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Review

A history of Australian pasture genetic resource collections

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Abstract. The introduction of exotic pasture germplasm has formed the foundation of many Australian grazing systems. Scientists have searched the world for plants to improve the feedbase, amassing collections of diverse genetic material, creating genebanks that have made a large contribution to feedbase productivity. These genebanks contain a vast range of legumes, grasses, herbs and shrubs with growth habits ranging from small herbaceous plants to woody trees and life cycles from annuals to short- and long-term perennial plants. They have been collected from cool temperate to tropical climates and arid to high-rainfall zones. Hundreds of cultivars have been developed from material either collected by Australian plant breeders overseas or introduced from overseas genebanks. The collection of this germplasm has enabled plant breeders to extend the area of adaptation of species into climates, soils and systems previously considered marginal. The importance to Australian and world agriculture is increasing as plant breeders seek traits to meet the challenges of a changing climate and animal production systems. Furthermore, urbanisation, landscape degradation and political instability are making it increasingly difficult to collect pasture and forage germplasm from native grasslands in many countries. This emphasises the need to maintain and improve the capacity of the Australian Pastures Genebank (APG). The APG houses ~85 000 accessions and is a modern, online source of diversity for plant scientists around the world. This paper summarises the history of the founding genebank collections, their environment and farming systems focus, and the visionary and resourceful individuals that built them.

Keywords: Australian Pastures collecting missions, forage, Genebank, germplasm, temperate, tropical.

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Introduction

In this paper, we review the development of the pasture and forage genebank collections in Australia and the centralisation of the genebanks under the Australian Pastures Genebank (APG). Emphasis is placed on the revolutionary approach to sourcing new plants by many Australian plant collectors and organisations and the critical roles of other international genebanks in sharing plant material for breeding and pasture improvement. Challenges to the maintenance and use of these valuable collections to produce future cultivars are also discussed.

Much of the Australian grazing landscape looks now vastly different from that before European settlement. More than 35 million hectares have been developed into improved pastures, and a further 305 million hectares have been classified as grazing land (Australian Bureau of Statistics 2018). Native grasslands containing grass genera such as *Austrodanthonia*, *Themeda*, *Austrostipa*, *Poa* and *Dichelachne* provided the feedbase for the early wool industry in southern Australia (Reed 2014), whereas further north in Queensland, Mitchell grass species (*Astrebla* sp.) were important (Ebersohn 1972). These native grasses are adapted to the extreme ranges of rainfall, temperature, soil type, soil fertility and, in some cases, response to fire. Native species had evolved for many thousands of years before European settlement under light grazing by soft-footed marsupials, adapting to poor and low-fertility soils and potentially a drier climate to be persistent in the landscape (Donald 1970).

Although some broadly distributed native grasses were persistent and readily grazed by cattle (e.g. *Atrebla* spp., *Hetropogon contortus*, *Themeda traindra*), growth was highly seasonal and feed quality rapidly declined as they matured to produce seeds, resulting in regular seasonal deficits in feed quantity and quality for cloven-hooved grazing livestock. Modern western agriculture has a strong focus on productivity and the plants for domesticated animals have generally followed this theme. The introduction of exotic plant species to feed domesticated livestock in Australia is likely to have begun in the late 1700s with the first shipments of livestock to Australia during European settlement. According to Whittet (1964), introductions fell into the following two categories (although there was likely to be overlap): accidental introductions with early introductions of species such as buffel grass (*Cenchrus ciliaris* L.), stylo (*Stylosanthes humilis* Kunth.), burr medic (*Medicago polymorpha* L.), subterranean clover (*Trifolium subterraneum* L.); and by design with species such as perennial ryegrass (*Lolium perenne* L.), Guinea grass (*Megathyrsus maximus* Jacq.), red clover (*Trifolium pratense* L.; Whittet 1964; Broue 1972) and lucerne (*Medicago sativa* L.; McMaster and Walker 1970). White clover (*Trifolium repens* L.) was possibly accidentally introduced; it was naturalised throughout temperate regions of the northern hemisphere and its spread was facilitated by the introduction of improved strains (Lane *et al*. 1997, 2000). Introductions during the pastoral era (European settlement to ~1930; Reed 2014) were to boost productivity. Grasses such as perennial ryegrass, phalaris (*Phalaris aquatica* L.), cocksfoot (*Dactylis glomerat*a L.) and tall fescue (*Lolium arundinaceum* Darbysh.), and legumes such as white clover and subterranean clover are now dominant species in improved pastures of southern Australia (Reed 2014). While the introductions of some exotic pasture and forage species have benefited agricultural productivity, there are many examples of accidental or intended introductions (including valuable species naturalising in native landscapes) that have become agricultural and/or environmental weeds.

As grazing systems developed across Australia, it became apparent that the species and cultivars originally introduced were suitable only for narrow agro-ecological regions. Thus, the search for species and breeding of cultivars with different traits, fit for certain environments, began. The first genetic resource centre is likely to have been formed in Victoria in the 1930s, initially collecting and evaluating local ecotypes (Reed 2014). However, it was soon realised that there was little scope for improvement within this material and the deliberate introduction of new lines began. Germplasm was collected mainly from the Mediterranean region initially with South America, and sub-Saharan Africa following (Fig. 1, Tables 1, 2). Cedric Neal-Smith's collection mission to Mediterranean countries in 1954 was one of the first major temperate collections and yielded 556 grass and 129 legume accessions across 73 species (Neal-Smith 1954; Table 2). Key collecting trips to southern and central America and Africa were conducted by staff of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and State Departments of Agriculture during the 1950s and 1960s to develop tropical germplasm (Table 1).

Plant-collecting missions were common throughout the second half of the 1900s, with the most productive period

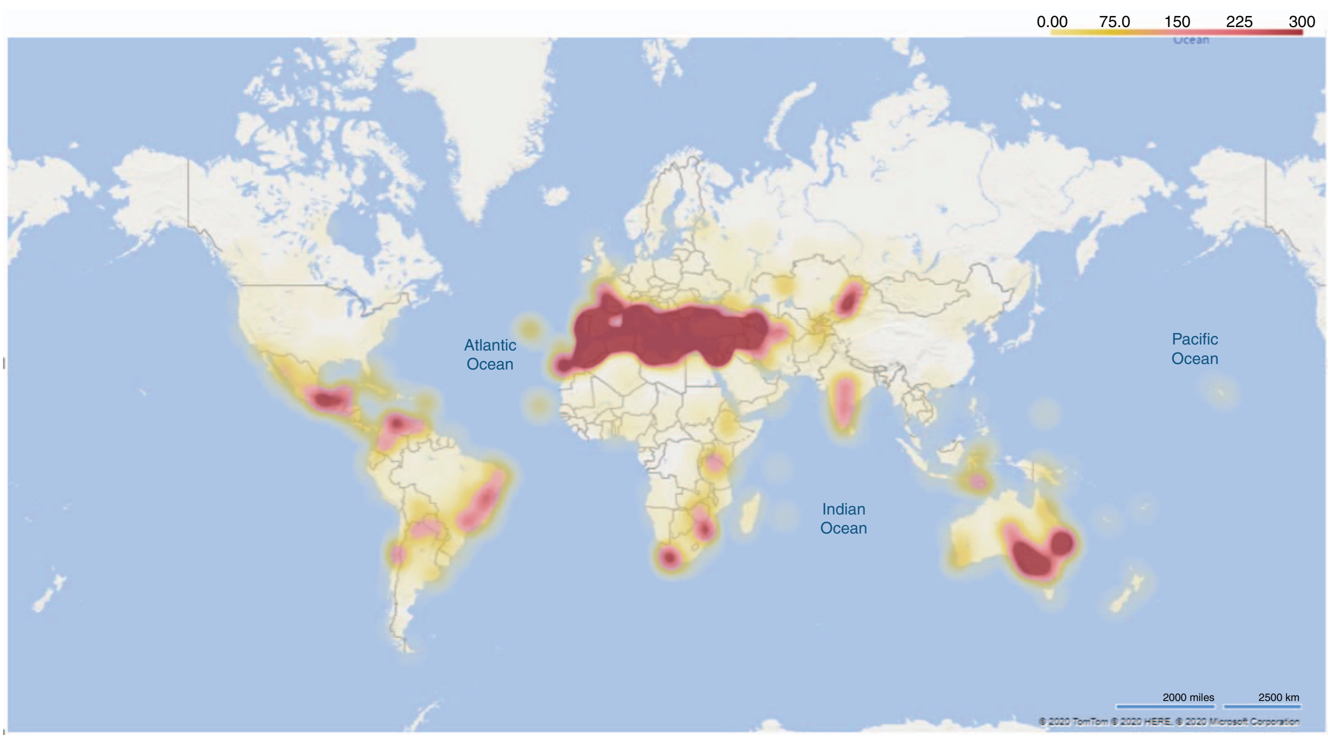

Fig. 1. Heat map showing the origins of the accessions collected in the Australian Pastures Genebank (where longitude and latitude data are available).

Table 1. Some key contributors to the development of the Australian tropical forages genetic resource collection

The data presented are based on APG records (composite of many collections) confirmed with tropical pasture plant specialists where possible. This table provides the names of the lead collectors and their institutes for some of the key pasture seed collections. Many of these collection missions have involved collaboration with local government institutions, international scientists and local guides and their support is duly acknowledged. Accessions, denotes indicative

Person	Organisation	Year(s)	Key countries	Accessions	Key taxa
W. T. Atkinson	NSW Government	1964–1965	Bolivia, Brazil, Ecuador, Mexico, Nicaragua, Peru, Venezuela, other countries in Central America	330	*Aeschynomene, Crotalaria, Desmanthus, Indigofera, Rhyncosia, Macroptilium, Stylosanthes, Paspalum, Trifolium*
A. J. Brown	Vic. Government	2005–1906	Australia	51	*Chloris, Cynodon, Enteropogon, Paspalum, Sporobolis, Themeda*
R. L. Burt (with Lazier)	CSIRO	1971–1972	Belise, Brazil, Guatemala, Peru, Panama and other countries in Central America	170	*Centrosema, Desmanthus, Desmodium, Galactia, Macroptilium, Stylosanthes, Vigna, Zornia*
R. L. Burt (with Keoghan)		1976–77	Mexico and Central America		*Centrosema, Desmanthus, Macroptilium, Stylosanthes, Teramnus*
D. F. Cameron	CSIRO	1980–1981	Brazil	195	*Centrosema, Desmodium, Macroptilium, Stylosanthes, Rhyncosia*
B. G. Cook	Qld Government	1993	Bolivia, Colombia	31	*Macroptilium, Desmanthus*
B. G. Cook (with Pengelly)	Qld Government	1996	Argentina		*Calopogonium, Desmanthus, Desmodium, Macroptilium, Galactia, Rhyncosia*
B. G. Cook	Qld Government	1999	Argentina		*Desmanthus*
R. Date	CSIRO	1976–1978	Colombia, Mexico, central America	45	*Centrosema, Macroptilium, Leucaena, Stylosanthes*
J. G. Davies	CSIRO	1960	Argentina, Brazil, Uruguay	34	*Paspalum, Megathyrsus, Desmodium, Macroptilium*
J. P. Ebersohn	Qld Government	1966	Brazil, Peru	65	*Aeschynomene, Chamaecrista, Desmanthus, Centrosema, Desmodium, Galactia, Rhyncosia, Stylosanthes*
L. Edye	CSIRO	1969	Brazil	319	*Macroptilium, Stylosanthes*
		1985–1986	Brazil, Venezuela		*Stylosanthes*
R. Ellis (with Pengelly)	South Africa Government	1990	South Africa	94	*Cenchrus, Digitaria, Panicum/Megathyrsus, Setaria*
J. E. Ferguson	CIAT	1976	Brazil, Colombia	11	*Stylosanthes, Zornia*
P. Gillard	CSIRO	1968–1969	South Africa	24	*Urochloa*
B. Grof	Qld Government	1965, 1972	Colombia, Brazil, Suriname, Ecuador, Mexico and other countries in central America	33	*Centrosema, Desmodium, Stylosanthes, Vigna*
H. Gullove	(IRI) Brazil	1962, 1964	Brazil	41	*Clitoria, Desmodium, Macroptilium, Stylosanthes*
J. B. Hacker	CSIRO	1979–1983	Australia	235	*Desmodium, Galactia, Zornia* (many taxa)
	CSIRO	1994	Paraguay		*Cassia/Chamaecrista, Centrosema, Desmanthus, Macroptilium*
	CSIRO	1995	Laos		Vigna
W. Hartley	CSIRO	1947–1948	Argentina, Brazil, Paraguay	22	*Stylosanthes* (mostly), *Paspalum, Phaseolus* (probably *Macroptilium*) *Desmodium*
S. Hughes, A. Humphries, T. Powell	SA Government	2004–2006	Australia	151	*Astrebla, Enneapogon, Enteropogon, Eragrostis, Cenchrus, Themeda* (many grass taxa), *Glycine*
E. M. Hutton	CSIRO	1963	El Salvador, Mexico, Costa Rica	48	*Desmodium, Macroptilium*
	CSIRO	1970	Brazil		*Centrosema, Macroptilium, Stylosanthes*
E. J. Johnston	FAO (coffee), Guatemala	1972–1973	Colombia, Guatemala	67	*Desmodium, Leucaena, Rhyncosia, Stylosanthes*
K. Keogh	Private, Zimbabwe	1972–1985	Zimbabwe	59	(many taxa) *Bothriochloa, Brachiaria, Chloris, Cynodon, Paspalum, Setaria, Desmodium, Macrotyloma, Macroptilium, Indigofera, Tephrosia*

J. Keoghan (with Burt)	University of West Indies, Jamaica	1976–1977	Mexico and Central America	146	*Centrosema, Desmanthus, Macroptilium, Stylosanthes, Teramnus*
A. Kretschmer	IRFL, University of Florida	1974–1976	Brazil, Colombia, Central America	63	*Aeschynomene, Arachis, Centrosema, Desmanthus, Stylosanthes*
A. J. Kruger	South Africa Government	1990	South Africa	160	*Brachiaria, Cenchrus, Digitaria, Megathyrsus, Setaria*
A. J. Kruger (with Pengelly)		1994	South Africa		*Andropogon, Digitaria*
J. R. Lazier	(IDRC) Canada	1973–1977	Mexico, Belise, Trinidad, Guatemala	233	*Centrosema, Desmanthus, Desmodium, Leucaena, Stylosanthes, Vigna*
H. S. McKee	Burma (Myanmar) Government	1963–1964	Central America, Mexico	113	*Aeschynomene, Alysicarpus, Centrosema, Chamaecrista, Desmodium, Macroptilium, Stylosanthes, Zornia*
K. L. Mehra	India Government and United Nations	1984–1985	Indonesia	356	*Aeschynomene, Desmodium, Rhyncosia, Teramnus, Pseudarthria, Uraria*
J. F. Miles	University of Khartoum	1951–1952	Eastern and Southern Africa	37	*Digitaria, Panicum/Megathyrsus, Setaria, Centrosema, Neonotonia, Stylosanthes*
I. Miller	Organisation unknown	1971	Mexico, Venezuela	103	*Aeschynomene, Calopogonium, Centrosema, Desmodium, Macroptilium, Galactia, Stylosanthes*
B. Pengelly	CSIRO	1983	Papua New Guinea	214	*Aeschynomene, Alysicarpus, Clitoria, Desmodium, Codariocalyx, Flemingia*; acid soils
B. Pengelly (with Ellis)	CSIRO	1994–1996	South Africa		*Anthephora, Bothriochloa, Brachiaria/Urochloa, Chrysopogon, Digitaria, Panicum*
B. Pengelly (with Cook)	CSIRO	1996	Argentina		*Calopogonium, Desmanthus, Desmodium, Macroptilium, Galactia, Rhyncosia*
R. Reid	CSIRO	1977	Argentina, Cuba, Colombia	1111	(many taxa) *Aeschynomene, Alysicarpus, Centrosema, Chamaecrista, Desmanthus, Desmodium, Macroptilium, Rhyncosia, Teramnus*
		1981	Colombia		(many taxa) *Aeschynmene, Centrosema, Desmanthus, Desmodium, Macroptilium, Leucaena, Stylosanthes*
		1983	Indonesia		*Desmodium, Uraria*
		1979–1981	Mexico		(many taxa) *Acacia, Aeschynomene, Centrosema, Chamaecrista, Desmanthus, Desmodium, Galactia, Macroptilium, Rhyncosia, Teramnus*
		1985	Mexico		*Macroptilium, Leucaena*
C. R. Roberts	CSIRO	1980–1981	Indonesia, China	31	*Alysicarpus, Centrosema, Desmodium*
A. C. Robinson	CSIRO	1979	India	26	*Alysicarpus, Chamaecrista, Desmodium, Indigofera, Cenchrus, Sehima*
R. Schultze-Kraft (with R. Reid some trips)	CIAT	1975–1987	Brazil, Colombia, Venezuela, Peru, Panama	496	*Aeschynomene, Centrosema, Stylosanthes, Zornia*
P. J. Skerman	CSIRO	1965–1978	Tanzania, Kenya, Uganda, Sudan	38	*Stylosanthes*
H. M. Stace	CSIRO	1983–1984	Brazil	54	*Stylosanthes*
I. B. Staples	Qld Government	1970	Malawi, Zimbabwe, Kenya, Madagascar, South Africa, Zambia	909	(many grass and legume taxa) *Bothriochloa, Brachiaria/Urochloa, Cenchrus, Cynodon, Melinis, Megathyrsus/Panicum, Alysicarpus, Desmodium, Macrotyloma, Neonotonia, Rhyncosia, Teramnus, Zornia*
		1977	Cuba, Mexico		*Desmanthus, Rhyncosia*
		1984	India		*Bothriochloa, Cymbopogon, Dichanthium, Chrysopogon, Alysicarpus, Lablab, Zornia, Teramnus, Vigna*
R. W. Strickland	CSIRO	1971–1972	Kenya, Tanzania, Uganda, Zimbabwe	514	(many taxa) *Cenchrus, Cynodon, Digitaria, Panicum/Megathyrsus, Paspalum, Setaria, Urochloa, Alysicarpus, Clitoria, Stylosanthes, Zornia*
B. Walker	Tanzania Government	1968	Tanzania	144	*Cenchrus/Pennisetum*
R. Williams	CSIRO	1977	Mexico	314	*Centrosema, Desmanthus, Leucaena*
		1965	Bolivia, Brazil,		*Centrosema, Desmodium, Macroptilium, Stylosanthes*
G. P. M. Wilson	NSW Government	1976–1993	Australia	50	*Glycine*

Table 2. Some key contributors to the development of the temperate pasture and forage genetic resource collection

The data presented are based on APG records (composite of many collections) confirmed with temperate pasture plant specialists where possible. Note: this table provides the names of the lead collectors and their institutes for some of the key pasture seed collections. Many of these collection missions have involved collaboration with local government institutions, international scientists and local guides and their support is duly acknowledged

Collectors	Organisation	Year	Key countries	Number of accessions	Key taxa
C. Enlow, H. L. Westover	USDA	1934	Tajikistan	1	APG 39921, *Melilotus albus*
E. M. Hutton	CSIRO	1934	Australia	2	APG 8066, APG 8067, *Medicago sativa*
Frank Hely	CSIRO	1939	Australia	2	APG 1619 and APG 9328, *Medicago truncatula*
Colin M. Donald, John F. Miles	CSIRO	1951	Spain, France	102 (+500 more donated over next 15 years)	*Trifolium, Medicago*
C. A. Neal-Smith	CSIRO	1954–1956, 1967, 1980	Mediterranean region: Yugoslavia, Tunisa, Algeria, Morocco, Libya, Egypt Cyprus, Israel and Turkey Libya, Algeria, Morocco, Portugal, Greece, Spain	788: 73 species	*Trifolium, Phalaris, Lolium, Hordeum, Agrostis, Cenchrus, Medicago* (annual and perennial, Algeria). *Lotus, Onobrychis* and *Astragalus. Plantago. Rhizobium* collected
David Symon	Waite Institute	1956	Italy, Greece, Yugoslavia,	406	*Medicago, Phalaris, Phleum, Bromus, Trifolium*
Eric Baily	CSIRO	1959	Chile, Argentina, Brazil	241	*Trifolium, Bromus, Medicago, Stipa*
Joseph Sephi Katznelson	Agricultural Research Organisation	1959–1967	Israel, Croatia, Greece, Macedonia, Serbia, Israel, Syria, Turkey	114	*Medicago, Trifolium*
William Collins	DPIRD WA	1964, 1986, 1987	Italy, Sicily	791	*Trifolium* and *Medicago* (annual)
Eric Crawford	PIRSA	1967	Cyprus,Israel, Turkey, Spain, Portugal, Morocco	1112	*Medicago, Dactylis, Melilotus, Trifolium, Astragalus, Hymenocarpus*
Eric Baily, Joseph Sephi Katznelson	CSIRO	1967	Israel, Cyprus, France, Algeria, Jordan, Turkey	351	*Trifolium, Medicago*
Frank Hely	CSIRO	1968	Portugal, Spain	68	*T. subterraneum* plus rhizobia
Eric Crawford, Ted Higgs	PIRSA	1971	Israel		
Murray Mathison Lesins (Canada), Ian Kaehne Cornish (NSW), Broue (CSIRO)	PIRSA	1974	Tajikistan, Azerbaijan, Krasnodar, Stavrapol, Iran, France, Romania, Greece, Turkey, Tunisia, Algeria, Morocco, Lebanon, Afghanistan, Italy	2303	*Medicago, Astragalus, Scorpiuris, Hippocrepis, Trifolium, Hymenocarpus, Lotus, Coronilla, Vicia, Lathyrus*
Keith Bicknell	PIRSA	1975	Libya	304	*Medicago*
Clive Francis	DPIRD	1973–1976	Turkey, Greece	621	*Trifolium, Ornithopus*
Gerald M. Halloran	University of Melbourne	1975	Turkey, Syria, Iraq, Iran, Afghanistan	312	*Medicago, Trigonella, Trifolium, Bromus*
	DPI WA	?	Cyprus	259	*Trifolium, Medicago*
Eric Crawford	DA SA	1977	Tukey, Iran, Syria, Jordan,	1162 627 Turkey 500 Iran 35 Syria	*Medicago, Trifolium, Vicia, Lathyrus, Coronilla, Scorpiurus*
Dennis Gillespie	DPIRD WA	1977,78	Greece	203	*Medicago, Ornithopus, Hymenocarpos, Trifolium,*
Clive M. Francis, Dennis Gillespie	DPIRD WA	1977	Sardinia Italy, Italy, Yugoslavia,	1408	*Trifolium subterraneum, Medicago, Ornithopus*
Murray Mathison	PIRSA	1978	Turkey, Iran, Syria, Greece	1198	*Medicago, Astragalus, Onobrychis, Lotus, Trifolium, Coronilla, Scorpiurus*
Clive M. Francis, Carlos Gomez, Victor Cruz	DPIRD WA	1979	Portugal, Spain	493	*Trifolium, Ornithopus*
Enzo Piano	Consijlio per la Ricerca e la Sperimentzione in Agricoltura	1980	Italy	1156	*Trifolium subterraneum* sspp.
Gustave Gintzburger	DPIRD WA	1982	Algeria, Libya	307	*Medicago*

Dennis Gillespie, T. N. Kotze	DPIRD WA	1984	Greece, Italy	1427	*Medicago, Ornithopus, Hymenocarpos, Trifolium*
Jean-Marie Prosperi	Institut National de la Recherche Agronomique	1985–1992	France, Algeria, Greece, Portugal, Spain, Greece	342	*Medicago*
Geoff Auricht, Luigi Guarino	SARDI IPGRI	1986	Italy (Sicily)	702	*Medicago, Aegilops*
Michael (Mike) Ewing, John Howieson	DPIRD	1987	Greece	349	*Medicago, Trifolium, Ornithopus*
Geoff Auricht	SARDI	1988	Turkey	1240	54 *Astragalus*, 1 *Biserulla*, 20 *Cicer*, 17 *Coronilla*, 19 *Hippocrepis*, 22 *Melilotus*, 19 *Onobrychis*, 29 *Pisum*, 6 *Scorpius*, 389 *Trifolium*, 72 *Trigonella*, 333 *Vicia*
Philip Beale, Mustapha Bounejmate	International Centre for Agricultural Research in Dry Areas	1988	Morocco	900	*Medicago*
Dennis Gillespie, T. N. Kotze	DPIRD WA	1989	South Africa	315	*Medicago, Trifolium*
Michael Ewing, James Fortune	DPIRD UWA	1989	Spain	349	*Trifolium, Ornithopus, Medicago*
Kevin Reed, Brian Dear	DPI Vic NSW DPI	1990	USSR	165	*Anthyllis, Astragalus, Coronilla, Lathyrus, Lotus, Medicago, Onobrychis, Melilotus, Trifolium, Vicia Amaranthus Bromus, Dactylis, Festuca, Lolium, Poa* (and others)
Geoffrey Auricht, Kirsty Flower (Portugal and Spain), Andrew Lake (Bulgaria and Romania)	SARDI	1992	Portugal and Spain, south-western Bulgaria and Romania	701	80 taxa, including *Aegilops, Astragalus, Dactylis, Festuca, Lathyrus, Lolium, Ornithopus, Phalaris, Scorpiurus, Trifolium, Vicia, Biserulla, Bituminaria*
P. J. Cunningham	DPI Vic	1994	Tunisia, Sardinia, Morocco	475	*Lolium, Dactylis, Phalaris, Festuca, Trifolium*
Stephen Carr, Bradley Nutt	DPIRD	1995	Greece	1094	*Seradella, Biserulla, Trifolium* (including bladder clover), *Ornithopus, Medicago, Trigonella*
Kevin Reed and Stephen Hughes	DPI Vic SARDI	1997	Turkey, north-west	405	Grasses: *Lolium, Dactylis, Agropyron, Bromus, Poa, Phleum and Holcus Legumes: Trifolium, Medicago, Astragalus, Galega, Trigonella, Hippocrepis, Hymenocarpus, Coronilla, Vicia, Lathyrus, Scorpius, Lotus, Onobrychis.Herbs: Plantego Rhizobium*: collected
Stephen Hughes, Darryl McClements	PIRSA DPIRD	1999	Greece, Skiathos, Allonissos, Skopelos, Thessaloniki	550	*M. polymorhpa, Lotus Ornithopodioides, Ornithopus compressus, Dorycnium, Medicago arborea, M.s. falcata., Coronilla emerus Rhizobium*: collected
Graham Sandral	NSW DPI	2000, 2002	Portugal, Spain Italy, Cape Verde	516	*Lotus, Phalaris, Dactylis, Trifolium, Ornithopus*
Stephen Hughes, Eric Hall, Geoff Auricht	SARDI UTAS	2002	Kazakhstan	606	*Trifolium, Melilotus, Dactylis, Festuca, Hedysarum, Lotus, Trifolium, Astragalus, Agropyron, Glycyrrhiza, Lotus*
Stephen Hughes, Eric Hall, Alan Humphries	SARDI	2004	Azerbaijan	674	*M.s.caerulea, T. tumens, D. glomerata, L. perenne*
Jake Howie, Brad Wintle	SARDI CLIMA	2004	Canary Islands and southern Spain	298	23 species of *Astragalus, Lotus, Hedysarum, Medicago, Onobrychis. M. citrina, M.rigidula* from high elevation
Peter Jessop	NSW DPI	2006	Australia	300	*Atriplex* (saltbush)

being between the 1960s and 1980s when well resourced government departments sent experts abroad in search of exotic material. For example, subterranean clover germplasm was collected from more than 1800 sites in the Mediterranean region between 1968 and 1990, with Clive Francis being a central figure (Nichols *et al*. 2013). These collections would form the foundation for many subterranean clover cultivars. Introductions of serradella (*Ornithopus* sp.) and biserrula (*Biserrula pelicinus* L.) by collectors, particularly from the Department of Primary Industries and Rural Development, Western Australia, and the South Australian Research and Development Institute (SARDI) during the late 1970s to mid-1990s have proved important in developing cultivars for mixed pasture and cropping enterprises, allowing summer-sowing (hard seed breakdown), deeper-rooting characteristics, nitrogen fixation and extending the growing season. Later collections such as the Cunningham collection in 1994 (Cunningham *et al*. 1997) would prove important for breeding and evaluation efforts in phalaris, cocksfoot and tall fescue, with material being adapted to hot and dry conditions (Culvenor and Boschma 2005; Harris *et al*. 2008; Oram *et al*. 2009; Culvenor *et al*. 2017). There have been 185 direct releases from Australian genebanks plus a further 148 indirect releases, where accessions have been used as parents that have contributed to a commercial cultivar (G. Sweeney, pers. comm. ex SARDI, 2020).

As departments of agriculture began to rationalise resources during the 1990s, there were fewer staff and operating funds for maintenance of the genebanks. A central repository for pasture germplasm was often mooted but only started to gain real momentum in the late 2000s. Gregson (2010) highlighted the need for funding from both industry and government to develop a national centre with a database compatible with other international collections and the need to back up the germplasm resources in the Svalbard Global Seed Vault; Tony Gregson was later involved in the first deposit of Australian seed into the Vault in 2011 (Crawford Fund 2011). This view was shared by many and, after considerable negotiations, an agreement was struck between the research and development corporations (industry) and the state government departments (the owners of many of the collections) to develop a national centre. The Australian Pastures Genebank was launched in 2014 and is housed at the Waite Campus of the SARDI in Adelaide (Hughes *et al*. 2017).

Tropical forage collections

Role and scope of the collections

The tropical forages component of the APG was developed principally to create a pool of genetic material for the development of pastures and fodder crops in northern Australia, but its role has extended to forage development in other countries and to the conservation of Australian native warm-season grasses and legumes. The collection has underpinned the development of over 130 cultivars in northern Australia, principally in Queensland, but also significantly in northern New South Wales and the Northern Territory, where beef and (now to a lesser extent) dairy and sheep production are key primary industries (Oram 1990; Hacker 1997). The benefits of sown pasture development have accumulated over more than 50 years, mostly in higher rainfall environments where grass and/or legume systems have replaced native vegetation, but also in drier environments where legumes (and some grasses) have been used to complement extensive native grasslands (Walker *et al*. 1997). More recent roles include legumes for grazing leys in crop/graze systems and summer-active pasture plants for southern Australia. These tropical genetic resources have also become integral to the development of pasture systems in southern and western Australia where perennial subtropical species are of growing interest to provide warm-season fodder (Johnston 1996; Moore *et al*. 2014). Current research by government and university research teams mostly targets the development of legume-based pastures for beef production in seasonally dry areas of Queensland and northern New South Wales, with complementary roles in addressing production risks associated with climate change and reducing enteric methane emissions.

The Australian tropical forages collection in the AGP is a globally unique collection of grasses and legumes well adapted to tropical and subtropical environments. It presently comprises some 3770 grass accessions (across 80 taxa groups) and 11 400 legume accessions (79 taxa; see Appendices 1, 2). Most accessions were collected from natural environments across the tropical and subtropical zones of Africa, central and southern America and southern Asia. The collection also contains a substantial collection of native and naturalised grasses (e.g. *Astrebla*, *Heteropogon*, *Themeda*) and legumes (e.g. *Alysicarpus*, *Glycine*, *Rhyncosia*) collected in Australia (5% with detailed collection locations), particularly native grasses and legumes, which are key components of extensive grazed pastures and conservation areas. The collection includes breeding lines and early generation lines of cultivars (either public or under plant breeders rights protection).

The collection complements the collection held by the CGIAR (formerly the Consultative Group for International Agricultural Research) research centre Centro Internacional de Agricultura Tropical (CIAT) in Columbia, which was assembled to underpin forage research on acid soils in Latin America. The Australian tropical forages collection principally targeted pasture and forage cultivar development for the wet tropics (generally moderately acid soils of moderate to high fertility) and semiarid rainfall zones characterised by light and clay-textured soils of low (often low P) to moderate fertility. Some 6020 (53%) of the legume accessions and 2350 (62%) of the grass accessions represent narrow taxon groups (species) listed in the second edition of the *Tropical Forages* web application (Cook *et al*. 2020) as sown pastures or fodders (see Appendices 1, 2). The APG also contains taxa closely related to those listed in *Tropical Forages* where there may be potential for future cultivar development, plus key native grasses and legumes known to be useful components of native grazed pastures in Australia. The *Tropical Forages* web tool (Cook *et al*. 2005) was built using the collective knowledge of panels of international pasture specialists accrued over some 40+ years. Database content and function have recently been revised and the second edition is now live (Cook *et al*. 2020; https://www.tropicalforages.info/text/intro/index.html).

Development of the tropical forages collection

Key collectors and donors of tropical forage germplasm are presented in Table 1. Most collectors from Australian organisations worked for the CSIRO or state (particularly Queensland and New South Wales) agricultural science departments, although university researchers also made contributions at certain times. Collections during the 1950s and 1960s coincided with the development of government (principally CSIRO) pasture development programs in northern Australia (Reid 1997). A key early focus was the identification of suitable legumes to lift pasture productivity on infertile, acid soils. This approach was in its infancy globally and the researchers effectively created a new field of research and sought suitable plants for field testing in Australia. Collecting, mostly of legumes, was conducted initially in South America (e.g. Argentina, Brazil, Paraguay, Peru) (*Aeschynomene*, *Centrosema*, *Desmodium*, *Macroptilium*, *Stylosanthes*) and later further north (e.g. Colombia, Ecuador, Mexico; adding *Crotalaria*, *Desmanthus*, *Indigofera*). Key early collections were championed by William Hartley, Mark Hutton and Ron Williams (all CSIRO), Burt Grof and Joe Ebersohn (Queensland Government) and William Atkinson (New South Wales Government), to name a few. Southern and eastern Africa were mostly targeted for tropical grasses (e.g. *Digitaria*, *Panicum*/*Megathyrsus*, *Setaria*) and genetic material was also sourced from collaborating agencies (*Cenchrus*/*Pennisetum*).

Further collecting trips to these regions continued during the 1970s as Australia sought to add to the suite of cultivars being developed and to address the constraints of some key pasture legumes owing to disease (e.g. *Colletotrichum sporioides*), or other factors such as poor tolerance to grazing and drought. Researchers of state departments of agriculture became more involved at this time, although plant collecting trips were still principally conducted by CSIRO staff sometimes spending extended periods living in-country. Notable collectors included Robert (Bob) Reid (legumes in the Americas), Ian Staples and Ray Strickland (grasses in Africa). Field collecting and seed-sourcing trips continued into the 1980s, with the focus being extended to other regions, soil types and taxa (India, Indonesia) as pasture plants were sought for differing environments and roles. The last international collecting trips of note occurred during the mid-1990s, including a return to southern and central Africa and Argentina (Bruce Pengelly (CSIRO) and Bruce Cook (Queensland Government)) through partnerships with in-country research organisations. A key research focus at that time was the development of legumes for (alkaline) clay soils and crop–graze systems (Clem and Jones 1996). Disinvestment in tropical sown-pasture development during the late 1990s and 2000s effectively ended international collecting trips because research capacity in government agencies declined. Efforts were instead placed on capturing Australian and international technical knowledge in pasture plant development and identifying priorities for future development (Bell *et al*. 2016; Cook *et al*. 2020).

The contributions of international researchers and their organisations towards the collection of tropical forages and the benefits of collaboration with Australian researchers cannot be overstated. Significant contributions were sourced from researchers working for in-country agricultural development organisations. These include universities (e.g. University of Florida, USA, University of Khartoum, Sudan and the University of the West Indies, Jamaica), national research agencies such as the Brazilian Agricultural Research Corporation (EMBRAPA) in Brazil and the Agricultural Research Council (ARC) in South Africa, and agricultural development agencies (e.g. the International Development Research Centre). Special mention is reserved for the staff of CIAT (John Ferguson and Rainer Schultz-Kraft); this CGIAR institute, based in Colombia, has developed substantial germplasm resources and tropical pasture development programs across the tropics. In some instances (e.g. CSIRO collections in South Africa 1994–1996), collaboration extended to in-country seed multiplication before importing seeds to Australia. Collaborative plant collecting and the sharing of key germplasm across collections has benefitted all international partners as they seek to improve livestock production in their regions.

Plant evaluation and cultivar development

Well resourced government-funded tropical pasture research and development programs operated in northern Australia between the 1950s and 1990s. CSIRO initially took a lead role in germplasm characterisation, but later collaborated with state government researchers. A series (Genetic Resources Communications) of phenotypic profiles of key taxa (e.g. *Centrosema*, *Macroptilium*, *Paspalum*, *Bothriochloa*, *Urochloa*) was published until the end of the 1990s. An important component of this work was the description and testing of the CSIRO collection of *Rhizobium*/*Bradyrhizobium* bacteria, which included 4971 authenticated strains associated with 97 genera and 401 species of crop and forage legumes by 1999 (Eagles and Date 1999). Field testing and cultivar development were often conducted in collaboration with state departments of agriculture and co-funded by grazing industry research and development corporations. More recent examples include Coordinated Plant Evaluation (Pengelly and Staples 1996), Legumes for Clay Soils (Clem and Jones 1996) and Backup Legumes for Stylos (Bishop and Hilder 2005) to name a few. Plant evaluation data were collated in the Queensland Government QPastures database (championed by Richard Silcock) and were recently incorporated into a national database to identify research priorities (Bell *et al*. 2016). The research was published through peer reviewed journals (e.g. *Australian Journal of Experimental Agriculture*, *Tropical Grasslands*) and practical guides (*Queensland Agriculture Journal*). Pasture plant evaluation and cultivar adoption was facilitated over some 30 years by the Queensland government pasture seed research and development programs on the Atherton Tablelands (at Walkamin and Kairi (championed by John Hopkinson) and

Gympie (Don Loch)). A globally unique tropical pasture seeds industry developed in Queensland (Loch and Ferguson 1999). Strong international linkages were formed culminating in biological and agronomic reviews (e.g. *Brachiaria*, *Centrosema* and *Stylosanthes*) published in collaboration with international researchers.

A marked decline in funding for sown pastures research during the 1990s saw the dismantling of many government programs (Cox 2014). Industry support has improved in recent years following concerns about the decreased productivity and persistence of grasslands. Current government and university research in Queensland is principally focussed on the development of legume-based beef pastures and fodder systems in seasonally dry environments to maintain the viability and resilience of grazing enterprises, to overcome deficiencies in the current suite of cultivars and to address productivity losses owing to nitrogen depletion in sown pastures (Peck *et al*. 2011; Bell *et al*. 2016; Cox 2016; Gardiner 2016). The development of forages to address issues such as reliability of production and methane production in association with climate change is becoming a major priority for grazing industries (Suybeng *et al*. 2019). Key taxa include *Desmanthus*, *Leucaena*, *Macroptilium* and *Stylosanthes*, although research and cultivar development is being conducted across a range of grass and legume taxa.

Management of the tropical forage collections

The tropical forages collection has been managed by a succession of Australian federal and state government agencies with CSIRO, the principal custodian. Bruce Pengelly oversaw the development of the Collection over most of this time. At its height, the tropical forages collection contained some 29 000 accessions (Hacker 1997). Seeds collected or sourced overseas, which was the bulk of the collection, were subject to Australian quarantine procedures (Eagle Farm quarantine facility, Brisbane). First generation grow out was conducted at CSIRO quarantine nurseries near Brisbane (Beerwah, Samford and Gatton) and in Townsville. The first controlled-environment seed store was built at Samford in the 1950s. Technological advancements saw upgrades to the controlled-environment mechanisms and record keeping (computer records from punch cards). Duplicate collections for long-term storage were kept on site and at the national CSIRO genetic resource store at Black Mountain (Canberra); this backup collection was later used to source some accessions for the APG. The collection was complemented by pre-commercial seed produced within the Queensland government pasture seed production program and stored at Walkamin in medium term stores (10°C/50% RH) and backed up with freezers.

Organisational restructuring within CSIRO saw a reduction of the collection to 'priority germplasm' and transfer to the Queensland State Government (in Biloela) in the early 2000s. The prioritisation was completed in 2000 by a panel of experienced pasture plant-evaluation researchers and the collection was refined to taxa considered to be of best application to Australia. Replicates of the entire collection were sent either to CIAT (Colombia, mostly legumes) or the International Livestock Research Institute (ILRI; Ethiopia, mostly grasses but also *Neonotonia*, *Trifolium* and *Rhyncosia*) to bolster core regional collections. Replicates of pre-commercial seed (cultivar foundation stocks) were transferred to Walkamin to complement the pre-commercial seed collection. The transfer of seeds and passport data to Biloela was completed by February 2002, with the collection being reduced to 10 016 (614 species) warm-season grasses and 2677 (255) legumes (P. Lawrence, pers comm. 2002). The regeneration of ~1000 accessions was undertaken by Queensland government researchers at Walkamin to increase the availability of seed (Cox. *et al*. 2009) and regeneration and characterisation of priority grass and legume taxa for pasture cultivar development resumed at Walkamin following the establishment of the APG (see below).

Temperate forage collections

Role and scope of the collections

The collection of temperate germplasm has involved more agencies than have the tropical collections, owing to the wider geographical, climatic, soil-characteristic variability and farming-system diversity across southern Australia, as well as differing State Government priorities. State Departments in New South Wales, Victoria, Tasmania, South Australia and Western Australia, along with CSIRO, each had collections. Overlap in accessions in these collections was common as collaborative collection missions ensued. Collections were made for low-, medium- and high-rainfall zones, for Mediterranean (winter rainfall dominant) and continental (summer rainfall dominant) environments, for a range of soil types and farming systems.

The Australian Medicago Genetic Resource Centre (AMGRC) in South Australia was established in the 1960s, with the focus initially on broadening the availability of annual medics (*Medicago* sp.) and other species for alkaline soils. This was followed by improvement through the introduction and evaluation of material from the Mediterranean region (Auricht *et al*. 1999). In Western Australia, the need for species adapted to acid soils saw the establishment of Australian Trifolium Genetic Resources Centre (ATGRC) focusing on annual *Trifolium* species, *Ornithopus* and *Biserrula*, among other species. Collections in state government departments of agriculture in New South Wales, Victoria and Tasmania, and at CSIRO, were established around the need for perennial pasture species for the high-rainfall zone such as *Lolium*, *Dactylis*, *Phalaris*, *Festuca*, *Bromus* and *Trifolium* and other legume species. Over time, the focus shifted from traits such as flowering time to tolerance to drought (e.g. *Lolium*, *Dactylis*), insects (e.g. aphids in *Medicago*), increased persistence (e.g. *Trifolium repens*), hard seededness (e.g. annual *Medicago* and *Trifolium* species) and grazing tolerance (e.g. *Medicago sativa*, *Trifolium pratense*).

Development of the temperate collections

In Victoria, a comprehensive collection of pasture species seed was established at the Pasture Research Station, Burnley, in

Melbourne, from at least the 1930s until ~1980. This embraced grasses, legumes and diverse herbs and was initiated by Jim Harrison, Victoria's first agrostologist. It was dominated by ecotypes of *Lolium* (e.g. cv. Victorian) and *Dactylis*, *Trifolium* (especially *T. subterraneum*, e.g. cvv. Bacchus Marsh and Tallarook) and *Medicago*. A further collection of *Trifolium subterraneum* and annual *Medicago* species was later assembled by Gwen Hotton, a geneticist at the State Research Farm, Werribee ~1960–1984. Kevin Reed began expanding the pasture seed collection at the Pastoral Research Institute, Hamilton, in 1980, with seed being relocated from the Pasture Research Station, Burnley, which had been closed. Reed had contacts associated with various international collections (e.g. Sephi Katznelson, Israel) and imported seed of many pasture species and varieties with potential for environments in southern Australia. A major driver was the collapse of the lucerne industry following the invasion of aphid species (spotted alfalfa aphid, *Therioaphis maculata* Buckton, and bluegreen aphid, *Acyrthosiphon kondoi* Shinji) in the late 1970s and the funding of research to test imported cultivars and identify suitable lucerne varieties and alternative perennial legumes. Steve Clark took over as curator of the collection in 1982 (until 1995) and, by the end of 1985, there were over 1200 pasture seed lines in the collection.

The seed collection grew as Victoria joined other states in various national programs, such as, for example, National Subterranean Clover Improvement Program from 1983, Australasian Subterranean Clover and Alternative Legumes Improvement Program from 1994 and National Annual Pasture Legume Improvement Program from 1997 and successive Cooperative Research Centres (CRCs) from 2000. The collection grew further with the establishment of a contract merit-testing program in the late 1980s, with cultivars and breeder's lines sourced from companies all over the world. Between 1990 and 2004, staff from Hamilton (Kevin Reed, Peter Cunningham and Pedro Evans) organised and/or participated in forage plant collection trips to Morocco, Tunisia, Sardinia, Turkey, USSR, Argentina, Uruguay and Chile.

In Tasmania, several key figures were involved in plant introduction and breeding efforts in the period before 1985, including Jim Carpenter, Jeff Martin, Alan Stephens, Dennis Bishop and Stuart Smith. At that point, the now Department of Primary Industries, Parks, Water and Environment (DPIPWE) genebank collection mainly contained low numbers of accessions and breeding lines introduced and selected by Jim Carpenter and Alan Stephens. However, with the appointment of Bob Reid in 1985, a significant germplasm collection and breeding effort was initiated to find pasture plants suitable for the low–medium (<750 mm)-rainfall regions of Tasmania. This was known thereafter as the Herbage Development Program. From 1985 to 1987, Bob Reid initiated two significant introductions; the first, a collection of annual *Trifolium* sp. and cocksfoot accessions from the CSIRO collection in Canberra in 1987, followed by a collection of perennial grass accessions, including *Festuca* sp. and *Bromus* sp. from the United States Department of Agriculture (USDA) in Oregon in 1991.

In excess of 3000 accessions from >650 species were added in the years following by Bob Reid, and later, Eric Hall, by participating in collecting missions. Bob Reid was involved in a collecting mission to the Iberian Peninsula in Spain and Portugal in 1993, focussing on perennial grasses and annual legumes. This was followed by a collecting mission to Tunisia in 1995, focussing on Mediterranean grasses. In 1996, Eric Hall took over the Herbage Development Program and, in 2002, participated in an International collecting mission to Kazakhstan led by Geoff Auricht from the South Australian Research and Development Institute (SARDI; Auricht *et al*. 2009). From this mission, a significant number of *Dactylis*, *Bromus*, *Festuca* and *Phleum* sp. accessions were added to the collection. Eric Hall participated in a further International collecting mission to Azerbaijan in 2004 led by Steve Hughes (SARDI). This collection was extremely successful in that 35 accessions of the targeted species *Trifolium tumens* were collected, making it the largest single collection of this species ever made (Hall *et al*. 2013). Accessions of *Dactylis* sp., *Lolium perenne*, *Lotus* sp. *T. fragiferum*, *T. resupinatum*, *T. lappaceum* and *T. diffusum* were also added to the collection from this collecting mission. Eric Hall also introduced significant collections of perennial *Trifolium* and *Lotus* species, mostly being sourced from the USDA and the Margot Forde (New Zealand) collections.

The CSIRO Division of Plant Industry (Plant Introduction Section) at Canberra made a significant contribution to plant introduction into Australia, enhancing the activities of the state agricultural agencies (Burt and Williams 1990). The Plant Introduction Section established an inventory of all plant introductions, including the assigning of Commonwealth Plant Introduction (CPI) numbers. This publication evolved to the Australian Plant Introduction Review in 1975 and included all plant introductions brought into Australia by major seed-importing agencies.

The CSIRO at Canberra were also active in plant collection, including missions lead by C. M. Donald 1951 (1245 accessions; Neal-Smith and Johns 1967), C. A. Neal-Smith in 1954 (683 accessions; Neal-Smith 1963) and C. A. Neal-Smith and F. W. Hely in 1968 (276 accessions; Neal-Smith and Johns 1971) to various Mediterranean countries. Attention was directed towards capturing ecotypical variation within the genera *Phalaris*, *Dactylis*, *Lolium*, *Festuca*, *Trifolium* and *Medicago* to provide a more extensive gene pool for plant-breeding purposes (Neal-Smith 1963). In 1966, V. Rogers from CSIRO Deniliquin led a collection mission to Russian and the USA, to collect temperate annual legumes in the *Medicago* and *Trifolium* genera.

The CSIRO Black Mountain facility in Canberra has been an important national backup location for pasture genetic-resource collections in Australia. The centre continues to be a backup facility for the APG, with 23 770 accessions being duplicated at this location in case of an individual or large-scale problem (i.e. prolonged power failure, fire, flooding or other) at the APG in South Australia.

In South Australia, the AMGRC, originally known as the Plant Introduction Centre, was formed by Eric Crawford in the 1950–1960s. The activities of the centre were divided between two locations, with seed-storage facilities being maintained at

Northfield Research Laboratories and germplasm being evaluated at the Parafield Research Centre. It was realised after a few years that there was a need to increase the diversity of germplasm with the addition of wild lines from the Mediterranean region. However, the first 346 accessions donated to the collection (starting at SA 1, later APG 1) were not *Medicago* but *Trifolium subterraneum*, collected from Uruguay and introduced to the centre 1 December 1956. Other early genebank material was identified in the first formal annual report in 1965, describing the Plant Introduction Centre evaluations of *Bromus*, *Lolium*, *Phalaris*, *Festuca*, *Dactylis*, *Stipa* and *Poa* grass accessions, *M. truncatula*, *M. scutellata*, *T. subterraneum*, *T. hirtum*, *M. sativa*, *Coronilla*, *Dorycnium*, *Lotus* and *Onobrychis*. From 1967 to 1978, there were several important collection missions to countries in the Mediterranean region (Table 2), targeting centres of diversity of annual pasture legumes. As the leader of the Plant Introductions Centre, Eric Crawford was initially the most prolific collector, with assistance from colleagues Ted Higgs and Murray Mathison. The demands of requiring legumes for a range of crop rotations spanning diverse soil types led to the requirement for pasture legumes from a range of species, flowering times and hard-seededness. In 1983, the collection was recognised as one of eight Australian centres designated for the conservation of plant genetic resources in Australia under the Standing Committee of Agriculture, 1983. By 1990, the process of collection, introduction and evaluation of pasture genetic resources was in its 25th year. The collection then housed the world's largest collection of annual *Medicago* species, with 15 426 accessions representing 30 species of *Medicago*. At this point, the genebank was renamed the Australian Medicago Genetic Resource Centre. In ~1989, Geoff Auricht took over from Eric Crawford as the curator of the collection. He was a passionate advocate of plant genetic resources and the need to have a national collection with a sustainable funding model. Geoff passed on the curator position to Stephen Hughes in 1995, before becoming the first curator of the APG in 2014.

In Western Australia, the Australian Trifolium Genetic Resources Centre (ATGRC), located at the Department of Agriculture and Food Western Australia (DAFWA) in Perth, was established in 1984 (Snowball 2004) and had a focus on annual *Trifolium* species, *Ornithopus* and *Biserrula*, among other species adapted to acid soils, totalling more than 16 000 lines (Snowball *et al*. 2006). It once held the largest collection of subterranean clover (*Trifolium subterraneum* L.) in the world (Snowball 2004), comprising some 8800 accessions from countries in Europe and North Africa, plus additional naturalised strains from Australia (Nichols *et al*. 2013). The review by Snowball *et al*. (2006) is perhaps the most recent and comprehensive review of a germplasm collection in Australia. Further, the review of genetic improvement of subterranean clover by Nichols *et al*. (2013) summarised much of the history of the collection with particular refence to subterranean clover. John Millington (1960) introduced a subterranean clover breeding program and collected one of the most important strains (cv. Geraldton) at the University of Western Australia in 1949 (D. McClements, pers. comm.), and whereas C. M. Donald and J. F. Miles were the first on a collecting mission in 1951, it was Clive Francis who collected the most subterranean clover germplasm via 12 collecting missions across 10 countries (Nichols *et al*. 2013). The outstanding contribution of Clive Francis was recognised in a special issue of Crop and Pasture Science in 2013, with key papers by Ewing *et al*. (2013) and Berger *et al*. (2013) highlighting his achievements. Ewing *et al*. (2013) stated that Clive Francis made 'near 30 ventures in plant collection and covered much of Mediterranean Europe, and West Asia and North Africa'. During the 1960s, 1970s and 1980s, Brian Quinlivan, John Gladstones and Bill Collins, along with Clive Francis, undertook several collections of naturalised pasture legumes in Australia, along with several collection missions to Europe. A total of 39 separate collecting missions spanning 13 countries, undertaken between 1986 and 2002, added to the collection along with germplasm obtained from the International Center for Agricultural Research in the Dry Areas (ICARDA), Polish and New Zealand Genebanks (Snowball 2004).

Plant evaluation and cultivar development

The introduction of exotic temperate germplasm has contributed to a large and diverse range of evaluation and breeding programs, ultimately resulting in a huge number of cultivars. Evaluation and breeding programs were flagships among State Government Departments and CSIRO, whereas private seed companies were also developing their own proprietary material. These took various forms and were supported by a range of funding streams.

From 1978, the Victorian Department of Agriculture published a list of recommended pasture varieties, which was reviewed annually on the basis of the variety testing conducted across the state. The lucerne aphid disaster of the late 1970s and early 1980s provided funds and equipment that would facilitate pasture variety testing for the next 30 years. Plant breeding and cultivar development was an ongoing activity at Hamilton from the early 1980s and many cultivars were released through commercial partners and the efforts of Kevin Reed, Steve Clark, Choo Kiang Lee, Peter Cunningham, Jeff Rowe, Kevin Smith, Tony Leonforte, Zulfi Jahufer and Pedro Evans. Examples include subterranean clover cv. Leura, tall wheatgrass cv. Dundas, perennial ryegrass cvv. Avalon, Fitzroy and Bolton, tall fescue cv. Fraydo, Persian clover cv. Morbulk, cocksfoot (two cultivars selected from Moroccan ecotypes, not yet commercially available), white clover cv. Mink and *Melilotus alba* cv. Jota. Victorian-led national programs for perennial ryegrass, tall fescue and white clover resulted in cultivars being released after testing in up to six states. Ecotypes of white clover from marginal low rainfall areas of Victoria were used to breed cv. Mink and to develop experimental lines of genetically modified, virus resistant white clover.

After the *Plant Variety Protection Act* (1987) was passed, a Contract Merit Testing Program for seed company breeders commenced in Victoria. Tasmania joined as a partner in 1992. The Victoria and Tasmania testing program was later submerged into a national program, namely, the Australian Pasture Plant Evaluation Committee. Pasture biotechnology, breeding and evaluation were firmly established by a Victorian government Agricultural Strategy in 1989 when the comprehensive Pastures for Profit program commenced. This saw the construction of laboratories, controlled temperature glasshouses and 'crossitron' facilities for open-pollinated species and the seed collection was relocated to a new, climate-controlled facility at Hamilton. The plant breeders collaborated with district agronomists to collect persistent white clover and perennial ryegrass ecotypes across Victoria and perennial ryegrass in the Kangaroo Valley region of New South Wales. A 10-year, joint plant-breeding program between Agriculture Victoria and the Department of Scientific and Industrial Research, New Zealand (later AgResearch), was initiated by Warren Williams, John Lancashire and Kevin Reed in 1990. This further expanded the collection.

A national white-clover improvement program commenced at Glen Innes, New South Wales, in 1990, and later a collaborative breeding effort with AgResearch Ltd in New Zealand (Ayres and Lane 2008). This plant-improvement strategy included assembling a world-sourced white clover collection (Jahufer *et al*. 1996), and by 2000, the collection consisted of 730 accessions. The majority of the accessions sourced for the white clover collection were gathered from plant-collecting expeditions to south-western Europe, the Caucasus region, Turkey and Australia, as detailed in Table 2. Additional accessions came from South America, the former USSR, Asia, the Middle East, North and Central America, northern Europe and Africa. The contribution from New Zealand was mostly cultivars and ecotypes (Jahufer *et al*. 1996). This collection of white clover germplasm underpinned white clover breeding for Australian dryland environments.

The introduction of germplasm to Tasmania resulted in the release of several important cultivars of species, including cocksfoot (*Dactylis glomerata* cv. Porto); Hispanic cocksfoot (*Dactylis glomerata* ssp. *hispanica* cvv. Uplands & Sendace); and red clover (*Trifolium pratense* cvv. Astred & Rubitas).

The demands of requiring legumes for a range of crop rotations spanning diverse soil types led to the requirement for pasture legumes from a range of species, flowering times and hard-seededness. Breeding and evaluation work stemming from the AMGRC collection included, but was not limited to, the release of multiple cultivars from naturalised ecotypes or direct introductions, including *Medicago truncatula* (9), *M. polymorpha* (2), *M. littoralis* (1), *M. scutellata* (4), *M. tornata* (2), *M. rugosa* (3), *M. murex* (1) and *Trifolium subterraneum* (16, mostly from Western Australia; Oram 1990). Two of the most significant introductions include *M. truncatula* APG 400 cv. Cyprus (collected in Cyprus, 1951 by Colin Donald and John Miles) and *M. littoralis* APG 421 cv. Harbinger (collected in Turkey, 1941 by Walter Coelz), because the two accessions have each been used to breed three further generations of commercial annual medic cultivars, including Caliph, Sultan SU, Cheetah, and a new spineless cultivar originating from Cyprus and Harbinger AR, Herald, Jaguar and Angel from Harbinger (D. Peck, pers. comm., SARDI 2020).

Hunter River, a direct introduction with an unclear origin, was the dominant lucerne cultivar grown in Australia until spotted alfalfa and bluegreen aphids invaded Australia in 1977 (Passlow 1977*b*, 1977*a*; Irwin *et al*. 2001). There were early attempts to commercialise other introductions, with Siro Peruvian multiplied at Wanbi Research Station, South Australia, in 1934, from selections of the South American landrace 'Hairy Peruvian'. CSIRO initiated lucerne breeding in the 1960s to improve tolerance to grazing by developing rhizomatous and creeping rooted traits, and, by this time, evaluation of lucerne genetic resources was becoming more common (Rogers 1961; Crawford 1966; Leach 1969). During the 1970s, it became apparent that the plant diseases *Phytophthora* and *Colletotrichum* were contributing to poor lucerne persistence in Queensland and New South Wales (Irwin 1977; Rogers *et al*. 1978).

From 1974, pasture breeders Ian Kaehne, Andrew Lake and Geoff Auricht from South Australia collected significant lucerne genetic resources. Following the devastation of lucerne stands by aphids in 1977, the State Departments of Agriculture in South Australia, New South Wales and Queensland commenced evaluation of new lucerne genetic resources, initially predominantly from the USA, with formal breeding objectives that focussed on improving the resistance of lucerne to pests and diseases. Early and important lucerne cultivar releases from 1979 to 1999 included, in order of release, the following: CUF101, Siriver, Hunterfield, Trifecta, Sequel, Aurora, Quadrella, Pioneer L69, Aquarius, Genesis, Sceptre and Eureka (Irwin *et al*. 2001).

In the late 1990s to early 2000s, the centre serviced the seed requirements of new genetic resources for the National Annual Plant Legume Improvement Program (NAPLIP) and the Cooperative Research Centre Plant Based Management of Dryland Salinity (CRC PBMDS). The introduction of plant collections by these programs served to greatly increase the diversity of its collection, including genera such as *Lotus*, *Trigonella*, *Ononis*, *Trifolium*, *Hedysarum*, *Melilotus* and *Medicago*. This work culminated in the recent release of messina (*Melilotus siculus* Turra. (Vitman ex B.D. Jacks), which fills an important agroecological gap by being the first pasture legume to be tolerant to both waterlogged and saline soils (Rogers *et al*. 2011; Nichols *et al*. 2019). The cultivar Neptune was a direct release from the SA GRC (APG 40002) from Israel, donated by the USDA.

Alternative perennials (to lucerne) identified and evaluated by the CRC PBMDS included *Astragalus*, *Bituminaria*, *Chameacytisis*, *Coronilla*, *Dorycnium*, *Hermania*, *Hippocrepis*, *Medicago*, *Onobrychis* and *Pteronia.* With the collection now representing an ever-increasing diversity of genera, it was renamed the South Australian Genetic Resources Centre (SAGRC) in 1999/2000.

The CRC PBMDS (namely Graeme Sandral and Daniel Real) introduced and evaluated an extensive collection of *Lotus corniculatus* in 2001–2003 for evaluation in New South Wales and Western Australia. This CRC, in partnership with the SA GRC, was also responsible for the first large-scale collection and evaluation of native forbs and shrubs in southern Australia, which was completed over several years at the Waite Institute and Turretfield Research

Centre (Rosedale, South Australia). This activity resulted in 1942 new accessions of native plants with agricultural value being collected, with a focus on *Cullen*, *Swainsona* and *Lotus*. A national collection of saltbush (*Atriplex* sp.) was also established as *in situ* collections at Monarto, South Australia, Tammin Western Australia and Condobolin, New South Wales, for evaluation and selection, resulting in the release of cv. Anameka saltbush in 2014; it was selected for higher feeding value and palatability to sheep (Norman *et al*. 2017). Owing to the variable reproductive characteristics of this species, the sites at Tammin and Monarto have been maintained and still exist in 2020.

During the late 1950s and 1960s, Brian Quinlivan (along with Clive Francis) was central to the collection and release of cv. Woogenellup (Quinlivan 1958), among others, publishing papers (Quinlivan 1957, 1962) on certified strains and registered cultivars of subterranean clover, their origin, potential use and identification. These publications were later updated by John Gladstones (Gladstones 1966; Gladstones and Collins 1984), and later Bill Collins (Collins *et al*. 1984; Collins *et al*. 1996), who made major contributions to collecting and breeding of pasture legumes in the 1970s and 1980s as the Western Australian Department of Agriculture's principle plant breeder along with Clive Francis. Apart from his internationally recognised work with developing the lupin industry in Australia, his significant work in seed collecting of *Trifolium* sp. is world renowned. In particular, the naturalised collections from southern Australia led to several very important cultivar releases (e.g. Dalkeith, which became a very significant variety in its own right, as well as a much-utilised parent in subsequent crossing programs). He played a major part in programs that yielded commercialised varieties such as cvv. Nungarin, Karridale, York, Trikkala, Green Range, Junee, Larisa, Goulbourn, and Demark. He also made extensive collection missions to Europe, in particular France and the Mediterranean. Bill Collins was a collector and selector, who provided the morphological description of many of the accessions coming into the ATGRC in the 1980s.

Many subterranean clover cultivars have resulted from collected material (e.g. cvv. Denmark, Leura), selected from naturalised germplasm (e.g. cvv. Enfield, Dalkeith) or bred (e.g. cvv. Karridale, Gosse; Snowball *et al*. 1992). Nichols *et al*. (2013) summarised the 45 cultivars that had been registered in Australia to that point consisting of 32 of the ssp. *subterraneum*, eight ssp. *yanninicum* and five ssp. *brachycalcycinum*. It is worth noting that a further 10 cultivars have since been registered with Plant Breeders Rights (PBR; either as granted or accepted; IP Australia 2021). The development of these cultivars has been by the DAFWA (Phil Nichols) in Western Australia, and by SARDI (Carolyn De Koning, David Peck) and Pristine Forage Technologies in South Australia. Much of the breeding work has focussed on traits such as resistance to fungal pathogens and, more recently, red-legged earth mite (*Halotydeus destructor*).

The ATGRC also played a support role in the development of serradella cultivars such as yellow serradella (*O. compressus*) cv. Santorini and French serradella (*O. sativus*) cv. Cadiz (Snowball 2004), and later, cvv. Margurita and Erica, following collection missions by people such as Dennis Gillespie, Mike Ewing, John Howieson, Stephen Carr and Brad Nutt. More recently, in 2006, Richard Snowball and Phil Nichols collected *Trifolium* species such as bladder clover (*T. spumosum*), gland clover (*T. glanduliferum*), eastern star clover (*T. dasyurum*) and biserrula (*B. pelicinus*) in Israel (Snowball 2007).

The plant exploration and introduction of phalaris have provided the basic breeding material for present-day cultivars of phalaris developed by the CSIRO Canberra (Oram and Culvenor 1994). Major collections in 1951 and 1954 gave cultivars Sirocco and El Golea through selection within Moroccan ecotypes, and cultivars Sirosa, Sirolan, and Holdfast by hybridisation with 'Australian', followed by recurrent selection for various traits. Selection within the seed-retaining Argentinian cultivar El Gaucho, gave 'Seedmaster', and a single mutant seed-retaining plant within 'Australian' gave 'Uneta' (Oram 1990; Oram and Culvenor 1994).

A CSIRO breeding program to develop a subterranean clover cultivar resistant to stunt virus commenced in 1954. This resulted in cv. Howard, the first bred subterranean clover cultivar, selected from a cross between cvv. Tallarook and Northam (Morley and Peak 1961). The cultivar did not succeed commercially because of it being oestrogenic and being highly variable for flowering, and no more cultivars were released from this program (Nichols *et al*. 2013).

Management of the temperate collections

The AMGRC was responsible for maintaining genetic resources of annual *Medicago*and associated species. The collection included a range of species outside the *Medicago*, which are adapted to alkaline soils. The major genera represented were *Trifolium*, *Astragalus*, *Hedysarum*, *Lotus*, *Ornithopus*, *Onobrychis*, *Scorpiurus*, *Tetragonolobus* and *Trigonella*. The focus on alkaline soils resulted from a rationalisation of curator roles, with the Western Australian Department of Agriculture collection focusing on *Trifolium* and other genera adapted to acidic soils. In 1994–1995, the AMGRC moved its facilities to the Waite Institute, a shared location with the University of Adelaide and CSIRO. The new location included modern seed-storage facilities, a drying room and land on-site for pasture seed regeneration. The collection by now was extensively used by the annual medic, clover and lucerne breeding programs in South Australia.

The AMGRC/SAGRC was recognised by the International Board for Plant Genetic Resources (IBPGR) as a world base collection for annual *Medicago* species. At the time of the formation of the Australian Pastures Genebank in 2014, the AMGRC was Australia's largest forage collection with 44 507 accessions.

Indigenous forage collections

Australian native species form the backbone of many rangelands used for grazing and are also of interest in revegetation works. There has also been renewed interest in collecting indigenous Australian plants and evaluating their suitability as grazing forage (Snowball *et al*. 2021). There are ~2700 accessions of indigenous Australian germplasm in the collection, represented by some 133 genera. The APG is currently working to accurately identify these plants at an accession level, with the aim of allowing users to filter exotic accessions from results of a web-based search of the APG germplasm. Some of the major Australian indigenous taxa represented (number of accessions in parenthesis) in the APG include *Heteropogon contortus* 35, *Astrebla* spp. (30), *Themeda triandra* (69), *Dichanthium* spp. (42), *Dichanthium sericeum* (37), *Poa* spp. (33), *Rytidosperma* spp. (47), *Austrostipa* spp. (43), *Microlaena stipoides* (17), *Panicum decompositum* (9) and *Cymopobogan ambiguous* (10).

The Australian Pastures Genebank

How was APG formed?

The Australian Pastures Genebank (APG) was formed in 2014 and is located at the Waite Campus of the SARDI in Adelaide. Development of the APG followed concerns regarding long-term resourcing of pasture and forage collections in Australia, and declines in maintenance of the collections. However, it took many years of negotiation between government agencies and research and development corporations after it was first proposed in the 1990s to establish the genebank. Steve Hughes and Geoff Auricht were key proponents of the APG. The complexities of obtaining funding from the five research and development corporations (RDCs) with a stake in the germplasm, namely, Meat and Livestock Australia (MLA), Australia Wool Innovation (AWI), Grains Research and Development Corporation (GRDC), Dairy Australia (DA), and Rural Industries Research and Development Corporation (RIRDC, later AgriFutures Australia), and agreements from the State Government departments, was a challenging process.

The transfer of genetic resources then followed in a staggered process from the 12 major collections around Australia held by state governments and CSIRO. Germplasm transferred to the APG conformed to the mandate of the collection, which includes ‘all pasture and forage species of actual or potential value to Australian agriculture, including plants to be grown for livestock, food and fibre, crop rotation and the environment’ (Hughes 2015). Once acquired, the objective was then to ‘document, conserve, maintain and distribute seed for scientific research, plant breeding, genetic resource conservation and education’ (Hughes 2015). The initial transfer of more than 250 000 individual seed packets and 116 000 accessions to the APG is summarised in Table 3. The collection currently houses 85 000 unique accessions (Table 4). Germplasm has been collected from all over the world, with the major source being from countries in and around the Mediterranean (Fig. 1). Other major seed sources are central and south America, southern and eastern Africa, the China–Kazakhstan border region, India and Australia. Australian collections are combinations of native species and naturalised exotics of interest to plant-breeding programs.

Collection, acquisition and introduction of germplasm

New material is obtained either through the collection of wild lines from centres of diversity or through the exchange with other genetic-resource collections around the world. Material is inspected, treated and processed by quarantine on its arrival in Australia. The lines are indexed with an APG number and their passport data (information obtained from the collection site including coordinates, elevation, soil type, land use remarks, and associated species), are entered onto the GRIN-Global database.

Evaluation and characterisation

Efficient processes are used to maximise the number of accessions regenerated each year. Each line is grown as spaced plants in the field, with sufficient numbers to ensure genetic representation of the taxon. Plants of each line are hand-planted, with seedlings raised from seeds in greenhouses.

Table 3. Summary of seed deposits to the Australian Pastures Genebank from collections around Australia
Note: updated from Hughes *et al*. (2017)

Institution	Collection	Major focus	Number of accessions
CSIRO	Black Mountain	Tropical forages	21 827
DAF Queensland	AusTRCF	Tropical forages	12617
DAF Queensland	Walkamin	Commercial tropical forages	120
DAF Queensland	Toowoomba	Naturalised medic	432
DPIRD	ATGRC	Trifolium and temperate legumes	19 009
DEDJTR Victoria	Hamilton, ARD	Temperate grasses and legumes	2082
DEDJTR Victoria	Hamilton, BRD	Temperate grasses and legumes	2436
DPIPWE Tasmania	Mount Pleasant	Temperate legumes and grasses	5569
NSW DPI	Glenn Innes	White clover and forages	730
NSW DPI	Grafton	Subtropical forages	1364
NSW DPI	Wagga Wagga	Lotus	1527
SARDI	AMGRC	Medicago and temperate legumes	44 507
Various	Various	Pasture and forages	2020
		TOTAL	116 006

Table 4. Summary of current collection of unique accessions within APG pasture groups

Pasture group	Number of accessions	Pasture group	Number of accessions
Aeschynomene	447	*Lablab*	285
Arachis	48	*Leucaena*	627
Astragalus	902	*Lotus*	2771
Biserulla	376	*Lucerne*	3765
Bothriochloa	235	*Macroptilium*	692
Brome	3252	Medics	24 842
Brachiaria urochloa	238	*Melilotus*	741
Cenchrus	475	*Panicum megathyrsus*	461
Centrosema	931	*Paspalum*	298
Chamaecrista	147	*Phalaris*	470
Chicory	158	Plantain	93
Chloris	154	Ryegrass	984
Clitoria	162	Sainfoin	517
Clover annual	7495	Saltbush	404
Clover *Balansae*	208	*Serradella*	2997
Clover bladder	554	*Setaria*	98
Clover perennial	1201	*Stylosanthes*	2049
Clover Persian	915	*Sulla*	317
Clover red	357	Temperate grass	1191
Clover sub	9641	Temperate herb	422
Clover talish	78	Temperate legume annual	812
Clover white	1066	Temperate legume perennial	612
Cocksfoot	699	Temperate shrub	955
Cullen	225	*Trigonella*	681
Cynodon	80	Tropical grass	993
Desmanthus	486	Tropical grass aquatic	5
Desmodium	1148	Tropical legume herbaceous	2717
Dichanthium	124	Tropical legume shrub	383
Digitaria	441	Tropical legume tree	165
Fescue	2190	*Vigna*	416
Glycine	595		
		Total	83 910

Included with the introduced lines are a range of cultivars and controls, which are used to benchmark characterisation data.

Out-crossing species represent a considerable challenge for regeneration as seed needs to be produced in isolated conditions to exclude pollen from other plants (neighbouring accessions or local, wild plants). Insect-pollinated plants are placed in a tent with a honeybee hive. Wind-pollinated plants are isolated by distance, with the aid of a barrier crop such as cereal ryecorn (*Secale cereale* L.). Strict quarantine measures are observed to prevent inadvertent release of plants.

Throughout the growing season, a wide range of characteristics are recorded for each line. These fall into the following two categories:

(1) Morphological characters that include plant characteristics such as habit, length of internodes, branching, foliage, and details of leaf markers as well as a range of flower, pod and seed characteristics.
(2) Agronomic characters that include visual assessments of forage production in relation to checks, as well as recordings of flowering date and a range of yield details, including seed and pod production.

Recording of these details provides data that are necessary for taxonomic classification and, in the subsequent selection of lines, for further evaluation by plant breeders.

Storage and maintenance

Seed harvested from the rows forms the basis of the genetic resource collection. All seed is placed in a dehumidifying room to reduce moisture content before storage. In all, 6000–10 000 seeds of each accession are stored in the Base collection for long-term conservation. This seed is not distributed and replaces the original seed, which is moved to a Reference collection. The remaining seed (or up to 50 g) is kept in an Active collection for distribution to scientists around the world. Seed is sealed in foil packets and stored at –20°C for the Base collection and 2°C for the Active collection. A seed-viability program monitors 4000 accessions per year. Seedlots with low Base or Active store numbers, or poor viability, are selected for Regeneration at one of four locations in Australia (Mareeba, Launceston, Adelaide or Perth).

Distribution and data management

Where available, 100 seeds of self-pollinating species and 200 seeds of out-crossing species are distributed free of charge under a Standard Material Transfer Agreement for any legitimate research purpose to workers around the world, in line with the FAO Treaty for Plant Genetic Resources for Food and Agriculture.

The collection is available online for ordering, using the international standard database management software Germplasm Resource Information Network (GRIN) GRIN-Global (available at https://apg.pir.sa.gov.au/gringlobal/search.aspx). Further searches for germplasm can be undertaken with the web-based discovery tool Genesys, which is a database of genetic materials being conserved worldwide (available at https://www.genesys-pgr.org/). The international genebanks, including the APG, send their basic accession and its related passport, habitat and characterisation/observation data to the Genesys system. This collection of plant genetic data helps explore information from a single website. The system has some useful features, such as showing monthly temperature and precipitation data of the area where the material is collected.

The value of the APG and its future

The impact of the APG on pasture productivity improvement through genetic gain has recently been estimated at 0.5–2% per annum (Rainbow and Begley 2017). On the basis of these values, the potential value to pasture improvement and resulting production from the APG was calculated at AU $62.5–250 million per annum. Rainbow and Begley (2017), then calculated that the return on investment derived from access to APG germplasm would deliver a benefit/cost well in excess of at least 20:1, and likely up to 38:1. However, funding of the APG is complicated and insecure, despite the recognised high value of pasture genetic resources. The current funding model is split between state governments and five RDCs (MLA, GRDC, AWI, DA and AgriFutures Australia). A range of alternatives has been considered, including national funding and commercial investment from private seed companies, but a long-term sustainable model is yet to be identified.

The APG is large by international standards, partly owing to the effectiveness of the plant collectors and success of the Australian seed industry in commercialising new cultivars. As an example, the APG has ~55 000 temperate accessions, compared with only 13 000 accessions held in the USDA National Plant Germplasm System (B. Irish, pers. comm.). The collection may require rationalisation to match capacity of available resources. Current funding levels support the annual regeneration of ~800 accessions per year, so, on average, seed needs to survive for 80 years to support 64 000 seed lots (accessions). Long-term storage is achievable for many legumes (particularly those with hard seed), but is problematic for many grass species. For example, seeds of *Bromus* spp. have short shelf-lives and need to be regenerated every 5, or so, years, creating a resource issue for this pasture grass that is not currently a major species in Australian agriculture.

One way to reduce the size of the collection would be to reduce duplication that exists within and between other collections. For example, the entire Australian tropical collection has been sent to ILRI and/or CIAT, and a significant proportion of the CIAT collection is held in Australia (Pengelly 2015). Significant duplication for other species also results from large-scale germplasm exchanges (such as *Medicago* sp. with the USDA Genebank, where 4579 of the 7540 accessions are duplicates. Duplication is desirable, as biosecurity and political barriers often prevent the international exchange of seeds. Other forms of duplication include over-sampling of collection sites, resulting from multiple collections in the same location over time, or by excessive sampling strategies. A third example of duplication can originate from the splitting of original accessions for phenological traits such as flowering time and leaf markers. Although this can be justified in some circumstances (i.e. it can be argued that it is useful to identify and split plants with disparate flowering times, >15 days), it should be recognised that a wild accession can be segregating for multiple traits. There are some examples of original accessions (of self-pollinating species) being split into more than 20 new accessions, which then all need to be conserved. Accession splitting and repeated collections at the same (or very close) location have been identified as major sources of duplication in the APG. An initial calculation of the number of unique accessions, collected at least 10 km or 300 m in elevation apart, has identified 34 000 georeferenced unique accessions in the collection. These accessions will be tagged as 'high maintenance priorities' and will be promoted for regeneration and distribution. Further identification of high value and or unique accessions (including those not georeferenced) will be an ongoing activity.

Rationalisation will require additional resources to seek expert advice on approaches for management of different pasture groups. With such a diverse collection, it is not possible for a curator to have expert knowledge of all pasture groups and, as such, a significant level of expert consultation will be required. An optimisation strategy was proposed by van Treuren *et al*. (2009) that uses hierarchical structuring of the gene pool and assigning relative importance to each of the different components. The development of agro-ecological 'cores' has been suggested by Pengelly (2015) to promote key species and accessions for enhanced utilisation (seed production) and conservation efforts where evidence-base selections (phenology and or genomic information on diversity) are not available for the species. The development of core collections can then be used to promote a first-stop shopping point for customers requiring diverse germplasm and knowing this upfront allows the genebank to produce more seed of these accessions in preparation for higher use (and as a consequence conserving smaller amounts of seed of >90% of the collection).

Successes

In a few short years, the APG has amalgamated seed from 12 different collections into a single repository. The collection as a whole is available online for ordering, using the international standard database management software, GRIN-Global. The base collection has recently been audited, identifying accessions with low quantities of seed for priority regeneration. A program of viability testing of 4000 accessions per year assists with identifying accessions in poor health and will build knowledge of the viability of the collection over time. An efficient seed-regeneration program has been established, with expertise in four centres around Australia to regenerate lines adapted to specific environments. Although the APG still has some tasks to overcome, it has been extremely successful in getting to this point and being open for distribution.

The APG still has many improvements to make, and among these are considerations proposed by van Hintum *et al*. (2000), which include the following: (1) an accurate understanding of how the collection is composed (through the use of diversity trees), (2) an analysis of germplasm gaps and over-representation, improved knowledge of inventory and viability of samples in the collection, (3) an understanding of who the users (including potential) are and why they do or do not use the collection, (4) an improvement in data accessibility for users (including final reports and historic evaluation data), and, finally, (5) an understanding of what accessions are most frequently requested and the reasons why they are being requested.

Importance of the APG and other genebanks

Many of the accessions held in the APG are from regions that have undergone significant land-use change since the time that they were collected. For tropical species, the urban expansion in South and Central America has seen forests, grasslands and savannas being replaced by urban spaces and areas of intensive cropping (Pengelly 2015). There are regions in north Africa, the Middle East and Mediterranean Europe (the focus area of the collection) that have also become urbanised or are inaccessible because of political turmoil or war (e.g. Syria, Iraq, Afghanistan and Iran). Overgrazing in many countries has also contributed to loss of habitat and reduction in species diversity. More recently, the diversity of many crop wild relatives (CWR) of agricultural plants have been identified as threatened by the loss of habitat from the impacts of climate change in the Crop Trust CWR Project 'Adapting Agriculture to Climate Change: Collecting, Protecting and Preparing Crop Wild Relatives' (http://www.cwrdiversity.org/).

Conclusions

The collection and introduction of exotic germplasm, both accidental and intentional, has undoubtedly changed the grazing landscape in Australia. The intentional introduction of accessions has underpinned pasture improvement across many of Australian agro-ecological regions through direct introduction of cultivars and plant selection and breeding. Many collectors and donors have helped build genebanks, which are now centrally housed under the Australian Pastures Genebank. Challenges remain to maintain and utilise this germplasm for the continued improvement of pastures across Australia in the face of a changing climate and agricultural systems.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix 1. Summary of tropical grass taxa held and recently regenerated within the APG

Taxa included in the Tropical Forages web tool and application are noted. Regeneration cycle number: 1 = 2005–2008, 2 = 2014–2020

Grass taxon group – Tropical Forages collection	Species	Accessions	Regeneration cycle number
Achnatherum	1	3	
Aerva	1	3	1
Alloteropsis	2	19	1
Andropogon[B]	6	57	1
Anthephora[A]	4	53	1
Apluda	2	5	1
Aristida	5	10	
Arthraxon	4	8	1
Arundinella	1	1	1
Astrebla[A]	4	34	
Austrostipa	1	2	1
Axonopus	1	3	
Bewsia	1	1	
Bothriochloa[A]	12	237	1, 2
Bouteloua	3	6	1
Brachiaria urochloa[A]	24	241	1, 2
Capillipedium	3	5	1
Cenchrus pennisetum[A]	14	643	1, 2
Chloris[A]	13	157	1, 2
Chrysopogon	7	72	1
Cymbopogon	5	35	1
Cynodon[A]	8	80	1
Dactyloctenium	6	50	1
Dichanthelium	1	1	
Dichanthium[A]	5	124	1, 2
Digitaria[A]	23	443	1, 2
Echinochloa	4	14	1
Echinopogon	2	2	
Eleusine	3	39	
Enneapogon	8	23	
Enteropogon	5	33	1
Eragrostis[A]	12	108	1
Eriachne	3	6	
Eriochloa	4	9	1
Eulalia	1	6	
Eustachys	4	16	1
Fingerhuthia	1	1	
Heteropogon[A]	1	38	1
Hymenachne[B]	2	2	
Hyparrhenia[B]	6	18	1
Ischaemum	3	14	1
Iseilema	3	15	1
Leptochloa disakisperma, Diplachne Trogonochloa	6	14	1
Lintonia	1	1	
Manisuris	1	1	1
Melinis[A]	5	6	1
Mnesithea	1	1	
Monachather	1	4	1
Moorochloa	1	2	
Nassella	1	1	
Panicum megathyrsus[A]	25	465	1, 2
Pappophorum	1	1	
Paspalidium	4	4	1
Paspalum[A]	37	301	1
Piptochaetium	1	1	
Pleuraphis	1	1	
Poa	2	3	
Polypogon	1	1	

(*continued next page*)

Appendix 1. (*continued*)

Grass taxon group – Tropical Forages collection	Species	Accessions	Regeneration cycle number
Redfieldia	1	1	
Roegneria	1	1	
Rottboellia	1	1	
Schizachyrium	1	1	1
Schmidtia	2	28	1
Sehima	3	25	1
Setaria[A]	10	97	1, 2
Sorghastrum	1	2	
Sporobolus	13	38	
Steinchisma	1	3	
Stenotaphrum[A]	1	2	
Stipagrostis	2	5	1
Tetrapogon	1	6	1
Themeda	2	78	1
Thyridolepis	2	10	
Trichloris	1	1	
Tridens	1	1	
Triodia	4	10	1
Tripogon	1	1	
Triraphis	1	1	
Zoysia	2	10	
Zuloagaea	1	1	
Zygochloa	1	2	
Total	362	3769	

[A]Listed in Tropical Forages application as a tropical forage.
[B]Listed in Tropical Forages with a precautionary note.

Appendix 2. Summary of tropical legume taxa held and recently regenerated within the APG

Taxa included in the *Tropical Forages* webtool and application are noted. Regeneration cycle number: 1 = 2005–2008, 2 = 2014–2020

Legume taxon group – Tropical Forages collection	Species	Accessions	Regeneration cycle number
Abrus	1	2	1
Acacia/Acaciella[B]	7	44	
Adesmia	6	29	1
Aeschynomene[A,B]	30	448	1
Albizia[A]	4	7	1
Alysicarpus[A]	11	311	1, 2
Aphyllodium	1	1	
Arachis[A]	12	48	
Argyrolobium	5	40	
Bauhinia	1	1	
Caesalpinia	1	1	
Calliandra[A]	5	16	1
Calopogonium[A]	5	41	1
Camptosema	1	1	
Cassia chamaecrista[A]	14	179	1
Centrosema[A]	22	932	1, 2
Chaetocalyx	2	2	
Chrysoscias	1	1	
Clitoria[A]	6	162	1, 2
Codariocalyx[A]	2	31	1
Crotalaria[A]	57	221	
Cyamopsis	3	7	
Dalea	4	11	1
Delonix	1	1	
Dendrolobium	2	6	1
Desmanthus[A]	15	496	1, 2
Desmodium grona Bouffordia[A]	71	1149	1, 2

(*continued next page*)

Appendix 2. (*continued*)

Legume taxon group – Tropical Forages collection	Species	Accessions	Regeneration cycle number
Dichilus	1	2	
Dioclea	1	1	
Dolichopsis	1	2	
Dunbaria	1	2	
Eriosema	2	2	1
Erythrina	1	2	
Flemingia[A]	2	10	
Galactia	10	162	1
Gliricidia[A]	1	45	1
Glycine neonotonia[A]	15	598	1, 2
Indigastrum	1	1	1
Indigofera[B]	47	307	1
Isotropis	1	1	
Kummerowia	2	6	
Lablab[A]	4	286	1, 2
Lespedeza	2	34	
Lessertia	11	14	1
Leucaena[A]	17	627	1
Lotononis listia[A]	9	64	1
Lysiloma	2	2	1
Macroptilium[A]	16	695	1, 2
Macrotyloma[A]	6	107	1, 2
Marina	1	1	
Mucuna[A]	2	21	1
Mundulea	1	1	
Neptunia	7	24	1
Otoptera	1	4	
Ottleya	1	1	
Phyllodium	2	4	
Pseudarthria	3	71	
Pseudeminia	1	1	
Pseudovigna	1	1	1
Psoralea	1	5	1
Pterocarpus	1	1	1
Pueraria neustanthus[A]	1	7	1
Pycnospora	2	14	1
Requienia	1	1	
Rhynchosia	32	360	
Rothia	2	7	
Senna	15	60	1
Sesbania[A]	24	244	
Strophostyles	2	4	1
Stylosanthes[A]	23	2054	1, 2
Tadehagi	1	7	1
Tephrosia	43	134	1
Teramnus[A]	9	258	1
Tylosema	1	1	
Unident	1	1	
Uraria	2	65	1
Vigna cochliasanthus Sigmoidotropis[A]	40	489	1, 2
Zapoteca	1	1	1
Zornia[A]	26	398	1
Trifolium with potential tropical adaptation (separate collection)			
Trifolium[A]		226	
Total	691	11 624	

[A]Listed in Tropical Forages application as a tropical forage.
[B]Listed in Tropical forages with a precautionary note.