# The invasibility of tropical granite outcrops ('inselbergs') by exotic weeds

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## Abstract

Granitic and gneissic rock outcrops ('inselbergs') that rise abruptly from surrounding plains are of widespread occurrence on old crystalline shields. In the tropics this geologically old ecosystem occurs throughout a broad spectrum of vegetational and climatic zones. Inselbergs usually bear a vegetation that is drastically different from those of the surroundings due to their edaphic and microclimatic aridity. Because of their low agricultural potential, tropical inselbergs form in many regions the last refuges of natural vegetation types. However, there is increasing evidence for non-native weeds getting established within inselberg plant communities by using roadsides and fallow land as stepping stones. In both Africa and South America, exotic weeds have become a severe danger for indigenous plant communities on rock outcrops because of their high competitive ability. A survey is provided about the most important weeds on tropical inselbergs which shows that intentionally-introduced species, like *Ananas comosus* in West Africa, cause the most serious problems. Moreover, different rock outcrop habitats are analysed in regard to their invasibility.

Keywords: conservation, disturbance, endemics, fragmentation, inselbergs, weeds

## Introduction

More or less dome-shaped granitic or gneissic rock outcrops are called inselbergs when they rise abruptly from the surrounding plains. They form geologically and geomorphologically old landscape elements that are often more than 50 million years old (Bremer & Jennings 1978). Throughout the tropics, subtropics and temperate regions they are widespread on the old crystalline shields where they form conspicuous landmarks (Plates 1 & 2). Environmental conditions on inselbergs are severe due to high insulation and evaporation rates, and because of the lack of a continuous soil cover this explains their large degree of floristic distinctiveness. The harsh growth conditions on inselbergs have led to the development of specific adaptive traits. Of particular importance in this respect are desiccation-tolerant vascular plants for which inselbergs are among the most important growth sites (Porembski & Barthlott 2000). Certain floristic regions harbor an inselberg vegetation rich in endemic plants, such as Madagascar or the Brazilian Atlantic rainforest, with numerous species being known to occur in only a few localities.

For a long time, the vegetation of inselbergs was denoted as lithophytic without further differentiating between individual habitats. Today, however, it is evident that inselbergs form ecosystems that, despite large differences in regional floristic composition, comprise clearly circumscribed plant communities (Porembski *et al*. 2000). Cryptogamic crusts, monocotyledonous mats, shallow soil-filled depressions, seasonally water-filled rock pools and ephemeral flush vegetation are particularly characteristic among those communities which occur under open, fully-exposed conditions on rock outcrops.



Over the last decades, a considerable number of studies devoted to the knowledge of the vegetation and ecology of both temperate and tropical inselbergs have been published (for reviews see Porembski *et al.* 1997; Barthlott & Porembski 1998). Because of their low agricultural potential and sometimes difficult access, inselbergs form in many regions the last refuges of natural vegetation types (Plates 3 & 4). However, it has already been noted (Wyatt & Allison 2000; Porembski *et al.* 1998) that under certain circumstances inselbergs may lose their island-like refugial character with severe consequences to their often highly unique vegetation. In many tropical and subtropical ecosystems, alien plants are the biggest single threat to plant conservation (Crawley 1997) and in certain regions introduced plants have become a problem on inselbergs too. It is the aim of this paper to provide a short overview of the threats to the vegetation of inselbergs in general and of the causes of plant invasions within this ecosystem.

### Alien plants on tropical inselbergs

Due to the open character of their vegetation cover and because of frequent climatic disturbances, inselbergs are susceptible to new colonists. Today, however, apart from native plant species, exotic weeds that are good dispersers invade from adjacent disturbance-prone sites (*e.g.* roads, pastures). The importance of introduced species on inselbergs in temperate regions has been discussed concisely by Ornduff (1987), Hopper *et al.* (1997) and Wyatt (1997). In particular inselbergs in Western Australia bear a large number of introduced annual weeds which may comprise more than 20% of the whole outcrop flora (for details see Ornduff 1987 and Ohlemüller 1997). According to Wyatt (1997) weedy species on granite outcrops in the south-eastern United States have once been endemics restricted to this ecosystem. Moreover, it can be assumed that granite outcrops obviously have played a role as evolutionary springboard for certain present-day widespread weeds in the Piedmont region.

In the following, regional accounts of alien plants on tropical inselbergs are presented. The data given are mainly based on experience in the field obtained over the last decade in different tropical regions but otherwise published information was also considered. The alien weeds that are mentioned here represent non-indigenous plant species that were introduced intentionally or unintentionally and thereafter became established in considerable quantities. Individual sightings of non-indigenous plants on inselbergs are not included. Since data about Asian inselbergs are almost non-existent, the focus will be on African and South American inselbergs.

**Africa, Madagascar, Seychelles**

The vegetation of African inselbergs shows considerable regional differences in floristic composition and species richness (for review see Barthlott & Porembski 1998). Granitic and gneissic inselbergs are found in all vegetational and climatic zones of Africa. They occur over a broad range of primary and secondary plant formations and are frequently associated with religious purposes that have given them in certain regions a protective status. The most serious dangers to this ecosystem are deliberately lit fires, quarrying, to a lesser extent cattle grazing (Plate 5) and subsequently the arrival and establishment of non-native plants.

Since inselbergs in the Ivory Coast have been most thoroughly investigated hitherto within Africa, I concentrate in the following account on this country. Like most parts of West Africa, the Ivory Coast is characterized by a rapid conversion of primary forests into plantations, various stages of forest regrowth and fallow land. Over the last decades the speed and extent of landscape fragmentation has reached massive proportions. Inselbergs situated in rainforest are ecologically highly-isolated, sharing almost no species with their surroundings. Today outcrops situated in the Ivorian rainforest region have successfully been invaded by introduced weeds (Porembski *et al.* 1996) that probably have used roadsides and other open sites as ways of access. Most prominent invaders are certain South American grasses *e.g. Axonopus compressus* and *Panicum laxum* that preferentially can be found in shallow soil-filled depressions and rock fissures. With regard to invasibility, shallow soil-filled depressions, crevices and rock pools are colonized preferentially by alien plants. Far less threatened by invading alien species are monocotyledonous mats and ephemeral flush vegetation.

Inselbergs occurring in the neighbourhood of villages and near pineapple plantations occasionally became infested by the bromeliad *Ananas comosus* that is able to colonize a broad range of habitats. When established (frequently due to dispersal by humans) on inselbergs in humid parts of West Africa, this South American species becomes highly competitive. Preliminary observations indicate that *Ananas comosus* is a strong competitor to the indigenous mat-forming Cyperaceae *Afrotrilepis pilosa*. At certain localities in the Ivory Coast *Afrotrilepis pilosa* has already succumbed to *Ananas comosus* which there is now the dominant mat-forming species (Plate 6).

Similar to the situation in the south-eastern USA, Ivorian inselbergs act as an evolutionary springboard for weedy species. Most of all short-lived species that are typical for exposed habitats on outcrops are nowadays widespread colonisers along roadsides and other ruderal sites. The Commelinaceae *Cyanotis lanata* is the most prominent representative of these inselberg escapees. This species preferentially colonizes stony road banks where it forms dense stands, like its natural growth sites on rock outcrops. Other inselberg escapees belong mainly to the Poaceae (*e.g. Sporobolus* spp) and Cyperaceae (*e.g. Fimbristylis* spp) which likewise colonize roadsides and open ground. At the moment, however, it is difficult to predict whether these taxa will in the long run become successfully established members of ruderal plant communities.

The Madagascan rock outcrop flora is well known for its high percentage of endemics. In particular, granitic and gneissic outcrops on the Plateau Central are famous as a ‘succulent paradise’ (Rauh 1995). In certain areas of Madagascar the neotropical *Agave sisalana* which is cultivated for fibre has invaded inselbergs where it has become a serious threat to the indigenous vegetation. Due to its large size and rapid propagation, it must be feared that *Agave sisalana* has the potential for out-competing numerous native outcrop species in Madagascar.

On the granitic islands of the Seychelles, granitic outcrops are occasionally colonized by alien plants. Species like *Cinnamomum verum* and *Alstonia macrophylla* are among the most important alien species (Fleischmann *et al.* 1996). However, it seems that these inselbergs are not yet seriously endangered by invasive plants because of extremely high degrees of native regeneration. Moreover, the aridity of this ecosystem and the low fertility of the soils limits the probability for the establishment of these mesic invaders.

**South America**

As in Africa, inselbergs occur over a broad range of South American vegetational and climatic zones. The threats to their frequently highly diverse flora are the same as in other tropical regions. More pronounced, however, are disturbance effects caused by tourists and rock climbers in certain regions. Inselbergs in the Brazilian Atlantic rainforest (*e.g.* the famous Pão de Açucar of Rio de Janeiro) are particularly prone to these anthropogenic pressures and are in the focus of the following considerations.

Deforestation and landscape fragmentation have caused the near disappearance of the Atlantic rainforest, leaving only *ca* 4% of its original extension. Rock outcrops situated in this region are exceptionally diverse and rich in endemics (Porembski *et al.* 1998). However, because of the deforestation these outcrops have lost their island-like attributes (*e.g.* their isolation). This enabled a certain number of exotic weeds to successfully invade inselbergs via roads and other ruderal sites. Of major importance in this respect are neophytic grasses (*Melinis repens, M. minutiflora*, *Panicum maximum*) that today are found throughout south-eastern Brazil on nearly all inselbergs. The two species of *Melinis* occur in dense populations and colonize with preference clefts and fissures and sites that showed signs of human disturbance (Meirelles *et al.* 1999). During rainless periods the then dry grasses

**Plate 1.** Rock outcrops like inselbergs attract much tourism interest, as is the case with the famous Pão de Açucar of Rio de Janeiro which is accessible by cable car. Situated within a large city, the Sugar Loaf still bears much of its typical vegetation.

**Plate 2.** Stone Mountain in Georgia is the largest granite outcrop in the United States. A cable car brings thousands of visitors each year to the summit of the mountain, which causes considerable damage to the unique plant communities.

**Plate 3.** Inselbergs surrounded by pastures form the last refugia of natural vegetation within eastern Brazil where the Atlantic rainforest has largely been destroyed.

**Plate 4.** Over much of West Africa the rainforest has disappeared. Today a mosaic of different forest succession types and agricultural land forms the typical surroundings of inselbergs.

**Plate 5.** Cattle grazing has become a serious threat to the vegetation of inselbergs in most parts of the tropics.

**Plate 6.** The invading bromeliad *Ananas comosus* has become a serious threat to native plants on inselbergs in the humid parts of West Africa.

enhance the risk of fire considerably. Near human settlements and depending on the extent of anthropogenic disturbance, further neophytes can be observed. Fairly frequent are leaf succulent species of the genera *Kalanchoe* and *Aloe* that sometimes occur as dominants on inselbergs. Preferred habitats of these introduced weeds which mainly escaped from gardens are crevices and monocotyledonous mats.

**Inselbergs as potential sources of future weeds**

As could be demonstrated in the south-eastern USA (Wyatt 1997), granitic outcrops in the tropics too may act as an evolutionary springboard for weedy plants. With deforestation and landscape fragmentation still advancing one can predict that the number of weedy escapees from inselbergs will increase. Most of all short-lived species on inselbergs with effective modes of dispersal represent suitable candidates that have the potential of becoming future weeds. In being adapted to cope with frequent disturbances these species already possess many key adaptive traits for a successful career as a ruderal plant. In contrast to this, it can be ruled out that strict inselberg specialists such as slow growing desiccation-tolerant vascular plants are of any importance in this respect. In West Africa some indigenous elements (*e.g. Cyanotis lanata*, *Dissotis rotundifolia*) of the widespread weed flora probably have been originally restricted to azonal habitat patches, such as granite outcrops. Other potential weeds from West African inselbergs are contained within the Poaceae and Cyperaceae that are richly represented within shallow soil-filled depressions and rock fissures. As the number of annuals on South American inselbergs is much lower their importance as sources of future weeds is considerably lower. However, it is remarkable that a number of local inselberg endemics is closely related to widespread ruderals. It is not clear, however, whether these endemics really have acted as sources of ruderal species.

## Conclusions and recommendations

The widespread opinion of rock outcrops as possessing no value for agricultural purposes and their religious importance had protected them over long periods. As has been shown above, alien plants are today a potential threat to the unique vegetation of inselbergs in different tropical regions. With increasing habitat destruction in the surroundings of rock outcrops, it can be expected that this ecosystem will become in the future more exposed to the invasion and establishment of exotic weeds. This could have serious consequences for the regeneration and long-term survival of many endemic species whose competitive ability is relatively low. On both South American and African inselbergs, the invasibility by alien plants is enhanced by human activities (*e.g.* fire, off-road driving) that destroy the natural vegetation cover and thus provide open, disturbed establishment sites. In particular, near plantations and villages inselbergs became in certain regions infested by exotics to such a large extent that an eradication of the alien plants is no longer possible without considerable effort. Scenarios like this are only to be avoided if damage to the vegetation of inselbergs is kept to a minimum. Up to now, inselbergs have only accidentally been included in conservation measures (Meirelles *et al.* 1999). Due to their highly unique ecological character they form local biodiversity hot spots and refugia of eminent importance for both flora and fauna. Granite outcrops therefore should be consequently integrated within management plans for nature conservation and particular priority should be given to outcrops situated within biodiversity hot spot regions.

***Acknowledgements:*** The author thanks various colleagues and institutions for extensive support and fruitful discussions. Financial support by the Deutsche Forschungsgemeinschaft is gratefully acknowledged. W Barthlott (Bonn) is thanked for his long-term encouragement to conduct inselberg studies.

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Journal of the Royal Society of Western Australia, 83:135-137, 2000

# Environmental weeds and granite outcrops: possible solutions in the "too hard basket"?

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## Abstract

Granite outcrops and the myriad plant communities found associated with them are particularly vulnerable to weed invasion. Undesirable impacts can result from many species or just one aggressive invasive species. Suggestions for weed planning and management are made in relation to granite outcrops, but knowledge gaps are discussed as well.

Keywords: environmental weeds, biotic threat, threatened flora, granite outcrops

## Introduction

Weeds are a major threat to the conservation of biodiversity in Australia, at species and ecosystem levels (Adair 1995). Known impacts for ecosystem function include competition for resources, prevention of recruitment, and altered fire regimes (Csurhes & Edwards 1998). Weed invasions are known to alter vegetation structure (Bridgewater & Backshall 1981) and have been implicated in the extinction of threatened species (Leigh & Briggs 1992).

Granite outcrops have unique features such as 'rock meadows' and crevices, which have high levels of floristic richness and endemism (Hopper *et al.*, 1997). Soils in these environments as well as around the base of outcrops often have seasonally high moisture levels. Combined with possible exposure to fertilizer drift and disturbance from fire or recreational activities, these habitats are likely to be highly vulnerable to opportunistic invasions from introduced plant propagules (Pigott & Sage 1997).

Studies of flora on granite outcrops in south-west WA have reported high numbers of exotic species (Hopper *et al.* 1997; Hussey 1993). Another granite outcrop study found a lower than expected proportion of weeds but the negative impacts of a few serious species (Pigott & Sage 1997). Increased proportions of weeds in relation to native species as well as evidence of aggressive species are alarming as both situations ultimately lead to breakdown of plant communities.

## Types of weeds

Some 54 exotic plants (presumed naturalized) have been recorded as associated with granitic habitats and soil types in WA (Anon 1998). The true number is likely to be higher as many weed invasions remain unvouchered (Pigott 1999), existing specimen labels lack sufficient details, or the habitat association has not been databased. Weeds worth noting here include *Asparagus asparagoides*, a Weed of National Significance (Thorp 1999), *Watsonia meriana* var *bulbillifera*, recorded in granite outcrops at Helena Valley (Hussey 1993), *Juncus bufonius* and *Casuarina cunninghammiana* subsp *cunninghammiana*, examples of herbaceous and woody weeds with high potential invasiveness and impact. For example many of the cosmopolitan weeds collected at Yilliminning Rock in south-west WA (Pigott & Sage 1997) are not included above. Some of the weeds recorded were *Aira careophyllaceae, Briza maxima, B. minima, Hypochoeris glabra, Romulea rosea* var *australis* and *Ursinia anthemoides.*

As in this study, weeds recorded for granite outcrops and surrounding vegetation are mostly annual species *e.g.* Poaceae (Hopper *et al.* 1997) or those with annual emergent cycle, such as the Iridaceae family (Hussey 1993). These plants are able to respond rapidly to changing environments through spread of wind-borne seed or underground reproductive parts. Spread of weeds by rabbits is common, introducing quite noxious species such as cape weed (*Arctotheca calendula*) to disturbed areas adjacent to healthy bushland (Hussey 1998).

## Examples of weed threats

For south-western Western Australia, some 5 species of threatened flora associated with granite habitats are recorded as threatened by environmental weeds (Brown *et al.* 1998; Sage & Pigott 1999). These are *Caladenia caesarea* subsp *maritima* ms, *Darwinia acerosa* and *Villarsia calthifolia* (all declared Rare), *Caladenia integra* (Priority 4) and *Goodenia drummondii* subsp *megaphila* (Priority 3). All are threatened by annual herbaceous weeds (unpublished data). An example of a woody weed affecting biodiversity conservation in granite outcrops is known from Victoria. Boneseed (*Chrysanthemoides monilifera* spp *monilifera*), another Weed of National Significance, is threatening populations of *Pterostylis truncata* at the You Yangs Regional Park, near Melbourne, Victoria (Miller & Eales 1999).

Rapidly spreading and aggressive environmental weeds threaten other special plants, such as the granite endemic *Pimelea graniticola* (formerly a P4). In this example *Freesia alba* x *leichtlinii* is altering the structure and potentially the composition of several plant communities at Yilliminning Rock in WA's wheatbelt (Pigott & Sage 1997).

To date there are no reports of endangered plant communities directly threatened by environmental weeds. This could largely be due to reporting and the relatively low numbers of vegetation studies on granite outcrops in the region. However for Victoria, rock outcrop vegetation (including granite) is threatened by 26 serious weeds (about 25% of local weeds) (Carr *et al.* 1992).

## Weed management planning

Weed management in granite outcrops is no different to weed management in other types of remnant vegetation. Identification and mapping of priority weeds is an important first step in the overall planning process (Brown 2000). Site-specific information on native plant communities, threatened flora and other special issues is essential. A grid system can be used to plot populations of weed species and other important information (Brown 2000). These maps can then be used by whoever carries out the control work, *e.g.* community group or local government workers. Choice of control methods is important as resources in local government and community groups are limited. Monitoring is also critical, particularly where eradication of a weed is the desired result (Brown *et al.* 1999). Weed management plans should relate or be integrated with management or rehabilitation plans for a remnant.

However, it is also important to consider the source of the weed and the likely impacts of any control work. Other weeds are also likely to invade, taking advantage of disturbance activity associated with the removal of primary target weeds. For degraded granite outcrops, intensive management should include fencing off stock, fire management and direct seeding of appropriate native species. Some excellent case studies are provided by Hussey (1998), listing steps to take for particular situations.

## Weed management techniques

The most difficult and controversial topic of remnant bushland management is undoubtedly weed control techniques. Is herbicide use appropriate at a particular site? If so, what products, rates and time of application will work best? These questions are intrinsically more difficult to answer than in an agricultural situation (Ainsworth 2000). In a crop or pasture the aim is to kill weeds whilst leaving a single crop species or a few pasture species relatively unaffected. By contrast in natural ecosystems the aim is to kill weeds whilst having no adverse effect on a wide range of different native species. Not only is the problem harder but herbicide use on most environmental weeds is commercially insignificant and therefore companies have no financial incentive to do the appropriate research. The most successful herbicides in use are those that selectively affect grasses, rather than those with a broad spectrum.

Pulling individual plants of serious environmental weeds can result in successful long-term control and improve recruitment of native species (Kirkpatrick 1986). Community groups can successfully apply techniques of pulling or killing individual weeds with a spot application of herbicide after careful planning. This practice could be applied to weed management on granite outcrops such as removal of *Freesia alba* x *leichtlinii* at Yilliminning Rock.

## Conclusions

Weeds are certainly a threat to the conservation of the unique biodiversity of granite outcrop communities. As for other specialized habitats, weeds are poorly recorded and collected for granite outcrops in WA, and particularly with respect to threatened species and communities. Careful planning can assist in removal of serious weeds and also play an important role in the management of key granite outcrop reserves. Some manual and chemical techniques are already available but there is a large knowledge gap in this subject. As in all areas of Landcare today, community groups have an important role to play in the conservation and management of granite outcrops. However resources for research into the ecology and management of environmental weeds in Australia are low and do not meet higher community expectations. It may be another example where weed science is in the "too hard basket".

***Acknowledgements***: The author gratefully acknowledges the assistance of N Ainsworth and the encouragement of P Withers.

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