Invasion history and ecology of the environmental weed balloon vine, *Cardiospermum grandiflorum* Swartz, in Australia

Scott P. Carroll[A,B], Michael Mathieson[C] and Jenella E. Loye[A,B]

[A]Department of Entomology, University of California, Davis, CA 95616, USA.
[B]Department of Zoology and Entomology, University of Queensland, St. Lucia, Queensland 4072, Australia.
[C]Environmental Protection Agency, Wildlife Ecology Unit, 80 Meiers Road, Indooroopilly, Queensland 4068, Australia.

Abstract

The tropical American balloon vine, *Cardiospermum grandiflorum*, is declared as an environmental weed throughout Queensland and in many districts of New South Wales. Using Australian herbarium records we documented its introduction and spread, mapped its invasion, described its habitats, and documented its shift from domestic to natural environs and from garden plant to recognized threat. Balloon vine was introduced into Sydney, northeastern New South Wales and southeastern Queensland in the 1920s and 30s from unknown sources. Range expansion was relatively slow until the 1960s, and major increments have occurred in the past 15 years. It was collected near Adelaide in the 1980s, and Perth in the 1990s. Naturalization is evident in some of the earliest collections. Local eradication efforts occurred as early as 1935, and its weed status was recognized in some regions by the 1960s. It grows on a diversity of soil types and is particularly abundant in riparian corridors, where it may cover other vegetation in uninterrupted stands kilometres in length. Much of its inland spread is along watercourses.

Key words: alien, balloon vine, ecology, exotic species, history, naturalized, plant invasion, Sapindaceae, weed.

Introduction

Environmental weeds are nonindigenous plants that invade natural habitats. In Australia, the transformation of alien plants to environmental weeds is recognized as problem of great ecological and economic significance (e.g., Humphries *et al.* 1991, Csurhes and Edwards 1998, Martin 2002). Of approximately 28 000 plant species brought into Australia in the past 200 years, close to 10% have become environmental weeds (Martin 2002, Groves *et al.* 2003). This frequency greatly exceeds the conventional '1% rule' for naturalization that stems from temperate zone studies (e.g., Kowarik 1995). An estimated two-thirds of Australia's weeds are escapes from ornamental plantings in parks and gardens (Martin 2002). For nearly all Australian weeds there is a lack of historical information on dates of introduction and rates of spread, deficiencies that will need to be overcome if our ability to predict future negative impacts is to be refined (Groves *et al.* 2003).

Naturalization is a key element of the invasion process. If factors influencing the probability of naturalization are substantially different in Australia than in the temperate Northern Hemisphere, case studies of invasions on this continent will be an especially valuable component of control science here. Such documentation should include analyses of a taxon's origin, residence status, and invasion status (Pysek *et al.* 2004). Data on invasion after introduction can give insight into the processes that underlie successful establishment and potentially aid in control (Williamson 1996). A large proportion of invaders may be 'sleeper weeds' that begin to spread only decades or centuries after introduction (Groves 1986, Kowarik 1995), suggesting that a variety of environmental and genetic factors may come into play in determining an invader's subsequent spread and abundance (Hobbs and Humphries 1995, Crooks and Soulé 1999). Chief among these may be natural or anthropogenic habitat alteration (e.g., Hobbs 1991, Hobbs and Atkins 1988) and adaptive evolution (Lee 2002). These ecological and evolutionary aspects of invasion biology may be examined by reconstructing the introduction and spread of an environmental weed. For example, notes on the habitat or ecology commonly accompany botanical specimens in herbaria. Such records may reveal the extent to which an invader is dependent on disturbed habitats, or the chronology by which it began to colonize natural (versus domestic) environments.

Among native plant communities, riparian habitats, which typically harbour high native species diversity, may be particularly prone to invasions. This vulnerability may stem from their physically dynamic nature, high nutrient levels and ability to transport organisms (Planty-Tabacchi *et al.* 1996, Stohlgren *et al.* 1998). Here we report on the history of the introduction and colonization of one such invader, balloon vine (*Cardiospermum grandiflorum* Swartz; Sapindaceae) in Australia. While recognized as an environmental weed for at least fifty years, it has received formal attention only recently (Batianoff and Butler 2002). Batianoff and Butler (2003) rank it 13th in terms of prospective environmental impact among 66 'priority' environmental weeds in south-east Queensland. It is one of the 26 'Class 3' species listed for Queensland (Land Protection Act 2003). These are declared pest plants the sale of which is illegal. We are particularly interested in balloon vine because of its incursions into threatened rainforest habitats in eastern Australia, and because specialized insects that attack its seeds in its Neotropical homeland have close relatives here that may play a role in limiting its rate of spread (Carroll *et al.* in press).

As structural parasites, vines that grow into the upper canopy may have disproportionate impacts on native tree-dominated communities. Notably, several of the most serious environmental weeds in rainforest areas of Queensland and New South Wales are indeed vines (e.g., Madeira vine, *Anredera cordifolia*, cat's claw creeper, *Macfadyena unguis-cati*, and climbing asparagus fern, *Protoasparagus africanus*. Nine (35%) of the declared Class 3 pest plants for Queensland (Land Protection Act 2003) are vines. Large vines such as balloon vine may be regarded as 'transformer' species because of their ability to markedly alter ecosystem properties (Vivian-Smith and Panetta 2002, Pysek *et al.* 2004). Thus, the control of these plants is of particular conservation interest. Balloon vine is especially recognized as a threat in southeastern Queensland, northern New South Wales, and in the vicinity of Sydney (Batianoff and Butler 2002, Muyt 2001) and below.

Native distribution

Cardiospermum grandiflorum is widely distributed in its native Neotropical range, occurring from southern Mexico to Brazil and the Caribbean (e.g., Cowan 1983, Balick *et al.* 2000, Brako and Zarucchi 1993, Moraes 1990). The type specimen is from Jamaica. For 180 specimens in the Missouri Botanical Garden and New York Botanical Garden databases, the elevational range is 10–1800 m. In South America it occurs in the Caribbean lowlands, at low to mid elevations in moister areas of the equatorial Andes, in southwestern Amazonia, and in Paraguay and southern Brazil. In Belize, Central America, it occurs commonly on river and stream banks at low elevations, while in Costa Rica it also occurs on forest edges at roadsides up to more than 1000 m elevation (SPC personal observation). Populations in South Africa and Oceania

are nonnative and of conservation concern (Olckers 2003, Meyers 2002, respectively).

Seeds are dispersed by wind and water (Harden 2002). In the Neotropics, seeds of *C. grandiflorum* and its congeners are attacked by a variety of insects (Carroll and Loye 1987, Carroll 1988, Carroll and Loye in press). Little else is known of its biology and ecology.

Materials and methods

We investigated the history of balloon vine's incursion and spread within Australia by examining 122 specimens from the National Herbarium (17 specimens), Queensland Herbarium (48 specimens), National Herbarium of New South Wales (44 specimens), University of New England Beadle Herbarium (seven specimens), and the North Coast Regional Herbarium in Coffs Harbour, New South Wales (six specimens). Both cultivated and naturalized plants were present.

Where duplicate specimens were held among herbaria, only a single occurrence was tabulated. All specimen data from the Western Australian Herbarium were duplicated in the National Herbarium, and that from the CSIRO Atherton Herbarium was duplicated in the Queensland Herbarium. No specimens were found in the herbaria of the Australian National University, James Cook University, or the Northern Territory.

We mapped the plant's history of spread based on places and dates of collections. The goal of mapping was to give a clear sense of the time course of geographic expansion. Where data are few, as in the earliest collections, we mapped the points individually. We grouped later collections into four intervals of 15 years. The manner in which we depicted the spatial extent of each 15 year grouping was based on two assumptions. The first is that some of the outlying points are derived from geographically intermediate populations that have not yet been discovered or reported. The second is that many of the known locales are but single sites in widespread metapopulations. This approach may imply the existence of interstitial populations for which we lack collection data, but reveals the time course of change in a manner that individually-mapped records cannot. A majority of the locales we used are available on the worldwide web at Australia's Virtual Herbarium, and the complete data set is available from the first author.

Lastly, at several points we make reference to general observations on the extent of infestations made in field surveys conducted in 2002–2004.

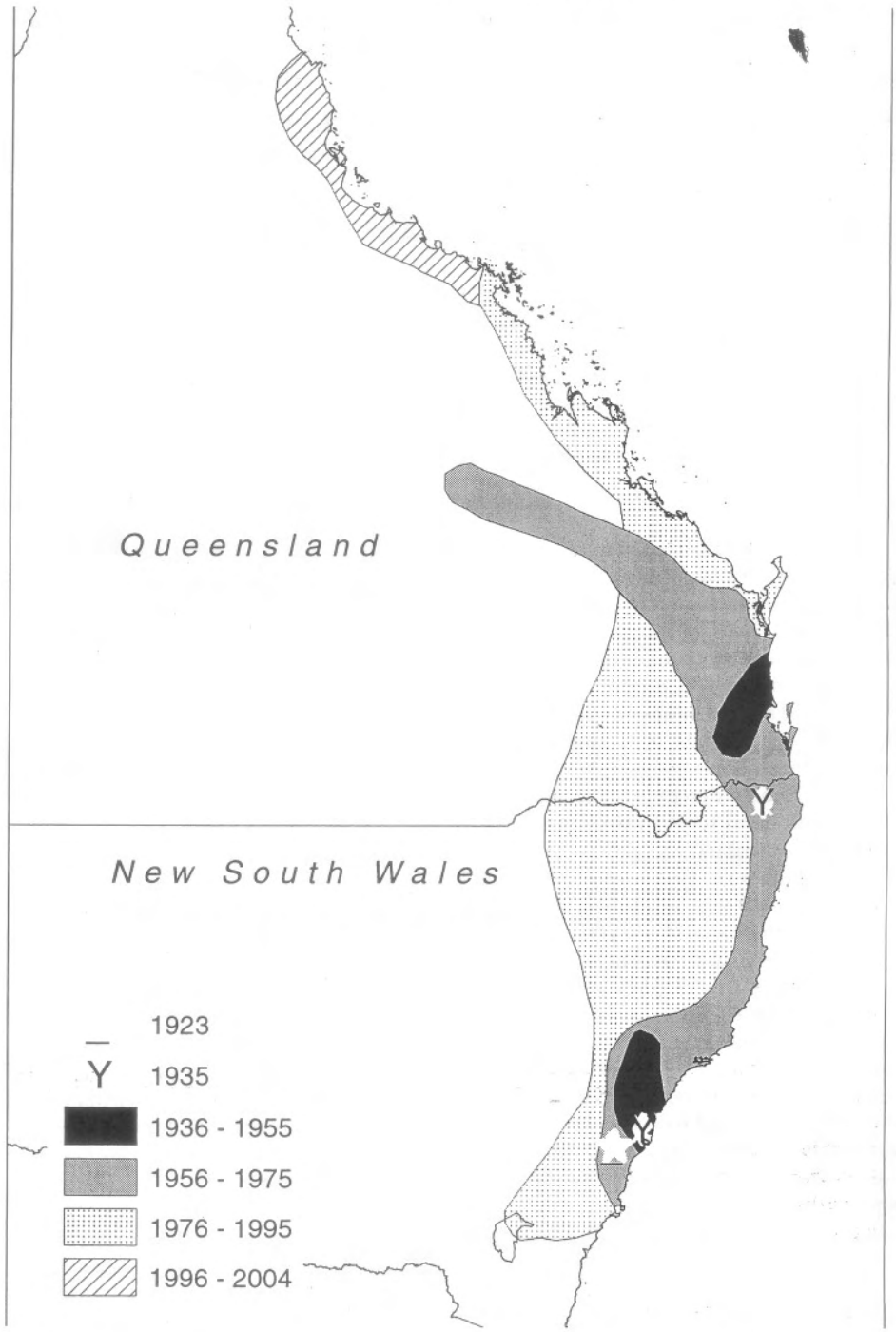

Figure 1. Map of the invasion of eastern Australia by balloon vine, *Cardiospermum grandiflorum*, since 1923. See text for collections from South Australia and Western Australia.

Results

Introduction to Australia

The earliest herbarium specimen of *C. grandiflorum* in Australia was taken from a river bank near Sydney in Camden, New South Wales, in 1923. The species is absent from the early floristic treatments of New South Wales by Dixon (1906) and Maiden and Betche (1916). The second herbarium record for is also from the Sydney region, in Lane Cove in 1935. In that year another specimen was collected 600 km to the north in Kyogle (Figure 1). Additional New South Wales specimens were collected adjacent to these foci in the subsequent decades. In notes on a specimen collected at Bellvue Hill (near Sydney) in 1954, E.J. McBarron remarked that the vine was 'cultivated in many country towns'. Likewise, a 1949 specimen taken 150 km north of Sydney at Singleton (Hunter River Valley) was from the fence of a hotel. Garden introduction is a likely source of the vine in both southern (Beadle *et al.* 1962) and northern New South Wales, and its continued cultivation may in part underlie the coalescence of the northern and southern distributions in the 1960s (Figure 1).

Early floras of Queensland did not reference the plant (e.g., Bailey 1909). Hill (1875) lists the small congeners *C. halicacabum* and *C. h.* var. *microcarpum* in the holdings of the Queensland Botanic

Gardens (in Brisbane) at that time, but makes no mention of *C. grandiflorum*. The earliest Queensland records are both in the southeast of that state: at Laidley near Gatton in 1944, and at Coolum in 1945. While not far removed from northern NSW latitudinally, two factors suggest that they may be separate from the Kyogle introduction. First, they are on the opposite side of the Border Ranges, which should form a natural barrier to water and wind dispersal of the seeds. Second, they are both adjacent to the greater Brisbane region, a likely area for horticultural plantings, with potential for escape.

Subsequent expansion of the range was most pronounced in the 1960s, and from the 1990s to the present (Figure 1). The first substantially inland records occurred in the early 1960s in Queensland at Emerald. In 1969, a specimen was collected in South Australia in Adelaide, and again in the same region a decade later. Few collections took place beyond the established range perimeters in the 1970s and 1980s, but since 1990 many collections have been made both inland and farther north in eastern Australia (Figure 1). In addition, specimens were taken along the Canning River in Perth, Western Australia, in 1995.

On a state-by-state basis, the herbaria hold a total of 59 specimens from NSW, 58 from Queensland, two from SA and one from WA. (Two additional specimens from ACT are from cultivated specimens at the National Botanic Gardens, originally from Queensland stock.) Major portions of eastern Australian habitats now either support balloon vine populations, or are close to such populations.

History of naturalization

We searched for the starting point of naturalization in collection notes accompanying the herbarium specimens. Feral individuals appear early in the collection history. As noted above, the earliest collection (1923) is from a 'river bank'. The next note is for the Lane Cove NSW specimen, taken from a 'gully' in 1935. A 1947 record from Longueville (near Sydney) is from an 'open eucalypt forest'. In 1951 it was 'in the bush and on roadside' in nearby Wahroonga, and McBarron's 1954 note reports the species in that region as 'over scrub, also naturalized at Cheltenham'.

The first habitat characterization for northeastern NSW is from Ulmarra in 1957, where the plant was described as 'wild on roadside'. Six of the seven specimens collected in this region in the 1960s were from river banks (see below for more results on habitat).

Habitat notes are not present for Queensland specimens before 1968. Eight of 12 specimens collected from that time through the 1970s were from river banks, indicating a naturalized status by that point in time.

Habitat, soil and phenology

Of the 122 collections, 79 included information about the habitat of the specimen, or strong clues thereto. Fifty-two of these collections were reported from along watercourses, and another six were almost certainly so, yielding a total of 70% riparian. Another two were from gullies, and a third from the 'margin of mangrove swamp', further indicating a predilection for this type of environment (77%). The remaining records consist of roadsides (6%), waste sites (5%), cultivated or suburban (5%), open forest (3%), and disturbed forests (4%).

Soil types varied substantially among the collected specimens. Among the 11 records were four alluvial, two gravely, and one each skeletal, dark grey, basalt, rich loamy and mud sandy loam. This result indicates that a diversity of soil types is suitable for the growth of balloon vine.

There appears to be a latitudinal influence on reproductive seasonality. In NSW, all records mentioning flowers or fruit took place February–July. In contrast, Queensland records indicate fruiting and flowering in spring and summer in addition to autumn and winter. The more equably warm climate of the north may support a longer breeding period on an annual basis.

Evidence of pest status and control

The collection records indicate that balloon vine was recognized as a weedy pest species early on. For example, the 1935 specimen from a gully in Lane Cove was from an individual that was 'poisoned'. E.J. McBarron's collection notes from the greater Sydney region offer the most detailed observations on the status of balloon vine. In addition to his notes about its naturalization and cultivation in 1954, he noted it climbing over trees and 'proving troublesome' where cultivated by 1965. In 1965, at Wooloomooloo, another collector annotated a specimen with 'An order for the destruction of this vine has been served on the owner'. In a collection at Windsor in 1971 it was simply described as a 'weed', and a 1977 specimen includes a newspaper article about the spread of the weed in Fairfield (near Sydney). Specimens from the 1980s and 1990s include notes of 'Over trees to 9 m' and 'forming vine towers'.

In far northeastern NSW, the Richmond River near Kyogle currently supports many linear kilometres of balloon vine arrayed along its floodplain (SPC personal observation). However, in 1964, E.F. Constable described the population in that region as 'localized on rainforest edge...' At the same site four years later, A.G. Floyd described it as 'commonly growing over trees and shrubs...' By 1990 G.J. White described it as 'vigorous' in the rainforest there.

For collections in Queensland there are far fewer status notations. Details do not appear until the 1990s, with notes such as 'vigorous', 'abundant', 'rampant', 'smothering trees', and 'climbing over canopy 16-20 m' appear with increasing frequency. It was collected in Lamington National Park (Kerry Valley) in 1991. We observed it at 1900 m elevation in Springbrook National Park in 2004.

The two collections from South Australia simply refer to the vine as 'vigorous'. In Western Australia, the vines along the Canning River were described as 'rampant... 8–10 m over trees... locally abundant'.

Discussion

Cardiospermum grandiflorum is a canopy-climbing vine that is native in warm habitats from southern Mexico to southern Brazil. It is not well studied in its native region, but supports a number of seed eating insects (Carroll and Loye 1987, Carroll and Loye in press). Due to its curious seedpods and attractive appearance, it is planted as an ornamental in many warm areas of the world. In addition to its declaration as an environmental weed in many areas of eastern Australia, it is a very serious environmental weed in South Africa (Olckers 2003) and the Cook Islands (Meyers 2002).

The geographic origin of the *C. grandiflorum* imported into Australia is unknown. There appear to have been at least five Australian foci for its introduction. Residence time on the continent is at minimum 80 years. We treated the three main east coast introductions in some detail, and reported introductions at Adelaide and Perth. While data are lacking, there is substantial indication that horticultural plantings of this species were popular historically, and as we know of no other practical reasons for its introduction, we suspect that balloon vine was originally a garden escape.

The large size and distinctive appearance of *C. grandiflorum* suggest that its absence from collections prior to 1923 is not a result of its having been overlooked. As a contrast, its comparatively diminutive and uncommon congener *C. halicacabum* was noted in Bentham (1863), and was frequently collected from the 1800s on in both Queensland and NSW, including in areas from which *C. grandiflorum* was later collected. As a result, we surmise that the early herbarium collections give a good chronology of the plant's introduction.

From among the first collections, there is evidence that balloon vine began reproducing outside of cultivation early in its tenure on the continent. The great majority of herbarium specimens are from non-cultivated plants, and many of them are from bush lands, especially riparian habitats. While the rate at which specimens are taken has increased in the 80 years span,

the proportion that is from noncultivated and wild habitats has been high throughout. Continued horticultural plantings may have seeded new areas of escape all through this period.

We lack information on the exact places and dates at which *C. grandiflorum* was introduced in various areas of Australia. As a result, it is difficult to determine whether there was any substantial lag time between introduction and naturalization. Data showing that lags of up to 150 years are commonplace (e.g., Kowarik 1995) make it tempting to speculate that balloon vine was introduced well before the 1920s. Such a 'pre-naturalization' period would have increased the number of available propagules and better-adapted genotypes, and provided time for response to any strong selection (*sensu* Hobbs and Humphries 1995, Crooks and Soulé 1999).

On the other the other hand, studies showing both lags and low establishment rates under natural conditions (i.e., the '1% rule', Kornas 1990, Kowarik 1995) are all from temperate sites. Establishment rates in Australia are closer to 10% (Martin 2002, Groves *et al.* 2003). High establishment frequencies may indicate that the native flora is comparatively invasible or that there exists a large global pool of subtropical species pre-adapted to prevailing abiotic and edaphic conditions here. If either is the case, lag periods during which substantial evolution takes place before naturalization can commence may not typify many of the invasions in Australia, and balloon vine may actually have moved out of the garden early on. The multiple foci of its invasion reinforce this interpretation of its endogenous invasive power in eastern Australian habitats.

The seeds of *Cardiospermum* are dispersed by both water and wind (Harden 2002). Mature fruits that remain attached to the plant dehisce and release seeds carried on specialized wings. Fruits may also drop intact, and float readily on water (Vivian-Smith and Panetta 2002). This two-tactic dissemination strategy serves to permit thorough colonization within and between watersheds. Our findings indicate that soil type is relatively immaterial. Presumably, the colonization of new watersheds requires propagules to cross topographic divides, an act best accomplished by air. In recent field surveys (unpublished) we noted interesting heterogeneity in the saturation of adjacent watersheds by balloon vine. For example, the herbarium collection data indicate that in northeastern New South Wales, the Richmond River catchment has supported balloon vine for at least 50 years and probably longer. Currently many reaches of that catchment (including tributaries) appear dramatically 'smothered' by balloon vine. In contrast, there are no collections from the large Tweed River Valley just to the north. In 2002 we found no balloon vine in cursory surveys of that valley, and in similar surveys in 2004 found just four individuals, none of them large. The impression, then, is that even in long-occupied regions, certain catchments (perhaps those with comparatively high elevation margins such as the Tweed) are still in early stages of colonization.

As balloon vine colonizes westward along watercourses, wind dispersed propagules may become even more important in the colonization of new 'oasis' habitats capable of supporting the plant. The much smaller congener *C. halicacabum* occurs patchily in central and northern coastal Queensland, and more commonly in monsoonal areas of NT and WA. Based on its native range, it is likely that *C. grandiflorum* has both the adaptive and dispersive ability to ultimately occupy these habitats as well.

By their capacity to enter the canopy, invasive vines may be particularly detrimental to their host communities. Balloon vine has been recognized as troublesome for at least 60 years. Current infestations appear massive to the extent that floral and faunal relations are probably deeply altered, although this has not been measured. Listing as a Class 3 pest in Queensland means that selling any plant material without permission is illegal. However, such a measure is unlikely to directly impact its further colonization and establishment. Local legislation is exercised in an increasing number of districts, and has the greatest prospect for controlling balloon vine, particularly in and near cities and towns. A Google internet search of 'balloon vine Australia' reveals many local organizations actively working against it in New South Wales and Queensland. The Canning River population that was the source of the 1995 Perth collection appears to have been eliminated by local bush regeneration efforts as of late 2001 (SPC and JEL personal observations). We are not aware of extensive naturalization in SA at present.

The invasion of riparian and adjacent habitats by balloon vine may be especially threatening to declining rainforest communities in eastern Australia (sensu Randall 1986, Planty-Tabachi *et al.* 1996, Martin 2002). We have observed numerous areas in which the vine has spread from creek banks into forest, particularly in sites with some physical disturbance (SPC and JEL personal observations). Invasions are often triggered by rare events (Rejmánek *et al.* 2004). Landscape level disturbances such as hurricanes may open and deposit seeds in habitats from which this plant was previously excluded. In addition to specialized structures for wind dispersal, balloon vine fruits are capable of floating in water for months (Vivian-Smith and Panetta 2002). The invasion of Rarotonga's national parks by balloon vine is attributed to a tropical cyclone (Meyers 2000), and Brisbane area naturalists comment on the great spread of balloon vine in that region following the major cyclone and flooding of 1974 (D. Sands personal communication). Furthermore, even if substantial evolution has not attended its initial invasion of Australia, subsequent evolution may improve its ability to colonize other habitats. Such a process would be facilitated by its now massive population size, as well as its continued ecological release from directly adapted parasites and competitors. Once established, ecological transformers such as balloon vine may perennially inhibit recolonization by natives. Accordingly, the invasion of Australia by this Neotropical exotic deserves continued attention and control efforts.

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