

Diversity of *Brassica* (Brassicaceae) species naturalised in Canterbury, New Zealand

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Abstract Field surveys were undertaken of *Brassica* naturalised in Canterbury, investigating taxonomic diversity, morphological variation, distribution, and abundance of naturalised taxa, crop escapes, and crop–weed hybrids. As a result, six species, nine varieties, and two natural hybrids were recognised as naturalised in Canterbury. *B. rapa* var. *oleifera* was the most common taxon, while *B. rapa* var. *chinensis*, *B. rapa* var. *glabra*, *B. rapa* var. *rapa*, *B. napus* var. *oleifera*, and *B. oleracea* var. *acephala* were less abundant and generally occurred in small populations of only a few individuals in rural areas. Single plants of *B. oleracea* var. *gongyloides* (kohl rabi) and *B. napus* var. *napobrassica* (swede) were collected. An additional species, *B. juncea*, is recorded as a new naturalised plant in Canterbury. Most of the *Brassica* populations sampled were small, with 64% of the 107 populations observed comprising fewer than 10 plants.

Flow cytometry profiles were obtained for 168 samples of *B. juncea*, *B. napus*, *B. oleracea*, and *B. rapa*, and these usually confirmed morphological identifications to a particular species. However, there were some identification uncertainties with *B. napus*, as some plants had a flow cytometry profile of that species but the morphology of either *B. rapa* var. *oleifera* or *B. oleracea* var. *acephala*. Tetraploid plants of *B. rapa* (var. *chinensis*, var. *oleifera*, and var. *rapa*) and *B. oleracea* var. *acephala* were recorded. We also identified two instances of

hybridisation. One plant has a flow cytometry profile and a high percentage of malformed pollen that are consistent with being the putative interspecific F₁ hybrid *B. napus* × *B. rapa*. Another population included plants of the putative intraspecific hybrid *B. rapa* var. *oleifera* × *B. rapa* var. *chinensis* growing with the two parental species.

Keywords naturalised plants; crop escapes; *Brassica*; *B. juncea*; *B. rapa*; *B. napus*; *B. oleracea*; flow cytometry; hybrids; Canterbury flora

INTRODUCTION

The potential escape of genetically modified (GM) crops into the environment, hybridisation with wild relatives, and possible environmental effects of gene transfer are increasingly being investigated worldwide. The cultivation of GM crops in New Zealand is subject to a rigorous approval process, with applications being governed by the Hazardous Substances and New Organisms Act and administered by the Environmental Risk Management Authority. The merits and risks of each GM crop application are considered on a case-by-case basis.

We are seeking to evaluate environmental risks due to gene flow from crops in New Zealand and to determine the ecological factors promoting gene flow by crop escape or hybridisation with wild relatives. *Brassica* was adopted as a case study because of the numerous GM taxa available, and the fact that several *Brassica* crops have been genetically engineered and field trialled in New Zealand (Christey & Woodfield 2001). There is also an extensive literature on interspecific hybridisation. However, little information on the rates of crop escapes or of the presence of compatible relatives exists in a New Zealand context, and this information is important for risk assessment. *Brassica* is also one of the most-studied GM crops in the world in regard to gene flow and invasiveness, and is considered to be a potential worse-case scenario and, therefore, a critically important model system (Conner et al. 2003).

Our study is the first step in addressing risk assessment for *Brassica* by establishing accurate and contemporary information on the taxonomic and morphological diversity, distribution, and abundance of naturalised weed species, crop escapes, and crop–weed hybrids. This biodiversity information is a necessary prerequisite to ecological and molecular studies for risk assessment of GM *Brassica* crops. We selected Canterbury in which to undertake a survey of naturalised *Brassica*, as *Brassica* crops are grown there for both seed certification and forage (Charlton & Stewart 2000; Stewart 2004), and several species are known to be naturalised there (Healy 1969; Webb et al. 1988). In this paper we report on the current taxonomic diversity, morphological variation, distribution, and abundance of *Brassica* taxa naturalised in Canterbury.

METHODS

Field surveys

Field surveys of *Brassica* were undertaken during September and October 2003 (Fig. 1) to coincide with peak flowering. We randomly selected 50 plots in Canterbury using Arcview data for the region. Plot dimensions were 3 × 3 km and their location was constrained to slopes of less than 10°, their centres were greater than 2.5 km from the sea, they did not overlap, were not in established urban areas, and had more than 3 km of roads. Within each plot we drove along all public roads recording *Brassica* plants on road verges, in and around drainage ditches, channels, and natural watercourses, around shelterbelts, and on wasteland. Samples were also collected when travelling between plots. Aerial helicopter surveys were undertaken of the Ashburton and Rakaia rivers from the foothills to the coast and along the coast between these two rivers (Fig. 1), as both flow through a large area of *Brassica* grown for seed certification. We did not examine pastoral and cropping land during this survey.

From each plot and collection sites between the plots we collected plants for identification, morphological examination, mapping distributions, and flow cytometric analysis. The number of individual plants per population were counted. Herbarium vouchers representing plants collected during the field survey are deposited in the Allan Herbarium (CHR). Specimen searches were also undertaken at New Zealand herbaria (AK, CHR, and WELT) for other records of *Brassica* naturalised in Canterbury.

Plant identification

Naturalised and crop species and varieties of *Brassica* are usually reliably identified by a specific set of vegetative, floral, and fruit characters (e.g., Webb et al. 1988; Zhou et al. 2001). These include leaf shape, colour, and hairiness, petiole distinctiveness and shape, open flower position relative to flower buds, petal length and colour, sepal and stamen orientation, and fruit shape, orientation, and size. Specimens were identified in the field on the basis of these morphological characters, and identifications were subsequently verified by flow cytometry data.

To estimate male fertility of putative hybrid plants their pollen was stained with Alexander's Differential Stain (Alexander 1969) to establish whether the cytoplasm was normally developed. Five hundred pollen grains per plant were counted. Pollen grains were considered normal if they were turgid and the cytoplasm fully stained red. Abnormal pollen grains were not rigid, having collapsed walls, lacking cytoplasm, or the cytoplasm was shrunken, unstained, or only partially stained.

Nomenclature follows Zhou et al. (2001), a recent and comprehensive treatment of *Brassica* completed for the *Flora of China* series. The main differences between Zhou et al. (2001) and Webb et al. (1988) are that wild turnip is treated in Zhou et al. (2001) as *B. rapa* var. *oleifera* DC. rather than *B. rapa* subsp. *sylvestris* (L.) Janch., and intraspecific names are applied to *B. napus*, *B. oleracea*, and *B. rapa*.

Flow cytometry

Brassica species used for seed certification, forage, and with naturalised populations in Canterbury have different chromosome numbers and comprise different combinations of three genomes (A, B, and C) (U 1935). These genomes have different nuclear DNA content, which facilitates the reliable identification of *Brassica* species and hybrids using flow cytometric analyses that estimate 2C nuclear DNA content of individual plants (Sabharwal & Doležal 1993). This technique has previously been successfully used to detect hybrids between *B. napus* and *B. rapa* (Wilkinson et al. 2000; Jenkins et al. 2001). Freshly collected leaf material from wild populations and cultivated specimens of known species and crop cultivars were analysed. A hexaploid specimen of *Hieracium pilosella* × *H. caespitosum* was used as a control standard of known ploidy. For each sample the results are presented as the ratio of the *Hieracium* value, which was standardised to 1.0.

Leaf material was finely chopped in 0.4 ml of buffer for cell extraction and liberation. The cell

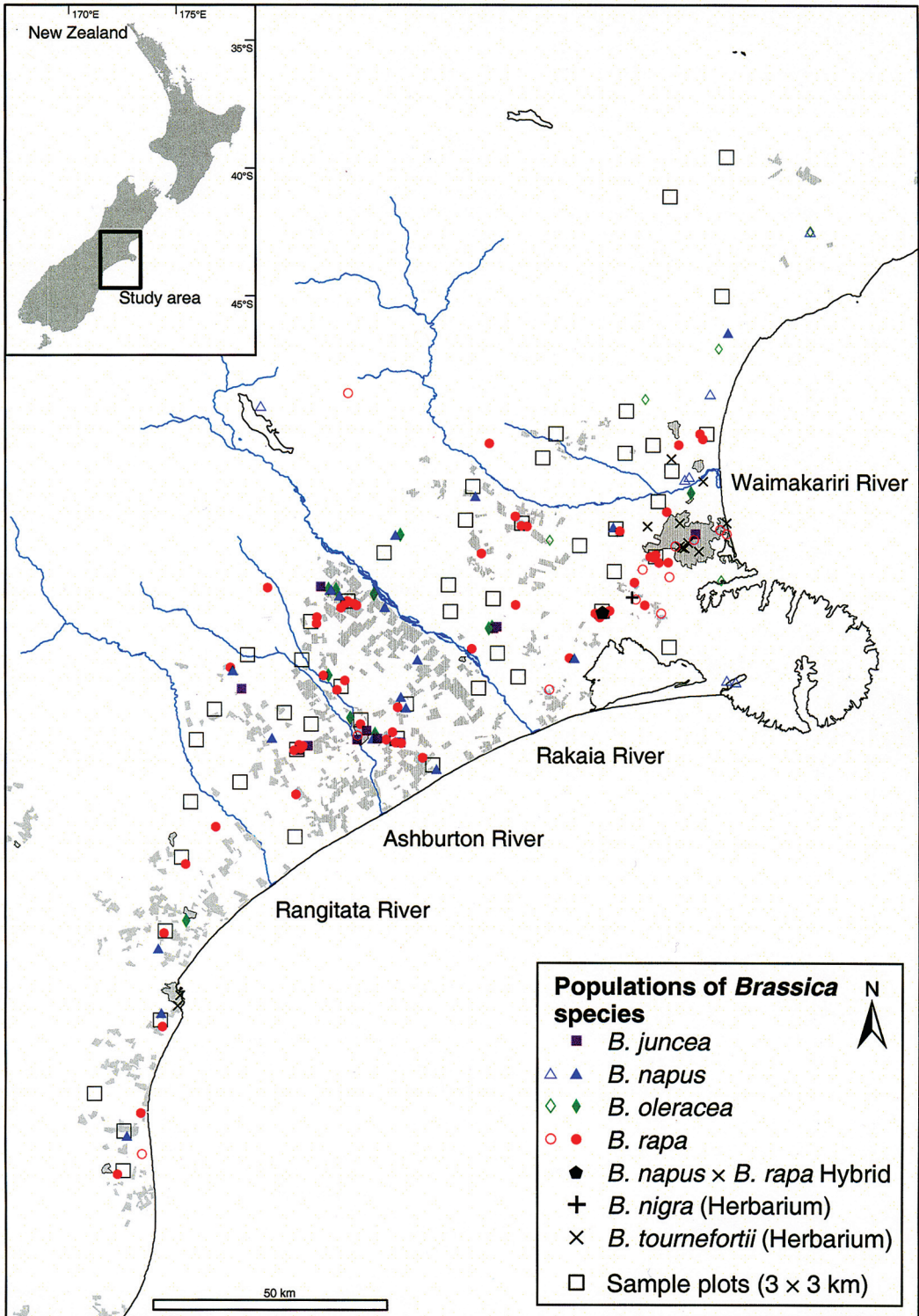


Fig. 1 Distribution of *Brassica* species naturalised in Canterbury. Grey shading represents areas cultivated for *Brassica* seed certification crops 1990–2003.

suspension was then filtered through a 30- μ m mesh into a sample tube and incubated for 2 min before the addition of 1.6 ml of DAPI stain. The buffer and stain are included in the proprietary Partec T kit (CyStain UV precise T (05-5003)). The cell suspension was passed through a flow-cytometer (Partec Ploidy Analyser PA-II) with the detector operating at 355 nm. A minimum of 5000 nuclei were counted for each sample, at a rate of about 30 nuclei per second. Data analysis was performed using PA-II's Partec FloMax software, and Gaussian curves were fitted to the histograms.

Chromosome counts

Plant material used for chromosome counts (Table 1) was grown in a greenhouse at Landcare Research, Lincoln. Voucher specimens are deposited in the Allan Herbarium (CHR).

Mitotic chromosome preparations were made from root tips that had been pretreated with a mixture of 70 ppm cycloheximide and 250 ppm 8-hydroxyquinoline, fixed in methanol-chloroform-propionic acid (6:3:2), hydrolysed in 1 M hydrochloric acid, macerated in 5% pectinase, and stained with Feulgen and lactic-acetic-orcein. These techniques follow Dawson (1993).

RESULTS

Field surveys

Over half (58%) of the 50 plots surveyed did not contain any naturalised *Brassica* species, although a number of *Brassica* specimens were sometimes collected from just outside the plot boundaries (Fig. 1, 2); several plots had more than one population. In total we identified 107 populations during the field surveys with more than half (56%) of these occurring outside the plots. The survey covered 3050 km by car, and an additional 166 km were travelled by helicopter during the Rakaia and Ashburton river surveys. Of the 107 populations recorded during the survey, 27% were represented by one plant, 57% had less than 5 plants, and 64% fewer than 10 plants (Fig. 3). Ten (9.3%) of the populations had two or more species or varieties of *Brassica* (Table 2).

Flow cytometry and cytology

We obtained chromosome counts and flow cytometric profiles for eight control samples of known species and crop cultivars (Table 1). These provide the basis on which we made identification decisions of field-collected material using the ratio values of the flow cytometry profiles. On the basis of flow

Table 1 Controls for the flow cytometric analyses. *, *Brassica* values standardised as a ratio of the *Hieracium* control (1.0).

Accession	<i>Brassica</i> type	Collection locality	Collector	Flow cytometry value*	Chromosome number	CHR voucher
<i>B. juncea</i>	Indian mustard	Rakaia, site 17	<i>P. B. Heenan & R. G. FitzJohn</i>	0.362	2n = 36	CHR 569877
<i>B. napus</i> var. <i>napus</i> 'Winfred'	rape	cultivated	<i>A. V. Stewart</i>	0.397	2n = 38	CHR 569878
<i>B. oleracea</i> var. <i>capitata</i> L.	wild cabbage	Portabello, Dunedin	<i>P. N. Johnson</i>	0.233	2n = 18	CHR 569879
<i>B. oleracea</i> var. <i>acephala</i> 'Maris Kestrel'	kale	cultivated	<i>A. V. Stewart</i>	0.229	2n = 18	CHR 569880
<i>B. oleracea</i> var. <i>acephala</i> tetraploid	tetraploid kale	cultivated	<i>A. V. Stewart</i>	0.467	2n = 36	CHR 569881
<i>B. rapa</i> var. <i>oleifera</i>	wild turnip	Portabello, Dunedin	<i>P. N. Johnson</i>	0.173	2n = 20	CHR 569882
<i>B. rapa</i> var. <i>rapa</i> 'Barabas' tetraploid	turnip	cultivated	<i>A. V. Stewart</i>	0.337	2n = 40	CHR 569883
<i>B.</i> 'Ceres Hunter' (<i>rapa</i> var. <i>oleifera</i> \times <i>B. rapa</i> var. <i>glabra</i>)	turnip-rape	cultivated	<i>A. V. Stewart</i>	0.163	2n = c. 20	CHR 569884
<i>Hieracium pilosella</i> \times <i>H. caespitosum</i>	control	cultivated	<i>R. A. Bicknell</i>	1.0	2n = 54	CHR 569993

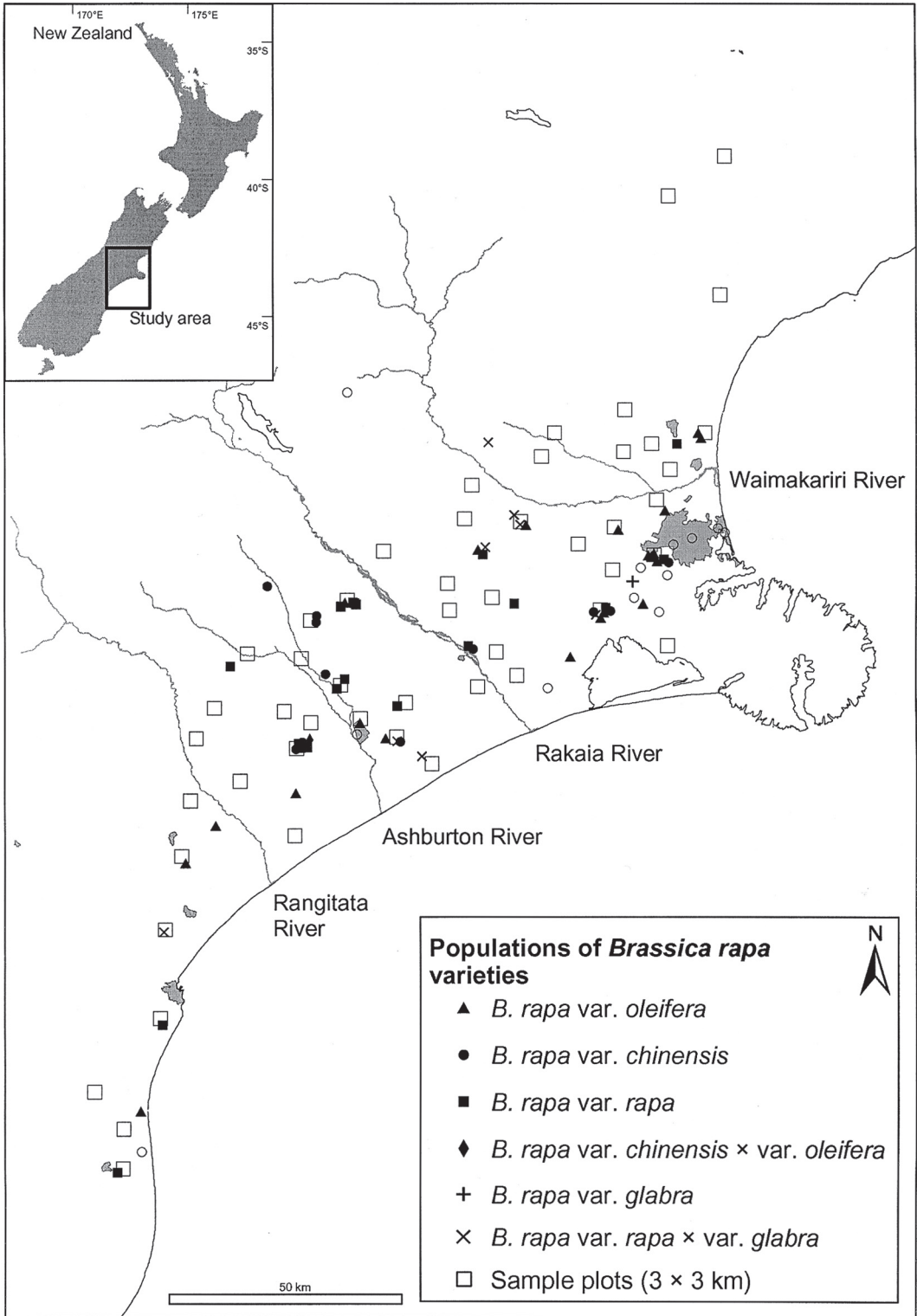


Fig. 2 *Brassica rapa* distribution.

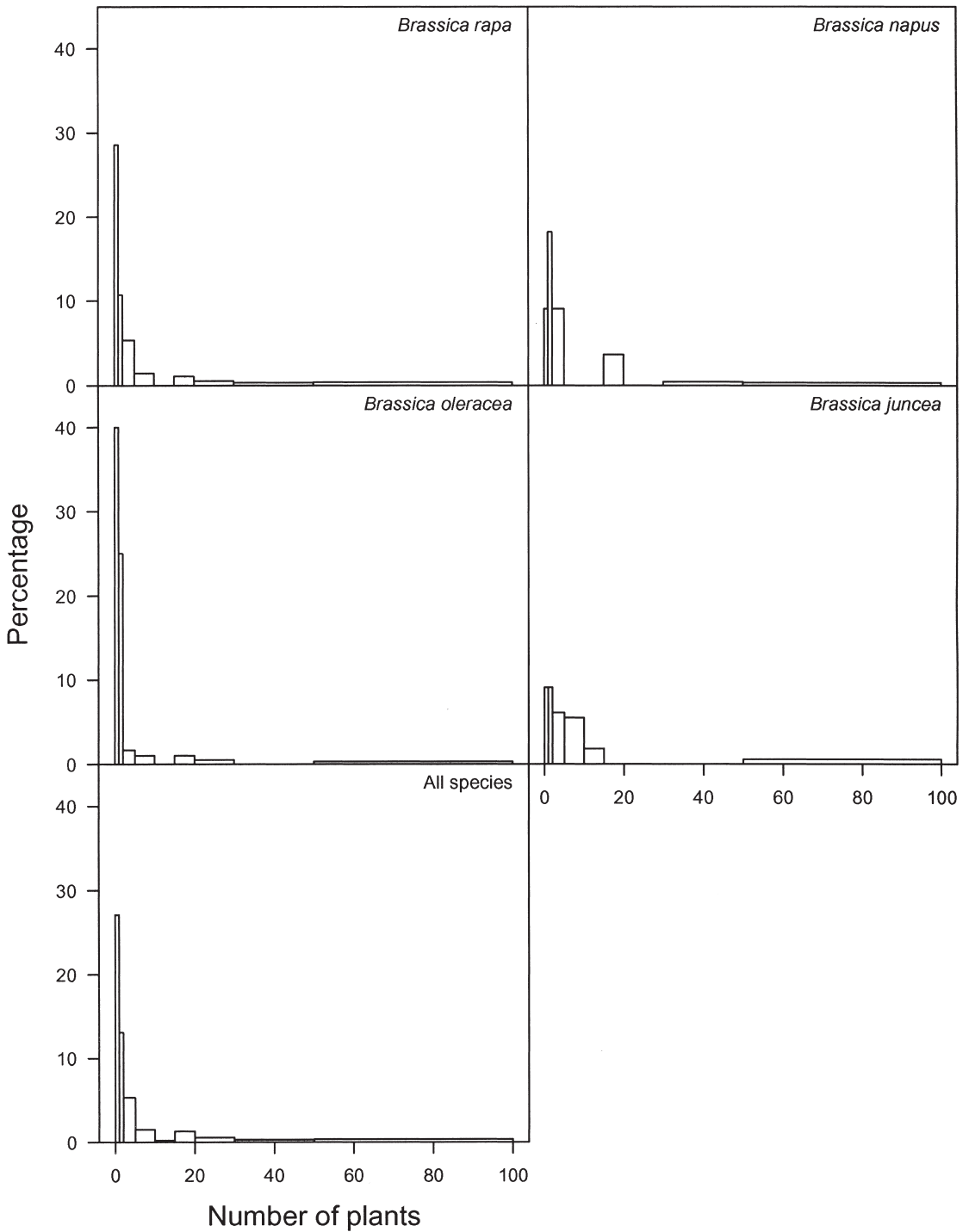


Fig. 3 Population sizes for *Brassica* species naturalised in Canterbury. The rectangle areas for each graph sum to 100%.

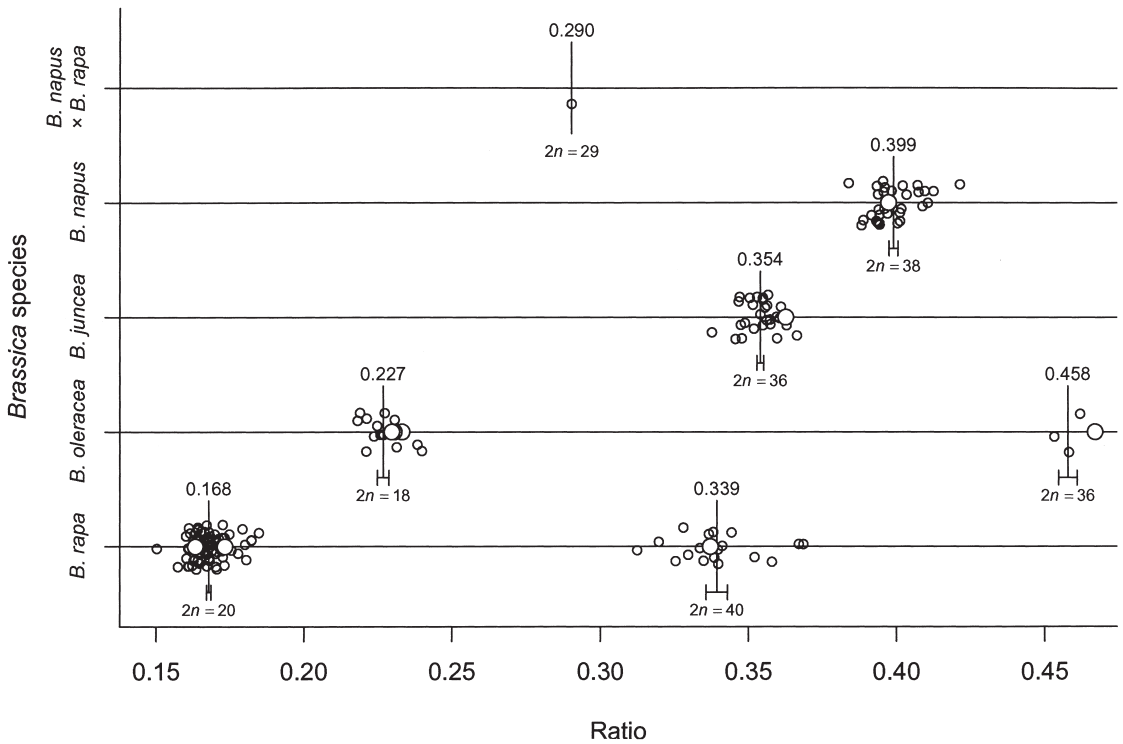


Fig. 4 Flow cytometry data for individual plants assigned to four species and one putative hybrid. The large symbols represent control plants for which chromosome counts were done. For each taxon the mean and standard error are indicated. *Brassica* values standardised as a ratio of the *Hieracium* control (1.0).

Table 2 Sympatry of *Brassica* species and varieties.

Site	<i>B. juncea</i>	<i>B. napus</i>	<i>B.r. chinensis</i>	<i>B.r. olerifera</i>	<i>B.r. rapa</i>	<i>B. oleracea</i>
Tinwald 1	*		*	*		
Tinwald 2	*		*			
Ashburton		*	*			
East Ashburton 1	*	*				*
East Ashburton 2	*			*		
Rakaia bridge				*	*	
Rakaia railway	*					*
Methven		*				*
Leeston		*		*		
Glentunnel		*				*

cytometry profiles the samples were generally reliably assigned to a species (Fig. 4), but within each species we were not able to discriminate to varietal rank (e.g., *B. rapa*; Fig. 5, 6). However, within species we identified tetraploid plants of *B. rapa* (var. *chinensis*, var. *oleifera*, and var. *rapa*) and *B. oleracea* var. *acephala*. For each species, the chromosome

counts documented here (Table 1) are the same as those reported previously (e.g., Gómez-Campo & Hinata 1980).

Flow cytometry profiles were obtained for 169 plants of *Brassica*, with 28 of these assigned to *B. juncea*, 31 to *B. napus*, 16 to *B. oleracea*, and 93 to *B. rapa*. The remaining one sample had an

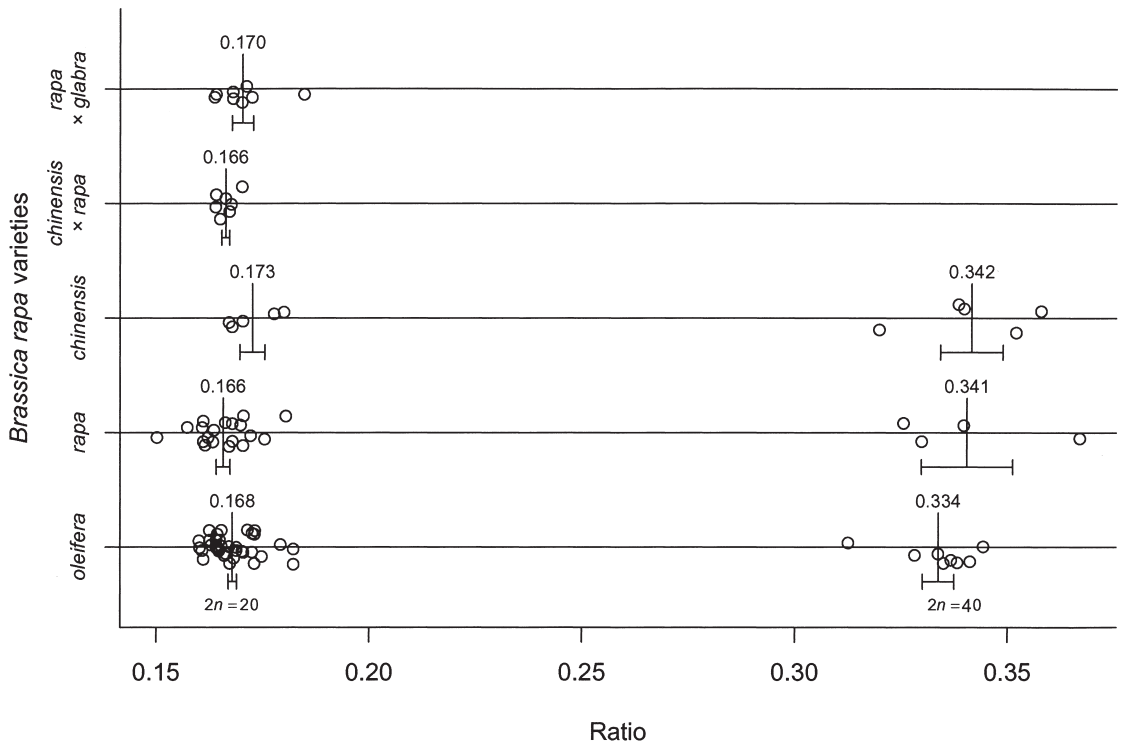


Fig. 5 Flow cytometry data for individual plants assigned to different varieties of *B. rapa*. For each taxon the mean and standard error are indicated.

unusual profile, representing the F₁ hybrid between *B. napus* × *B. rapa* (Fig. 4, 6). In this study the only uncertainty in using flow cytometric profiles for identification was that tetraploid *B. rapa* ($2n = 4x = 40$; genome AAAA) and *B. juncea* ($2n = 4x = 36$; genome AABB) have very similar flow cytometry profiles (Fig. 4, 6) and these species were best distinguished by their morphology.

TAXONOMY

Six species and nine varieties (including the unnamed *B. rapa* var. *rapa* × *B. rapa* var. *glabra* hybrid), as well as two natural hybrids, are recognised as naturalised in Canterbury, and information for each of these is presented below. The taxonomic treatment of *Brassica* for the *Flora of China* (Zhou et al. 2001) includes identification keys and descriptions at the rank of species and variety, and these were particularly useful for the identification of

naturalised plants of *Brassica* in Canterbury. Webb et al. (1988) provide a key and formal descriptions to all of the species reported here, but not for varieties within a species.

Brassica juncea (L.) Czern. var. *juncea*

Indian or brown mustard

REPRESENTATIVE SPECIMENS: west of Tinwald, *P. B. Heenan* & *R. G. FitzJohn* 64/8, 16 Oct 2003, CHR 568671; east of Ashburton, *P. B. Heenan* & *R. G. FitzJohn* 36/2, 14 Oct 2003, CHR 568562; NE of Rakaia, *P. B. Heenan* & *R. G. FitzJohn* 25/2, 14 Oct 2003, CHR 568543; NE of Rakaia, *P. B. Heenan* & *R. G. FitzJohn* 17/3, 7 Oct 2003, CHR 568531; Ashburton, *P. B. Heenan* & *D. Peltzer* 104/1, 10 Nov 2003, CHR 568670; near Methven, *P. B. Heenan* & *R. G. FitzJohn* 92/1, 30 Oct 2003, CHR 568653; Ashburton, *P. B. Heenan* & *R. G. FitzJohn* 65/1, 16 Oct 2003, CHR 568623; SE of Ashburton, *P. B. Heenan* & *R. G. FitzJohn* 7/2/1, 14 Oct 2003, CHR 568556.

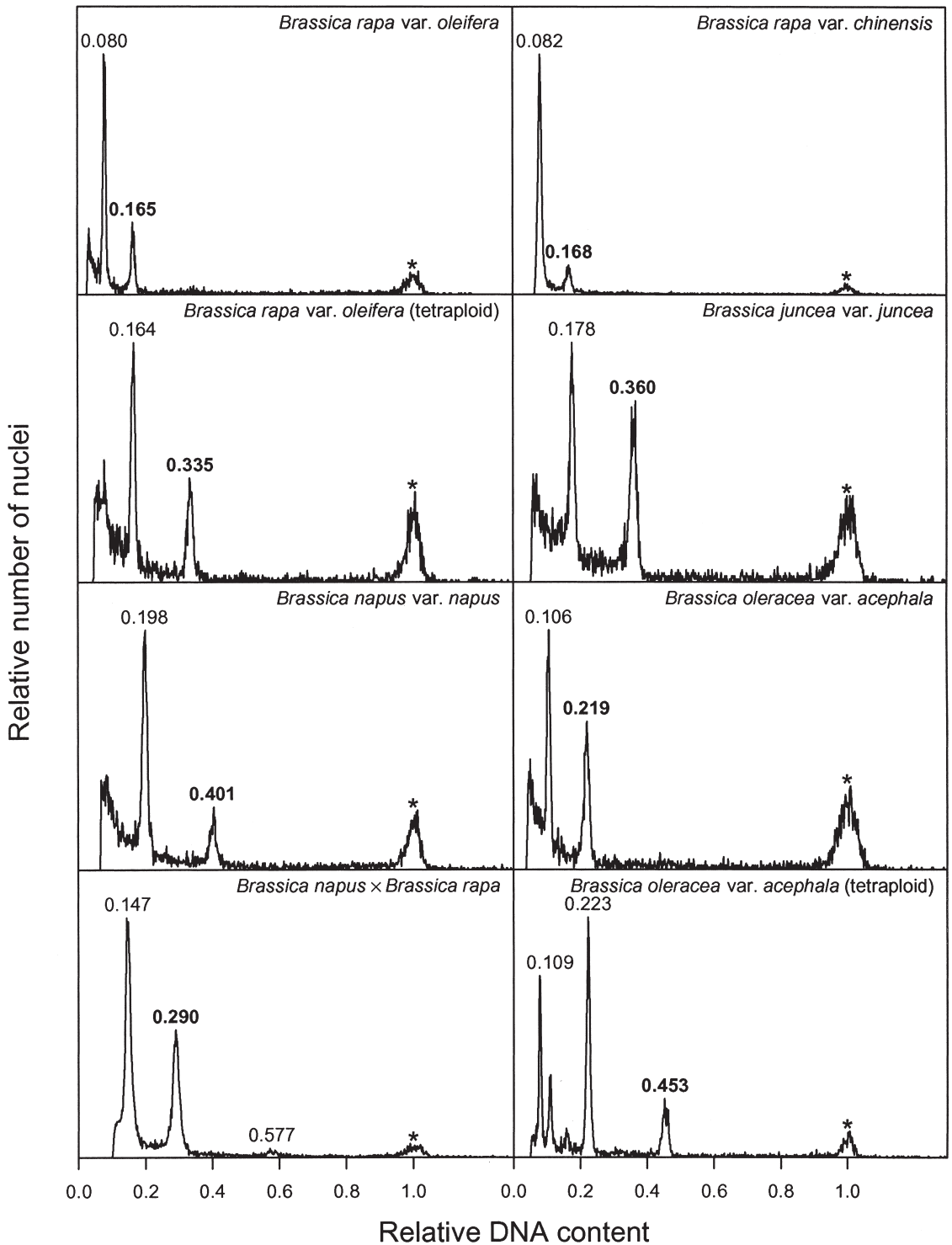


Fig. 6 Flow cytometry profiles of *Brassica* taxa investigated. *, *Hieracium pilosella* × *H. caespitosum* control.

DISTRIBUTION: Previously recorded from the North Island in North Auckland (Webb et al. 1988). Collected during this study from Canterbury where it is known from near Ashburton and Mt Somers. *B. juncea* is almost certainly recently naturalised in Canterbury and is reasonably common in the Ashburton area, although it is not considered to be a common crop (Stewart 2004).

NOTES: *B. juncea* is distinguished by the rosette and cauline leaves being sessile or petiolate and not amplexicaul or auriculate, and bright yellow petals usually 0.7–1.1 mm long. *B. juncea* var. *juncea* is naturally variable in a number of leaf characters (Zhou et al. 2001), and we recognise three different forms in Canterbury. The most common of these has green and toothed or lobed leaves. We have also made collections of a form with anthocyanin coloration in the leaves (e.g., CHR 568652) and others with dissected leaves (e.g., CHR 568592).

***Brassica napus* L.**

NOTES: *B. napus* is distinguished by the leaves often being glaucous, open flowers below the buds, and petals usually 10–16 mm long and pale yellow or creamy yellow. Within *B. napus* we identified two varieties as naturalised in Canterbury. Webb et al. (1988) did not distinguish rape and swede, referring both to *B. napus* L.

***Brassica napus* var. *napobrassica* (L.) Rchb.**

swede

REPRESENTATIVE SPECIMEN: north of Mayfield, *P. B. Heenan & R. G. FitzJohn* 98/1, 30 Oct 2003, CHR 568662.

DISTRIBUTION: In Canterbury we collected it from a single locality near Mayfield.

NOTES: *B. napus* var. *napobrassica* is distinguished from *B. napus* var. *napus* by its swollen root.

Brassica napus* L. var. *napus

weed rape, rape

REPRESENTATIVE SPECIMENS: Lake Forsyth, *E. Edgar & K. R. West*, 17 Sep 1975, CHR 276561; near Waimakariri River gorge, *D. R. Given*, 13 Oct 1976, CHR 286329; NE of Rakaia, *P. B. Heenan & R. G. FitzJohn* 18/1, 7 Oct 2003, CHR 568535; near Pleasant Point, *P. B. Heenan & R. G. FitzJohn* 88/1, 23 Oct 2003, CHR 568647; SW of Timaru, *P. B. Heenan & R. G. FitzJohn* 60/1/3, 23 Oct 2003, CHR 568645; east of Dromore, *P. B. Heenan & R. G. FitzJohn* 6/1/1, 14 Oct 2003, CHR 568550; SW of Glentunnel, *P. B. Heenan & R. G. FitzJohn* 11/1, 30 Sep 2003, CHR 568517; NW of Darfield, *P. B. Heenan & R.*

G. FitzJohn 13/2, 2 Oct 2003, CHR 568523; near Methven, *P. B. Heenan & R. G. FitzJohn* 56/1, 16 Oct 2003, CHR 568581; near Waimate, *P. B. Heenan & R. G. FitzJohn* 0/1/2, 23 Oct 2003, CHR 568641; west of Christchurch, *P. B. Heenan & R. G. FitzJohn* 56/1/1, 21 Oct 2003, CHR 568635; SE of Ashburton, *P. B. Heenan & R. G. FitzJohn* 48/1/1, 14 Oct 2003, CHR 568557; near Dromore, *P. B. Heenan & R. G. FitzJohn* 26/1, 14 Oct 2003, CHR 568545; near Ashburton, *P. B. Heenan & R. G. FitzJohn* 36/3, 14 Oct 2003, CHR 568560; Leeston, *P. B. Heenan & R. G. FitzJohn* 21/1, 7 Oct 2003, CHR 568538; north of Amberley, *P. B. Heenan & R. G. FitzJohn* 22/1, 9 Oct 2003, CHR 568540; west of Ashburton, *P. B. Heenan & R. G. FitzJohn* 99/1, 30 Oct 2003, CHR 568663; west of Rakaia, *P. B. Heenan & R. G. FitzJohn* 45/1, 14 Oct 2003, CHR 568570.

DISTRIBUTION: Occurs in the North Island and South Island where it is locally established on coasts, and is an occasional escape from cultivation on roadsides and in cultivated fields (Webb et al. 1988). In Canterbury *B. napus* var. *napus* occurs in scattered and small populations across the Canterbury Plains, and it is generally not locally abundant. The largest population seen during the survey occurred near Methven and comprised about 100 plants that were growing on a roadside verge with *B. oleracea* var. *acephala*.

NOTES: *B. napus* var. *napus* varies considerably in leaf and inflorescence characters and is sometimes difficult to identify using traditional morphological characters (e.g., using the keys provided by Webb et al. (1988) and Zhou et al. (2001)). The leaves of some plants approach *B. rapa* in being green, semi-coriaceous, and with a prominent amplexicaul or auriculate cauline leaf base, whereas other plants are more like *B. oleracea* in that the leaves are glaucous, coriaceous, and with only slightly amplexicaul or auriculate bases. The height of flower buds to open flowers, petal length, and petal colour are also unreliable characters, and can approach and indeed overlap with either *B. rapa* (buds below open flowers, petals 7–10 mm long, bright yellow) or *B. oleracea* (buds above open flowers, petals 15–25 mm long, creamy yellow). Fortunately, flow cytometry provides excellent data for the identification of *B. napus* (Fig. 4).

***Brassica nigra* (L.) W.D.J.Koch**

black mustard

REPRESENTATIVE SPECIMEN: near Lincoln, Canterbury, *T. Kirk*, CHR 3431.

DISTRIBUTION: Occurs in the North Island in North Auckland, and in the South Island in Canterbury

and Otago (Webb et al. 1988). In Canterbury it is known only from a single collection made by Kirk near Lincoln; this was probably made between Nov 1881 and April 1884 when Kirk is known to have collected in the area (Hamlin 1965). It was not collected during this study.

NOTES: *B. nigra* is most easily recognised by the short (up to 25 mm long) and 4-angled fruit that are strongly appressed to the rachis, and the short pedicels (3–5 mm long).

***Brassica oleracea* L.**

NOTES: *B. oleracea* is distinguished by glabrous, glaucous, and coriaceous leaves, open flowers well below the buds, erect sepals, and petals usually 15–25 mm long and creamy yellow. Within *B. oleracea* we identified two varieties as naturalised in Canterbury. Webb et al. (1988) did not distinguish the different varieties of *B. oleracea*.

***Brassica oleracea* var. *acephala* DC.** kale

REPRESENTATIVE SPECIMENS: NE of Methven, *P. B. Heenan & R. G. FitzJohn* 57/1, 16 Oct 2003, CHR 568582; south of Temuka, *P. B. Heenan & R. G. FitzJohn* 80/1, 23 Oct 2003, CHR 568639; north of Belfast, *P. B. Heenan & R. G. FitzJohn* 76/1, 21 Oct 2003, CHR 568634; NE of Rakaia, *P. B. Heenan & R. G. FitzJohn* 25/1, 14 Oct 2003, CHR 568544; east of Ashburton, *P. B. Heenan & R. G. FitzJohn* 36/1, 14 Oct 2003, CHR 568561; NE of Rakaia, *P. B. Heenan & R. G. FitzJohn* 17/6, 7 Oct 2003, CHR 568534; NE of Methven, *P. B. Heenan & R. G. FitzJohn* 93/1, 30 Oct 2003, CHR 568660.

DISTRIBUTION: In Canterbury *B. oleracea* var. *acephala* occurs in scattered and small populations across the Canterbury Plains.

NOTES: *B. oleracea* var. *acephala* can be confused with some forms of *B. napus* (see notes under *B. napus* var. *napus*). Older herbarium collections of *B. oleracea* (e.g., from near Amberley (CHR 286321) and Lyttelton (CHR 68340)) are not able to be determined to a particular variety due to the lack of diagnostic characters.

***Brassica oleracea* var. *gongylodes* L.** kohlrabi

REPRESENTATIVE SPECIMEN: NW of Ashburton, *P. B. Heenan & R. G. FitzJohn* 42/2, 14 Oct 2003, CHR 568567.

DISTRIBUTION: Collected during this study from a single site near Ashburton.

NOTES: *B. oleracea* var. *gongylodes* is distinguished from other varieties of *B. oleracea* by the swollen stem that produces the vegetable kohlrabi.

***Brassica rapa* L.**

NOTES: *B. rapa* is distinguished by the open flowers overtopping the buds; the basal leaves are green, and the petals are 6–10 mm long. Within *B. rapa* we identified four varieties and an unnamed intraspecific hybrid as naturalised in Canterbury. Webb et al. (1988) did not distinguish the different varieties of *B. rapa*, although they did refer to wild turnip (var. *oleifera*) as *B. rapa* subsp. *sylvestris*.

***Brassica rapa* var. *chinensis* (L.) Kitam.**

pak choi, Chinese cabbage

REPRESENTATIVE SPECIMENS: SW of Springston, *P. B. Heenan & R. G. FitzJohn* 17/2/1, 17 Sep 2003, CHR 568503; south of Methven, *P. B. Heenan & R. G. FitzJohn* 50/1/1, 14 Oct 2003, CHR 568568; SE of Ashburton, *P. B. Heenan & R. G. FitzJohn* 7/3/1, 14 Oct 2003, CHR 568559; east of Ashburton, *P. B. Heenan & R. G. FitzJohn* 30/1, 14 Oct 2003, CHR 568551; west of Tinwald, *P. B. Heenan & R. G. FitzJohn* 64/23, 16 Oct 2003, CHR 568598; west of Tinwald, *P. B. Heenan & R. G. FitzJohn* 54/2/2, 30 Oct 2003, CHR 568665.

DISTRIBUTION: In Canterbury *B. rapa* var. *chinensis* occurs in scattered and small populations across the Canterbury Plains.

NOTES: *B. rapa* var. *chinensis* is distinguished by the usually simple, entire, broadly elliptic basal and lower cauline leaves and the petiole is usually distinct, fleshy and without wings.

***Brassica rapa* var. *glabra* Regel**

Chinese cabbage

REPRESENTATIVE SPECIMEN: near Prebbleton, *P. B. Heenan & R. G. FitzJohn* 107/1, 17 Jun 2003, CHR 568677.

DISTRIBUTION: In Canterbury we consider *B. rapa* var. *glabra* to be a persistent crop escape in the area in which it was cultivated as well as colonising adjacent soil heaps; it has also been seen but not collected in a drainage ditch near Halswell, Christchurch (PBH pers. obs.).

NOTES: *B. rapa* var. *glabra* is distinguished by having more than 10 basal leaves, the leaves being obovate to oblanceolate, and the petioles are flattened and with incised or toothed wings.

***Brassica rapa* var. *oleifera* DC.**

rape,
wild turnip

REPRESENTATIVE SPECIMENS: Wainono Lagoon, *R. Ma-son* 9512, 28 Dec 1962, CHR 126856; Middleton, Christchurch, *A. J. Healy* 64/463, 10 Dec 1964,

CHR 152088; New Brighton, Christchurch, *P. B. J. Molloy*, 26 Oct 1970, CHR 212056; Prebbleton, *W. R. Sykes* 411/91, 20 Oct 1991, CHR 474040; west of Methven, *P. B. Heenan & R. G. FitzJohn* 4/4/1, 16 Oct 2003, CHR 568576; west of Tinwald, *P. B. Heenan & R. G. FitzJohn* 64/31, 16 Oct 2003, CHR 568603; west of Springston, *P. B. Heenan & R. G. FitzJohn* 17/4/5, 17 Sep 2003, CHR 568506; south of Springston, *P. B. Heenan & R. G. FitzJohn* 7/1, 17 Sep 2003, CHR 568513; SW of Lincoln, *P. B. Heenan & R. G. FitzJohn* 2/3, 17 Sep 2003, CHR 568500; outskirts of Christchurch, *P. B. Heenan & R. G. FitzJohn* 2/2/1, 21 Oct 2003, CHR 568624; outskirts of Halswell, Christchurch, *P. B. Heenan & R. G. FitzJohn* 73/3, 21 Oct 2003, CHR 568632; south of Rangitata, *P. B. Heenan & R. G. FitzJohn* 91/1, 23 Oct 2003, CHR 568650; near Waimate, *P. B. Heenan & R. G. FitzJohn* 83/1, 23 Oct 2003, CHR 568642; near Leeston, *P. B. Heenan & R. G. FitzJohn* 21/2, 7 Oct 2003, CHR 568539; south of Woodend, *P. B. Heenan & R. G. FitzJohn* 24/2/1, 9 Oct 2003, CHR 568542.

DISTRIBUTION: Occurs in the North Island and South Island where it can be a common and persistent weed of pastures, roadsides, waste places, and gardens (Webb et al. 1988). In our survey of Canterbury, *B. rapa* var. *oleifera* occurred in scattered and small populations in rural areas where it was generally not locally abundant. It is most abundant and common in and around the periphery of urban areas.

NOTES: *B. rapa* var. *oleifera* is distinguished by a slender and cylindrical taproot, having few basal leaves (less than 10), and petioles that are slender and not winged.

Brassica rapa* L. var. *rapa turnip

REPRESENTATIVE SPECIMENS: Dromore, *P. B. Heenan & R. G. FitzJohn* 27/1, 14 Oct 2003, CHR 568548; Halswell, Christchurch, *P. B. Heenan & R. G. FitzJohn* 73/1, 21 Oct 2003, CHR 568630; near Dunsandel, *P. B. Heenan & R. G. FitzJohn* 79/1, 21 Oct 2003, CHR 568638; NW of Ashburton, *P. B. Heenan & R. G. FitzJohn* 8/1/1, 14 Oct 2003, CHR 568564; near Rakaia, *P. B. Heenan & R. G. FitzJohn* 19/1, 7 Oct 2003, CHR 568537; north of Mayfield, *P. B. Heenan & R. G. FitzJohn* 59/1, 16 Oct 2003, CHR 568584; near Waimate, *P. B. Heenan & R. G. FitzJohn* 39/1/1, 23 Oct 2003, CHR 568640; west of Methven, *P. B. Heenan & R. G. FitzJohn* 53/1, 16 Oct 2003, CHR 568578; west of Methven, *P. B. Heenan & R. G. FitzJohn* 4/5/1, 16 Oct 2003, CHR 568579; west of Methven, *P. B. Heenan & R. G. FitzJohn* 4/1/1, 16 Oct 2003, CHR 568573; west of

Charing Cross, *P. B. Heenan & R. G. FitzJohn* 12/2, 30 Sep 2003, CHR 568521; south of Rangiora, *P. B. Heenan & R. G. FitzJohn* 16/2, 2 Oct 2003, CHR 568527; west of Tinwald, *P. B. Heenan & R. G. FitzJohn* 54/1/1, 16 Oct 2003, CHR 568586.

DISTRIBUTION: Scattered individuals and small populations of fewer than five plants of *B. rapa* var. *rapa* are often seen in rural areas of Canterbury. We located only one significant population of more than 100 plants, and this occurred on disturbed and sparsely vegetated roadside gravels in an isolated area with no obvious seed source such as seed storage silos or farmyards; this population probably originated from seed spilt from farm machinery or a truck transporting seed. We were not able to tell if this population was naturally reproducing or whether new plants were germinating from the soil seed bank.

NOTES: Plants of *B. rapa* var. *rapa* are distinguished by their large and fleshy taproot. They usually grow as biennials although may grow as annuals when autumn-germinated seed is vernalised during the following winter. There is considerable variation in the size, shape, and colour of the fleshy taproot in wild-collected material.

***Brassica rapa* L. var. *rapa* × *B. rapa* var. *glabra* Regel** turnip-rape

REPRESENTATIVE SPECIMENS: SE of Ashburton, *P. B. Heenan & R. G. FitzJohn* 33/1, 14 Oct 2003, CHR 568558; west of Kirwee, *P. B. Heenan & R. G. FitzJohn* 21/3/1, 30 Sep 2003, CHR 568516; west of Kirwee, *P. B. Heenan & R. G. FitzJohn* 21/2/1, 30 Sep 2003, CHR 568515; west of Charing Cross, *P. B. Heenan & R. G. FitzJohn* 12/3, 30 Sep 2003, CHR 568519; SW of Oxford, *P. B. Heenan & R. G. FitzJohn* 14/1, 2 Oct 2003, CHR 568525; SW of Temuka, *P. B. Heenan & R. G. FitzJohn* 26/1/1, 23 Oct 2003, CHR 568648; SW of Springston, *P. B. Heenan & R. G. FitzJohn* 17/4/1, 17 Sep 2003, CHR 568510; SE of Ashburton, *P. B. Heenan & R. G. FitzJohn* 7/2/5, 14 Oct 2003, CHR 568554.

DISTRIBUTION: Canterbury, scattered localities.

NOTES: Turnip-rape is derived from crossing turnips (*B. rapa* var. *rapa*) with related Asiatic leaf vegetables (*B. rapa* var. *glabra*) (Charlton & Stewart 2000). These are fast-growing and non-bulb-producing leafy turnips that produce high leaf quality and have excellent regrowth after being browsed. The higher leaf density and better regrowth of turnip-rape cultivars may mean that they are able to compete and persist among other naturalised plants better than other cultivars and varieties of *B. rapa*.

Cultivars of turnip-rape grown in Canterbury include 'Pasja' and 'Ceres Hunter', and the wild-collected specimens are very similar to these cultivars in that the leaves are oblanceolate and with distinctly winged petioles.

Brassica tournefortii Gouan

mediterranean mustard

REPRESENTATIVE SPECIMENS: Timaru, *A. J. Healy* 56/255, 20 Dec 1956, CHR 92184; Addington, Christchurch, *A. J. Healy* 59/261, 20 Mar 1959, CHR 121496; Wetheral, North Canterbury, *A. J. Healy* 59/343, 13 Apr 1959, CHR 121623; Papanui, Christchurch, *A. J. Healy* 59/665, 29 Dec 1959, CHR 122772; Linwood, Christchurch, *A. J. Healy* 63/358, 3 Dec 1963, CHR 143862; Kaianga, Waimakariri River, *A. J. Healy* 64/127, 13 Aug 1964, CHR 143966; Rangiora, North Canterbury, *A. J. Healy* 59/351, 13 Apr 1959, CHR 121625; New Brighton, Christchurch, *A. E. Wright* 6002, 4 Nov 1983, CHR 396815.

DISTRIBUTION: Occurs in the North Island in North Auckland, South Auckland, Taranaki, and Wellington, and in the South Island in Canterbury and Marlborough (Webb et al. 1988). Known in Canterbury from Timaru and Christchurch, and several areas just to the north of Christchurch. *B. tournefortii* was not collected during this study.

Natural hybrids

Brassica napus × *B. rapa*

REPRESENTATIVE SPECIMEN: SW of Springston, Canterbury, *P. B. Heenan & R. G. FitzJohn* 17/1/1, 17 Sep 2003, CHR 568502.

DISTRIBUTION: A single plant was identified near Springston.

NOTES: A single plant of this hybrid was identified by flow cytometry (Fig. 4, 6). This hybrid is probably between *B. napus* var. *napus* and *B. rapa* var. *oleifera*, both of which occur in the Springston area. Pollen of the putative hybrid plant stained with Alexander's Differential Stain showed considerable irregularity in pollen development, with 75% of the grains having abnormal or aborted cytoplasm.

Brassica rapa var. *chinensis* × *B. rapa* var. *oleifera*

REPRESENTATIVE SPECIMENS: west of Tinwald, *P. B. Heenan & R. G. FitzJohn* 64/13, 16 Oct 2003, CHR 568620; west of Tinwald, *P. B. Heenan & R. G. FitzJohn* 64/10, 16 Oct 2003, CHR 568588; west of Tinwald, *P. B. Heenan & R. G. FitzJohn* 64/14, 16 Oct 2003, CHR 568604; west of Tinwald, *P. B.*

Heenan & R. G. FitzJohn 64/9, 16 Oct 2003, CHR 568617.

DISTRIBUTION: Known from a single site near Tinwald, Ashburton.

NOTES: The basal and lower cauline leaves of the *Brassica rapa* var. *chinensis* × *B. rapa* var. *oleifera* hybrid are intermediate between those of the putative parents. The basal leaves of the hybrids are simple and with the margin dentate, crenate, or sinuate, they are distinctly petiolate, and the base of the petiole is sometimes slightly auriculate or amplexicaul (Fig. 7). *B. rapa* var. *chinensis* has simple, broadly elliptic, entire, and distinctly petiolate leaves, and *B. rapa* var. *oleifera* has lyrate-pinnatifid leaves with sinuate or toothed margins and 1–3 pairs of lateral lobes, and the petiole is auriculate or amplexicaul at the base. Pollen stainability of these hybrids varies between 97% and 100%. About 20 plants of this putative hybrid were identified in the field near Tinwald.

Intraspecific crosses among the different botanical varieties of *B. rapa* are easily undertaken and particularly fertile, and hybrid plants typically have pollen stainability of 73–97%, and usually above 90% (Olsson 1954, and references therein). In particular, wild turnip (var. *oleifera*) crosses easily and spontaneously with cultivated turnip (var. *rapa*) and turnip-rape (e.g., Davey 1939).

Habitats

In this study we observed that the species and varieties of *Brassica* that are naturalised in Canterbury are mainly weeds of disturbed roadside verges, drainage ditches, and hedges, at the approaches to culverts and bridges, at the bases of telegraph poles and road signs, on gravel ballast along railway tracks, and in wasteland and on soil stockpiles. They are particularly common along road verges where they most frequently occur in the narrow zone of loose gravel between the consolidated road and the usually densely grassed berm. At these sites *Brassica* usually occur in association with other introduced annual and short-lived perennial dicotyledon weeds such as *Capsella bursa-pastoris* (L.) Medik., *Cerastium glomeratum* Thuill., *Lepidium didymus* L., *Sisymbrium officinale* (L.) Scop., *Stellaria media* (L.) Cirillo., *Vicia sativa* L., and *Viola arvensis* Murray. This suite of short-lived species reflects regular seasonal disturbance and exposed soil and open habitat for *Brassica* to establish and mature. *Brassica* rarely occur in stable fertile habitats dominated by introduced grasses, except where they established synchronously.

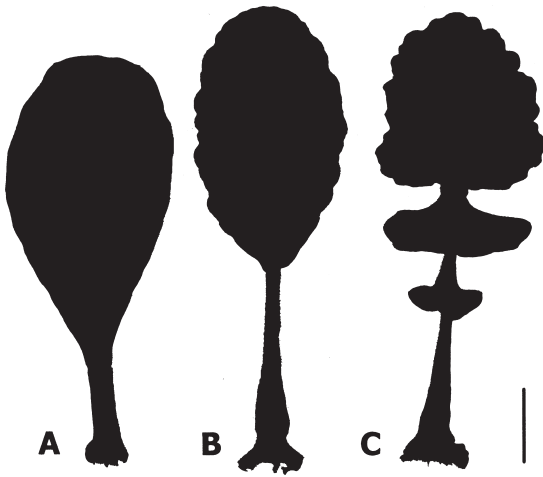


Fig. 7 Leaf profiles of the putative *B. rapa* intraspecific hybrid and its parents. A, var. *chinensis*; B, var. *chinensis* × var. *oleifera*; C, var. *oleifera*. Scale bar = 10 mm.

DISCUSSION

Historical and current distributions

The present study recognises six species of *Brassica* naturalised in Canterbury. *B. rapa* is the most variable and common species with var. *chinensis*, diploid var. *oleifera*, tetraploid var. *oleifera*, and var. *rapa* occurring in the wild. Population sizes vary, but most rural populations of var. *chinensis* and var. *rapa* comprised only a few individuals (Fig. 3). Populations of *B. rapa* var. *oleifera* ranged from a few individuals to several thousand plants, and the tetraploid var. *oleifera* plants usually occurred in populations that mainly comprised diploid var. *oleifera*. *B. napus* var. *napus* and *B. oleracea* var. *acephala* are less abundant and generally occur in small populations of only a few individuals in rural areas, and only single plants of *B. oleracea* var. *gongyloides* (kohlrabi) and *B. napus* var. *napobrassica* (swede) were collected. An additional species, *B. juncea*, is a new naturalised plant record for Canterbury where it occurs near Ashburton and Mt Somers. Although *B. juncea* has been considered to be an uncommon crop in Canterbury (Stewart 2004), its presence as a naturalised plant at a number of sites suggests it has naturalised relatively quickly and is likely to become more common in the future. Although not collected during the present study, *B. tournefortii* and *B. nigra* are additional species of

Brassica naturalised in Canterbury (Healy 1969; Webb et al. 1988).

Brassica rapa var. *oleifera* is the most common and widespread naturalised *Brassica* in New Zealand. In Canterbury it is primarily an urban and urban-periphery weed and occurs where there is frequent disturbance due to road maintenance, more intensively managed roadside verges and drainage ditches, and ongoing land development (e.g., housing and industrial subdivision). *B. rapa* may also occur more frequently around the urban-periphery where market gardening has perhaps provided a seed source and seed bank for subsequent invasions. This may in part explain the prevalence of naturalised *B. rapa* on the periphery of Christchurch, for example in the vicinity of Halswell, Lincoln, Prebbleton, and Springston. There are generally few substantial populations of *B. rapa* var. *oleifera* in rural areas due to the established and stable dense sward of introduced grasses along road verges and berms, drainage ditches, and fence lines. In New Zealand, *B. napus* has previously been considered to be mainly a coastal species (e.g., Allan 1940; Webb et al. 1988), and the reasonable number of inland Canterbury occurrences reported here for *B. napus* var. *napus* may be a result of breeding for increased hardiness (Charlton & Stewart 2000).

Our study of *Brassica* naturalised in Canterbury differs from early accounts that described the naturalised plants of Christchurch (Armstrong 1872) and Ashburton County (Smith 1904). Among the naturalised plants listed for these areas were several species of *Brassica* and *Sinapis*, a genus to which some species of *Brassica* are often assigned. Armstrong (1872) and Smith (1904) both recorded *B. napus*, *B. oleracea*, and *B. rapa* (including its synonym *B. campestris*). In the Christchurch area, Armstrong (1872) reported that these three species were observed as occasional individuals but were not common on cultivated land. Armstrong (1872) also recorded *Sinapis arvensis* L. (= *Brassica kaber* (DC.) L.C. Wheeler) as being very abundant along roadsides in the Christchurch area. In the Ashburton area, Smith (1904) also listed *Brassica alba* (L.) Rabenh. (= *Sinapis alba* L.), *Sinapis arvensis* (including *Brassica sinapistrum* Boiss.), and *Sinapis nigra* L. (= *Brassica nigra*). These historical records of *S. arvensis* and *B. nigra*, as well as the more recent records of *B. tournefortii*, are particularly interesting as although these species are known from Canterbury (Webb et al. 1988), and are common and often invasive weeds of cultivated areas, roadsides,

and waste places overseas (Holm et al. 1979), we did not find them during this survey. Unfortunately, there are no known herbarium specimens to verify the identifications of Armstrong (1872) and Smith (1904).

It is important to note that the present survey examined only roadsides, waterways, and waste places and did not survey pastoral and cropping land. In this regard we sometimes observed volunteer plants of *Brassica* in pastures, but did not record this. Interestingly, we did not record any populations of volunteers spreading from their paddock into adjacent roadside verges and drainage ditches. On agricultural land in Canterbury, *B. rapa* var. *oleifera* has been considered to be a common weed in the past (Hilgendorf & Calder 1952; Symons 1956). Smith (1904) considered that "*B. campestris* [= *B. rapa*] and *B. sinapistrum* [= *B. kaber*] have long been great scourges, and have in certain years taken almost complete possession of large cultivated areas." Later, Healy (1969) observed on cultivated land on the Canterbury Plains that *B. rapa* (as *B. campestris*) was one of the most widespread and abundant species. Today, *B. rapa* var. *oleifera* is not considered to be a significant weed of agricultural land (Bourdôt et al. 1999), and in wheat and barley crops in Canterbury it occurs as volunteers at a rate of <0.5 plant/m² (Bourdôt et al. 1998). *B. napus* often grows as a volunteer in agricultural areas where it occurs at a rate of 1 plant/m² in wheat and barley fields (Bourdôt et al. 1998), and it often occurs as a volunteer in crops grown in rotation with oilseed rape (Bourdôt et al. 1999).

The presence of *Brassica* along some road verges in rural areas may be due to farming practices, whereby farm machinery used for drilling and harvesting seed is the prime dispersal agent while in transit between farm paddocks along public roads. This explanation was offered on one occasion by a farmer to explain the origin of three plants established on a road verge near Geraldine. Wind dispersal may also be locally important as it was also reported to us that in the Geraldine area during 2002 a very strong north-west wind blew seed from a cut but not harvested crop of *B. rapa* var. *chinensis* throughout a rural neighbourhood subsequently producing hundreds of plants in gardens and on roadsides. An alternative and possibly important seed source may be provided by the soil seed bank. At a number of sites it is possible that plants originated from seed in the seed bank rather than from recently dispersed or distributed seed. Studies of farming practices relevant to *Brassica* and the seed

bank are needed to determine their role in the establishment of naturalised *Brassica*.

Flow cytometry and morphological variation

Flow cytometry proved particularly useful in distinguishing the species of *Brassica* naturalised in Canterbury, as *B. juncea*, *B. napus*, *B. oleracea*, and *B. rapa* all have different chromosome numbers and nuclear DNA contents (Fig. 4, 6). The only problem encountered was in distinguishing *B. juncea* ($2n = 4x = 36$; genomes AABB) from tetraploid *B. rapa* ($2n = 4x = 40$; genomes AAAA). However, they are reliably identified by their leaf morphology (Webb et al. 1988; Zhou et al. 2001). A number of tetraploid plants of *B. rapa* var. *oleifera* were detected by flow cytometry, and these usually occurred among populations of diploid *B. rapa* var. *oleifera*. The origin of these plants is difficult to determine, although they are most likely to be crop escapes as tetraploid fodder turnips are grown in Canterbury (Charlton & Stewart 2000; Stewart 2004). Tetraploid turnips (e.g., *B. rapa* var. *rapa* 'Barabas' and 'Marco') are also grown in New Zealand (Charlton & Stewart 2000), and we identified four tetraploid turnips by flow cytometry. We also collected several plants of tetraploid kale (*B. oleracea* var. *acephala*) growing amongst diploid kale, and this is of interest as tetraploid kale is not considered to have been grown in Canterbury (Stewart 2004). Either there is tetraploid kale grown or these plants are autotetraploids.

We encountered some identification difficulties involving *B. napus*. Firstly, some naturalised plants were initially identified by their morphology as *B. napus* var. *napus*, as they had glaucous leaves, open flowers below buds, and petals 10–16 mm long (Webb et al. 1988; Zhou et al. 2001). However, these plants had flow cytometry profiles consistent with *B. rapa*, which usually has green leaves, open flowers overtopping buds, and petals 6–10 mm long (Webb et al. 1988; Zhou et al. 2001). Other plants had the morphology of *B. rapa* but flow cytometry profiles of *B. napus*. The origin of these plants is unknown, although plant breeders, in improving disease resistance and production, have crossed *B. napus* and *B. rapa* and then backcrossed the progeny to one of the parental species (e.g., Namai et al. 1980; Olsson & Ellerström 1980). Depending on the traits being selected for and the inheritance of other characters, the resulting plants could comprise the chromosome number and hence flow cytometry profile of one parental species but have inherited some of the morphological characteristics of the other parental species. Several such hybrid cultivars have been

raised in New Zealand including, for example, the turnip 'Kapai' and the swede 'Kiri' (Palmer 1983).

Secondly, we also encountered difficulties in identifying a number of plants as either kale (*B. oleracea* var. *acephala*) or rape (*B. napus* var. *napus*), as some of the morphological characters contradicted the flow cytometry profiles. *B. oleracea* has petiolate or sessile upper cauline leaves (compared with auriculate or amplexicaul in *B. napus*), the petals are 15–25 mm long (cf. 10–16 mm long), and the sepals and stamens erect (cf. spreading) (Webb et al. 1988; Zhou et al. 2001). Interspecific hybridisation between these two species by plant breeders has also been used to improve disease resistance and production (e.g., Palmer 1983), and this is the most likely explanation to account for discrepancies between the flow cytometry profiles and morphological characters.

In regard to the problems of identification involving *B. napus*, this species is an allotetraploid ($2n = 4x = 38$) derived from *B. oleracea* ($2n = 2x = 18$) \times *B. rapa* ($2n = 2x = 20$) (U 1935). Many of the modern *B. napus* cultivars have been artificially bred by crossing selected forms of the two parental species (Olsson & Ellerström 1980). Therefore, the hybrid origin of *B. napus* may also account for some of the morphological variation present in naturalised *B. napus* and the difficulty of distinguishing some forms of that species from either *B. rapa* or *B. oleracea*.

Natural hybrids

Flow cytometry identified a single plant with a nuclear DNA content consistent with being an F₁ hybrid of *B. napus* \times *B. rapa* as the flow cytometry profile of this plant is intermediate between those of the putative parents (Fig. 4, 6). From this it can be inferred that this hybrid plant is probably a sesquiploid with a chromosome number of $2n = 29$, this being intermediate between the chromosome numbers of *B. rapa* ($2n = 20$) and *B. napus* ($2n = 38$). A chromosome number of $2n = 29$ was obtained for F₁ plants from the interspecific cross *B. napus* and *B. rapa* by Lu et al. (2001). The hybrid plant documented here has a low level of stainable pollen (25%), and this is at the lower end of the range (12.9–89.3%) of pollen stainability reported from a set of interspecific crosses between different cultivars of *B. napus* and *B. rapa* (Lu et al. 2001). In New Zealand, in experimental field/crop conditions, natural hybrids between *B. rapa* var. *oleifera* ♀ (wild turnip) and *B. napus* ♂ (rape) have previously been documented to occur at frequencies of 87.9% (Palmer 1962) and 0.06–2.13

% (Jenkins et al. 2001). The reciprocal interspecific cross *B. napus* ♀ \times *B. rapa* ♂ gave 10.8% hybrid progeny (Palmer 1962).

The morphology of the *B. napus* \times *B. rapa* hybrid was very much like other plants of *B. rapa* var. *oleifera* collected from Canterbury, and without the identification of the putative hybrid by flow cytometry it would have been very difficult to detect using leaf, flower, and inflorescence characters. *B. rapa* var. *oleifera* is naturalised in the general area where the hybrid was collected but *B. napus* was not seen at all, although it is grown in the vicinity as a fodder crop. The possible origin of this hybrid is that it is derived from hybridisation of a crop *B. napus* with a naturalised *B. rapa* var. *oleifera*. If this is the case, this hybrid provides evidence of gene flow from a crop to a wild population and this may represent the early formation of a crop–weed hybrid complex in the area.

A population from near Tinwald was particularly unusual in that it contained three different forms of *B. rapa* (diploid var. *oleifera*, tetraploid var. *oleifera*, and var. *chinensis*), *B. juncea*, and the putative intraspecific hybrid *B. rapa* var. *oleifera* \times *B. rapa* var. *chinensis*. Plants representing the putative hybrid *B. rapa* var. *oleifera* \times *B. rapa* var. *chinensis* were distinguished by the lower cauline leaves being simple, ovate, and entire or dentate, the petiole being distinct, and the auricles being small and inconspicuous (Fig. 7). These plants had a flow cytometry profile consistent with being an intraspecific *B. rapa* cross, and are therefore unlikely to be derived from *B. rapa* \times *B. juncea*, also a known and fertile cross (Choudhary et al. 2002). At the Tinwald site the putative hybrid plants were directly associated with two subpopulations that included plants of *B. rapa* var. *chinensis* and *B. rapa* var. *oleifera* growing only a few centimetres apart, and hybrid plants were not found to occur in other subpopulations that contained only one of the putative parents.

SUMMARY AND CONCLUSIONS

This study has shown that there is considerable taxonomic and morphological diversity of *Brassica* species and varieties naturalised in Canterbury, and that crop escapes are an important part of this diversity. However, there is considerable disparity between phenotype and genotype in some species, particularly *B. napus*. Much of this disparity is most likely to be due to the breeding and selection of particular

traits through the hybridisation of *B. napus* with *B. rapa* and *B. oleracea*. Some of the traits selected by plant breeders may offer certain advantages for the naturalisation of *Brassica* including, for example, increased hardiness in *B. napus* and the improved leafiness and resprouting ability of turnip-rape (*B. rapa*) cultivars.

In Canterbury, the distribution of naturalised *Brassica* would best be described as sparse and infrequent, and each population usually comprised only a few individuals. In rural areas many of the small populations appear to be ephemeral and comprise casual crop escapes that do not form persistent natural populations. The lack of recent collections of *B. nigra* and *B. tournefortii* suggests that these species have not been successful in establishing themselves as naturalised species in Canterbury. In contrast, the collections of *B. juncea* made during this survey indicate that this species has become established as a fully naturalised plant in a relatively short time. The most common *Brassica* is wild turnip (*B. rapa* var. *oleifera*), and the largest populations of this variety usually occur on the urban periphery where there is regular disturbance.

Our field observations suggest that disturbance and the open habitats that this often creates are among the most crucial factors in the establishment of naturalised *Brassica*. We also suspect that farming practices such as seed harvesting and transport and the movement of farm machinery along roads are important in the distribution of *Brassica* in the rural landscape.

Sympatry is not a common occurrence and there were few populations with more than two species or varieties. Nevertheless, the recognition of interspecific and intraspecific hybridism confirms that gene flow can occur in two ways in the species of *Brassica* naturalised in Canterbury: (1) between crop plants that have naturalised (*B. rapa* var. *chinensis*) and their naturalised wild relatives (*B. rapa* var. *oleifera*); (2) between naturalised wild plants (*B. rapa* var. *oleifera*) and crop plants (*B. napus*). The two instances of hybridism reported here are considered to be a significant finding given the few occurrences of sympatry (Table 1) and small numbers of plants that usually occur in naturalised populations (Fig. 3). As *B. rapa* var. *oleifera* is the most widespread and common naturalised species, it is not surprising that it is involved in the two instances of hybridisation. It is anticipated that further surveys of *Brassica* are very likely to identify additional occurrences of hybridism.

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