Review

The Biology of Australian Weeds
27. *Parthenium hysterophorus* L.

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Name

Parthenium is derived from the Latin word *parthenice*—a reference to the plant now known as *Tanacetum parthenium* (L.) Bernh. or 'feverfew'; *hysterophorus* was derived from the Greek *hystera* (womb) and *phoros* (bearing), referring to the prolific seeding habit of the plant (Parsons and Cuthbertson 1992). *Parthenium hysterophorus* L. (parthenium weed) is a member of the tribe Heliantheae of the Asteraceae, an extremely diverse family with a cosmopolitan distribution. The genus *Parthenium* contains 15 species which are native to North and South America. *Parthenium hysterophorus* has become naturalized in Australia and is the only member of the genus naturalized in this country.

Parthenium hysterophorus is commonly known as parthenium weed in Australia, but there are a host of alternative common names in use overseas. Some of the more commonly used names include bitter weed, carrot weed, broom-bush and congress weed (India); whitetop, escobar amarga and feverfew (Caribbean); false ragweed and ragweed parthenium (USA).

Description

The following description of parthenium weed is derived from Jayachandra (1971), Haseler (1976), Gupta and Sharma (1977), Williams and Groves (1980), Auld *et al.* (1983), and Genn (1987). Parthenium weed is an erect and much branched annual, or ephemeral, herb and is known for its vigorous growth. It can grow up to 2 m high though most individuals do not exceed 1.5 m. The chromosome number of parthenium weed is $2n=18$.

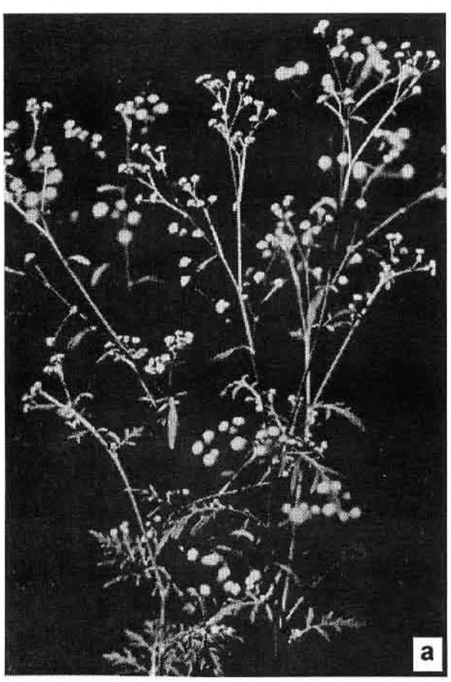
The cotyledons of the seedling are hairless and possess only a short petiole. The young plant forms a basal rosette of leaves that are up to 20 cm in length and 4–8 cm broad. These leaves are pubescent and strongly dissected into narrow pointed lobes. Upon stem elongation, upper leaves (which are smaller, narrower and less dissected than the basal leaves) are produced alternately on the stem. The stem is pubescent, rigid, and longitudinally grooved. Both the leaves and stem of parthenium weed are covered with short, soft trichomes (Figure 1).

The flower heads of parthenium weed are composed of many florets formed into small white capitula that are 3–5 mm in diameter. Each head consists of five fertile ray florets and about 40 male disc florets, hence only ray achenes are produced. The first capitulum forms in the terminal leaf axil, while subsequent capitula form progressively down the stem on lateral branches emanating from the axils of the lower leaves. Thousands of flower heads, forming in branched clusters at the top of the plant, may be produced by one plant during flowering.

The diaspore is a cypsela with two sterile florets adhering as 'wings', and is usually referred to as an achene. These appendages act as air sacs, making the diaspore more air-mobile as well as increasing its ability to float on water, therefore aiding the dispersal of the seed. The cypsela is obovate in shape, flattened and crowned by a pappus of orbicular scales. Cypselas vary between 2–3 mm in length and are about 2 mm wide. The seed is black, flattened, spatulate in shape, about 2 mm long and weighs about 40–50 µg.

Distinguishing characters

Parthenium weed may be confused with several ragweed species (*Ambrosia artemisiifolia* L., *A. psilostachya* DC., *A. confertiflora* DC., and *A. tenuifolia*



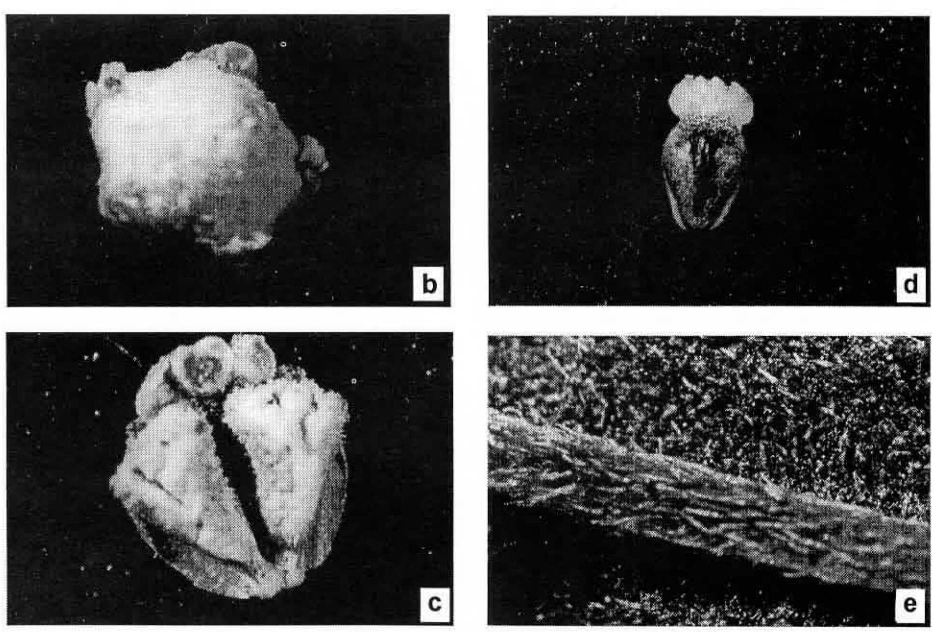


Figure 1. *Parthenium hysterophorus* (a) mature plant, (b) flower head, (c) diaspore, (d) seed, (e) underside of leaf showing trichomes.

Sprengel), especially when in the vegetative stage of growth. However, it can be easily distinguished from these species as they have opposite leaves in the early stages of growth, and lack the distinct longitudinally grooved stem which parthenium weed possesses. These species may be even more clearly distinguished from parthenium weed during the flowering stage. The small white flower heads of parthenium weed are borne in much-branched terminal panicles and are quite distinct from the spike-like racemes of *Ambrosia* spp. which possess flower heads that are monoecious, inconspicuous and predominantly green in colour.

Intraspecific variation

In North and South America there seem to be two distinct races of parthenium weed, which have been termed the 'South American' and 'North American' races by Dale (1981). The 'North American' race has been introduced into Australia and many other parts of the world. The 'South American' race shows a greater degree of variation between populations and differs from the 'North American' race as it has larger flower-heads and disc florets, yellow petals and pollen, and less development of axillary branches (Dale 1981). Hymenin is the dominant sesquiterpene lactone found in plants of the 'South American' race, whereas parthenin is dominant in the 'North American' race. These differences in the chemistry and morphology of populations of parthenium weed in North and South America indicate the possibility of the existence of several forms, subspecies, or perhaps even different species (Picman and Towers 1982).

There are also reports of two distinct biotypes within the 'North American' race growing in different regions in Mexico (Parker 1989). The first of these biotypes produces a rosette of leaves and the stem does not elongate until flowering, while the second biotype has no rosette stage and its leaves are more hirsute. All Australian populations exhibit the same characters as the first of these biotypes (Parker 1989, Parker *et al.* 1994).

In Australia, variation in the leaf morphology of parthenium weed has been observed in the field, but no significant variation in reproductive morphology or chemical composition has been detected (Picman and Towers 1982). Of the two separate introductions of parthenium weed into Australia, plants from the Clermont (Queensland) introduction seem to be much more aggressive than those from the Toogoolawah (Queensland) introduction. Detailed comparisons between plants from the two introductions have not yet been made so it is unclear whether this is due to some genetic difference or if it is the result of environmental differences between the two sites of introduction.

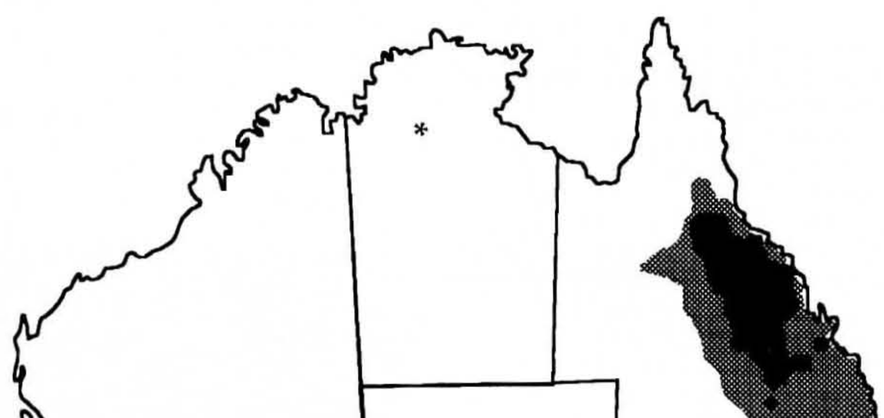


Figure 2. Distribution of *Parthenium hysterophorus* in Australia. (■) heavy infestations, (▒) scattered infestations, (*) localized infestations.

History

Parthenium weed was first reported in Australia near Toogoolawah in south-east Queensland in 1955, although this infestation did not spread appreciably (Auld *et al.* 1983). It has been suggested that this introduction was probably due to the movement of aircraft and machinery parts into Australia during World War II (Parsons and Cuthbertson 1992). A second accidental introduction occurred in central Queensland, north of Clermont, and originated from the importation of contaminated pasture seed from Texas (USA) in 1958 (Everist 1976). This infestation remained unnoticed until 1973, when mild winters and high rainfall for the next four years caused rapid spread through central Queensland (Haseler 1976, Butler 1984). Parthenium was recognised as a serious weed in Queensland in 1974 (Sullivan 1977), and by 1976 it was present in 14 shires and had invaded areas in many central Queensland towns (Anon. 1976a). During the 1970s parthenium weed spread at an exponential rate (Auld *et al.* 1983). It is now a major weed of grazing lands in central Queensland and is often dominant along roadsides (Williams and Groves 1980).

Distribution

Australia

Parthenium weed occurs in Queensland, New South Wales and the Northern Territory. All of the major infestations of parthenium weed are found in the sub-coastal regions of central Queensland, in areas with an average annual rainfall of 500–700 mm (Haseler 1976). Scattered infestations extend throughout the eastern half of central and southern Queensland and into the sub-coastal regions of New South Wales (Figure 2). Parthenium weed is prominent where substantial development of brigalow scrubs has occurred (Holman 1981). The areas of land primarily affected are beef producing pastures, but the weed is also spreading into cropping areas and the sugarcane growing areas nearer the coast (Anon. 1985a). The potential distribution of parthenium weed in Australia is much wider than at present according to Doley (1977) and Williams and Groves (1980). Doley (1977) stated that parthenium weed has the potential to become a weed of significance throughout the warm and temperate, humid and sub-humid regions of Australia based on its ability to grow over a wide range of temperature regimes.

Parthenium weed's distribution seems to be limited to areas that do not experience extremes of temperature (<5°C, >40°C) during the period when there is enough rainfall to permit growth (Doley 1977, Dale 1981). It has also been

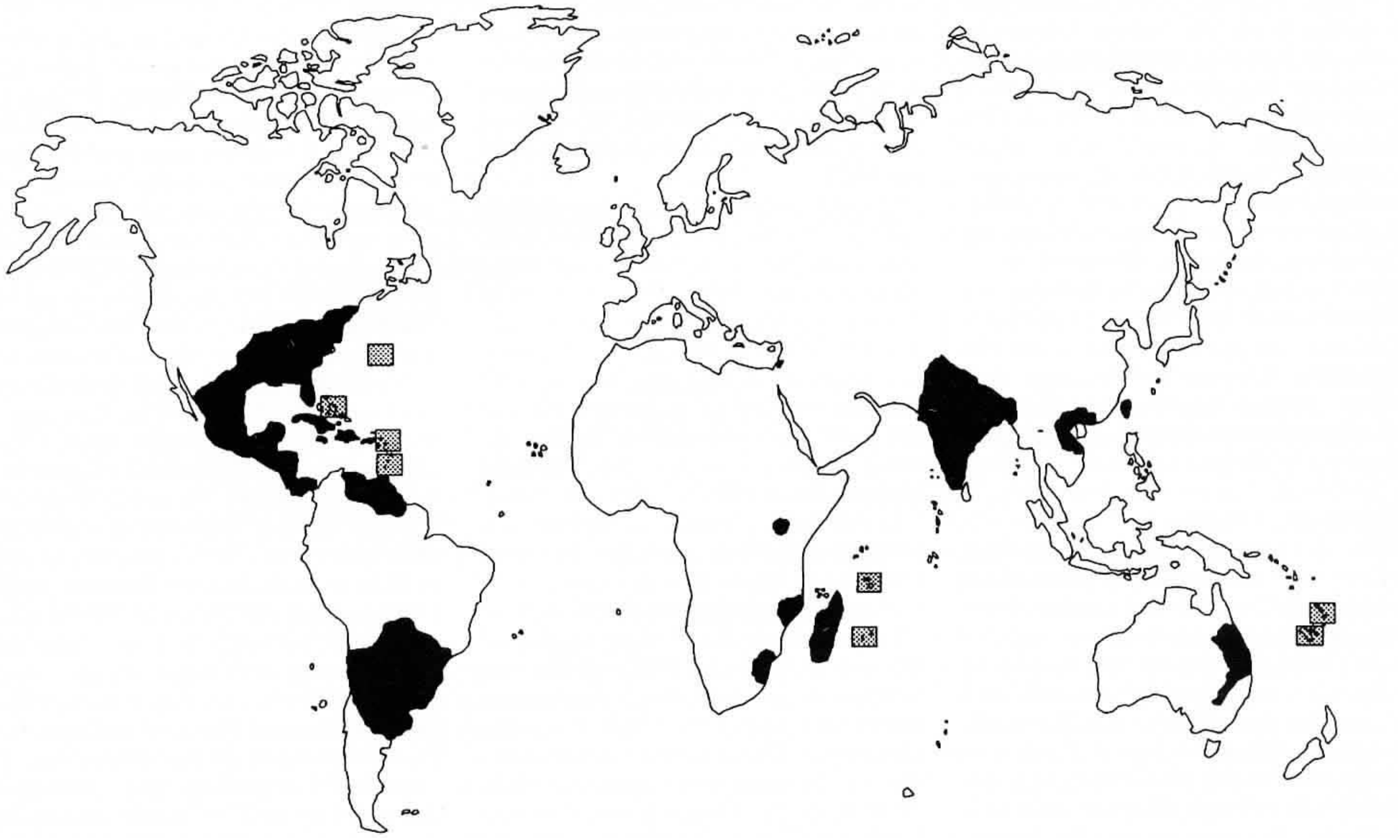


Figure 3. Global distribution of *Parthenium hysterophorus* (modified from Picman and Towers 1982). (■) mainland distribution of *Parthenium hysterophorus*, (▦) islands where *Parthenium hysterophorus* is present.

suggested that the distribution of this weed may also be limited by heavy shading (>80% shade) and so it should not be a problem in closed forest habitats in Australia (William and Groves 1980).

Outside Australia

Parthenium weed probably originated in the area surrounding the Gulf of Mexico or in central South America. In North America, South America and the Caribbean it is widespread and has probably spread from its original range as a result of recent anthropogenic disturbances. This spread is most apparent in the Caribbean where it has spread to all Commonwealth Caribbean countries (Hammerton 1981).

From North America parthenium weed has been introduced to the Republic of South Africa, Madagascar, Kenya, Mozambique, Mauritius, Rodriguez, the Seychelles, Israel, India, Bangladesh, Nepal, China, Vietnam, Taiwan, Australia, and many South Pacific Islands (Towers and Mitchell 1983, Joel and Liston 1986, Njoroge 1989) (Figure 3). It has had by far the greatest impact in India, where it is widespread (Pandey and Dubey 1991).

Habitat

Parthenium weed is especially prolific in disturbed situations and occurs in naturally disturbed areas, as well as those that receive constant traffic from vehicles or livestock (Haseler 1976, Holman 1981). It shows a marked preference for black, alkaline, cracking, clay soils of high fertility, but will grow on a wide variety of soils. On other soil types it usually requires a more severe soil disturbance to establish, and rarely forms the extensive stands often found on the heavy black soils (Dale 1981) (Figure 4).

Parthenium weed grows in a wide variety of habitats throughout the world including: vast areas of wastelands (Pandey and Dubey 1988), cleared land (Holman 1981), pastures (Dubey and Pandey 1988), all types of crops (Anon. 1976b), orchards (Pandey and Dubey 1991), forest nurseries (Jayachandra 1971), public lawns and open spaces in towns (Anon. 1976b), the sides of railway tracks (Jayachandra 1971), roadsides (Haseler 1976), new construction sites (Anon. 1976b), and along streams and rivers (Maheshwari and Pandey 1973, Holman 1981).

In Australia the weed predominantly inhabits pasture areas and has had little impact in cultivated areas in contrast to the situation in the Americas and India. Parthenium weed is vigorous in both established and developing pastures. However, it will not invade pastures when there is a high level of ground cover present (Williams and Groves 1980). The initial occurrence of parthenium weed in a new area is frequently along roadsides, and it is from this foothold that it spreads laterally and extensively into agricultural land (Haseler 1976).

Growth and development

Morphology

Parthenium weed, in its early stages of growth, exists as a rosette and so requires a suitably open area in which to establish. This rosette spreads radially very close to the ground and interferes with the emergence of other seedlings. The stem of the weed then elongates rapidly and starts branching at the apex. Mature plants are much-branched, and axillary branches also form down the stem as the plant gets older. This growth form coupled with the weed's high growth rate allows it to be very competitive and enables it to exclude the growth of other species. Parthenium weed also produces a long tap root which enables it to obtain water from deep within the soil profile. In addition, this tap root stores energy reserves for rapid regrowth if the plant is slashed or grazed.

Phenology

Parthenium weed is able to germinate, grow and flower over a wide range of temperatures and photoperiods, and can complete its life cycle at any time of the year in Queensland (Haseler 1976). The main season of growth, however, is during the summer months (November–March) when rain is usually more abundant. Four or more successive cohorts of seedlings may emerge at the same site during a good growing season (Everist 1977, Pandey and Dubey 1989). In the field, plants that emerge in the spring usually attain a greater size and have a longer life span than those that emerge in the summer. Plants that emerge after early spring rains can have a life span of 6–8 months if adequate soil moisture is maintained, whereas plants emerging during summer often live only about half as long. This occurrence may be a consequence of the soil drying more quickly during the hot summer months, thereby causing the reduction of available moisture during autumn. Soil moisture seems to be the major contributing factor to the duration of flowering as well.

Plant biomass production increases with increasing temperature up to an optimum day/night temperature regime of 33/22°C (Williams and Groves 1980) (Figure 5). Williams and Groves (1980) discovered that temperature was a factor controlling the length of the vegetative phase prior to flowering and that plants produced flowers earliest under a 27/22°C day/night temperature regime when compared to a 21/16°C and 33/28°C regime. They also observed that there was no specific day length requirement for flowering, but that it occurred slightly earlier under a 13 h photoperiod than under a 10 h or 16 h photoperiod.

Reproduction

Floral biology

Flowering can be initiated as early as four weeks after seedling emergence (Jayachandra 1971). In developmental studies conducted on North American plants, the time from the initial appearance of the first flower bud to the production of a mature inflorescence and dispersal of the first achenes was found to be about 30 days, while the time from pollination to achene maturation is only about 14 days (Lewis *et al.* 1988). The floral head consists of a conical receptacle surrounded by an outer involucre of five persistent bracts, five peripheral ligulate and fertile ray florets, and centrally numerous tubular disc florets which are staminate. Each disc floret possesses four connate anthers. Pollen grains are mostly spheroidal, 15–20 µm in size, and possess short to medium length spines often permeated with micropores (Lewis *et al.* 1991). An average of 150 000–350 000 pollen grains are produced in each flower head and, as thousands of flower heads can be present on each plant, pollen production by an average plant is extremely large; i.e. 15–850 million pollen (Kanchan and Jayachandra 1980b, Lewis *et al.* 1988, Gupta and Chanda 1991). In the USA and India, airborne pollen from parthenium weed has been detected in significant amounts at a variety of altitudes (2–915 m) and distances (up to several km) from populations of the weed (Lewis *et al.* 1991). However, Lewis *et al.* (1991) stated that the mechanism of wind pollination in parthenium weed is less developed than in many other wind pollinated species, and long distance dispersal of pollen is limited.

There are conflicting reports as to whether parthenium weed is self-compatible or self-incompatible. Lewis *et al.* (1988), looking at North American populations, detected self-compatibility in the species (95% of achenes produced in this way were viable). They observed that insect visits to parthenium weed were rare, and concluded that wind must be the major means of pollen dispersal and that self-fertilization must account for at least some seed production. However, Gupta and Chanda (1991) noted that parthenium weed appears to be entomophilous (insect pollinated) or at most amphiphilous (pollen dispersed mainly by insects and partially by wind), and that honey bees, ants, house flies and other dipterans frequently visited parthenium weed flowers. They concluded that parthenium weed is not normally a self-pollinated plant but observed that ants may occasionally induce self-pollination after visiting flowers from the same plant. Self-compatibility of parthenium weed has not been observed in plants grown in isolation in Australia (T. Armstrong personal communication.).

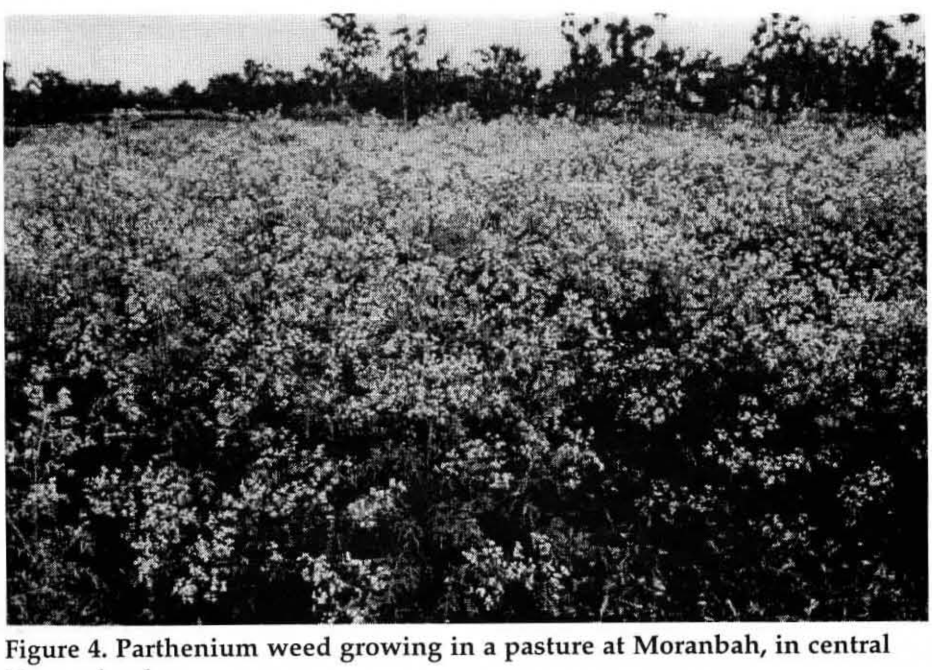


Figure 4. Parthenium weed growing in a pasture at Moranbah, in central Queensland.

Seed production and dispersal

Parthenium weed is a very prolific seed producer and will continue to flower and fruit profusely until senescence. The achenes are shed gradually or retained on the inflorescence until after senescence. Each flower head produces 4 or 5 achenes of uniform size, ranging from 0.2 to 0.4 mg.

Haseler (1976) stated that a typical mature plant produced over 15 000 achenes. Joshi (1991c) found that parthenium weed plants growing in a pure stand in India produced 5952 inflorescences per plant, which equates to about 25 000 achenes per plant. In India, Kanchan and Jayachandra (1980b) found that there were an average of 15 parthenium plants m^{-2} in a stand of the weed. Thus it could be assumed that in excess of 300 000 achenes m^{-2} could be produced under these circumstances. These figures for achene production would only be applicable when sufficient moisture was available to produce a dense stand of vigorous plants. In good seasons two stands of parthenium weed may be produced, so the numbers of seed produced in some conditions could be even greater. Joshi (1991a) estimated the parthenium weed seed bank in the soil to be about 200 000 m^{-2} in abandoned fields in India.

In India, parthenium weed produces polymorphic achenes that vary in size and weight (Pandey and Dubey 1988). Dubey and Pandey (1988) placed achenes into six different categories, based on size and weight, and suggested that the variation in achene morphology may be due to differences in the maturation of capitula borne at different positions on the parent plant. They also found that small achenes were more common at lower latitudes (i.e. in southern India) and larger achenes common at higher latitudes (i.e. in northern India). Therefore, it seems that the climatic conditions occurring at different latitudes have a bearing on the frequency of the various achene polymorphs (Pandey and Dubey 1988).

Dispersal of parthenium weed achenes occurs locally by wind and water (Maheshwari and Pandey 1973). Wind transport is usually only in the order of a few metres, but whirlwinds can carry large numbers of the light achenes for considerable distances (Haseler 1976). Dispersal of achenes by water is important as indicated by large populations of the weed spreading along waterways in central Queensland (Auld *et al.* 1983). Native animals, livestock and feral animals are also involved in the dispersal of parthenium weed seed.

Parthenium weed achenes are capable of being transported long distances in mud and debris (Haseler 1976, Auld *et al.* 1983). In the majority of cases of long distance dispersal, achenes are transported on motor vehicles or machinery, on livestock, with crop and pasture seed, or in fodder (Anon. 1976b, Gupta and Sharma 1977). As a result, new infestations of the weed may appear thousands of kilometres from the nearest plants.

Physiology of seeds and germination

Most parthenium weed seeds are capable of germinating when they are shed from the parent plant. McFadyen (1994), using ripe seeds that were collected directly from plants, reported that nearly 100% germinated within 21 days. Therefore, in this case, no initial physical or physiological dormancy mechanism was present. However, the seeds may be induced into a state of conditional physiological dormancy by the ambient environmental conditions, as is the case with many other species that have a light requirement for germination when they are buried (Baskin and Baskin 1989). It could be expected that parthenium weed achenes, when buried, will exhibit a form of conditional dormancy which would lead to the formation of a more persistent seed bank (McFadyen 1994).

As is the case with achene dormancy, very little is known about the longevity of parthenium weed achenes. In one study it was found that, of the seeds recovered, germination declined from 66% after one week of burial to 29% after burial for two years (Butler 1984). Depth of burial did not affect subsequent germination percentage. These germination tests were conducted in the dark, and at constant incubation temperature, so adequate conditions may not have been present for the breaking of any induced dormancy that may have been present. It is possible, therefore, that the viability of these seeds may have been much higher than was reported, since they may have been dormant rather than non-viable (McFadyen 1994). Some evidence exists that parthenium weed achenes can remain viable after being buried for at least 4–6 years (White 1994).

The longevity of surface-lying achenes seems to be rather short. Research shows that most unburied parthenium weed achenes germinate (Anon. 1977), become non-viable, or are harvested by ants (Butler 1984) within two years.

Many authors have noted that parthenium weed achenes have a viability of 85% or more under ideal conditions (Haseler 1976, Williams and Groves 1980, Dubey and Pandey 1988, Pandey and Dubey 1988, McFadyen 1994). Williams and Groves (1980), working with threshed Australian parthenium weed seeds, reported that maximum germination (88%) occurred in the dark under a day/night temperature regime of 21/16°C. They also noted that the germination percentage increased with increasing mean temperature (Figure 5), and the germination percentage decreased as the day/night temperature differential was increased. Pandey and Dubey (1988), working with Indian parthenium weed, found that there was significant germination of parthenium weed achenes in continuous light or in continuous dark, and suggested that this species does not have a strict light requirement for germination. However, they observed that germination was enhanced under the influence of a diurnal photo-period and/or alternating day/night temperatures. They concluded that a 14 h photo-period and 25/20°C day/night temperature regime was optimum for germination of Indian populations of parthenium weed (Dubey and Pandey 1988).

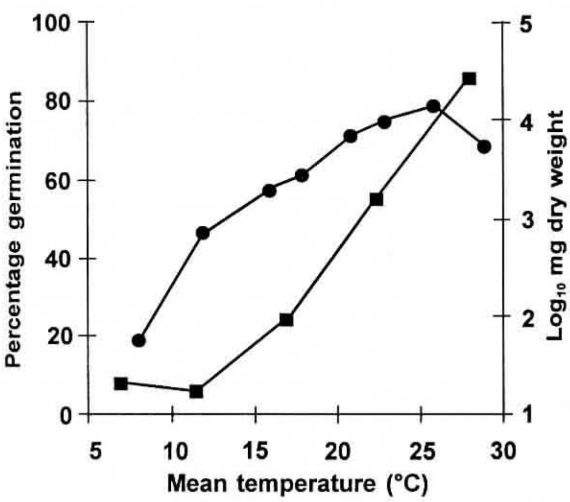


Figure 5. Germination (■) and growth (●) responses of *Parthenium hysterophorus* to temperature. Seeds and plants were maintained at a 16 h photoperiod and thermoperiod. Day temperatures were 11 and 5°C higher than night temperatures for germination and growth experiments respectively (drawn from Panetta and Mitchell 1991).

Parthenium weed seeds from Australian populations will germinate over a wide range of temperatures and have been shown to exhibit greater than 20% germination in regimes with night temperatures as low as 10°C or day temperatures as high as 36°C (Williams and Groves 1980). However, germination decreased from 91% when soil was at field capacity to 50% when soil moisture was reduced to -0.07 MPa, and 0% when soil moisture was reduced to -0.90MPa. This demonstrates that parthenium weed seeds are very dependent on high moisture availability for germination.

Vegetative reproduction

Parthenium weed does not reproduce vegetatively from plant parts or by apomixis.

Hybrids

No hybrids of parthenium weed with closely related species have been reported, but speculation has been made of their possible existence. Picman and Towers (1982) have suggested that many of the morphological and chemical characters of the highly variable South American populations of parthenium weed appear to derive from both *P. confertum* Gray and *P. bipinnatifidum* (Ortega) Rollins, so hybrids with these species may exist. This, they also noted, was unlikely as these species have only been recorded growing near parthenium weed in Mexico, where such extensive diversity in parthenium weed is not found.

Population dynamics

Pandey and Dubey (1989) observed, in India, that seedlings of parthenium weed were recruited in three successive cohorts after the first monsoon rains. They found that seedling density and survivorship to maturity declined in successive cohorts. In the same study it was found that the pattern of recruitment and population density was remarkably similar in two successive years. The average recruitment for the two years was 110 plants m^{-2} of which 14 plants m^{-2} were able to reach maturity. The results indicated that the established cohorts adversely affected the growth, and probably survivorship, of the latter accessions through resource competition (Pandey and Dubey 1989). The reported plant density in a mature stand of parthenium weed is compatible with an earlier report of 15 plants m^{-2} (Kanchan and Jayachandra 1980b) but is less than the 24.7 plants m^{-2} reported by Joshi (1991c).

As parthenium weed often grows in pure stands, few studies have been conducted on its population dynamics in relation to competition with other species.

Some research has been conducted on the interference effects of *Cassia* species on *P. hysterophorus*. These *Cassia* species are short-lived shrubs that have been studied as potential biological control agents for parthenium weed. Joshi (1991c) found that seedlings of *Cassia uniflora* Mill. could suppress parthenium weed seedlings and as a result the average parthenium weed plant height dropped from 1.75 m without competition from *C. uniflora* to 0.99 m with competition. In addition there was a reduction in plant dry weight and the number of inflorescences produced under competition when compared to a nearby pure stand of parthenium weed. Joshi (1991b,c) reported that five years after the introduction of *C. uniflora* to a site that was heavily infested with parthenium weed, there was an 84% reduction in the population of mature parthenium weed plants.

Importance

Detrimental

Parthenium weed is an extremely prolific weed that has the ability to spread quickly and colonize new areas (Jayachandra 1971). In the pastoral regions of central Queensland parthenium weed can become the dominant species under certain conditions, to the exclusion of all beneficial forage plants resulting in a monoculture of non-nutritious, vegetable matter in which it is impossible to sustain cattle (Chippendale and Panetta 1994). This causes a catastrophic drop in the productivity of pastures, in which the carrying capacity can be reduced to negligible proportions (Haseler 1976, Anon. 1980).

The worst infestations in Australia occur in areas that have undergone clearing or have been overgrazed. Under continued heavy grazing, parthenium weed will come to dominate native pastures on many soil types in central Queensland (McFadyen 1992). The presence of stock on newly cleared country is the most consistent pair of factors that heavily infested areas have in common (Holman 1981). By 1991 parthenium weed was present throughout 170 000 km^2 of Queensland's prime grazing country, or 10% of the entire State (Chippendale and Panetta 1994). Chippendale and Panetta (1994) determined that the annual losses to beef producers as a result of parthenium weed were in the vicinity of $A16.5 million. These losses were due to reduced stock numbers and liveweight gains, and additional production and control costs. Enforced stocking rate reductions are common and McFadyen (1992) reported an estimated 40% reduction of carrying capacity on some affected farms. It was estimated that cattle production in the entire region was reduced by 4.7% in 1990/91 as a result of the weed (Chippendale and Panetta 1994). The presence of this weed has also caused the need for the establishment of new improved pastures and the production of extra cultivated forage, both of which have added to the cost of beef production. About $A1.8 million dollars is spent annually by producers and the government on the chemical control of the weed in central Queensland (Chippendale and Panetta 1994).

In India parthenium weed has encroached on cultivated pastures and grasslands, and can reduce the grass forage to 10% of its normal yield (Jayachandra 1971). Parthenium weed is also a serious weed of crops and orchards throughout India as well as in many other countries around the world (Gupta and Sharma 1977, Pandey and Dubey 1991). Khosla and Sobti (1979) stated that the weed invades all sorts of crops in India, causing a subsequent loss of yield.

In Israel parthenium weed has been encountered in tomato (*Lycopersicon esculentum* Miller), cotton (*Gossypium* spp.) and forage fields (Joel and Liston 1986), while in the Caribbean parthenium weed is regarded as the fourth most serious weed species (Hammerton 1981) and was found to be one of the main weed species in a selection of 18 different crops grown throughout Jamaica (Hammerton 1974). In North America the weed has been recorded in a range of crops including sugarcane (*Saccharum officinarum* L.), maize (*Zea mays* L.), cotton, sorghum (*Sorghum bicolor* (L.) Moench), onions (*Allium cepa* L.), and citrus orchards, although not in sufficient numbers to significantly affect production (Dale 1981).

Parthenium weed is not yet a major weed of crops in Queensland but it has the potential to become a serious problem in many areas of Australia (White 1994). Although crop yields have rarely been affected, Chippendale and Panetta (1994) noted that ground often needs to be reworked to kill the initial germination of parthenium weed seedlings prior to planting, therefore almost doubling the cultivation costs. Within the last 20 years parthenium weed has started to spread into sugarcane areas and is becoming a weed of this important crop (Anon. 1981, 1985). Parthenium weed also competes strongly with sunflowers (*Helianthus annuus* L.), and has been reported to infest some sorghum crops in sufficient amounts to suppress the yield (Parsons and Cuthbertson 1992).

Parthenium weed acts as an alternative or dry season host for crop pests, including nematodes in Florida and black scarab (*Pseudoheteronyx* sp.), a pest of sunflower, in Queensland (McFadyen 1992, Robertson and Kettle 1994).

Parthenium weed seed is also a contaminant of produce (i.e. grain, pasture seed and forage), the sale and movement of which can be subsequently restricted (Chippendale and Panetta 1994). The weed has spread from Queensland to New South Wales as a result of contaminated pasture seed. In one example an average of 600 parthenium weed seed were discovered per kilogram of contaminated pasture seed (Anon. 1994). Parthenium weed achenes are also spread by harvesters and other agricultural or industrial machinery. This has led to the construction and use of wash-down facilities, which are both costly and an inconvenience to those who are forced to use them.

Parthenium weed is an environmental weed which can cause a total habitat change in native grasslands, the understorey of open woodlands and along rivers and floodplains (Chippendale and Panetta 1994). In areas that are regularly flooded, parthenium weed is difficult to control because the grass cover is killed as a result of submersion and the weed then has no competition (McFadyen 1992).

One of the major detrimental effects of parthenium weed, and a reason for its aggressiveness, is its allelopathic effect on other plants. Allelopathy is defined as the direct or indirect injurious effect of one plant upon another through the exudation of phytotoxic chemicals (Swaminathan *et al.* 1990). In many studies, water soluble phenolics and sesquiterpene lactones, mainly parthenin, have been found in the roots, stems, leaves, inflorescences, achenes and pollen of parthenium weed (Kanchan and Jayachandra 1979, 1980a, Jarvis *et al.* 1985, Patil and Hegde 1988, Pandey *et al.* 1993). These chemicals have been observed to exhibit an inhibitory effect on both the germination and growth of a wide variety of plants including pasture grasses, cereals, vegetables, other weeds, and even tree species (Nath 1981, Srivastava *et al.* 1985, Mersie and Singh 1987, 1988, Swaminathan *et al.* 1990). Research has shown that the growth and nodulation of legumes is also inhibited by the weed (Kanchan and Jayachandra 1981, Dayama 1986). Kanchan and Jayachandra (1980b) have reported that parthenium weed pollen can have an adverse effect on the chlorophyll content of leaves into which it comes into contact, and can interfere with the pollination and fruit set of nearby species. Towers *et al.* (1977) reported that heavy deposition of parthenium weed pollen on the stigmatic surface caused a 40% reduction in the grain-filling of maize, and claimed that as a result, the weed may still exhibit an inhibitory influence on crops even when growing at a considerable distance from cultivated fields.

Such detrimental toxic effects are not limited to plants, and it has been observed that a wide variety of organisms are influenced by the allelopathic substances produced by parthenium weed. Megharaj *et al.* (1987) found that when dried leaf powder of parthenium weed was placed in the soil the native algal flora was inhibited, as was the growth of nitrogen-fixing bacteria in culture in experiments conducted by Kanchan and Jayachandra (1981). Luke (1976) noticed a general suppression in the growth of fungal species in the rhizosphere of parthenium weed and concluded that root exudates can influence the composition of the soil microflora near the weed's roots.

Although parthenium weed is usually avoided by stock it is toxic to animals, and in situations where the weed forms almost pure stands animals may consume significant quantities of it. Studies in India on the toxicity of the weed to cattle and buffaloes have shown that a significant amount (10–50%) of the weed in the diet can kill these animals within 30 days (Narasimhan *et al.* 1977a,b, 1980, More *et al.* 1982). In such cases the animals often developed dermatitis with pronounced skin lesions, became highly emaciated, and eventually died due to the rupture of tissues and haemorrhages in their internal organs (Nisar Ahmed *et al.* 1988). Narasimhan *et al.* (1980) found that by the end of a six week period all three bull calves that were fed a diet of 5% parthenium weed had died.

Sheep consume parthenium weed more readily and seem to be more resistant to its toxic effects. However taints have been detected in the meat from sheep given a diet of 30% parthenium weed (Tudor *et al.* 1982). Towers and Subba Rao (1992) have also reported the tainting of cows' milk by parthenium weed in India.

One of the most detrimental effects of parthenium weed is the human health hazard that it poses. Those who have continued close contact with the weed can develop allergic eczematous contact dermatitis. Parthenin is the causative agent of this reaction, and is one of the very reactive toxic class of compounds known as sesquiterpene lactones (Towers 1981). The flower heads of parthenium weed can contain up to 8% of their dry weight as sesquiterpene lactones, with parthenin being the major component (Rodriguez *et al.* 1976). There has been an epidemic of hundreds of cases of parthenium weed dermatitis in India and several cases have been reported from the USA (Subba Rao *et al.* 1977, Towers 1981). The contact allergy can be developed from repeated contact with the weed or its disseminated parts, and can be perpetuated in sensitized individuals by airborne pieces of dried plant material, such as trichomes (Towers 1981, Towers and Mitchell 1983). Patients with severe dermatitis suffer fatigue and weight loss, and about 12 deaths have occurred in such severely affected patients (Lonkar *et al.* 1974). Complete remission of the disease was observed when patients were transferred to an area not infested with parthenium weed. Cross-sensitivity with other species of plants, particularly other members of the Asteraceae, may also occur, causing patients to react to plants to which they previously had not been sensitive (Rodriguez *et al.* 1977).

In Queensland several sensitized individuals have had to change residences and leave employment as a result of the dermatitis caused by the plant (Burry and Kloot 1982). Data collected from a survey conducted in Queensland indicated that 10% of workers on properties in the parthenium weed infested area had developed visible skin allergies to parthenium weed (Chippendale and Panetta 1994).

The pollen of parthenium weed has also been observed to cause allergic rhinitis (hayfever) and allergic bronchitis (asthma) in humans (Lonkar *et al.* 1974, Parsons and Cuthbertson 1992). In research conducted in the USA, Wedner *et al.* (1987) suggested that parthenium weed pollen was a cause of allergic disease whose importance had largely been overlooked. Lewis *et al.* (1991) stated that parthenium weed was a major allergen despite producing significantly less ambient pollen than other allergenic species (e.g. *Ambrosia* sp.), and they suggested that this may be due to the higher allergenicity of parthenium weed pollen toxins or the longer season over which parthenium weed pollen is present in the air.

Beneficial

Parthenium weed may be a useful source of potash and oxalic acid (Mane *et al.* 1986, Parsons and Cuthbertson 1992). The weed is also a good source of easily extractable, high quality protein that can be used in stockfeeds and resembles products made from conventional forage species (Gore and Joshi 1972, Savangikar and Joshi 1978).

The sesquiterpene lactones present in parthenium weed deter insect feeding and exhibit oral toxicity to insects, hence the plant may have some potential as an insecticide source (Ahmed and Bhattacharya 1991, Parsons and Cuthbertson 1992). The allelopathic nature of the weed has also led to studies on the use of extracts from parthenium weed to inhibit the growth of other weed species (Mersie and Singh 1987, Pandey *et al.* 1993). Khosla and Sobti (1979) noted that parthenin extracted from parthenium weed seems to have a greater inhibitory effect on monocots than on dicots and suggested it could be used selectively to control monocot weeds. The antifungal activity of parthenin may also lead to its utilization as a fungicide. Patil and Hegde (1988) noted that parthenin inhibited the growth of *Aspergillus* spp. and suggested it could therefore be exploited in agriculture. Similarly, Ganeshan and Jayachandra (1993) observed that parthenin had the ability to inhibit the germination of several species of pathogenic fungi.

Parthenin also has many medicinal properties. Mew *et al.* (1982) demonstrated that sublethal doses of parthenin exhibited antitumour activity in mice, and that the drug could either cure mice completely or increase their survival time after they had been injected with cancer cells. Other authors have found its antiamoebic activity to be comparable to standard drugs in fighting hepatic amoebiasis (Sharma and Bhutani 1988). Uphof (1959) noted that a decoction of the boiled roots of parthenium weed is used by South American Indians to cure dysentery, a disease that is amoebic in origin. Mexican chemists have reported that parthenin is also pharmacologically active against neuralgia and certain types of rheumatism (Dominguez and Sierra 1970).

In the Caribbean and central America parthenium weed is used as a folk-remedy. It is applied externally on skin disorders and the bitter decoction of the plant is often taken internally as a remedy for a wide variety of ailments (Dominguez and Sierra 1970, Morton 1981). In Jamaica the decoction is prized as a flea-repellent bath for dogs and other animals (Morton 1981).

Legislation

Parthenium weed was declared noxious throughout Queensland in 1975 (Anon. 1980). The plant is now categorized P2 (i.e. it must be destroyed) throughout the whole state, except in specified areas where it is designated P3 and P4 (i.e. infestations are to be reduced and prevented from spreading). In New South Wales, Victoria, Tasmania, South Australia, and the Northern Territory it is declared noxious in all areas, and in Western Australia it is declared noxious north of 26°S latitude (Parsons and Cuthbertson 1992). In Queensland parthenium weed seed is declared under the Agricultural Standards Act, which prevents the sale of commercial seed containing prohibited seed (Sullivan 1977, Genn 1987). Legislation has also been enacted to prevent the movement of vehicles carrying parthenium weed seed from Queensland to New South Wales, and penalties have been imposed to deter illegal entry of such vehicles (Parsons and Cuthbertson 1992).

Weed management

Herbicides

Herbicides are available that provide effective control of parthenium weed in almost any situation, and those registered for this purpose in Australia are presented in Table 1. Unfortunately, after the successful application of herbicides the weed will usually reappear from seed in the soil. Residual herbicides help to overcome this problem to a certain extent. However the spraying of plants before they set seed is critical to obtain long term control and a close watch should be kept on treated areas for at least 2 years. Such control is only feasible in cultivation or in small areas of pasture. Where parthenium weed covers very large areas chemical control is unlikely to be economically viable (Parsons and Cuthbertson 1992).

Pastures. Trials have shown that parthenium weed is susceptible to a number of herbicides when these are applied at high volume (2000 L ha^{-1}). The plant can be killed by 2,4-D (4 kg a.i. ha^{-1}), picloram (0.8 kg a.i. ha^{-1}), dicamba (1 kg a.i. ha^{-1}), diuron (2 kg a.i. ha^{-1}), bromacil (2 kg a.i. ha^{-1}), karbutilate (1 kg a.i. ha^{-1}) and atrazine (3 kg a.i. ha^{-1}) (Haseler 1976). In general it is better to spray with a mixture of atrazine and 2,4-D, as 2,4-D kills existing plants, while atrazine provides long term residual activity but has very little knockdown effect by itself (Parsons and Cuthbertson 1992). Aerial spraying trials have demonstrated that atrazine (4–6 kg a.i. ha^{-1}) and hexazinone (0.75 kg a.i. ha^{-1}) give good results, but the latter has the disadvantage of damaging trees (Anon. 1978). Parthenium weed is also susceptible to many of the newer herbicides such as imazapyr, oxadiazon, oxyfluorfen, pendimethalin and thiobencarb (Parsons and Cuthbertson 1992). Dense infestations will often require herbicide treatment in conjunction with pasture management to attain effective long-term control (Anon. 1993).

Cereals. In Queensland parthenium weed is not a serious problem in winter cereal crops, especially when the cultivation is left fallow during summer (Parsons and Cuthbertson 1992). In grain sorghum any parthenium weed plants appearing in the crop can be spot-sprayed with atrazine with a non-ionic surfactant added to the spray solution (Parsons and Cuthbertson 1992). Dutta *et al.* (1976) reported that pre-emergence application of atrazine (1.5 kg a.i. ha^{-1}), chlorobromuron (1 kg a.i. ha^{-1}) and monuron (0.75 kg a.i. ha^{-1}) gave safe and effective control of the weed in sorghum and maize in India. The same authors also concluded that post-emergence spraying of DSMA (2 kg a.i. ha^{-1}) in maize, or 2,4-D amine (2 kg a.i. ha^{-1}) in sorghum and maize, safely controlled parthenium weed if applied in the vegetative stage.

Grain legumes. Post-emergence application of DSMA at a rate of 2 kg a.i. ha^{-1} has been observed to give effective parthenium weed control in cowpea (*Vigna unguiculata* (L.) Walp.) and various species of beans in India (Dutta *et al.* 1976).

Sugarcane. Pre-emergence control can be effected with atrazine, hexazinone or picloram, while post-emergence control can be attained by using 2,4-D (Anon. 1985a). Diuron (4 kg a.i. ha^{-1}) and 2,4-D (1-2 kg a.i. ha^{-1}) are recommended for use in fields of existing sugarcane but need to be sprayed in high volumes (1000 L ha^{-1}) and at a high pressure in order to successfully penetrate the crop and ensure effective control (Anon. 1976c).

Horticultural crops. In India diquat is suggested for use against parthenium in orchards, with complete safety to fruit trees (Gupta and Sharma 1977). Parthenium weed was also found to be controlled by metribuzin in potato (*Solanum tuberosum* L.) and tomato, by terbacil in watermelon (*Citrullus lanatus* (Thumb.) Matsumura & Nakai), and by bromacil and diuron in grapes (*Vitis vinifera* L.), pineapple (*Ananas comosus* (L.) Merr.) and citrus orchards. Menges and Tamez (1981) noted that the use of bromoxynil, methazol and oxadiazone gave satisfactory control of the weed in onions if applied when the weeds were young. They also reported that linuron, applied post-emergence, gave effective control of parthenium weed in carrots (*Daucus carota* L.). Zanbrana and Corona (1973) studied the effects of paraquat and diuron on parthenium weed in alfalfa (*Medicago sativa* L.) in Cuba. They reported that 3 L a.i. ha^{-1} of diuron gave complete control of parthenium weed but paraquat at the same application rate gave no control. Hammerton (1974) reported on the control of parthenium weed in a large number of vegetable crops in Jamaica. In general he concluded that glyphosate was very effective in controlling parthenium weed. MSMA and diquat also gave good control of the weed in these trials but paraquat was ineffective. He also reported that trifluralin, isopropalin, chlorprophan and pebulate gave at least significant control of parthenium in capsicum (*Capsicum annuum* L.), and alachlor was most effective in containing the weed in groundnuts (*Arachis hypogaea* L.). In Kenya it was discovered that as little as 0.5 L a.i. ha^{-1} of glyphosate applied in 100 L of water effectively controlled parthenium weed in coffee (*Coffea arabica* L.) plantations (Njoroge 1989).

Table 1. Herbicides registered for parthenium weed control in Australia.[A]

Use	Herbicide	Rates (a.i. ha^{-1})
Non-agricultural	Atrazine	4 kg
	Atrazine + 2,4-D	1.8–3.2 kg + 0.4–1 kg
	Dicamba	300 g
	Hexazinone	875 g
	Metsulfuron	3–4.2 g
	Picloram + 2,4-D	225 g + 900 g
	2,4-D amine	200 g
	2,4-D ester	200 g
Fields and fallow	Atrazine	1.8–3.2 kg
	Atrazine + 2,4-D	1.8–3.2 kg + 0.4–1 kg
	Dicamba	160–280 g
	Glyphosate + Metsulfuron	290–430 g + 3–4.2 g
	Picloram + 2,4-D	75 g + 300 g
Pastures	Hexazinone	875 g
	Metsulfuron	3–4.2 g
	Picloram + 2,4-D	225 g + 900 g
	2,4-D amine	200 g
	2,4-D ester	200 g
Broom millet	Atrazine	1.2–3.2 kg
Forage sorghum	Atrazine	1.2–3.2 kg
Maize	Atrazine	2.2–3.2 kg
	Dicamba	160–280 g
	Picloram + 2,4-D	75 g + 300 g
Sorghum	Atrazine	1.2–3.2 kg
	Dicamba	160–280 g
	Picloram + 2,4-D	75 g + 300 g
Sweet corn	Atrazine	2.2–3.2 kg

[A] Sources: Anon. (1985b) and Anon. (1993).

Table 2. Species released as biological control agents of *Parthenium hysterophorus* and their establishment in Australia.[A]

Species	Country of origin	First released	Establishment
Insects			
Coleoptera			
Conotrachelus sp.	Argentina	1993	?
Listronotus setosipennis	Brazil/Argentina	1983	Yes
Smicronyx lutulentus	Mexico	1980	Yes
Zygogramma bicolorata	Mexico	1980	Yes
Homoptera			
Stobaera concinna	Mexico	1983	Yes (local)
Lepidoptera			
Bucculatrix parthenica	Mexico	1984	Yes
Epiblema strenuana	Mexico	1982	Yes
Platphalonidia mystica	Argentina	1992	?
Pathogens			
Uredinales			
Puccinia abrupta var. *partheniicola*	Mexico	1992	Yes

[A] Source: White (1994).

Non-cropping situations. In non-crop situations including industrial areas, high volume applications of dicamba, hexazinone, atrazine + 2,4-D or picloram + 2,4-D are probably the most cost-effective treatments (Parsons and Cuthbertson 1992). Infestations along roadsides and around yards can be controlled using atrazine at a rate of 8 L a.i. ha^{-1}. Two sprayings a year of atrazine is usually sufficient to permanently suppress the weed (Holman 1981). In Australia atrazine is recommended as the cheapest effective chemical for large-scale usage as its control of the weed has been excellent, particularly on roadsides (Anon. 1978).

In India, spraying with 2,4-D at the rate of 1 kg a.i. ha^{-1}, applied in 500 L of water, was found to kill parthenium weed (Chandras and Vartak 1970). Bromacil at the rate of 2 kg a.i. ha^{-1} was also reported to kill parthenium weed in the flowering stage in fallow land (Jayachandra 1971). Gupta and Sharma (1977) reported screening trials that had shown diquat, 2,4-D, linuron and bromacil gave quick and effective control of parthenium weed. In similar studies, glyphosate, terbacil and amitrole were also effective but were slower acting, while paraquat was effective only against seedlings of the weed. Dhanaraj and Mittra (1976) reported that diquat at a rate of 0.5 kg a.i. ha^{-1} in 500 L of water effectively controlled parthenium weed at all stages of growth, and its efficacy was increased when 2,4-D (2 kg a.i. ha^{-1}) was added.

Other treatments

Pasture and grazing management. As there seems to be a definite relationship between the invasion of parthenium weed and the vigour of pastures, it is apparent that property management is fundamental to the control of this weed (Anon. 1978). Pastures should not be grazed heavily as this increases the likelihood of invasion by parthenium weed, and the severity of existing infestations. Rehabilitation of infested pastures requires them to be spelled for at least one full summer, and they must also be grazed very lightly in the following winter (Holman 1981). Pasture species may be sown to encourage the restoration of the pasture, but newly sown areas must also be spelled to allow the pasture to re-establish (Parsons and Cuthbertson 1992). Once cover is established, stocking rates have to be carefully adjusted according to season and rainfall to maintain grass dominance. Badly infested areas can be fenced off and destocked to prevent seed spreading to parthenium-free areas (Holman 1981).

Physical methods. Fire will produce beneficial results only after the first heavy rains, when the majority of parthenium weed seed has germinated (Holman 1981). Burning usually gives only short term control but may be effective when used in conjunction with the sowing of pasture seed and implementation of responsible management practices (Haseler 1976). However it is often hard to obtain sufficient fuel for a fire once parthenium weed has invaded (Holman 1981).

Mechanical treatments such as grading, slashing and ploughing are not considered to be efficient as such methods may aid the spread of parthenium weed achenes (Haseler 1976). Mowing or slashing also results in the rapid regeneration of plants from lateral shoots close to the ground (Gupta and Sharma 1977).

Hand pulling of individual parthenium weed plants must be done carefully as it can be a health risk. Protective clothing should be worn and subsequently washed to prevent the possibility of allergic reaction (Gupta and Sharma 1977, Parsons and Cuthbertson 1992). These means of control are not recommended in Australia and are more commonly practised in India and the West Indies. Removal by hand has often been ineffective in India because it has not been carried out properly. To ensure effective control by this method, plants must be removed before they seed and the whole crown of the weed must be removed to prevent regeneration from remaining lateral shoots (Khosla and Sobti 1979).

Hygiene. Proper cleaning of cultivating and harvesting vehicles, sowing of uncontaminated seed, and short term quarantine of stock that have been in parthenium weed infested areas will reduce the risk of spreading parthenium weed. Machinery and vehicles that have been in infested areas must be thoroughly cleaned by washing them with a high pressure hose (Parsons and Cuthbertson 1992). A small paddock or yard on each property should be set aside as a washdown area and any parthenium weed plants that subsequently germinate in this area must be destroyed (Holman 1981, Parsons and Cuthbertson 1992). Stock brought from infested areas should be kept in a holding yard for a few days before transferring them to clean pasture or transporting them elsewhere (Holman 1981).

Natural enemies

There is a large amount of literature concerning investigations of the natural pests of parthenium weed and how they have been employed as biological control agents. Observations have also been made of the effects of endemic insects in countries into which the weed has spread. Biological control seems to offer the best long-term solution to the parthenium weed problem (Haseler 1976). However, to date the biological control campaign against parthenium weed in Australia and India has resulted in only limited and inadequate control (McFadyen 1992).

Many species of insects have been found feeding on parthenium weed in its countries of origin (i.e. Mexico, Brazil and Argentina), although most of these are only occasional feeders and have little adverse effect on the plant (Anon. 1978, McClay 1981). Of the species found to be damaging and suitable for introduction into Australia, eight have been released in Queensland since 1980 (White 1994). Of these, five have successfully established and two (*Platphalonidia mystica* Rakowski and Becker and *Conotrachelus* sp.) are still being released and it is not yet known if they have established (Table 2).

The species that are successfully established in Queensland are: the leaf-feeding beetle, *Zygogramma bicolorata* Pallister; the stem boring weevil, *Listronotus setosipennis* Hustache; the leaf-mining moth, *Bucculatrix parthenica* Bradley; the seed-feeding weevil, *Smicronyx lutulentus* Dietz.; and the stem-galling moth, *Epiblema strenuana* Walk. (White 1994). The larvae of *L. setosipennis* are very damaging to parthenium weed, and when several are present they may kill young plants (Wild *et al.* 1992). This species has become established at several sites where it is having some effect locally, but these areas are comparatively small and the weevil's rate of spread is very slow. The larvae of *B. parthenica* eat the leaves of parthenium weed, and where the moth becomes periodically and locally abundant, it can cause extensive defoliation of the host plant (McClay *et al.* 1990). Even though this species is widespread its overall effect on the weed is probably quite small (Parsons and Cuthbertson 1992). The eggs of the weevil *S. lutulentus* are laid in the capitula of parthenium weed and the larvae feed on the disc florets and the developing achenes (McClay 1981). This species, thought not to have established, has only recently been found in the field and its degree of control is not known. *Z. bicolorata* was initially very promising as a biocontrol agent for parthenium weed as it breeds rapidly and when present in large numbers can severely defoliate the weed, thereby preventing seed production (McFadyen and McClay 1981). However, for many years the population and spread of *Z. bicolorata* was very low. The beetle is now becoming adapted to central Queensland conditions and is appearing in greater numbers and having a more significant impact each year (McFadyen 1993).

Epiblema strenuana is the only insect to have any significant impact on parthenium weed in Australia. Parthenium weed has become less competitive and easier to manage than it was prior to this insect's release (McFadyen 1992). The moth's larvae form galls in the stems and growing points of parthenium weed and can considerably stunt growth, ultimately reducing seed production (McClay 1987). Research has shown that if *Epiblema* larvae are released onto parthenium weed when it is less than 20 cm in height, in the presence of grass competition, they significantly reduce growth and seed production (T. Priest personal communication). Stands of parthenium weed 1.5–2 m tall were common in central Queensland before *E. strenuana* was released; now they rarely exceed 1 m in height (McFadyen 1989).

The larvae of the weevil *Thecesternus hirsutus* Pierce burrow into the roots of parthenium weed, causing a gall-like swelling around each feeding site (McClay and Anderson 1985). This species was imported into Australia but rearing it was difficult and no field releases of the insect were made (McFadyen 1992).

Stobaera concinna Stal. is a sap-sucking bug which may do some damage to younger developing parthenium weed plants if present in large numbers (McClay 1983). This species was released in Australia but is only very locally established and is causing no significant damage (McFadyen 1992, White 1994).

In India a number of indigenous insects attack parthenium weed, and can be damaging to individual plants, but none causes appreciable damage on a large scale in the field (Jayanth 1987). These include several species of aphid, *Aphis* spp. (Rajulu *et al.* 1976); a moth, *Diacrisia obliqua* Wlk. (Vaidya and Vartak 1977); two species of mealy bug, *Ferrisia virgata* Cockerell (Char *et al.* 1975) and *Planococcus* sp. (Hegde and Patil 1979); and a spider mite, *Brevipalpus phoenicis* Geijskes (Dagar and Singh 1979). *Z. bicolorata* has also been released in India and is starting to have some impact on the weed in the Bangalore area. Jayanth and Visalakshy (1994) noted that plants attacked by the beetle produced up to 98% fewer seeds, and concluded that this insect has the potential to reduce parthenium weed density in many parts of India.

Parthenium weed is a host to two species of pathogenic rust fungi, *Puccinia abrupta* var. *partheniicola* (Jackson) Parm. and *P. melampodii* Diet. & Holw., in Mexico (Parker 1989). *P. abrupta* var. *partheniicola* can be quite damaging, infection with the rust often resulting in a 90% reduction in flower production (Parker *et al.* 1994). This species was deemed sufficiently host-specific for introduction into Australia and has recently been released, although it is winter acting and the area where parthenium is currently a problem has a summer-dominant rainfall. A research project designed to search for other more suitable rust strains and other pathogenic species has commenced in Mexico.

In 1973 a large number of parthenium weed plants was found to be affected by a mycoplasma-like organism in India (Varma *et al.* 1974). These plants produced a profusion of small branches with reduced leaves and minute phylloid flowers. A mycoplasma has since been found to be the causal agent of a similar phyllody disease of parthenium weed in Australia and methods of transmitting the disease have been investigated, but with little success (Anon. 1982, McClay 1983).

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