Chapter 3
Australia and New Zealand

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Abstract This chapter outlines the historical context of phenological observation and study in Australia and New Zealand. Details of early records are given as they provide a valuable baseline against which current phenology may be assessed. It also summarizes the results of phenological studies undertaken in recent years and identifies further long-term phenological data yet to be analysed. The information presented here begins to address the acknowledged lack of phenological studies undertaken in both countries. Community-based phenological networks and their contribution to the collection of phenological data are also described.

3.1 Historical Context

The Northern Hemisphere, particularly Europe and parts of Asia, have a long history of recording phenological events (Nekovář et al. 2008; Sakurai et al. 2011). In the last 20 years or so these records have been used to contribute to the understanding of the impacts of climate change on natural and managed systems (Rosenzweig et al. 2007). In the Southern Hemisphere, phenological records are sparse by comparison. However, this chapter highlights recent advances that have been made in documenting phenology in Australia and New Zealand and that significant historical information exists in the form of traditional knowledge.

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M.D. Schwartz (ed.), *Phenology: An Integrative Environmental Science*,
DOI 10.1007/978-94-007-6925-0_3,

3.1.1 Traditional Knowledge

Traditional Ecological Knowledge (TEK) is increasingly being studied because of the insights it can offer into climate forecasting and climate change (Riseth et al. 2011).

Aboriginal people have occupied the Australian landscape for over 50,000 years making their culture the oldest living culture in the world (Head 1993). They have endured major climatic changes such as earthquakes, severe drought and flood, ice ages and the rise and fall of oceans, which have produced long-term vegetation changes, yet they managed to adapt, survive and acquire knowledge of these occurrences (Gott 2005).

3.1.1.1 Traditional Ecological Knowledge

There are more than 500 different Countries[1] in Australia and each Aboriginal group has detailed knowledge pertaining to the ecosystems within their traditional boundary and how they fit into it. Castellano (2000) explains,

> Indigenous Knowledge is gained by three processes: observation, traditional teachings and revelation. Indigenous observation is undertaken over long time scales ... traditional teachings encompass knowledge that has been passed down through generations, for example creation stories. Knowledge acquired through revelation, such as dreams, visions and intuition, is sometimes regarded as spiritual knowledge.

Country is understood on many levels (social, emotional, spiritual and physical) with various weather conditions and signs of particular culturally significant species and the interaction with them. It is these species that signify the cues for ceremonies, hunting, gathering, breeding times and movements, with the transition of seasons interpreted through cultural values and beliefs. TEK is a holistic form of many types of environmental knowledge and practice now studied within a variety of scientific disciplines, including phenology.

3.1.1.2 Traditional Ecological Knowledge and Phenology

TEK and the study of phenology share three common factors; they are both dependent and built upon observations of ecological timing, in a specific area, and utilise key species or events of interest triggered or influenced by climate. One observable example of this is documented using Aboriginal seasonal calendars. There are also differences between phenology and TEK, one obvious difference is the timescale of recorded knowledge. For example, the D'harawal from Sydney

[1] Country is a place that gives and receives life. It encapsulates everything from flora and fauna, topographical features, dreaming stories, values, totems and the ancestral spirits within the land (Parks Victoria 2010 Healthy Country, Healthy People Digital Story. http://www.youtube.com/watch?v=2UmVNOpC1zU. Accessed February 2012).

area have two cycles that run considerably longer than the yearly cycle, the Mudong, or life cycle which covers about 11 or 12 years, and the Garuwanga, or Dreaming, which is a cycle of about 12,000–20,000 years (Kingsley 2003). The second difference is how environmental observations are interpreted through language, cultural values and beliefs systems that are shaped by lore and society. A third difference is the way of accumulating that knowledge such as oral histories, songs, dance and art rather than written data and modern technologies, such as carbon dating. In Aboriginal communities, specialised knowledge holders have varying responsibilities with imparting knowledge that is collective. Much was remembered and shared through stories, songs and art. Other knowledge is earned through demonstration of trust to ensure the knowledge will not be exploited to the detriment of Country or community.

3.1.1.3 Seasonal Calendars

There have been several studies of Australian seasonal calendars (e.g. Hoogenraad and Robertson 1997; Rose 2005). A commonly used western method of recording this information is the calendar wheel, to show the ongoing cycles of life. There are mixed views on whether this captures Aboriginal knowledge in an appropriate way (Rose 2005). However, some acknowledged benefits are that seasonal calendars prompt discussion about TEK and the use of local language by the traditional owners, where other languages are dominant, and allow the information to be passed on to younger generations (Hoogenraad and Robertson 1997). Some Aboriginal calendars are more detailed than others, reflecting contrasting weather patterns across the Australian continent.

3.1.1.4 Ecological Timing

Known seasonal calendars range from the two seasons (wet – Wantangka and dry – Yurluurrp) of the Wallabunnba people north of Alice Springs, to the 13 seasons in the Ngan'gi Seasons Calendar of the Nauiyu – Daly River people (http://www.bom.gov.au/iwk). This highlights a very complex and detailed understanding of climatic variations, events and accumulation of ecological knowledge. Within Victoria, the numbers of seasons recorded are fairly consistent (e.g. the six seasons of Gariwerd, the Gunditjmara six seasons and the seven seasons of the Wurundjeri) probably reflecting a more similar climate. Each season has particular cues for selected resource use, ceremony, management practice or movement to another area. To explain this further, Uncle Banjo Clarke (Gunditjmara people) describes the custom of *keeping the bird families strong* (Clarke and Chance 2003): they would visit a particular lake at a certain time of year (*Flowering Time* season) when thousands of swans would gather to nest and breed. It was traditional practice to collect swan eggs specifically from the nests in excess of four eggs. Only the excess would be taken carefully without leaving human scent. This prevented any food from being wasted on the weakest cygnets that would eventually be kicked out of the nest.

The European phenology calendar for the Middle Yarra (Victoria), defines six seasons of the Melbourne area as Autumn, Winter, Pre-spring, True Spring, Early Summer and Late Summer (Jameson 2001). Some of these align with observations recorded by Wurundjeri, but the descriptive language of the seasons imposed from the Northern Hemisphere is still evident.

In a holistic approach, one link that is not captured by phenology is the use of the stars. Aboriginal people believe that what happens on the land is reflected in the night sky. The appearance and disappearance of certain constellations were linked with regulating hunting regimes, so breeding times would be undisturbed. During various times of the year, the brightness and movements of the stars and planets signaled the arrival of particular birds or other species and the blooming of certain vegetation.

> For the Boonwurrung (people), the coastal cliffs and beaches along the bay were the focus of Old-Man Sun activity. The seasons were not mapped by a calendar but by the movement of the stars and the blooming of the plants. In the bay area the beginning of summer and the return of the snapper in the bay were signalled by the flowering in early November of the coast tee-tree and the late black wattle (Briggs 2008).

The connection Aboriginal people have to their Country is built upon evolutionary interrelationships and life cycles. This is demonstrated by the tracts of collective knowledge that has been shared and recorded as well as the specialized knowledge that is earned. It is evident the landscape has shaped their culture and their culture has shaped the land. This is why Traditional Ecological Knowledge is so important in understanding the story of that Country and for advancing the study of phenology and improving the management of that land.

3.1.2 *Early European Phenological Observations*

Having an understanding of why phenological observations were recorded can assist in locating data sources for examination which in turn can add to our understanding of the impacts in the climate change in the Southern Hemisphere.

The following section summarizes some of the known early European phenological observations undertaken in Australia and New Zealand.

3.1.2.1 Australia

There is no confirmed date as to when systematic European phenological observation or monitoring commenced in Australia. Table 3.1 summarizes early (prior to 1970) Australian phenological history, focusing on plants, and reflects extant records.

The earliest series of phenological observations undertaken by an individual are those attributed to von Mueller in 1856 (Prince 1891) – 21 years after the official European settlement of Victoria (Carron 1985). In the same year Hannaford (1856)

Table 3.1 Early phenological studies undertaken in Australia

Date	Comments	References
1856–?	List of plants with their month/s of flowering; Victorian focus	Hannaford (1856)
1856–?	Phenological recordings undertaken by Baron von Mueller, Victorian government botanist	Prince (1891)
1857–1895 (?)	Irregular collection of flowering observations by Maplestone	Maplestone (1895b)
1856–1885	Leafing, flowering, and fruiting of standard plants recorded in the Royal Society of Tasmania's Garden	Anon (1856) and Chambers and Keatley (2010b)
1886–1887	Monthly listing of plants in flower around Sydney	e.g. Haviland (1886, 1888)
1891	Call for establishment of phenological network in Victoria	Prince (1891)
1895	Flowering phenology of orchids, method outlined for recording phenological observations	French (1895) and Maplestone (1895a, b)
1903	Nature Study Calendar for Victoria	Gillies and Hall (1903)
1905, 1908	New South Wales Undersecretary for Lands requests that foresters record flowering within their district	Maiden (1909)
1906	Call for South Australian Royal Society's field naturalist's section to commence a list of flowering times	Anon (1906)
1907–1954	Climate observers requested to undertake phenological observations	Bureau of Meteorology (1925, 1954) and Commonwealth Meteorology (1907)
1909–1921	Broad information of flowering times of honey flora published in apiarists' journals	e.g. Beuhne (1914), McLachlan (1921) and Penglase and Armour (1909)
1909– 1924	Books published on general flora and fauna observations taken throughout the year	Mack (1909, 1924)
	A plea for the study of Australian phenological phenomena by New South Wales government botanist	Maiden (1909, 1924)
1925	Positive response to the Royal Meteorological Society's Phenological Committee 1924 call for the establishment of an International Phenological Network	Clark (1924, 1925) and Ploughshare (1926)
1929–1949	Flowering dates of 7 orchid species at 3 locations in Western Australia	Erickson (1950)
1925–1981	Monitoring undertaken by the Forest Commission of the various States	Keatley et al. (1999), Loneragan (1979), Steane (1931) and Tout (1935)
1934–1949	Arrival dates of Pallid Cuckoo and Nankeen Kestrel, breeding dates of Willie Wagtail in Western Australia	Sedgwick (1947, 1949, 1950)
1940–1962	Records of eucalypt flowering undertaken by the Victorian Forest Commission.	Keatley et al. (2002)

(continued)

Table 3.1 (continued)

Date	Comments	References
1949	Another call for phenological studies to be undertaken.	Gentilli (1949)
	“Meteorological Service” established a program for phenological observations.	Anon (1949) and Wang (1967)
1949–1954 (?)	Australia-wide ornithological program	Jarman (1950)

published a list of plants, primarily focused on Victoria, with months of flowering provided for most species within the list. Whilst lists without specific dates of flowering are now considered limited, it is highly likely that the range and months of flowering of many of the species were unknown at the time.

Other early observations were primarily undertaken by individuals (e.g. Haviland 1886–1888, Maplestone 1861–1895) associated with scientific organisations. It was not until the late eighteenth century that the general public in Australia were encouraged to be involved in science (Newell and Sutherland 1997).

The Royal Society of Tasmania appears to have instigated the earliest set of phenological recordings undertaken by an Australian organisation (1856–1885). The majority of the observations, leaf break, leaf colouration and falling, flowering, fruit ripening and harvesting, are of exotic plant species (Chambers and Keatley 2010b).

Between 1905 and 1924, Joseph Maiden, the New South Wales’ government botanist and director of the Sydney Botanical Gardens (1896–1924) (Hall 1978), made requests of the Bureau of Meteorology and the Forests Department of New South Wales, to undertake phenological observations (Maiden 1909, 1924).

In the early 1920s the English Royal Meteorology Society put out a call for the establishment of an international phenological network (Clark 1924) and apparently received a positive response from Australia (Clark 1925; Ploughshare 1926).

The Bureau of Meteorology recognized the value of undertaking phenological observations and requests were made of meteorological observers to record the flowering of native plants, the arrival of migratory birds and butterflies in their weather notes (Commonwealth Meteorology 1907; Bureau of Meteorology 1925, 1954). The Bureau did not, however, insist on these being taken.

There is also a specific mention of a phenological network being established in 1949 (Wang 1967). It seems that the Bureau of Meteorology endeavored to establish a network after the 1947 Conference of the International Meteorological Organisation (International Meteorological Committee 1949), but again apparently relied on volunteers (Anon 1949).

In 1948, the Annual Congress of the Royal Australian Ornithologists’ Union (now Birdlife Australia) adopted a proposal that an Australian-wide community network of observers be established to provide data on bird distributions and movements and the influence of climate on these. The program had commenced by 1949 with 200 observers. It seems that Tasmania and South Australia were not included as they already had similar networks operating (Jarman 1950).

Table 3.2 Early phenological studies, prior to 1972, undertaken in New Zealand

Date	Comments	References
1883	List of flowering months for 23 orchid species	Adams (1883)
1900	Records of first flowering dates for nine species (1893–1900)	Cockayne (1899)
1914–1955	Weekly sightings of Humpback whales in Cook Strait	Dawbin (1956)
1936–1954	Laying dates of Yellow-eyed Penguins on Otago Peninsula	Richdale (1957)
1938–1946	Departure dates of the New Zealand Bronze Cuckoo from Dunedin as well as detailed arrival dates from across New Zealand (>120 locations) for 1945	Fell (1947)
1938–1947	Arrival (8 seasons) and breeding (6 seasons) records of a single Erect-crested Penguin on Otago Peninsula.	Richdale (1950)
1938–1953	Arrival dates of Shining Cuckoo at various locations	Cunningham (1953, 1955)
1964–1969	Laying dates of Southern Royal Albatross at Campbell Island later than those reported by Richdale on Otago Peninsula	Waugh (1997)
1954–1964	Breeding timing of California Quail in Central Otago and Central North Island	Williams (1967)
1964–1972	Laying dates (3 seasons) of Red-billed Gulls at Kaikoura Peninsula	Mills (1979)

3.1.2.2 New Zealand

As with Australian records, it is not known when European phenological recording commenced in New Zealand and long-term studies are also limited (McGlone and Walker 2011). Table 3.2 lists the early New Zealand records.

In 1883, Adams (1883) listed the months of flowering for 23 orchid species and, as with the Haviland and Hannaford records, it is highly likely that the months of flowering of many of the species were unknown at the time. The earliest plant phenological exact dates located so far for New Zealand are first flowering dates for nine species, encompassing the years 1893–1899 (Cockayne 1899).

Using historical sources (e.g. logbooks, diaries, catch numbers) and his own research, Dawbin (1956) defined the north and south migration routes of Humpback whales around New Zealand. The number of whales sighted per week for Cook Strait is provided for the period 1914–1955, providing early phenological information. For example, the mean length of migration over that period was 86 days (range of 64–110 days). The longest seasons were in 1920 and 1937 when the first whales were sighted in the first week of May and last sighted in the third week of August (Dawbin 1956).

Prominent in the early avian phenology literature is Lance Richdale. A teacher in Otago and an amateur ornithologist, Richdale undertook a number of major research projects on seabirds (including penguins, albatross and petrels) from the 1930s to 1950s, mainly during weekends and evenings (Fleming and Warham 1985). Early records indicated very little variability from year to year in arrival and breeding timing in Royal Albatross (Richdale 1942) or in breeding timing of Erect-crested Penguins (Richdale 1950).

3.2 Forest Agency Data and Research

Australian forest agencies have collected phenological data in the majority of states (Fig. 3.1). The early history of which has been detailed by Keatley and Fletcher (2003). These observations cover various durations of flowering and/or budding of commercial forest and/or 'honey' trees. The original aim seems to have been the enumeration of seed crops for silvicultural management. Currently, phenological studies are much reduced but continues in major commercial species (e.g. *Eucalyptus regnans*) and now includes the forecasting of the size of flowering and seed crops (Bassett in prep).

The New Zealand Forest Service was formed out of its predecessor the State Forest Service in 1949. In the same year the Forest Experiment Station in Rotorua became the Forest Research Institute (FRI). One example of early phenological research undertaken by FRI is the study of the seed abundance and crop periodicity of Rimu (*Dacrydium cupressinum*), Kahikatea (*Dacrycarpus dacrydioides*), Matai (*Prumnopitys taxifolia*), Miro (*P. ferruginea*) and Totara (*Podocarpus totara*) between 1958 and 1970 (Beveridge 1964, 1973).

The Department of Conservation (DOC) was launched in 1987, encompassing the New Zealand Forest Service as well as other previous land management agencies, Department of Land and Survey and Wildlife Service. DOC, often in association with volunteers, monitors many aspects of native and introduced species in New Zealand, including phenology (e.g. Mander et al. 1998). Monks (2007)

Fig. 3.1 Overview of Australian forest agencies' phenological data collection (1925–1981)

used seed data collected by DOC (and its predecessors) as well as other researchers to predict seedfall in Beech species (*Nothofagus* spp.), snow tussock (*Chionchloa* spp.) and Rimu.

3.3 Data and Research by Other Organisations

As shown by the Royal Society of Tasmania records there was, and remains, an interest in determining what crops would be suited to particular areas. Annual crops may be considered to have "false" phenophases in that their timing is influenced by management (Menzel and Sparks 2006). However, historical agricultural (annual and perennial) and horticultural records have been shown to be useful in determining the response of crops to climate (Sparks et al. 2005) and are required in developing adaptation measures to climate change and variability (Craufurd and Wheeler 2009). Table 3.3 highlights that long-term phenological data related to horticulture are available in Australia (Darbyshire et al. 2013); though much of data still needs to be uncovered and analysed in relation to climate (though this work is currently underway, personal communication, R. Darbyshire, 2011).

Table 3.3 Examples of horticultural data (provided by R. Darbyshire, University of Melbourne)

Location	State	Variety	Phenology phase(s)	Years	Source
Lenswood	SA	Jonathan apple	Green tip	1963–ongoing	SARDI
Tatura	Vic	Granny Smith apple	Full bloom	1982–ongoing	Grower
Tatura	Vic	Josephine pear	Full bloom	1983–2007	Grower
Tatura	Vic	Packham's Triumph pear	Full bloom	1982–ongoing	Grower
Tatura	Vic	Williams' Bon Chretien pear	Full bloom	1982–ongoing	Grower
Tatura	Vic	Golden Queen peach	Full bloom	1945–ongoing	DPI
Yarra Valley	Vic	Golden Delicious apple	Full bloom	1977–2005	Grower
Yarra Valley	Vic	Red Delicious apple	Full bloom	1977–2001	Grower
Yarra Valley	Vic	Granny Smith apple	Full bloom	1976–2005	Grower
Batlow	NSW	Fuji apple	Full bloom & first pick	1992–ongoing	Grower
Batlow	NSW	Pink Lady apple	Full bloom & first pick	1995–ongoing	Grower
Batlow	NSW	Royal Gala apple	Full bloom & first pick	1991–ongoing	Grower
Donnybrook	WA	Gala apple	Full bloom & first pick	1996–ongoing	Grower
Donnybrook	WA	Golden Delicious apple	Full bloom & first pick	1996–ongoing	Grower
Donnybrook	WA	Pink Lady apple	Full bloom & first pick	1996–ongoing	Grower

In the 1890s New South Wales established agricultural research stations. "Farm cards" (covering the period 1927–1969) provide a synopsis of experiments on wheat and oat varieties (e.g. seeding rates, fertilizer applied) and list the dates of several phenostages (e.g. planting and harvesting commencement dates) along with rainfall and yield per plot (Keatley et al. 2009).

The South Australian Research and Development Institute (SARDI) focuses on primary industry research (e.g. from understanding the effects of fishing on wild fisheries to the development of new horticultural varieties). SARDI has been recording the phenological phase "greentip" in Jonathan apples since 1963 (Table 3.3). They are also investigating the impacts of climate on maturity dates of wine grapes (Sadras and Petrie 2011), as part of their climate applications and crop physiology program. SARDI also monitors Australian Sea Lions *Neophoca cinerea* in South Australia, including breeding season timing from 2002 at eight colonies (Goldsworthy et al. 2009) and for Seal Bay, Kangaroo Island, from 1985. In conjunction with the South Australian Museum, SARDI also monitors New Zealand fur seals *Arctocephalus forsteri* on Kangaroo Island (since 1989; personal communication, Simon Goldsworthy, 2011).

In Victoria, the Dept. of Primary Industries (DPI) is responsible for agriculture, fisheries, earth resources, energy and forestry. Full bloom of Golden Queen peach has been recorded since 1945 at its Tatura research centre (Table 3.3).

3.3.1 Waite Arboretum

Recording of eucalypt flowering began at the Waite Arboretum (formerly the Waite Agricultural Research Institute) around 1951 (Boomsma 1972). The arboretum contains 998 individual trees made up of 432 species. The trees were planted between 1911 and 2011 and approximately 42 % of the trees have had their flowering observed. Observations of the timing and intensity of flowering were undertaken weekly between approximately 1958 and 1993. These data contributed to determining the flowering period of 37 of the eucalypts in the early 1970s (Boomsma 1972).

In addition to the eucalypt flowering records the arboretum also has an extensive collection of ornamental pears (approximately 90 specimens) on which they record various phenological phases including leafing, leaf drop, leaf colour, budding, the beginning, full and ending of flowering.

3.3.2 Pollen Studies

Short-term aerobiological studies were undertaken in Australia initially to determine which species are present and likely to cause allergic respiratory symptoms such as hay fever (e.g. Sharwood 1935; Stevenson et al. 2007). A long running (since 1984) data set of pollen grains counts is held by the University of Melbourne www.botany.unimelb.edu.au/botany/pollencount/counts_pollen.html.

The daily count of pollen grains usually commences at the beginning of September and finishes at the end of December (austral spring through to early summer). These data have been used to predict hourly grass pollen counts in Melbourne and to determine the influence of climate on grass pollen (de Morton et al. 2011).

3.3.3 New Zealand

New Zealand has a long history of agricultural crop research (since 1928) with research stations established across the country (e.g., Havelock North, Te Puke, Clyde, Motueka).

Apple breeding research commenced at Havelock North in 1969 (White 1988) with leafing and flowering dates being two of the commonly assessed traits (Kumar et al. 2010). Peach breeding research began in 1976 (Malone 1994). Using 20 years of flowering data from the Havelock North research centre for calibration, Atkins and Morgan (1990) modelled the impacts of climate change on pip and stone fruit. Flowering dates of Delicious apples from Havelock North (1987–1997) and Nelson (1969–1987) were used to examine the changes in bloom and maturity dates as well as apple size under three different greenhouse gas emission scenarios (Austin and Hall 2001). Unfortunately, the flowering data are not included in these papers.

3.4 Community-Based Phenological Networks

The need for volunteers to be involved in phenological monitoring has gone hand-in-hand with the call for the establishment of phenological networks (e.g. Prince 1891; Kanangra 1949; Keatley and Fletcher 2003) and some of the major community-based groups collecting phenological data are listed below.

3.4.1 ClimateWatch

In the first edition of this chapter the authors (Keatley and Fletcher 2003) highlighted the need for a national Australian phenological network. They recognized that in order to be successful in a country the size of Australia a website would be required as a focus for data collection. ClimateWatch (http://www.climatewatch.org.au), launched in 2009, is now meeting this need. By December 2011 ClimateWatch had around 11,300 observations from over 2,800 registered participants at over 1,200 locations. Participants can record phenological information on over 100 species of plants, birds, mammals, insects, etc.

A recent addition to the ClimateWatch project is the development of ClimateWatch trails. The use of trails, where observers record phenological observations along an established route, can be an effective means to introducing people to ClimateWatch and encourages repeat visits to sites (increasing data reliability and usefulness).

3.4.2 Timelines

The main philosophy behind Timelines is that European seasons are inappropriate for Australia (Reid and Beckett 1995). Timelines aims to develop appropriate Australian seasonal calendars similar to the aboriginal calendars of Northern Australia (Jameson 2001).

Participants are encouraged to record anything of interest to them as long as the reason for recording the data is also listed. Hence, people may concentrate on birds, insects, flowers or any one particular species of these. They are also asked to record the month, species, activity (e.g. preening), number and location.

A national Timelines program was launched in 1997, although individual programs operated at a local level from 1994 (Jameson 2001). Timelines is coordinated by Alan Reid (personal communication, Alan Reid, 2012), with earlier sponsorship by The Gould League of Victoria, an environmental education organization, who published a recording diary called "Banksias and Bilbies" (Reid and Beckett 1995) and a CD called "Timelines" (Gould League of Victoria 1998).

The project has developed 64 bioregions for Australia (http://www.timelines.org.au/australias-bioregions) which in time will be populated with the characteristics of each of their seasons.

3.4.3 Birdlife Australia

Birds Australia (BA; http://www.birdlife.org.au/) and Bird Observation and Conservation Australia (BOCA) merged in 2012 to become Birdlife Australia. BA brings to Birdlife Australia about 8,000 members, 25,000 supporters and two observatories. The organisation's journal, The Emu, is one of Australia's oldest scientific journals and the source of many historical phenological observations. BOCA has 61 branches, affiliates and Special Interest Groups around Australia with activities including education and bird surveys, including the long-running Melbourne City Bird Watch (1959–1996).

Key activities of Birdlife Australia, of relevance to phenology, include bird atlasing, Birds in Backyards and the Nest Record Scheme. Birds Australia had two main atlas periods, 1977–1981 and 1998 onwards. Although the main aim of the atlas project is to collect information on bird distributions, the information collected can also be used to investigate migration and breeding timing (though only in a limited sense, see Gibbs et al. 2011). Birds in Backyards (http://www.birdsinbackyards.net) started in 1998 and activities include online surveys (e.g. recording the arrival dates of the Common Koel and Channel-billed Cuckoo). The Nest Record Scheme is Australia's longest-running bird survey, with the database containing breeding information (including timing) for hundreds of species.

3.4.4 New Zealand Plant Phenology Websites

The New Zealand Plant Conservation Network hosts a Phenology Recording System (http://nzpcn.org.nz/page.asp?flora_phenology) where phenological observations on any vascular plant (native or exotic species) in New Zealand can be submitted. Officially launched in June 2010 (Crisp 2010), by February 2011 the network had more than 3,000 records (Anon 2011).

Landcare Research and Lincoln University have developed the New Zealand Biodiversity Recording System (http://www.nzbrn.org.nz/index.aspx). The system covers birds, plants, fungi, mammals, invertebrates, frogs and lizards. Observations are wide ranging from feeding resting, mating and egg laying in invertebrates, regeneration under exotic canopy for plants to records of road kill for animals. The Biodiversity Recording System therefore has a wider focus than the phenological recording system of the Plant Conservation Network. As of February 2012 there were more than 370,000 records covering the period 1882–2012 contributed by over 7,800 individuals.

3.4.5 Ornithological Society of New Zealand

The Ornithological Society of New Zealand (OSNZ; http://osnz.org.nz) was founded in 1939. As at 2005, OSNZ had ~1,000 members. The Society's aims include encouraging the recording and archiving of observations and studies of birds, particularly for the New Zealand region. OSNZ also runs a number of projects which are of particular relevance to phenology:

The Moult Recording Scheme, started in 1981, collates information on the timing and pattern of moult in New Zealand birds, particularly wing and tail moult.

The OSNZ Nest Record Scheme began in 1950 and has over 26,000 cards for 144 species (as of January 2012). Information contained within this scheme was used to show that Welcome Swallows in New Zealand have advanced their breeding timing (Evans et al. 2003).

eBird New Zealand was launched in May 2008 and provides a real-time on-line checklist for bird observations. Information from this project can provide regional information on migration timing and so far has been used to map arrival timing in Shining Cuckoos throughout New Zealand.

3.5 Recent Phenological Research

The last two IPCC assessments (IPCC 2001, 2007) highlighted the lack of phenological studies in both Australia and New Zealand. However, a comprehensive survey of the literature reveals that many additional phenological studies have appeared in recent years (Tables 3.4 and 3.5, Fig. 3.2) and that further long-term phenological data are available for analysis (Sect. 3.3). Most of the studies to date assessing temporal trends in phenology have come from Australia (722 of 732 data sets analysed).

Overall, most species studied in Australia and New Zealand have not shown any tendency to shift their phenology in response to climate change, with ~70 % having no significant trend towards either earlier or later life-cycle events (Fig. 3.2). Where a shift was observed, it was generally towards earlier events over time, around 20–25 % of data series, though some later events have been observed. Birds were the most commonly studied group (318 data series), followed by plants (252), invertebrates (160) and reptiles (2). The average rate of change for species with significant advances in life-cycles was 1.55 d/y earlier (range 0.09–6.94), while the later events averaged 2.12 d/y later (range 0.19–13.09) (Fig. 3.3).

3.5.1 Australia

A summary of recent long-term phenological studies undertaken in Australia is given in Table 3.4 and is discussed below.

3.5.1.1 Plants

Two studies (Gallagher et al. 2009; Green 2010) have examined flowering focus on the alpine region of New South Wales. Of the 20 species Gallagher et al. (2009) examined, only Alpine groundsel (*Senecio pectinatus*), showed a significant advance in its first flowering date (0.69 days per year (d/y)). Green (2010) found that the first flowering of Marsh marigold (*Psychrophila introloba*) and Mueller's snow gentian (*Chionogentias muelleriana*) was significantly correlated with the date of snow melt. Over the observation period (1954–2008), snow melt has advanced significantly, by 0.3 d/y.

Along the Victorian coastline the first flowering of four species: Marsh saltbush (*Atriplex paludosa*), Mistletoe (*Dendrophthoe vittellina*), Leafy peppercress (*Lepidium foliosum*) and Oval-leaf logania (*Logania ovata*) advanced by an average of 0.86 d/y (Rumpff et al. 2010). In South Australia peak flowering of the wall-flower orchid (*Diuris orientis*) shifted by 0.17 days earlier per year between 1897 and 2005 (MacGillivray et al. 2010).

Table 3.4 Recent long-term (>10 years) phenological studies undertaken in Australia

Region	Phenological change	Years of study	
South-eastern Australia	Arrival of cherries into Adelaide and Sydney metropolitan markets became significantly earlier	Longest individual series Sydney: 1836–2009	Keatley (2010)
	Generally earlier events over time; no evidence of later phenology, based on date of designated maturity & harvest date	Longest individual series 1895–2009	Webb et al. (2011)
	2 of 6 bird species shifted migration phenology. Rainfall and/or temperature influenced phenology of 4 species	Longest individual series 1958–2004	Chambers and Keatley (2010a)
	Earlier avian arrival & later departure, differences between short and long distance migrants. Earlier arrival linked to increasing minimum temperature	1960–2004	Beaumont et al. (2006)
	Earlier arrival (7 of 15 species) & later departure (2 of 13 species) of migrants at Blaxland, near Sydney	1981–2010	Smith and Smith (2012)
South-eastern Australia, Alpine	5 of 20 species earlier flowering when warmer; 1 species earlier flowering over time	1950–2007	Gallagher et al. (2009)
	Earlier flowering linked to earlier snow melt. Arrival of Richard's Pipit earlier when snowmelt earlier, Flame Robin migration timing linked to low-altitude temperatures	1979–2008	Green (2010)
Victoria	Flowering dates of 65 native species, over 24 years; 8 species flowered significantly earlier, 5 later	1983–2006	Keatley and Hudson (2007)
	8 of 101 species showed trend towards earlier flowering over time	Longest individual series 1854–2007	Rumpff et al. (2010)
	Daily pollen count significantly influence by spring precipitation over 16 seasons in Melbourne	1991–2008	de Morton et al. (2011)
	Earlier breeding in Helmeted Honeyeater related to reduction in rainfall and mild warming	1989–2006	Chambers et al. (2008b)
	Little Penguin: warmer oceans leads to earlier laying & more successful breeding seasons	1968–2009	Cullen et al. (2009)
	Shifts in arrival (3 of 12 species), departure (4 of 11 species) & timing of peak abundance (2 of 13 species). 68 % of all seasonal movement associated with climate drivers	1976–1997	Chambers (2010)
	Earlier emergence of the Common Brown Butterfly	1941–2005	Kearney et al. (2010)

(continued)

Table 3.4 (continued)

Region	Phenological change	Years of study	
South Australia	Earlier peak flowering in 2 Australian orchids.	1893–2005	MacGillivray et al. (2010)
	Pairing dates in Sleepy Lizards earlier when winters warmer & drier	1983–1997	Bull and Burzacott (2002)
	Earlier maturity (3 grape varieties; 18 locations). Advance in maturity associated with higher temperatures in Chardonnay and Cabernet Sauvignon	Longest individual series 1993–2006	Petrie and Sadras (2008)
	Earlier maturity (3 grape varieties; 3 climate regions) associated with higher temperatures	1995–2009	Sadras and Petrie (2011)
Western Australia	Avian migration timing shifts in south-west Australia; stronger relationship to rainfall than temperature	1973–2000	Chambers (2008)
	Arrival & departure dates of birds in semi-arid region; overall trend for earlier arrival &departure; generally earlier arrivals with increasing maximum and minimum temperatures	1984–2003	Chambers (2005)
	Stronger Leeuwin Current & warmer ocean temperatures extend the egg laying period in Little Penguins on Penguin Island	1986–2009	Cannell et al. (2012)
	Later breeding of 3 tern species at Pelsaert Island	1991–2007	Surman and Nicholson (2009)
Continental Australia	6 of 68 butterfly species delayed first flight dates, while 6 advanced their date	1950–2010	McClellan (2011)
	Shifts in breeding timing in Masked Lapwings varied by region (later in south-east; earlier in north-east) – rainfall effect in some regions	1957–2002	Chambers et al. (2008a)
	Shifts in breeding timing in 16 species of Australian birds – climate variables: latitude, altitude, South Oscillation Index	1963–1999	Gibbs et al. (2011)
	Shifts in breeding timing in Australian magpie influenced by latitude, altitude, South Oscillation Index	1967–2001	Gibbs (2007)

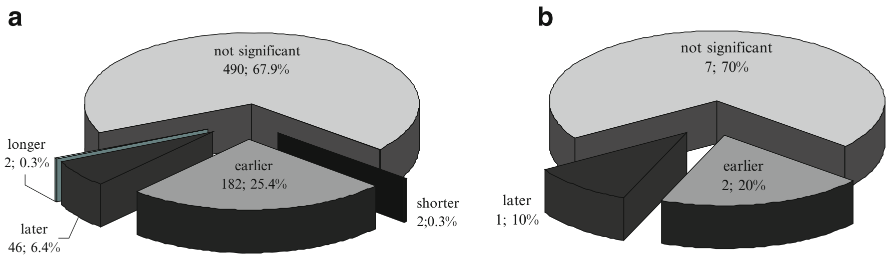

Fig. 3.2 Summary of observed direction of trend for long-term phenological studies (>10 years) in Australia (**a**) and New Zealand (**b**); confined to studies including data post 1970. Total number of data series is 732. Also shown are the number and percentage of data series in each category. Note that the New Zealand trend results are only for avian studies

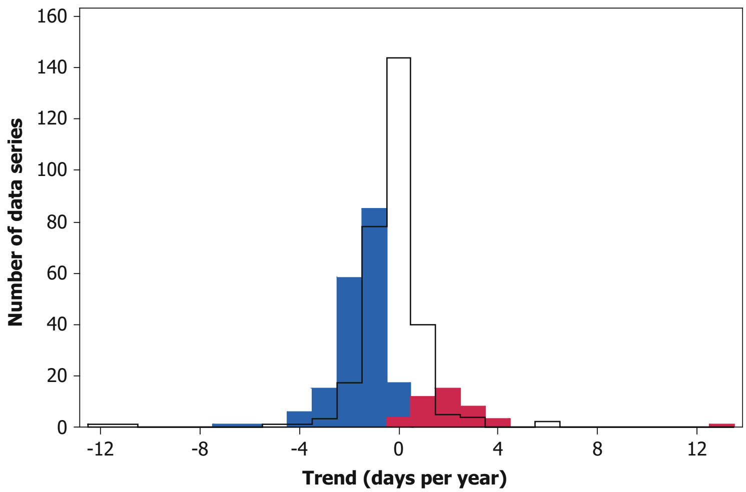

Fig. 3.3 Magnitude of trends observed for long-term phenological studies. Trends significant at the 5 % level are colored

Examination of the first flowering dates of 65 species at a single location in Victoria found that the first flowering dates in 13 species had changed significantly: eight species flowered on average 1.7 d/y earlier and 5 species 1.8 d/y later (Keatley and Hudson 2007).

Three studies (Petrie and Sadras 2008; Sadras and Petrie 2011; Webb et al. 2011) have examined the changes in wine grape (*Vitis vinifera*) phenology. Each study found an overall shift toward earlier maturity.

Of the phenological studies presented in this chapter, plants have the highest percentage of data series with significant trends over time. Most were towards earlier events (113 of 252 data series), particularly for harvest and maturity dates (Fig. 3.4), though some plants were observed to flower later (Keatley and Hudson 2007; Gallagher et al. 2009). The average rate of change for plants with significantly

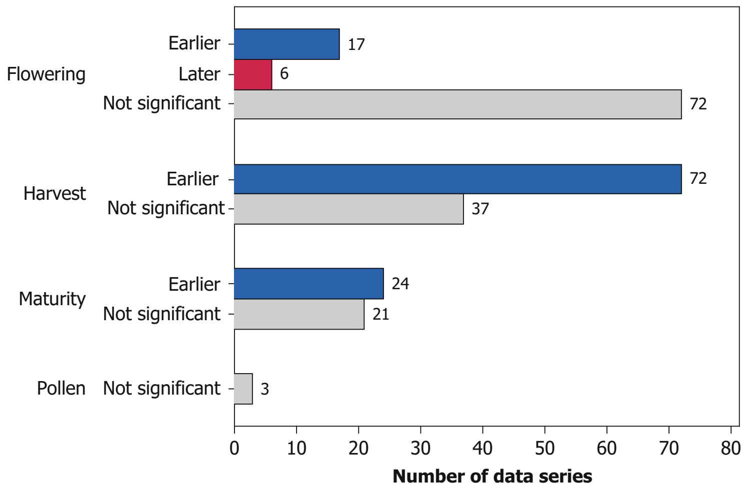

Fig. 3.4 Summary of observed direction of trend for long-term phenological studies in Australia plants. There were no records for New Zealand plants

earlier events over time was 1.6 d/y, while later events averaged 1.9 d/y. Although based on a small number of studies, the percentage of species with significantly changed phenology (45 %) is greater than that determined via meta-analysis for European plant phenology (30 %) (Menzel et al. 2006). However, the percentage of species with significantly delayed phenology is similar (2 % this study; 3 % Menzel et al. 2006).

3.5.1.2 Birds

The majority of the bird data series (218 of 318 data series) did not show any significant trend over time. When a trend was observed, it was more often towards earlier (63 data series) than later events (33 data series). This was particularly true for migration (Fig. 3.5). The average rate of change for birds was similar to that observed for plants, with significantly earlier events occurring around 1.6 d/y earlier (range 0.1 – 6.9), and while later events averaged 2.5 d/y later (range 0.2–13.1).

Three studies assessed shifts in the timing of breeding for terrestrial Australian birds over wide-spatial scales (Gibbs 2007; Chambers et al. 2008a; Gibbs et al. 2011). Importantly, these studies highlighted both regional and species differences in response to climate variability and change. For example, the timing of breeding in most Australian bird species, as is the case in many other countries, varies with both altitude and latitude, with later breeding occurring at higher elevations and at more southerly latitudes (Gibbs et al. 2011) (i.e. in generally cooler locations). Trends towards earlier breeding over time were only consistently observed in south-eastern Australia, with most other regions showing either few significant trends over time or mixes of both earlier and later breeding, depending on the species. For

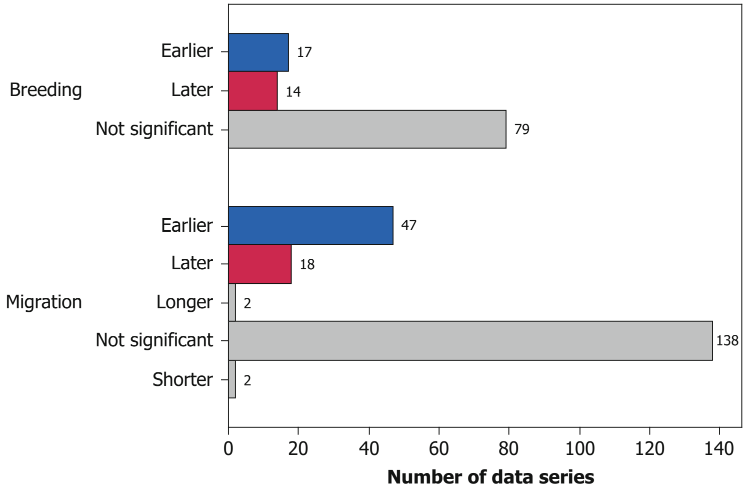

Fig. 3.5 Summary of observed direction of trend for long-term phenological studies in Australia and New Zealand for birds

individual species, differences in the sign and magnitude of trends in timing were observed, according to where in Australia breeding took place; a result also found by Chambers et al. (2008a), Gibbs (2007), and in general (Fig. 3.5).

For marine species, breeding timing has been linked to oceanographic conditions. Warmer ocean temperatures in south-eastern Australia have been linked to an earlier start to breeding in the Little Penguins *Eudyptula minor* of Phillip Island, Victoria (Cullen et al. 2009). In seasons where breeding commences earlier, more and heavier chicks are produced, resulting in a more successful breeding season. Similarly, in south-western Australia, warmer ocean temperatures and a stronger Leeuwin Current correspond to longer breeding seasons, again resulting in improved likelihood of a successful breeding season (Cannell et al. 2012). Further north, in the Houtman Abrolhos, the timing of breeding in tern species is becoming later while, for the long-distance migrant, the Wedge-tailed Shearwater *Ardenna pacifica*, breeding timing remains unchanged. The shearwater has a relatively long breeding season length (120 days) and this, together with its migratory strategy, is likely to constrain its ability to alter its breeding timing in response to changes in environmental conditions (Surman and Nicholson 2009).

A number of studies have investigated shifts in migration timing in Australian birds (Table 3.4), including in relation to climate variability and change. Although many of the species studied have no noticeable trend in their migration timing (Fig. 3.5), when changes were observed they were much more likely to be towards earlier events. Arrival dates, generally in spring, were more likely to occur earlier over time (32 of 105 earlier, compared to 7 later), while there was a fairly even split towards both earlier and later departure dates (13 and 11 of 74, respectively) and the date of peak abundance (1 of 19 for both earlier and later). Many studies (e.g. Chambers 2005, 2008, 2010; Chambers and Keatley 2010a; Green 2010) found significant associations between migration timing and climate variables, particularly temperature, the number of raindays or rainfall totals. Rainfall changes appeared to be particularly important for the timing of movement in waterbirds and those associated with littoral zones, as well as for regions where rainfall has declined (e.g. south-western Australia, Chambers 2008).

3.5.1.3 Mammals

Improved census methods have enhanced our knowledge of the timing of breeding in marine mammals. In South Australia, Goldsworthy et al. (2009) found that both environmental and physiological factors affect the timing and duration of the Australian Sea Lion reproductive cycle. For this species a seasonal drift in timing of pupping was observed (over the period 2002–2006); thought to be due to a breeding cycle of slightly less than 18 months. This species does not have synchronous breeding between colonies, which may indicate the ability of the species to adjust its breeding timing in response to local prey availability.

Environmental variability also plays an important role in the timing and success of breeding in Australian fur seals *Arctocephalus pusillus doriferus*. Over the period 2003–2007, at Kanowna Island in Bass Strait, median birth dates varied from 21 to 25 November (Gibbens and Arnould 2009). Earlier pupping dates corresponded to more pups being produced.

We were unable to locate any long-term phenological studies of Australian terrestrial mammals.

3.5.1.4 Other Vertebrates

The only known long-term phenological study of an Australian reptile, the Sleepy Lizard, is that of Bull and Burzacott (2002). Over a 15-year period, near Mt Mary in the mid-north of South Australia, reproductive timing, or pairing timing, became earlier. The start date of pairing was earlier in years when temperatures during the austral winter were warmer. There was no observed trend in the date when pairing ended, though pairing tended to end earlier in years with warmer spring temperatures. Years with higher spring rainfall corresponded to an increased likelihood of lizard pairings being observed.

3.5.1.5 Invertebrates

The results from McClellan's (2011) butterfly study dominated the observed trends seen in Australian invertebrate studies. There was a fairly even split between studies showing earlier events over time ($n = 7$; mean 7.3 d/y) and those that were later ($n = 8$; mean 1.0 d/y). However, for most species and regions no trend in the timing of migration or emergence was observed ($n = 145$).

One of the first long-term Australian phenological-climate change studies of an invertebrate was that of Kearney et al. (2010), who studied changes in emergence dates of the Common brown butterfly *Heteronympha merope* in relation to climate. Based on 65 years of data, emergence dates have advance by 1.6 days per decade (d/d), which were consistent with a modelled rate of advance of 1.3 d/d, adding strength to the argument that the earlier emergence is driven by the effects of warmer air temperatures on the butterflies' development rate.

Using data from 68 butterfly species from around Australia, McClellan (2011) found that, over the period 1950–2010, 12 of species had significant temporal trends in the date of first record. Six species were seen on average 0.8 d/y earlier, while 6 delayed their first flight date by 1.0 d/y. Trends towards earlier flight were more common in inland regions of south-eastern Australia and in south-western Australia, while species in the coastal regions of south-eastern Australia and those commencing flight later in the season were more likely to have delayed first flight dates over time.

Over a 30 year period in the Snowy Mountains, Green (2010) investigated the phenology of alpine species, including three invertebrates. In this region snow melt has advanced by 2.8 d/d, but was unrelated to the arrival or first emergence dates of the Bogong moth *Agrotis infusa*, Macleay's swallowtail *Graphium macleayanum* or march flies *Scaptia* spp., which showed varied responses over time. The Bogong moth arrived later over time and there was no change in march fly emergence dates. Green's (2010) study is important as it highlights that potential mismatches may be occurring in the Australia alpine region. In short, he found that the flowering season has advanced but that this was coupled with no change in pollinator timing (a key pollinator in this region being march flies). This is likely to affect plant reproductive success. In addition, the later arrival of Bogong moths may impact on many species dependent on them as a food source (e.g. Richard's Pipit *Anthus novaeseelandiae*, Flame robin *Petroica phoenicea*, Mountain pygmy possum and Dusky antechinus). Mismatches in timing are more likely if these dependent species change their phenology in response to changes in snow melt or temperature, as has been seen for the Flame robin and Richard's Pipit (Green 2010).

3.5.2 New Zealand

A summary of recent long-term phenological studies undertaken in New Zealand is shown in Table 3.5. Compared to Australia, few long-term phenological datasets have been compiled and analysed for change in this region.

3.5.2.1 Plants

A number of studies have examined the mast flowering and seeding in Snow tussocks (*Chionochloa* spp.), Beech (*Nothofagus* spp.) and other species (e.g.

Table 3.5 Recent long-term (>10 years) phenological studies undertaken in New Zealand

Region	Phenological change	Years of study	References
New Zealand	Earlier breeding in Welcome Swallow	1962–1996	Evans et al. (2003)
Lower Hutt	Later breeding in Common Starling; non-linear relationship with El Niño – Southern Oscillation	1970–2003	Tryjanonwski et al. (2006)
Kaikoura Peninsula	Laying date in Red-billed Gulls linked to food availability and population size	1983–2003	Mills et al. (2008)
New Zealand	Some indication New Zealand Dotterels nest earlier in years of warmer winter or early spring	1937–2000	Pye and Dowding (2002)
Invercargill	Date of first (14 years) and last egg (9 years) of Caspian Tern. There was no significant trend over time in either egg date[a]	1964–1993	Barlow and Dowding (2002)
Flea Bay, Banks Peninsula	Later relative laying date, increased hatching and breeding success in White-flippered Penguin. No significant temporal trend in laying date[b]	1996–2009	Allen et al. (2011)
Near Harihari, South Island	No significant correlation between seed-fall in Rimu and rainfall. Seedfall negatively correlated with temperature in summer and autumn two seasons prior to seedfall and positively with summer and autumn temperature of seedfall season. No assessment of trends over time	1954–1986	Norton and Kelly (1988)
Canterbury	Mountain Beech: Prolific flowering appears to follow warm temperatures at the time of floral primordia formation. Lack of seed after prolific flowering attributed to extreme frosts or wet conditions	1965–1988	Allen and Platt (1999)
Mt Hutt, Canterbury	Flowering in snow tussocks highly variable with heavier flowering following warm Januarys the year before flowering	1986–2008	Kelly et al. (2008)
Canterbury	Mountain Beech: 7 Year periodicity in total and viable seed counts at each elevation	1965–2007	Allen et al. (2012)
Takahe Valley, Fiordland	16 datasets from 11 species of snow tussock. Within and, to a lesser extent, between sites highly synchronous flowering. Heavier flowering following warm summers	1973–1998	Kelly et al. (2000)
New Zealand	25 datasets of 4 species Beech; 23 datasets from 10 species of Snow tussock; Rimu 4 datasets. Some of the datasets listed (e.g. Rimu 1954–1986 were used in other studies (Norton and Kelly 1988))	Longest individual series Beech: 1965–2002 Snow tussock: 1973–2003 Rimu: 1954–1986	Monks (2007)

[a] Calculated from values provided in Table 2 of Barlow and Dowding (2002)

[b] Calculated from raw data provided by WJ Allen

Norton and Kelly 1988; Monks 2007; Kelly et al. 2008; Allen et al. 2012). Some of these studies have also investigated the influence of climate on the mast flowering and seeding processes, along with the synchrony within and between species and the periodicity of flowering and seeding. Such studies form the basis of predictions of seedfall for the management of feral animals (e.g. Mice *Mus musculus* and stoats *Mustela erminea*) and endangered fauna (e.g. Kakapo *Strigops habroptila* and Kaka *Nestor meridionalis*) However, the methods in which the data have been collected, whilst appropriate for the particular study, preclude detection of trends over time. For example, Kelly et al. (1992) counted inflorescences per tussock in late January or early February for *Chionochloa* spp.

3.5.2.2 Birds

Only a small number of recent studies have assessed trends over time in breeding dates of New Zealand birds (Table 3.5). As was the case in Australia, a similar number of studies found either earlier or later breeding over time. Not all long-term phenological studies considered trends over time, with many instead concerned with identifying drivers of variability, both between years and between individuals. For example, the timing of laying in Red-billed Gulls is influenced by both environmental variability as well as the size of the population (Mills et al. 2008). However, Mills et al. (2008) found that these relationships are not always static. When the population was at its maximum, as prey increased in availability, laying dates became earlier and productivity increased, whereas later, when the population began to decline, even when prey availability increased, laying dates became later.

Laying date has also been shown to vary with the age of the individual (Mills 1973; Low et al. 2007). Generally, older females tend to lay earlier, possibly due to enhanced foraging skills allowing them to reach breeding condition earlier. For example, female Red-billed Gulls who retained mates from previous seasons also bred earlier, suggesting that establishing a new pair-bond may decrease the amount of time available for foraging prior to laying (Mills 1973). However, the relationship is not always linear, with a delay in breeding timing also evident after birds reach peak breeding age (Low et al. 2007) or after 3 years of age in the case of the Yellow-eyed Penguin (Richdale 1957).

Timing of laying has been described as a key variable influencing breeding success (e.g. Low et al. 2007), with earlier laying in many species providing an opportunity for multiple clutches in a season, thus increasing reproductive output.

Two studies examined the timing of breeding in the introduced Common Starling *Sturnus vulgaris* (Bull and Flux 2006; Tryjanonwski et al. 2006). Although laying in starlings, and many other birds, is generally delayed at higher latitudes, Bull and Flux (2006) found this was not the case in their study, with more birds at more southerly locations commencing breeding earlier and producing more young. Using a longer dataset from a single location, Tryjanowski et al. (2006) found a delay in laying date over time and observed that laying was earlier in both El Niño and La Niña years. The timing of egg-laying also varied spatially in the Welcome

Swallow *Hirundo tahitica*, with birds in eastern regions laying earlier than those in the west and there was a non-linear relationship between breeding timing and altitude (Evans et al. 2003). Over time egg-laying has become earlier in this species.

3.6 Conclusions

Although our current knowledge of the drivers of phenological change in Australia and New Zealand is limited (temporally, spatially and by taxa), significant advances have been made in recent years in understanding these drivers of change. Further advances in knowledge are expected as phenological data becomes more readily available, through the collation of historical information, continued monitoring programs and improved observation networks. Advances in knowledge are also expected through the further joint exploration of Traditional Ecological Knowledge. The increasing involvement of community-based science in phenology has benefits not only for expanding the network of data collection, but also for increasing community awareness and thus support for the importance of phenological studies.

Acknowledgments We thank Rebecca Darbyshire, University of Melbourne for supplying the details of the apple, pear and peach data, Jennifer Gardner, Waite Arboretum, University of Adelaide for information on the flowering of eucalypts and ornamental plums at the Waite Arboretum, Fran MacGillivray, University of Adelaide for additional information on the ornamental plums, Peter Smith and Judy Smith of P. & J. Smith Ecological Consultants, for providing a copy of their paper prior to publication, Owen Bassett, Forest Solutions for an early copy of his report. We would also like to thank Amy Winnard, Bureau of Meteorology for assistance with sourcing many of the papers on New Zealand phenology as well as the Australian National Meteorological Library for their assistance in sourcing historical information. We would also like to thank Tim Fletcher, University of Melbourne, and Lesley Hughes, Macquarie University, and to the anonymous reviewer for providing helpful comments on the manuscript.

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