potential distributions are likely to be conservative.

Thymus vulgaris (thyme) is presently largely restricted to the driest basin floors, although its potential range extends beyond the three woodland zones (I, II and III) and onto the foothill and lower hillslopes in the kanuka-kowhai-Hall's totara (IV), kowhai-Hall's totara-snow totara (V) and kowhai-beech-lancewood (VI) zones (Table 14). *Lupinus arboreus* (tree lupin) and *Malus domestica* (apple) have similar predicted ranges, although they are less common than *T. vulgaris* at higher elevations (e.g. the kowhai-Hall's totara-snow totara (V) zone) and their predicted range extends into the more mesic Beech-kowhai-cabbage tree zone (XI). *Cytisus scoparius* (broom), *Ulex europaeus* (gorse), *Sambucus nigra* (elderberry), *Crataegus monogyna* (hawthorn), *Ribes uva-crispa* (gooseberry) and *Populus* (poplar) and *Salix* (willow) species from species groups *f* and *g* in the classification of present vegetation, are distributed throughout both moist and semiarid lowlands. *Rosa rubiginosa* and *Pinus* spp. presently occur across a wide range of environments, and are predicted to invade more zones of pre-settlement woody vegetation than other major woody weeds. Optimum conditions for *R. rubiginosa* are found in the semiarid basin floor and basin rim foothill

TABLE 14 PREDICTED OCCURRENCE (P_s) OF THE 12 MOST COMMON EXOTIC WOODY SPECIES IN PRE-SETTLEMENT WOODY VEGETATION ZONES, FROM GENERAL ADDITIVE MODELS OF SPECIES PRESENCE ON ENVIRONMENT ONTO A 1 × 1 KM GRID.
Exotic woody species occur in five of the eight species groups (Gps *c* to *g*) identified in the classification of present woody communities (Table 3).

SPECIES GROUP	PRE-SETTLEMENT WOODY VEGETATION ZONE / EXOTIC SPECIES	I KANUKA-KOWHAI WOODLAND	II KOWHAI-KANUKA WOODLAND	III KOWHAI WOODLAND	IV KANUKA-KOWHAI-HALL'S TOTARA	V KOWHAI-HALL'S TOTARA-SNOW TOTARA	VI KOWHAI-BEECH-LANCEWOOD	VII BEECH-HALL'S TOTARA-SNOW TOTARA	VIII SNOW TOTARA-MOUNTAIN TOATOA	IX BOG PINE-SNOW TOTARA-MOUNTAIN TOATOA	X ALPINE	XI BEECH-KOWHAI-CABBAGE TREE	XII BEECH-MOUNTAIN TOATOA-KOWHAI-MANUKA
c	*Malus domestica*	5	7	7	2		7					1	
d	*Thymus vulgaris*	15	27	10	9	3	4						
	Lupinus arboreus	9	4	1	2		3					2	
e	*Cytisus scoparius*	20	30	27	13	5	31	2	1			45	21
	Ulex europaeus	12	17	15	6	3	18	2				37	21
	Salix fragilis	20	27	21	11	4	22	1				28	9
	Pinus spp.	15	14	11	9	4	13	3	1	1		15	11
	Sambucus nigra	14	19	17	13	5	20	4	1			21	10
	Crataegus monogyna	9	12	13	6	2	16	1				12	4
f	*Ribes uva-crispa*	5	4	3	7	2	3	2				2	1
	Populus nigra	3	3	2	2		3					4	
g	*Rosa rubiginosa*	71	61	48	59	39	38	17	3	1		25	7

TABLE 15 TABLE OF UNCOMMON, RARE AND LOCAL EXOTIC WOODY SPECIES IN THE 12 ZONES OF PRE-SETTLEMENT WOODY VEGETATION (I TO XII). Species were classified within four of the eight species groups of the rare species classification (Table 8). The cells show the number of recorded occurrences of each species within that zone.

SPECIES GROUP (FROM THE RARE SPECIES CLASSIFICATION)	UNCOMMON, LOCAL AND RARE EXOTIC SPECIES	I KANUKA-KOWHAI WOODLAND	II KOWHAI-KANUKA WOODLAND	III KOWHAI WOODLAND	IV KANUKA-KOWHAI-HALL'S TOTARA	V KOWHAI-HALL'S TOTARA-SNOW TOTARA	VI KOWHAI-BEECH-LANCEWOOD	VII BEECH-HALL'S TOTARA-SNOW TOTARA	VIII SNOW TOTARA-MOUNTAIN TOATOA	IX BOG PINE-SNOW TOTARA-MOUNTAIN TOATOA	X ALPINE	XI BEECH-KOWHAI-CABBAGE TREE	XII BEECH-MOUNTAIN TOATOA-KOWHAI-MANUKA
	PRE-SETTLEMENT WOODY VEGETATION ZONE	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
i	*Acer campestre*	1											
	Buddleja davidii				1	1	1					1	
	Clematis tangutica			1									
	Cotoneaster glaucophyllus	3			2		2						
	Cotoneaster simonsii		2		1		2						
	Cotoneaster franchetii	2	1										
	Cupressus macrocarpa	2					1					1	
	Fraxinus excelsior	4											
	Hedera helix	1											
	Larix decidua				1	1	2	1				3	2
	Populus alba	18		1	2	1	3						
	Prunus avium	1			1								
	Prunus domesticus	1											
	Pseudotsuga menziesii	4		2	7		4	4				2	
	Robinia pseudoacacia	1											
	Rosa micrantha	3								4	6		
	Rubus fruticosus	2			2		4					6	
	Salix babylonica	4					1						
	Solanum dulcamara	1					2						
	Sorbaria tomentosa	5	3		4	1		1		1			
ii	*Betula pendula*	1		1							3	1	
	Leycesteria formosa	1							1			2	4
	Prunus spp.	2	2		3							3	1
	Sorbus aucuparia	2	1		6		8	5	2			3	1
iii	*Acer pseudoplatanus*	2					2	3				3	3
	Clematis vitalba	2		1				1				8	2
v	*Cotoneaster lacteus*											1	
	Ilex aquifolium												1
	Ligustrum japonicum												1
	Potentilla anserinoides							1					
	Ribes sanguineum		1		1			1				3	

environment in the north of the region (zones I to IV), although *R. rubriginosa* also occurs in less extreme environments to the south (e.g. zones XI and XII). *Pinus* spp. presently occur mainly at low elevations, but attain heights greater than those of native woody species under equivalent envrionmental conditions, especially in the more extreme valley floor and alpine environments (Wardle 1963). Our models suggest that they will tolerate most environmental conditions in the Central Otago region, perhaps with the exception of those in some parts of the alpine tussock-shrubland pre-settlement woody vegetation zone.

TABLE 16 LAND AREA OF ZONES OF PRE-SETTLEMENT WOODY VEGETATION AND ENVIRONMENTAL DOMAINS WITHIN THE CENTRAL OTAGO STUDY AREA, AND LAND AREA AND PERCENTAGE OF LAND AREA ADMINISTERED BY THE DEPARTMENT OF CONSERVATION (DOC).

NUMBER	PRE-SETTLEMENT WOODY VEGETATION ZONE	APPROXIMATE AREA (km^2)	APPROXIMATE AREA ADMINISTERED BY DOC (km^2)	% OF ZONE ADMINISTERED BY DOC	NUMBER	ENVIRONMENTAL DOMAIN	APPROXIMATE AREA (km^2)	APPROXIMATE AREA ADMINISTERED BY DOC (km^2)	% OF DOMAIN ADMINISTERED BY DOC
I	Kanuka-kowhai woodland	739	15	2.1	1	Clutha Basin	951	18	1.9
II	Kowhai-kanuka woodland	1011	3	0.3	2	Alexandra Basin rim	810	11	1.4
III	Kowhai woodland	827	12	1.5	3	Maniototo Basin	1032	4	0.4
IV	Kanuka-kowhai-Hall's totara	1390	26	1.9	4	Recent semiarid soils	235	4	1.5
V	Kowhai-Hall's totara	722	8	1.1	5	Northern valley terraces	66	1	1.3
VI	Kowhai-beech-lancewood	948	7	0.7	6	Upper Maniototo	676	8	1.2
VII	Beech-Hall's totara-snow totara	2612	115	4.4	7	Northern basin rims	1565	34	2.2
VIII	Snow totara-mountain toatoa	1148	71	6.2	8	Lakes ranges	313	31	9.9
IX	Bog pine-snow totara-mountain toatoa	1356	279	20.6	9	Upper Nevis Valley	15	0	0.0
X	Alpine	977	205	21.0	10	Northern ranges	2454	223	9.1
XI	Beech-kowhai-cabbage tree	1373	14	1.0	11	Rolling ridge crests	999	192	19.2
XII	Beech-mountain toatoa-kowhai-manuka	2215	44	2.0	12	Manorburn uplands	2016	27	1.3
					13	Lammerlaw	1318	205	15.5
					14	Lammerlaw wetlands	42	4	10.0
					15	Recent Taieri soils	263	4	1.6
					16	South-eastern ranges	537	3	0.6
					17	South-eastern valleys	959	14	1.4
					18	Coastal hill country	1065	19	1.8
	Total	15318	800	5.2		Total	15318	800	5.2

6.5 PUBLIC CONSERVATION LANDS IN ZONES OF PRE-SETTLEMENT VEGETATION

In total, 800 km^2 (5.2%) of the Central Otago study region was included in the database of public conservation lands (including marginal strips) mapped by the Department of Conservation in February 2002 (Table 16).

Conservation Lands encompass 20.6% of the bog pine-snow totara-mountain toatoa (IX) and 21.0% of the alpine (X) zones, and between 4 and 6% of the beech-Hall's totara-snow totara (VII) and snow totara-mountain toatoa zones (VIII). Two percent or less of the remaining, low-elevation zones of pre-settlement woody vegetation are represented in public conservation lands.

A similar pattern is seen in the analysis of representation of environmental domains. The high-elevation rolling ridge crests (19.2%) and Lammerlaw (15.5%) domains are well represented, and 9–10% of the Lammerlaw wetlands, lakes ranges and northern ranges domains are included in public conservation lands. However, conservation lands account for 2% or less of the land area of the remaining 13 environmental domains.

The proportions of woody plant associations recorded, and the present extent of forest and shrubland (as mapped in the LCDB1) within environmental domains (Table 2) and zones of pre-settlement woody vegetation (Tables 10 and 13) provide an indication of the types and amounts of woody vegetation that are now present within public conservation lands. However, since our data were obtained from non-randomly distributed study plots, they are not sufficient to reliably estimate the present coverage of the present-day woody associations within conservation lands.

7. Discussion and conclusions

7.1 ORIGINS OF THE PRESENT WOODY VEGETATION

Multivariate analyses reveal that the present pattern of woody vegetation in Central Otago is primarily correlated with the steep altitudinal gradient in climate. We interpret the second important gradient to indicate the degree of past disturbance (principally by fire and grazing), and hence the fire- and grazing-intolerance of the woody flora. This gradient is itself related to topographic factors such as openness, aspect, and steepness of slope. Positions of species and of species groups on these two gradients enable us to interpret their environmental niche and their response to historical factors.

The results support the suggestions of McGlone (1989) and Leathwick & Whitehead (2001) that a suite of frost-and-drought tolerant but fire-sensitive tall woody species was eliminated from the valley floors, leaving only remnants of fire-resistant composition. Very few potential canopy species (*Kunzea ericoides*, *Sophora microphylla*, *Olearia lineata* and occasionally *Cordyline australis*) presently occupy the most drought- and frost-prone valley floors of

Central Otago. These species, and the disturbance-tolerant shrubs and lianes *Carmichaelia petriei*, *Coprosma propinqua*, *Discaria toumatou*, *Muehlenbeckia complexa*, *Melicytus alpinus*, *Olearia bullata*, *O. odorata* and *Pimelea aridula*, show a narrow range of values on the second, disturbance gradient, and are capable of withstanding periodic fire and grazing. More disturbance-sensitive species that occur on or near the valley floors are invariably restricted to the shelter of taller woody vegetation or bluffs (e.g. *Coprosma crassifolia*, *Hebe pimeleoides* var. *rupestris*, *Carmichaelia kirkii*, *Parsonsia capsularis*, *Scandia geniculata*, *Helichrysum lanceolatum* and *Muehlenbeckia australis*). The ordination plot of present woody species composition shows no species in the quadrant that combines arid, low-elevation environments with a low degree of fire- and grazing-disturbance. Clearly, some fire-sensitive woody species (i.e. those with high scores on the disturbance axis) now have truncated ranges, and may be more tolerant of drought and frost than their present distributions within the region suggest. Some examples of fire-sensitive species that have been eliminated from the valley floors may be those in species group *b* of the classification. This group comprises trees and shrubs that seldom occur in beech forest remnants, but are known from individual remnant plants confined to fire refugia at low elevations on the range slopes. Forest remnants with these species (e.g. *Fuchsia excorticata*, *Hoheria lyallii*, *Olearia aviceniifolia* and *Pittosporum tenuifolium*) no longer grow within Central Otago, although the pollen of some species is present in the fossil record. In pre-settlement times, their habitat may have been forest edges and streamsides, other naturally disturbed, regenerating woodlands, or sites where the moisture balance was marginal for tall forest. Their range may conceivably have extended onto valley floors, where they were destroyed by the early fires that followed human arrival. It seems likely that Central Otago valley floor woodlands also included *Phyllocladus alpinus* (species group *k*) and *Halocarpus bidwillii* (species group *n*), which survive in fire refugia on basin floors and fringes elsewhere in eastern South Island.

The presence of woody species typical of the few surviving, relatively intact beech forest remnants (i.e. species group *a* of the classification) clearly indicate the pre-settlement presence of closed forest communities on montane and subalpine hillslopes of Central Otago. Both groups of forest species (*a* and *b*) are now present as occasional plants in fire refugia within the matagouri-mingimingi woody plant association (E), and are unlikely to have dispersed there following the advent of human fire- and grazing-disturbance regimes. We conclude that the now widespread matagouri-mingimingi association is largely derived from the invasion of more disturbance-tolerant shrub species following the destruction of former forests by fire.

The higher-elevation equivalents of the induced, successional matagouri-mingimingi woody plant association are the matagouri-native broom association (G) and the highly-modified subalpine shrub association (H), all of which include fire-tolerant *Carmichaelia*, *Gaultheria* and *Pimelea* spp. These associations are characteristic of relatively moist upper range slopes and open rolling peneplain surfaces, which provide little topographic protection from fire or grazing. Taller, fire-sensitive species (e.g. *Phyllocladus alpinus*, *Podocarpus hallii*, *P. nivalis*, *Halocarpus bidwillii*, *Hoheria glabrata*, *Olearia arborescens* and shrubs such as *Dracophyllum longifolium*, *Coprosma ciliata*,

C. cuneata, *C. depressa*, *C. pseudocuneata*, *C. rigida*, *Hebe rakaiensis* and *H. subalpina*) persist in these environments where rock tors or permanent moisture provide protection from fire, e.g. on the summit of Rough Ridge. These species were undoubtedly widespread at these elevations in former times.

The broad tops of Central Otago's schist mountain ranges are characterised by gentle topography, and absence of screes and other fire-refugia. Like the lowlands, these environments were probably more susceptible to modification by fire than the steeper mid-elevation hillslopes below, although fires may have been less frequent due to cool, moist climatic conditions, than in the lowlands. Throughout the region, alpine woody species also show a relatively small range of values on the fire-tolerance gradient, and the low-disturbance, high-elevation quadrant of the ordination is empty. This suggests that a fire-sensitive upland woody flora may have been lost from the broad summits of the schist ranges, as a consequence of frequent fires in the early pastoral era that removed tall tussocks and led to truncated soil profiles or loss of the entire soil layer by erosion. Therefore, it seems likely that taller shrub species co-dominated with tall tussocks here in pre-settlement times, and that dwarf and mat-forming shrubs (those that cover extensive areas today) were more restricted to the highest, most exposed positions. This accords with conclusions from pollen evidence that 'alpine uplands were also affected by the destruction of shrubland' (McGlone et al. 1997 p. 43) and that a 'more complex penalpine shrubland-grassland' occupied the alpine areas of Central Otago prior to human settlement (McGlone 2001 p. 10).

7.2 PRE-SETTLEMENT WOODY VEGETATION

Numerous modified remains of pre-settlement woody vegetation persist in Central Otago where rock tors, steep slopes, or coarse talus provide shelter from fire. These remaining plants enabled us to estimate (i.e. predict) the potential distributions of woody species in the region prior to the arrival of humans in c. 800 yr BP. These predictions accord relatively well with the distribution of subfossil wood and charcoal remains in the district, and with interpretations from pollen sites. Nevertheless, our models have several limitations which must be taken into account:

1. Data from plots of uniform size would have been ideal for the purpose of our predictive models. However, due to the limited size of many Central Otago woody remnants, 1097 (c. 20%) of our woody species database records are based on observations of remnant stands or individual plants of area less than the 10 × 20-m plot samples. Moreover, 821 (c. 15%) of our records comprise presence-only data from a variety of sources, rather than presence/absence. Since it cannot be ascertained whether other woody species were present at these points, we restricted our use of presence data to the generalised additive models of individual species presence on environment, so as not to imply absence at that point for any other species.
2. Ideally, predictions such as these should be based upon data collected using a systematic probability sampling scheme. Our study utilised a large number of 'found' data sources that were collected for different purposes, and which

therefore reflect different biases. The most prevalent biases in the dataset were towards more high-elevation and native-species-dominated vegetation types. Our supplementary surveys partially correct these biases.

3. The models estimate the potential distributional patterns of species, but we cannot determine the relative abundance of species in the natural pre-settlement communities from them.
4. The models probably under-estimate the ranges of more fire-intolerant species.
5. Due to a higher incidence of fire and more complete vegetation clearance on the valley floors since human settlement, drought- and frost-tolerant woody species are unlikely to now extend to their pre-settlement low-elevation limits (McGlone 1989; Leathwick & Whitehead 2001). Refugia exist for plants on the steep, dissected range slopes, but are more scarce on broad ridge crests and intervening valleys in the region. Our models therefore probably underestimate the extent and richness of the pre-settlement woody flora to the greatest extent both at low (< c. 500 m) and high (> c. 1000 m) elevations.
6. Several woody species could not be included in our models of potential distribution because of their limited occurrence at sites in Central Otago. Potential forest dominants such as *Prumnopitys taxifolia* (matai) and *Plagianthus regius* (manatu), and smaller trees such as *Olearia fragrantissima* are now known only from sites outside the study area. On the basis of New Zealand-wide distributions, Leathwick & Whitehead (2001) suggested that matai and *Dacrycarpus dacrydioides* (kahikatea) showed considerable drought tolerance, and these species may once have occurred in Central Otago. Others exhibiting drought tolerance (e.g. *Melicytus ramiflorus*, *Pittosporum eugenioides*) are now restricted to the margins of the region but may have been more widespread. Species that are now too rare in Central Otago to allow predictions of their potential range to be made include *Fuchsia excorticata*, *F. perscandens*, *Hebe cupressoides*, *Hoheria lyallii*, *H. glabrata*, *Pittosporum tenuifolium*, *Melicope simplex*, *Olearia avicenifolia*, *O. arborescens*, *O. fimbriata*, *O. hectorii*, *Raukaua simplex*, *Scandia geniculata*, *Teucridium parvifolium*, *Coprosma linariifolia* and *C. virescens*. However, our multivariate analyses of the present-day vegetation offer an indication of the ecological niches of some of this group.
7. The models assume that woody species occupied their potential ranges in Central Otago prior to human arrival. However, certain species may not have fully adjusted their distributions since the last glaciation (e.g. *Nothofagus*: Wardle 1963; Leathwick 1998). Post-glacial spread may have been particularly slow in Central Otago because suitable habitats for woody species were spatially discontinuous. Furthermore, late-Holocene lowland fires caused by lightning may have locally removed selected woody plants from potentially favourable sites (McGlone & Moar 1998).
8. Local topography would probably have had an influence on the pre-settlement vegetation, particularly at low elevations: on sunny aspects, more severe seasonal droughts would have imposed limits on more moisture-demanding species, whereas the shelter provided by steep, shady slopes would have ameliorated these effects. In our predictive models, we do not account for the influence of aspect, slope, topographic complexity, and other micro-topographic factors. Firstly, slope and aspect are confounded with the degree

of human disturbance in the landscape and are therefore not reliable predictors of pre-settlement distributions, and secondly, local topography factors operate at finer scales than the 1 × 1 km grid we use to predict the potential vegetation of the region.

A more comprehensive estimate of the pre-settlement vegetation composition of Central Otago is gained by interpreting the predictive models in conjunction with the classification and ordinations of present-day vegetation, and with the fossil record. We summarise the implications from a combination of these approaches below.

Prior to the arrival of humans, the semi-arid valley-floor vegetation probably included forest, woodland, shrubland, and herbaceous communities (McGlone 2001). Our models suggest that Upper Clutha valley floors were dominated by *Kunzea ericoides* (kanuka), *Sophora microphylla* (kowhai), *Leptospermum scoparium* (manuka) and various drought-tolerant shrubs (e.g. *Coprosma*, *Carmichaelia*, *Hebe*, *Muehlenbeckia*, *Olearia* and *Discaria toumatou*). However, the predominance of these species is probably overestimated by the models. We are unable to predict the former extent of more fire-sensitive species in this zone, but evidence from the subfossils and pollen and occasional relict plants suggest that valley-floors may have formerly supported many woody species that are now either absent from Central Otago or too rare to include in our models (e.g. *Prumnopitys taxifolia*, *Fuchsia* and *Hoheria* spp., *Coprosma virescens*, *Hebe cupressoides*, *Olearia fimbriata*, *O. fragrantissima*, *O. hectorii*, *Pittosporum anomalum*, *Pseudopanax ferox* and *Teucridium parvifolium*). Shrubs that are now confined to refugia on the range toe-slopes, such as *Coprosma rugosa*, *C. linariifolia*, *Hebe salicifolia*, *Helichrysum intermedium* var. *selago*, *Melicope simplex* and *Myrsine divaricata*, and the lianes *Carmichaelia kirkii* and *Rubus cissoides*, may well have extended onto the valley floors. We suggest that these valley floors may have previously supported diverse, partly deciduous woodlands that have no modern analogues, but which included *Sophora microphylla* and less fire-tolerant deciduous tree species (*Olearia*, *Fuchsia*, and *Hoheria*) as well as *Phyllocladus alpinus* (mountain toatoa), *Halocarpus bidwillii* (bog pine) and a wide range of shorter divaricating and broad-leaved shrubs that were selectively eliminated by early human fires.

The models predict that tall forests descended almost to the semi-arid valley floors on the slopes of the main ranges in the north-west of Central Otago. Our models suggest that *Kunzea ericoides*, *Leptospermum scoparium*, *Podocarpus hallii* and *Sophora microphylla* may have been among the principal species on the lower slopes, although, again, the importance of these relatively fire-tolerant species is probably overemphasised. The models suggest that *Nothofagus menziesii* (silver beech) and *N. solandri* var. *cliffortioides* (mountain beech) are likely to have become increasingly dominant above c. 700 m. However, living remnants and the subfossil record both suggest that beech stands occurred only locally on the interior ranges (Wardle 2001b), and that *Podocarpus hallii* was probably the most important forest species on range mid-slopes. *N. menziesii* may have extended further south in the Central Otago region than *N. solandri* var. *cliffortioides*, which invaded later (McGlone et al. 1996), and which now occurs as remnants mainly in the north (Lindis Pass and Cardrona Valley). The models and the subfossil record suggest that the importance of *Phyllocladus alpinus*, *Halocarpus bidwillii* and *Podocarpus*

nivalis (snow totara) would have increased towards the upper treeline on the range slopes, but that they would have been progressively replaced by shorter shrubs and tall tussock grasslands at higher alpine elevations. Short-statured and mat-forming shrubs are likely to have dominated only in the highest alpine zones, and perhaps locally on exposed ridges at somewhat lower elevations.

Both our models and the fossil record suggest a somewhat different vegetation sequence on the ranges in the more mesic south and east of the district. The valley floors and lower hillslopes of the lower Clutha and Taieri valleys may have supported a mixture of kowhai, *Cordyline australis* (cabbage tree), *Carpodetus serratus* (marbleleaf), *Griselinia littoralis* (broadleaf) and *Pseudopanax crassifolius* (lancewood). *Nothofagus menziesii* and *N. fusca* (silver and red beech) were present in the Clutha Valley but were probably not widespread in the Taieri catchment. *Podocarpus hallii* and *Kunzea ericoides* were probably present on the lower range slopes of the southeastern ranges, but the models suggest that they are unlikely to have dominated here. Instead, the valley floor species may have been replaced by *Pseudopanax colensoi* (threefinger), *Phyllocladus alpinus*, and *Podocarpus nivalis* with increasing elevation, and *Halocarpus bidwillii* and *P. alpinus* may have been locally dominant on the gently sloping southern uplands and summits. Although the models predict that *Leptospermum scoparium* was more common here than in the north-west of Central Otago, its fire-tolerant and seral (successional) attributes suggest that it would have had a restricted occurrence in south-eastern climax forests.

7.3 FUTURE TRENDS IN WOODY VEGETATION

Our study did not address vegetation trends directly, but interpretation of multivariate analyses, predictive models and anecdotal evidence suggests that three trends in the woody vegetation of Central Otago are inevitable in the absence of intervention.

Continued decline in late-successional native woody vegetation

Although the frequency of fire in Central Otago has reduced over the last century, vegetation disturbance by grazing and browsing by domestic and feral animals continues. Wardle (2001a, b) suggested that existing forest remnants in the Upper Clutha were broadly similar in size and composition at the time of European arrival. However, this perspective overlooks the observed dieback of late-successional native vegetation across a range of environments in the region and, in some cases, the loss of significant relicts within the last decade, e.g. some of the last examples of *Podocarpus hallii* and *Phyllocladus alpinus* on Rough Ridge, and stands of tall *Olearia odorata* shrubland in the Maniototo Basin. Their decline is apparently due to browsing, old age, and desiccation through exposure to wind and drought in the absence of surrounding tall vegetation. Of equal concern is that most remaining stands of pre-settlement canopy dominant trees and their shade-intolerant associates contain only mature or senile individuals: seedling recruitment is negligible where grazing and browsing by sheep, rabbits or goats continues, and appropriate pollinators,

seed dispersers and nurse communities are lacking. The extent and diversity of disturbance-sensitive, late-successional woody vegetation is likely to continue to decrease within the region under present-day disturbance regimes.

Increase in seral woody vegetation

Seral woody vegetation is a prominent feature of the Central Otago montane landscape (Plates 5A–F). Scrub and shrublands comprising mixtures of native and exotic woody species tend to dominate the vegetation on steep hillslopes and gullies where the intensity of pastoral development or grazing is relatively low. These communities are typically matagouri-mingimingi, *Melicytus*, or matagouri-native broom associations that are occupying zones of that supported tall forest prior to human settlement. In the Upper Clutha district, taller woody associations, dominated by *Kunzea ericoides*, are spreading locally. Seral woody vegetation comprised almost entirely of *Discaria toumatou* (matagouri) characterise hillslopes where topdressing has been applied. The stature, composition, and areal extent of seral woody vegetation fluctuates with changes in pastoral management on different properties. However, because the Central Otago climate will support taller, woodier communities, there is an inherent trend to increasing woodiness below a certain disturbance threshold. On conservation land, we suggest that seral woody associations may have potential to function as nurse communities for taller, more disturbance-sensitive, late-successional native woody species and their associated vertebrate and invertebrate faunas.

Expansion of woody weeds

Because woody weeds are actively expanding from lowland sources, it is not possible to predict, with any certainty, how far a particular exotic species may spread on the basis of its present distribution. One approach to testing whether invading species occupy their full potential environmental range is to compare curves of species presence on environmental gradients between different areas (e.g. Walker & Lee 2000, 2002). Similar estimates for Central Otago's woody weeds would be possible only if there were comparable data on distributions from other regions in New Zealand, or overseas. Meanwhile, anecdotal evidence suggests that certain woody weeds (e.g. *Ulex europaeus*, *Cytisus scoparius* and *Rosa rubiginosa*) are spreading rapidly in the region. Elsewhere in the world, environments more cold and/or arid than Central Otago's valley floor and alpine zones support tall trees and shrubs. Many of these will grow well above New Zealand treelines (e.g. *Pinus* spp., Wardle 1985). There is therefore potential for a suite of taller non-native shrubs and trees to competitively suppress indigenous woody species, particularly in Central Otago's most extreme environments.

The impacts of woody weeds on co-occurring native species in Central Otago is poorly understood. Given appropriate sources of native seed, *Salix fragilis* (willow), *Crataegus monogyna* (hawthorn), *Rosa rubiginosa* (briar), *Lupinus arboreus* (tree lupin) might facilitate the regeneration of native woody plants by providing shelter and relative freedom from herbivores and exotic grass competition. Their potential as nurse communities should be investigated. However, longer-lived, evergreen woody weeds (e.g. *Pinus* spp.), seem unlikely to be of benefit to the persistence or recovery of native woody vegetation, and solutions for their control are needed.

7.4 POTENTIAL FOR THE RECOVERY OF WOODY VEGETATION

Although the frequency of fire in Central Otago has reduced over the last century, there are few areas where the full range of local herbivores have been excluded to enable woody vegetation to recover. Nevertheless, three cases suggest that certain woody species may regenerate and spread readily in the absence of fire and grazing and in the presence of seed sources (S. Walker, unpubl. data):

1. In Flat Top Hill Conservation Area, young stands of *Carmichaelia compacta*, *Kunzea ericoides*, *Pimelea aridula*, *Ozothamnus leptophyllus* and *Hebe pimeleoides* var. *rupestris* have established naturally from seed sourced from single-shrub relicts. This occurred within c. 8 years of the exclusion of feral and domestic grazing, despite the presence of competitive *Thymus vulgaris* (thyme) subshrubs.
2. In Locharburn Scientific Reserve, considerable regeneration of *Podocarpus hallii* has taken place since the exclusion of domestic herbivores in the last four decades. Within c. 35-year-old *Kunzea ericoides* stands inside the reserve fence, 176 small (<0.1 m height) *P. hallii* seedlings, 27 seedlings of 0.1–1.0 m height, and 19 saplings of 1.0–4.0 m height and aged 10–27 years were recorded in a typical 10 × 10 m plot. Bellbirds were seen and presumably act as seed dispersers, but *P. hallii* recruitment was not observed outside the exclosure fence, nor outside the *K. ericoides* nurse community.
3. On glacial outwash terraces near Luggate in the north of Central Otago *Carmichaelia petriei* and *Discaria toumatou* increased in stature to dominate a *Festuca novae-zelandiae–Poa colensoi–Elymus solandri–Carex colensoi* short tussock grassland community within 12 years of the exclusion of mammalian grazing and annual fertiliser addition. Outside the exclosure fences, a short grassland sward dominated by the exotic grass *Anthoxanthum odoratum* contains widely spaced stumps of browsed native shrubs, subshrubs and tussocks.

7.5 A CONSERVATION STRATEGY FOR WOODY VEGETATION IN CENTRAL OTAGO

The greatest loss of structurally and functionally significant biodiversity in eastern South Island regions since the time of human settlement is associated with the destruction of the lowland and montane woody flora. In this report we focus on woody plants, but an entire biota, from soil microbes and insects to lizards and birds, was simultaneously removed.

In Central Otago, as elsewhere in eastern South Island, high-elevation pre-settlement woody vegetation zones and environmental domains are far better represented in public conservation lands than those at low elevations (cf Leathwick et al. 2002b). Two factors are responsible for this bias. Firstly, ecosystem loss and degradation in low-elevation, deforested regions of the eastern South Island has left few areas sufficiently intact to be perceived as worthy of conservation. Secondly, low-elevation land has been more densely

populated, and highly developed for pastoral production and other land uses, creating limited opportunities for conservation (McGlone 2001). The present distribution of public conservation lands in Central Otago is therefore in approximately inverse proportion to the degree of ecosystem loss that has occurred in any given area.

Generous estimates (i.e. including marginal strips and other public conservation lands not managed principally for biodiversity conservation) indicate that less than 2.5% of the land area of the eight lowest-elevation pre-settlement woody vegetation zones is included in public conservation lands. Between 4.4% and 21.0% of the four remaining, higher-elevation pre-settlement woody vegetation zones lie within public conservation lands. To redress the balance, and to ensure that there is protection for the full spectrum of New Zealand ecosystems, it is clear that a greater area of modified, low-elevation land will need to be set aside for biodiversity conservation; in, for example, the tenure review of pastoral leasehold lands. However, for this to occur, concepts of conservation value will need to be revised to focus on the potential for future restoration of native biodiversity, rather than on current inherent natural value alone. Moreover, conservation goals for such areas will need to incorporate concepts of successional change and ecosystem restoration, and the presence of exotic species will have to be accepted in the short and medium terms.

An understanding of present, past, and potential future woody vegetation is required as a basis for conservation goals for ecosystems in eastern South Island rainshadow systems. Until now, the protection and restoration of woody plant biodiversity has probably been hindered by a lack of understanding of pre-settlement vegetation patterns. While efforts should continue to refine predictions of pre-settlement vegetation composition in areas such as Central Otago, we suggest that the present state of knowledge, at least in this region, should no longer be an impediment to conservation efforts to encourage native woody successions.

A further hindrance to efforts to conserve and restore woody communities in Central Otago has been a relatively poor understanding of vegetation potential; that is, of what might be achievable in terms of restoring succession towards native woody vegetation in deforested areas today. Uncertain future trajectories of change, and the perception that seral vegetation should advance only towards defined primeval goals, are further deterrents. Our limited experience with removal of herbivores from land in Central Otago suggests that there is considerable potential for the regeneration of certain woody species, and that this potential may have long been under-estimated. We therefore recommend an experimental approach to protected areas that seeks to maximise native woody plant biodiversity across the range of pre-settlement woody vegetation zones. It should be broadly guided by the existing, albeit incomplete, understanding of pre-settlement composition, but it should not be limited by uncertainties or by attempts to accurately replicate any predefined state. For example, our study suggests several drought-tolerant but fire-sensitive shrubs and trees now absent from valley floors would be suitable candidates for restoration trials. Where possible, reserve design should envisage and allow for the expansion and eventual restoration of sequences of native woody vegetation from the valley floors to the range tops, and existing remnants should be viewed as foci and seed sources. Small, isolated covenants or reserves of trees

surrounded by pastoral land (e.g. mid-altitude podocarp and beech remnants reserved on the Pisa Range) will not allow the unfolding of elevation sequences of successional woodlands and forests over time.

The re-establishment of a representative spectrum of pre-settlement native woody communities in the deforested environments of Central Otago will present considerable challenges, and research and monitoring should proceed in tandem with restoration efforts. Methods and technologies will need to be developed to facilitate woody succession, and this will require advanced understanding of successional trajectories, processes and timescales, and better knowledge of the ecology of individual species within the woody flora. Existing experience and information regarding the restoration of appropriate native woody species should be collated and applied where possible (e.g. Meurk et al. 2001). It may be necessary to establish nurse communities and reintroduce seed sources and dispersers. Certain shade-intolerant exotic species may not hinder native regeneration, but the removal and/or exclusion of domestic and feral browsing mammals will be a prerequisite for restoration. The prevention of recurrent fire may be a further challenge, although there is little evidence to suggest that regenerating woody vegetation is more susceptible to fire than herbaceous communities (e.g. *Kunzea ericoides* woodland has not been accidentally burned in Bendigo Conservation Area for c. 50 years).

General awareness of the past, present and future woody vegetation of Central Otago is extremely low. There is limited access to, interpretation of, and publicity for, the few existing reserved remnants of pre-settlement forests. Anthropogenic tussock grasslands are now widely regarded as natural and desirable in the lowland and montane zones (McGlone 2001), and art and other popular media reinforce the perception of a grassland equilibrium on Otago's block mountains and valley floors. Consequently, there is presently little public interest in the restoration of the pre-settlement woody biodiversity; indeed, there may be considerable resistance to the idea. We suggest that increased public understanding of the place of native woody plants in the Central Otago landscape may support efforts to restore pre-settlement woody vegetation at many different levels. Although it is encouraging to see that modified lowland ecosystems are increasingly included in Department of Conservation field days and summer programmes, in general, public access and information are poor. To initiate a trend towards greater public awareness and participation, public seminars or workshops may be an appropriate way to present information on pre-settlement woody vegetation and to promote discussion on conservation and restoration priorities. Community-based restoration initiatives should be encouraged, and the support of conservation organisations and local authorities should be fostered and mobilised. The focus need not be solely on public conservation lands: appropriate native shrubs and trees along roadways, in rural settlements, on private and leasehold pastoral land, and in urban parks and gardens, are all potential seed sources and corridors for the survival of faunal pollinators and seed dispersers, of benefit to the restoration of indigenous woody vegetation in the region as a whole.

8. Recommendations

1. There is an urgent need for more low- and mid-elevation land to be set aside for conservation and restoration to ensure that there is protection for the full spectrum of Central Otago ecosystems.
2. We suggest that knowledge of the composition and extent of pre-settlement zones is now sufficient to guide the placement and design of conservation areas to encourage native woody vegetation successions.
3. Prospective reserves should be assessed in terms of potential for the future succession and restoration of native woody vegetation, rather than on present intact natural value alone.
4. Goals for such protected areas should embrace long-term successional change, tolerate uncertain outcomes, and accept an element of exotic species presence. They should not be limited by attempts to accurately replicate predefined states.
5. Since experience pertaining to native woody vegetation succession in Central Otago environments is very limited, we suggest that an experimental approach should be adopted, and that restoration efforts should proceed hand-in-hand with research and monitoring.
6. We suggest that fostering increased public understanding and awareness of zones of pre-settlement woody vegetation in Central Otago may assist the restoration of native biodiversity in the region.

9. Acknowledgements

This work was funded by DOC S&R (Contract 3205), and we acknowledge additional financial support from the Foundation for Research, Science and Technology (Contract C09X0205). We are grateful to the Miss E.L. Hellaby Indigenous Grasslands Research Trust for funding summer student scholarships, and we thank M. Breach, R. Ewens, R. Lister, J. Nielsen, J. Wass and G. Wells for field assistance and data entry. The work is based on a compilation of data resulting from the efforts of numerous individuals over many years. We warmly acknowledge several people for generously making their data available: P. Grove, C. Brumley, M. Stirling, M. Manning, K. Dickinson, C.J. Bibby, B.D. Rance, J. Carter, J. Comrie, C. Ward, B. Fagan, D. Pillai, T. Partridge, P. Johnson, R. Allen, B. Kovacs, J.B. Wilson, P. Wardle, P. Williams, C. Meurk, and L. Basher. We are especially grateful to J. Leathwick, J. Overton, and G. Wilson (Landcare Research, Hamilton), who gave vital expertise and considerable time to the project, and to J. Overton, M. McGlone, P. Bellingham and A.F. Mark for valuable comments on drafts. A large number of Central Otago landowners kindly allowed access to their properties for survey, and many DOC staff gave advice and logistic support: we particularly thank J. Barkla, A. Perrett, M. Tubbs and D. Massam. We are grateful to C. Bezar for thorough editorial work on the manuscript, B. Elliott for word-processing, and E. Lang and B. Smith-Lyttle for technical support.

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Appendix 1

ENVIRONMENTAL FACTORS, ABBREVIATION, DERIVATION, AND RANGE OF VALUES IN THE STUDY AREA

FACTOR	ABBREVIATION	DERIVATION	RANGE
Climate factors		**Climate surfaces** [1]	
Mean annual temperature	MAT		Min 1.3°C Max 10.7°C
Temperature seasonality	Tw	$\left(\left[\frac{J-\overline{J}}{\sigma_J}\right]-\left[\frac{T-\overline{T}}{\sigma_T}\right]\right)*\sigma_J$ where J = July minimum temperature, T = annual temperature, $\overline{J}$ = mean of J, σ_J = standard deviation of J, etc	Min –3.99°C Max 3.56°C
Rainfall:potential evapotranspiration ratio	R:PET	Total annual rainfall Total annual potential evapotranspiration	Min 0.592 Max 2.709
October vapour pressure deficit	OCTVPD	Mean October air saturation deficit at 0900 hrs	Min 0.144 kPa Max 0.539 kPa
Annual precipitation deficit	DEF	Total annual potential evapotranspiration – total annual precipitation	Min 0 mm Max 394 mm
Mean annual solar radiation	MAS		Min 124 MJ m^{-2} d^{-1} Max 141 MJ m^{-2} d^{-1}
Solar radiation seasonality	Sw	$\left(\left[\frac{J-\overline{J}}{\sigma_J}\right]-\left[\frac{T-\overline{T}}{\sigma_T}\right]\right)*\sigma_J$ where J = June solar radiation, S = annual solar radiation, etc as for Temperature seasonality	Min –0.99 MJ m^{-2} d^{-1} Max 0.33 MJ m^{-2} d^{-1}
Soil factors		**NZLRI** [2]	
Soil age since last major reset of soil formation		1: pre-glacial, 2: 2000 years to post-glacial 3: younger than 2000 years	
Calcium		1 (low) to 4 (high)	
Acid soluble phosphate		1 (low) to 5 (high)	
Particle size		1 (clay) to 5 (massive)	
Salinity		1 (low) to 4 (high)	
Drainage		1 = Very poor, 2 = Poor, 3 = Impeded, 4 = Moderate, 5 = Good	
Other			
Predominant slope or relief	SLOPE	25-m digital elevation model	Min 0° Max 40°

[1] Leathwick & Stephens (1998).

[2] National Water and Soil Conservation Organisation (1979).

Appendix 2

DATA SOURCES, AUTHORS AND COLLECTORS OF THE WOODY SPECIES DATABASE FOR CENTRAL OTAGO

BASE PRESENCE/ABSENCE DATASET	NO. RECORDS	REFERENCE
Dunstan PNA survey	164	Ward et al. 1994
Dansey PNA survey	123	Comrie 1992
Hawkdun PNA survey	156	Grove 1992
Clutha Valley survey[1]	142	Hubbard & Wilson 1988
Kawarau Gorge survey[1]	233	Partridge et al. 1991
Lindis PNA survey	66	Ward et al. 1994
Manorburn PNA survey	125	Fagan & Pillai 1992
Macraes PNA survey	90	Bibby 1997
Otago alpine phytoecology[1]	111	Meurk 1982; C.D. Meurk, unpubl. data
Nokomai PNA survey	94	Dickinson 1989
Old Man PNA survey	628	Brumley et al. 1986
Pisa PNA survey	114	Ward et al. 1994
Rabbit and Land Management Programme[1]	106	K. Colhoun et al., unpubl. data
Rock and Pillar survey	120	B. Kovacs & K.J.M. Dickinson, unpubl. data
Umbrella PNA survey	188	Dickinson 1988
Upper Clutha survey[1]	28	Wilson et al. 1989
Waipori PNA survey	144	Carter 1994
	2632 (49%)	
Supplementary presence/absence dataset		
Central Otago survey plots	869	S. Walker, unpubl. data
Central Otago survey point observations	1097	S. Walker, unpubl. data
	1966 (36%)	
Supplementary presence dataset		
CHR herbarium collection and database	95	
OTA herbarium collection and database	234	
DOC land inventory	140	Department of Conservation 1995
RAP species lists, PNA survey reports	137	Authors of PNA reports, as above
Tenure Review files, DOC	187	
Peter Williams, personal notes	3	P. Williams, unpubl. data
Peter Wardle, personal notes	25	P. Wardle, unpubl. data
	821 (15%)	
Total	5419	

[1] Plot size differs from standard 10 × 20 m.

Appendix 3

SPECIES RECORDED IN THE 5419 PLOT RECORDS OF THE WOODY SPECIES DATABASE FOR CENTRAL OTAGO

Current frequency categories reflect the number of occurrence records: 'very common' > 400, 'common' 101–400 and 'less common' 41–100 (included in potential distribution GAMs and in classification and ordination), and 'uncommon' 13–40 (included in classification and ordination multivariate analyses) 'local' 7–12 , and 'rare 1–6 (not included in multivariate analyses or GAMs). Species Group refers to those from the classification of present woody vegetation (see Table 4). Pre-settlement woody vegetation zone categories were assigned in the classification and interpretation of pre-settlement woody zones for each species with > 40 occurrences. For species with < 40 occurrences, we list each zone in which they were recorded (see Table 6).

	CURRENT FREQUENCY	SPECIES GROUP	CATEGORY	PRESENT IN ZONES (UNCOMMON, LOCAL, AND RARE SPECIES)
Native species				
Aristotelia fruticosa	common	*f*	shade-tolerant shrub	
Aristotelia fruticosa × *A. serrata*	rare			V
Aristotelia serrata	local			I,V,VII
Brachyglottis cassinioides	local			IV,VII,VIII,XI
Brachyglottis revolutus	common	*j*	shade-intolerant shrub	
Carmichaelia arborea	rare			V,VII
Carmichaelia compacta	uncommon	*h*		I,II,IV,V,VI,VII,XI
Carmichaelia corrugata	rare			VII
Carmichaelia crassicaule	common	*h*	shade-intolerant shrub	
Carmichaelia kirkii	uncommon	*f*		I,II,V,VII,XI,XII
Carmichaelia nana	rare			XI
Carmichaelia petriei	very common	*g*	shade-intolerant shrub	
Carmichaelia vexillata	less common	*h*	shade-intolerant subshrub	
Carpodetus serratus	less common	*a*	canopy	
Clematis marata	common	*f*	shade-tolerant liane	
Clematis paniculata	rare			VII,X,XI, X
Clematis quadribracteolata	rare			I,IX
Coprosma 'alpina'	local			III,IV,VII,VIII
Coprosma aff. *pseudocuneata*	rare			VI
Coprosma antipoda	rare			IX,
Coprosma atropurpurea	uncommon	*h*		III,IV,VII,VIII
Coprosma cheesemanii	common	*k*	shade-intolerant subshrub	
Coprosma ciliata	common	*j*		
Coprosma colensoi	less common	*a*	shade-tolerant shrub	
Coprosma crassifolia	less common	*e*	shade-tolerant shrub	
Coprosma cuneata	uncommon	*a*		VII,VIII,IX,X
Coprosma depressa	uncommon	*h*		III,IV,V,VII,IX,X
Coprosma intertexta	common	*f*	shade-intolerant shrub	
Coprosma linariifolia	uncommon	*b*		I,VII,VIII,IX,X,XI
Coprosma lucida	rare			
Coprosma niphophila	rare			III
Coprosma perpusilla	common	*n*	shade-intolerant subshrub	
Coprosma petriei	common	*l*	shade-intolerant subshrub	
Coprosma propinqua	very common	*g*	shade-intolerant shrub	
Coprosma pseudocuneata	uncommon	*b*		III,IV,VII,VIII,IX,X
Coprosma rhamnoides	less common	*a*	shade-tolerant shrub	
Coprosma rigida	uncommon	*b*		I,III,VII,VIII,IX,X,XI,XII
Coprosma rubra	uncommon	*h*		I,VII,VIII,X
Coprosma rugosa	less common	*f*	shade-tolerant shrub	
Coprosma serrulata	rare			III,VII

APPENDIX 3 (CONTINUED)

	CURRENT FREQUENCY	SPECIES GROUP	CATEGORY	PRESENT IN ZONES (UNCOMMON, LOCAL, AND RARE SPECIES)
Coprosma 'taylorae'	common	*a*	shade-tolerant shrub	
Coprosma virescens	local			I,II,V,VI,VII,IX
Cordyline australis	less common	*e*	canopy	
Corokia cotoneaster	common	*f*	shade-intolerant shrub	
Cyathodes juniperina	rare			IX
Cyathodes empetrifolia	local			VII,IX
Cyathodes pumila	less common	*n*	shade-intolerant subshrub	
Discaria toumatou	very common	*g*	shade-intolerant shrub	
Dracophyllum kirkii	rare			VII
Dracophyllum longifolium	common	*j*	shade-tolerant shrub	
Dracophyllum muscoides	very common	*m*	shade-intolerant subshrub	
Dracophyllum politum	uncommon	*n*		III
Dracophyllum pronum	common	*m*	shade-intolerant subshrub	
Dracophyllum prostratum	rare			III,IV
Dracophyllum prostratum × *uniflorum*	rare			VIII
Dracophyllum uniflorum	common	*j*	shade-intolerant shrub	
Elaeocarpus hookerianus	rare			X
Exocarpus bidwillii	rare			VIII
Fuchsia excorticata	uncommon	*b*		I,V,VII,VIII,IX,X
Fuchsia perscandens	local			I,IX,X
Gaultheria antipoda	common	*k*	shade-intolerant shrub	
Gaultheria crassa	common	*j*	shade-intolerant subshrub	
Gaultheria depressa var. *depressa*	very common	*l*	shade-intolerant subshrub	
Gaultheria depressa var. *novae-zelandiae*	less common	*j*	shade-intolerant subshrub	
Gaultheria macrostigma	common	*k*	shade-intolerant subshrub	
Gaultheria nubicola	common	*l*	shade-intolerant subshrub	
Gaultheria parvula	uncommon	*b*		I,III,IV,V,VII,VIII,IX,XI
Griselinia littoralis	common	*a*	canopy	
Halocarpus bidwillii	less common	*n*	canopy	
Halocarpus biformis	rare			VII
Hebe aff. *rakaiensis*	rare			III
Hebe buchananii	common	*m*	shade-intolerant shrub	
Hebe cockayneana	rare			IV
Hebe cupressoides	rare			XI
Hebe epacridea	uncommon	*b*		III,IV,VII,VIII
Hebe hectorii var. *demissa*	local			III,VIII
Hebe hectorii var. *hectorii*	less common	*m*	shade-intolerant shrub	
Hebe hectorii var. *subulata*	local			III,IV,VIII
Hebe imbricata var. *poppelwellii*	less common	*n*	shade-intolerant shrub	
Hebe lycopodioides var. *lycopodioides*	uncommon	*m*		I,III,IV,VII,VIII,IX,XI
Hebe odora	common	*k*	shade-intolerant shrub	
Hebe pauciramosa	less common	*m*	shade-intolerant shrub	
Hebe petriei	rare			IV
Hebe pimeleoides var. *rupestris*	less common	*d*	shade-intolerant shrub	
Hebe pinguifolia	uncommon	*m*		III,VII,VIII,IX,XII
Hebe propinqua	uncommon	*n*		III,IV,VII,VIII
Hebe rakaiensis	common	*j*	shade-intolerant shrub	
Hebe salicifolia	common	*f*	shade-tolerant shrub	
Hebe subalpina	less common	*f*	shade-intolerant shrub	
Hebe tetrasticha	rare			IV,VIII
Hebe treadwellii	rare			X
Helichrysum intermedium var. *selago*	less common	*b*	shade-intolerant shrub	

	CURRENT FREQUENCY	SPECIES GROUP	CATEGORY	PRESENT IN ZONES (UNCOMMON, LOCAL, AND RARE SPECIES)
Helichrysum lanceolatum	less common	*e*	shade-tolerant liane	
Hoheria angustifolia	rare			I,VII,IX
Hoheria glabrata	uncommon	*a*		I,V,VII,VIII,IX,X
Hoheria lyallii	uncommon	*b*		I,V,VII,IX,X
Kunzea ericoides	common	*e*	canopy	
Leptospermum scoparium	common	*e*	canopy	
Leucopogon colensoi	common	*k*	shade-intolerant subshrub	
Melicope simplex	uncommon	*b*		I,VI,VII,IX,X,XI,XII
Melicytus ramiflorus	rare			I,IX
Melicytus alpinus	very common	*g*	shade-intolerant shrub	
Muehlenbeckia australis	common	*e*	shade-tolerant liane	
Muehlenbeckia axillaris	less common	*h*	shade-intolerant liane	
Muehlenbeckia complexa	very common	*g*	shade-intolerant liane	
Myrsine australis	local			V,VII,IX
Myrsine divaricata	less common	*a*	shade-tolerant shrub	
Myrsine nummularia	common	*j*	shade-intolerant subshrub	
Neomyrtus pedunculata	rare			XII
Nothofagus fusca	less common	*a*	canopy	
Nothofagus menziesii	less common	*a*	canopy	
Nothofagus solandri var. *cliffortioides*	less common	*a*	canopy	
Olearia arborescens	uncommon	*b*		I,III,V,VII,VIII,IX,X
Olearia aviceniifolia	uncommon	*b*		I,IV,V,VI,VII,VIII,IX
Olearia bullata	common	*f*	shade-intolerant shrub	
Olearia cymbifolia	uncommon	*b*		III,IV,V,VII,VIII,IX,XI,XII
Olearia lineata dartonii	rare			V
Olearia fimbriata	rare			VII,IX,X
Olearia hectorii	rare			I,VII,X
Olearia ilicifolia	rare			VII,IX
Olearia lineata	common	*e*	shade-intolerant shrub	
Olearia nummularifolia	less common	*k*	shade-intolerant shrub	
Olearia odorata	very common	*g*	shade-intolerant shrub	
Ozothamnus leptophyllus	very common	*k*	shade-intolerant shrub	
Parsonsia capsularis	uncommon	*f*		I,III,V,VI,VII,XI,XII
Parsonsia heterophylla	local			II,V,VII,IX,X,XII
Pennantia corymbosa	local			III,IV,VII,VIII,X
Pentachondra pumila	common	*k*	shade-intolerant subshrub	
Phyllocladus alpinus	less common	*k*	canopy	
Pimelea aridula	common	*d*	shade-intolerant shrub	
Pimelea oreophila	very common	*l*	shade-intolerant subshrub	
Pimelea poppelwellii	uncommon	*h*		III,IV,VII,VIII
Pimelea prostrata	uncommon	*h*		III,IV,V,VI,VIIVIII,X
Pimelea pseudolyallii	common	*i*	shade-intolerant subshrub	
Pimelea pulvinaris	rare			V,VI
Pimelea sericeovillosa	uncommon	*h*		III,V,VI,VII,VIII,XI
Pimelea traversii	less common	*h*	shade-intolerant subshrub	
Pittosporum divaricatum	rare			I
Pittosporum eugenioides	rare			VII,IX
Pittosporum tenuifolium	uncommon	*b*		I,VII,IX,X,XII
Podocarpus hallii	common	*a*	canopy	
Podocarpus nivalis	less common	*j*	canopy	
Pseudopanax arboreus	rare			IX
Pseudopanax colensoi	less common	*a*	canopy	
Pseudopanax crassifolius	less common	*a*	canopy	
Raukaua simplex	uncommon	*a*		VII,VIII,IX,X
Ripogonum scandens	rare			I,
Rubus australis	rare			I,IX

APPENDIX 3 (CONTINUED)

	CURRENT FREQUENCY	SPECIES GROUP	CATEGORY	PRESENT IN ZONES (UNCOMMON, LOCAL, AND RARE SPECIES)
Rubus cissoides	less common	*a*	shade-tolerant liane	
Rubus schmidelioides	very common	*g*	shade-intolerant liane	
Rubus squarrosus	local			I,VII,VIII,IX,X
Scandia geniculata	uncommon	*f*		I,II,V,VII,IX,X,XI
Schefflera digitata	rare			VII
Solanum laciniatum	rare			I
Sophora microphylla	common	*e*	canopy	
Teucridium parvifolium	rare			IX,X,XII
Urtica ferox	rare			I
Exotic species				
Acer campestre	rare			VI
Acer pseudoplatanus	local			I,VI,VII,IX,X
Betula pendula	rare			I,II,V,IX
Buddleja davidii	rare			I,V,X,XI
Clematis tangutica	rare			XII
Clematis tibetiana	rare			XII
Clematis vitalba	uncommon	*c*		I,VI,VII,IX,XII
Cotoneaster glaucophyllus	local			V,VI,X
Cotoneaster simonsii	rare			II,V,X
Cotoneaster franchetii	rare			II,VI
Cotoneaster lacteus	rare			I
Crataegus monogyna	common	*e*		
Cupressus macrocarpa	rare			I,VI,X
Cytisus scoparius	very common	*e*		
Fraxinus excelsior	rare			VI
Hedera helix	rare			VI
Ilex aquifolium	rare			IX
Larix decidua	local			I,V,VII,IX,X,XI
Leycesteria formosa	local			I,VI,VIII,IX
Ligustrum japonicum	rare			IX
Lupinus arboreus	less common	*d*		
Malus domestica	less common	*c*		
Pinus spp.	common	*e*		
Populus alba	uncommon	*d*		V,VI,X,XI,XII
Populus nigra	common	*f*		
Prunus avium	rare			V,VI
Prunus domesticus	rare			VI
Prunus spp.	local			I,II,V,VI,IX
Pseudotsuga menziesii	uncommon	*f*		I,V,VI,VII,X,XII
Ribes sanguineum	rare			I,II,V,VII
Ribes uva-crispa	common	*f*		
Robinia pseudoacacia	rare			VI
Rosa micrantha	local			III,IV,VI
Rosa rubiginosa	very common	*g*		
Rubus fruticosus	uncommon	*c*		I,V,VI,X
Salix babylonica	rare			VI,X
Salix fragilis	common	*e*		
Sambucus nigra	very common	*e*		
Solanum dulcamara	rare			VI,X
Sorbaria tomentosa	uncommon	*f*		II,III,V,VI,VII,XI
Sorbus aucuparia	uncommon	*f*		I,II,V,VI,VII,VIII,IX,X
Thymus vulgaris	common	*d*		
Ulex europaeus	common	*e*		

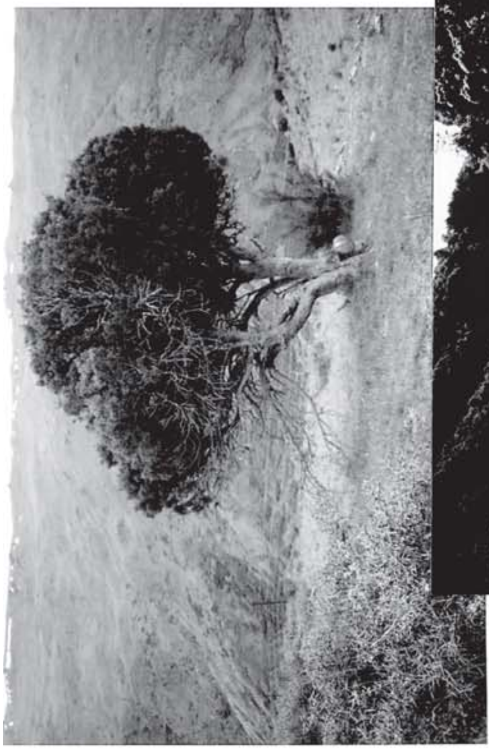
Colour plates

1A

1B

1C

1D



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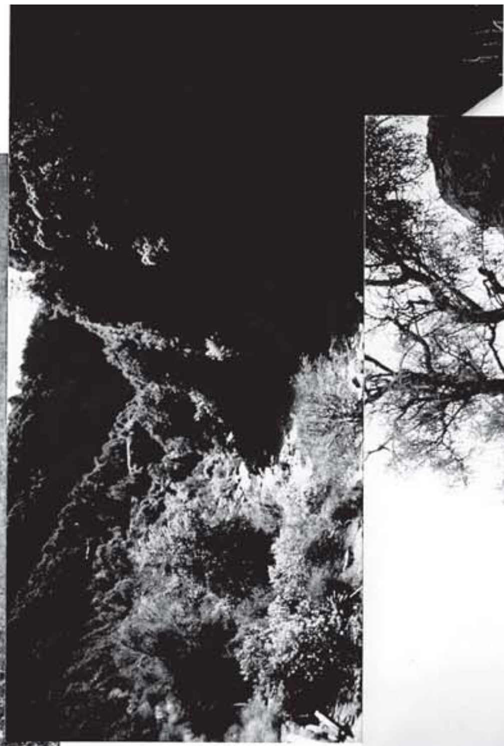
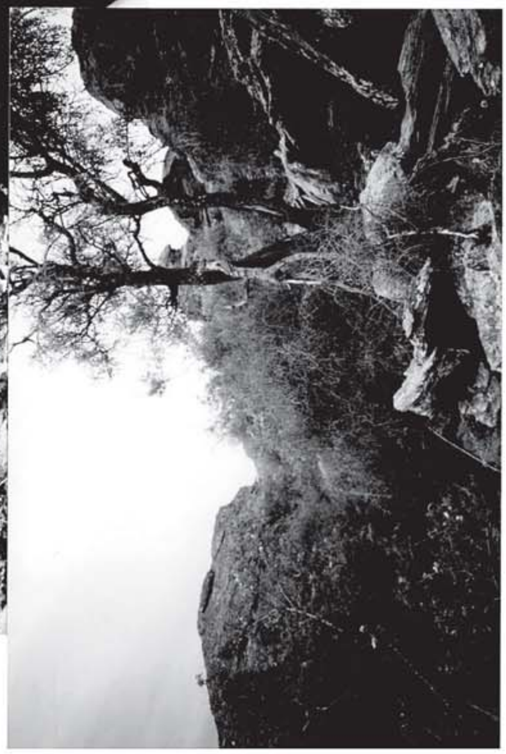


1F



Plates 1A–1F Some significant forest relicts in Central Otago.

Plate 1A Low forest (woody plant asssociations A and B) of *Podocarpus hallii* (Hall's totara) and *Kunzea ericoides* (kanuka) in Locharburn Scientific Reserve on the slopes of the Pisa Range, in the beech-Hall's totara-snow totara pre-settlement woody vegetation zone (VII). A ridge of schist tors has provided some shelter from fire, although the forest is probably secondary, and derived from pre-settlement beech (probably *Nothofagus menziesii*) forest. A small stand of *N. menziesii* trees survive in nearby Kidds Creek, and beech charcoals are present in the soils. On the true left of the Clutha River (background, in shadow) is Bendigo Reserve, which includes successional *Kunzea ericoides* shrubland that has established since c. 1940.

Plate 1B Dense *Podocarpus hallii/Kunzea ericoides* forest (height c. 8 m) at Locharburn Scientific Reserve, Pisa Range, at approx. 600 m a.s.l. Forest understorey species include *Coprosma crassifolia, C.* 'taylorae' and *Gaultheria antipoda*.

Plate 1C *Phyllocladus alpinus* (mountain toatoa) is now restricted to fire-protected positions in Central Otago. On the Pisa Range, in the snow totara-mountain toatoa pre-settlement woody vegetation zone (VIII), this single specimen emerges from the centre of a totara patch (*Podocarpus hallii* and *P. hallii* × *P. nivalis* hybrids) that has survived fire within a rock outcrop (approx. 800 m a.s.l.). Downslope, shrublands of *Kunzea ericoides* and *Coprosma propinqua* recover from recent fire.

Plate 1D A large specimen of *Halocarpus bidwillii* on the Pisa Range, in the bog pine-snow totara-mountain toatoa pre-settlement woody vegetation zone (IX). Grazing continues in the foreground. Although several other large specimens of *H. bidwillii* are present in the vicinity, no juveniles or seedlings were seen.

Plate 1E *Nothofagus menziesii* (silver beech: bright green trees left and right of stream) in a fire-sheltered gorge of Luggate Creek, Criffel Range. The site is at 400 m, and within the kanuka-kowhai-Hall's totara pre-settlement woody vegetation zone (IV). *Podocarpus hallii* (Hall's totara), *P. nivalis* (snow totara) and *Hoheria glabrata* (mountain ribbonwood) also occur beside the creek. Vegetation downstream (background) comprises *Kunzea ericoides*, *Coprosma crassifolia*, *C. pseudocuneata*, *Helichrysum intermedium* var. *selago* and *H. lanceolata*.

Plate 1F *Sophora microphylla* (kowhai) and the divaricating shrubs *Coprosma virescens* (now relatively rare in the district) and *Myrsine divaricata* (in the forest species group *a*) on an outcrop at 400m, overlooking Devils Creek on the western slopes of the Dunstan Mountains. The site is at the boundary of the kanuka-kowhai (I) and kanuka-kowhai-Hall's totara (IV) pre-settlement woody vegetation zones.