

# Chapter 2

## How to Quantify Endemism

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### 2.1 Number of Individuals (N)

Counting or estimating the number of individuals in a population is only possible if the whole population is rather small and well documented. Because of the high extinction risk faced by small populations, the number of individuals should be continuously monitored. The IUCN Red List of threatened plants (Baillie et al. 2004; Walter and Gillett 1998, see also IUCN on the internet) uses information about the number of individuals to categorize level of threat experienced. In practice, as the examples that follow will show, almost all taxa with low numbers of individuals are categorized as critically endangered. Some spectacular examples of plant species which at the moment are represented by only a few individuals have been published, and we detail some of these below. Many but not all examples of plant species represented only by few individuals are restricted to marine islands. Unfortunately, some other plant taxa recently disappeared altogether from the globe – no longer having a single living individual. Avoiding extinction cannot be guaranteed, regardless how intensive the efforts to rejuvenate the species are.

The following examples are primarily in 2011 and 2012 adopted from the very important IUCN Red List ([www.iucnredlist.org](http://www.iucnredlist.org)). However, some of the assessments are 10 or 20 years old and, therefore, cannot be assumed to represent recent conditions and should be updated. These examples are ordered in a geographical manner: from west to east and/or north to south, beginning with North America.

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### 2.1.1 California

*Cercocarpus traskiae* is a shrub or small tree, living on Catalina Island. Only a single wild population still exists, consisting of seven individuals in a canyon covering an area of approximately 250 km<sup>2</sup> (World Conservation Monitoring Centre 1998; Oldfield et al. 1998).

### 2.1.2 Mexico

*Diospyros johnstoniana* (syn. *D. xolocotzii*) is endemic to Michoacan de Ocampo, Mexico (Madrigal Sánchez and Guridi Gómez 2002; Madrigal Sánchez and Rzedowski 1988). It is known only from an area of 25 ha. Despite many surveys since 1998, no other locations have been found. In 2005, a census for this species found 36 trees, but in 2006 only 34 individuals remained. One was felled for agricultural expansion, and the other was severely damaged by human-caused fire in 2006 and died in the same year. The remaining population is fragmented.

*D. johnstoniana* grows in subtropical dry forest and woodland. It is a plant with a low number of fruits observed and a low rate of pollination success. It reaches sexual maturity at the age of about 25 years old. There is no trade in this species. But, the fruit is commonly eaten, and the species can be used as an ornamental plant. The plant can also be used for the genetic improvement of other species in the same genus. The species is severely impacted by habitat loss through agriculture, which directly threatens the remaining trees. Clear-cutting in the area is common practice to open new areas for agriculture. Furthermore, the presence of cattle and goats in the area threatens the remaining trees: livestock eat young plants and near-ground level foliage, severely affecting the surrounding habitat and compacting the ground. The human population is increasing in the area, and urban expansion is ongoing. This has several impacts on *D. johnstoniana*, as there is an increase in solid waste, human-caused fire, wood collecting, and the introduction of alien plant species, e.g. *Eucalyptus* trees. The species is included in Mexico's official list of species at risk, in the category of Special Protection. However, this is not enforced for this species and there is still no specific programme to protect this species (Villaseñor Gómez 2005; [www.iucnredlist.org](http://www.iucnredlist.org)).

*Mammillaria sanchez-mejoradae* is a critically endangered cactus endemic to a single area in Mexico. Since the discovery of the species more than 20 years ago, the population has diminished by an estimated 75 %. The wild population currently is estimated at less than 500 plants and, despite legal protection of the species, the population continues to be highly threatened by illegal collecting ([www.iucnredlist.org](http://www.iucnredlist.org)).

*Acharagma aguirreanum* is a cactus which occurs in semi-desert on calcareous rocks at an altitude of about 1,500 m in Sierra de la Paila over a range of 1 km<sup>2</sup>, in Coahuila, Mexico. The total population numbers less than 100 individuals. Illegal collecting is a major threat (Anderson et al. 2002; Anderson 2001; Hunt 1999; Glass 1998).

### 2.1.3 *Costa Rica*

The present adult population of the palm *Cryosophila cookii* is estimated to number less than 100 individuals. The species is living in atlantic lowland rainforest near Limon, Costa Rica. Habitat conversion to arable land has caused a major population decline. Logging, increasing settlements and decline in the populations of dispersal/pollination agents have also contributed to losses. The palm heart is eaten locally for medicinal purposes (Evans 1998; Oldfield et al. 1998).

### 2.1.4 *Ecuador*

*Centropogon cazaletii* is an endemic herb or subshrub in Ecuador where it occurs in high Andean forest (3,500–4,000 m). It is known from two collections in Napo Province, both made inside the Reserva Ecológica Cayambe-Coca. One was in the surroundings of the Laguna de San Marcos; another from Oyacachi. After two field trips of experts to search for the species in 1998, no individual was recorded around the Laguna and only four individuals were found in Oyacachi.

Although the taxon occurs inside a protected area, it might be threatened by fire set by humans around the Laguna de San Marcos and deforestation around Oyacachi.

Another species of the same genus, *Centropogon pilalensis* is also endemic to Ecuador. It is known only from one population of less than 50 individuals in Cotopaxi province where it is living in high Andean forest and dry paramos (Moreno and Pitman 2003; Valencia et al. 2000).

In the Red List of the IUCN ([www.iucnredlist.org](http://www.iucnredlist.org)) many critically endangered species of Ecuador are only known from the type collection and nobody knows how many of them have meanwhile become extinct (cf. Valencia et al. 2000).

### 2.1.5 *Juan Fernandez Islands, Chile*

In the following (Fig. 2.1), Skottsberg tells the story about a journey to the last living individual of *Santalum fernandezianum* which he saw and photographed on Robinson Crusoe Island (also known as Masatierra) in the year 1908.

### 2.1.6 *Cerrado, Brazil*

*Dimorphandra wilsonii* is a critically endangered tree, found only in Minas Gerais State in southeast Brazil. Before 2010 (last assessment 2006), there were only some ten mature trees and six juveniles growing in the wild, in the middle of pastures of *Brachiaria*, an alien invasive grass species, in a strongly deforested and fragmented

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IN MEMORY OF  
ALEXANDER SELKIRK,  
Mariner,  
A native of Largo in the county of  
Fife, Scotland.  
Who lived on this island in complete  
solitude, for four years  
and four months.  
He was landed from the Cinque  
Ports galley, 96 tons, 16 guns, a.d.  
1704, and was taken off in the  
Duke, privateer, 12th Feb. 1709.  
He died Lieutenant of H.M.S. Wey-  
mouth, a.d. 1723, aged 47 years.  
This tablet is erected  
near Selkirk's lookout by  
Commodore Powell and the  
officers of H.M.S. Topaze, a.d. 1868.

This is the historical basis of Defoe's work. It may look somewhat meagre, but one can understand that poor Selkirk had to work to preserve his life. What a mental trial, not to hear a word spoken by another, not to see a human soul for four years and four months! Thus his fate was pretty adventurous even if told without embellishment. On the other hand, he left his ship at his own request, discontented with the life on board. Besides, he might have chosen a worse place. The climate is very mild, it rains just enough, snow or frost is unknown. A few plants are edible, and the goats, which were much more numerous in Selkirk's time than they are now, provided him with fresh meat.

Through a walk lined with marvellous trees and precious ferns we pass the natural gate and are on the south side of the island. Down it goes, almost as precipitous as on the other side. We have a magnificent view of the coast and Santa Clara, where a tremendous surf roars. Soon we came out of the forest,

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and continued on to the barren slopes near the sea. The vegetation here is more like that of a steppe, with short grass and some heath-plants; only along the streams is there a bright green strip, a mosaic of gigantic pangue-leaves. And we bent the thick stalks at the side and drank to the health of Masatierra and Robinson and the whole world. There is only one way back, the way we had come; it was getting dark and we hurried on through showers of rain; large drops splashed on the heads of the rosette-trees, the soil emitted strong, peculiar scents. The last part of the way we slid down in the slippery clay.

Above I happened to mention the sandal-wood. The discovery of this kind of wood, famous since the days of Solomon, on Juan Fernandez most surely attracted notice. We have no reports of it previous to 1624, when, according to Burney, L'Heremite reported sandal-trees in great number. According to another authority ships used to visit the place as early as 1664 to bring the valuable wood to the coast, where it was highly appreciated. One did not think of preserving anything; a hundred years later it was hardly possible to find a living tree, and in the beginning of last century it was regarded as extinct. No botanist had ever seen the leaves or flowers. Suddenly F. Philippi in Santiago got some fresh twigs brought to him in 1888; he found them to belong to the genus *Santalum*; the species being new, it received the name of *S. fernandezianum*. The general interest in the tree was increased, but nobody told where the branches came from; a living tree was still unknown. Only in 1892 did Johow

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get news of one; a colonist had found it in Puerto Ingles, high up in the valley. He was the first botanist who saw this plant. It is easily understood that I was anxious to become the second. How many people had looked for other specimens! All their efforts were fruitless; as far as we knew Johow's tree was the very last. If it were still there!

The man who brought Johow to the spot still lived, and after we had explained our purely scientific interest he promised to send his son with us. It would have been more than uncertain for us alone to look for a single tree in a valley clad with virgin forest.

It is possible to climb across the ridge that separates Cumberland Bay from the English Harbour, but we preferred to go there with a well-manned boat. The landing is, as in most places on the islands, performed with some risk; one must jump just at the right moment, and there has to be a good crew in the yawl, or the boat would be thrown on the rocks and capsized. Perhaps I ought to mention that the place in question only has the name of a harbour. We walked up the valley and made an ascent of the western side; the place is so steep that one is forced to grasp the trees and shrubs to get a foothold. Our guide stopped, looked round for a minute, down a few hundred yards, and we had reached our destination. The last sandal-tree. Absolutely the last descendant of *Santalum fernandezianum*. It is so queer to stand at the death-bed of a species; probably we were the last scientists who saw it living. We look at the old tree with a religious respect, touch the stem and the firm, dark green leaves—it is not only

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an individual, it is a species that is dying. It cannot last very long. There is only one little branch left fresh and green; the others are dead. We cut a piece to get specimens of the peculiar red, strongly scented wood. A photo was taken, I made some observations on the place, and we said good-bye. Should I happen to go there once more I shall not see the sandal-tree; it will be dead and its body cut up into precious pieces—curiosities taken away by every stranger.

Fig. 2.1 Travelogue of Skottsberg about a journey to Robinson Crusoe Island where he visited the last individual of *Santalum fernandezianum* (Skottsberg 1911: 140–143)

region. The species is threatened by deforestation for charcoal production, which is the most important threat to the Cerrado Biome. There is also deforestation for pasture establishment and any seedlings face competition from *Brachiaria*. People also deliberately eradicate this species because its seeds can be harmful to pregnant cattle (cf. Moreira Fernandez 2006; Alves 2004, Mendonça).

### **2.1.7 Puerto Rico**

Some ten trees of *Auerodendron pauciflorum* are recorded on Puerto Rico where a single small population is found in woodland on a limestone cliff. Most individuals occur on land owned by a development company. The trees have not been seen to seed but efforts are being made to cultivate the plant from tissue culture. Information needs to be updated because the last year assessed was 1998 (cf. World Conservation Monitoring Centre 1998; Oldfield et al. 1998).

### **2.1.8 Anegada, Virgin Islands**

Anegada belongs to the British Virgin Islands and is located northwest of Puerto Rico. The population of *Acacia anegadensis*, endemic to Anegada, has been reduced by past exploitation for resin. The potential extent for *A. anegadensis* is approximately 25 km<sup>2</sup> because fieldwork has determined that the species is found primarily on limestone and scattered in sand dune habitats. Different numbers of individuals have been recorded, from a few mature trees to locally common (Baillie et al. 2004; Clubbe et al. 2003). However, many human and natural effects such as habitat destruction, livestock, invasive species, or hurricanes cause a risk of extinction. Anegada is under severe development pressure resulting in both loss of habitat to residential and tourism infrastructure, and further fragmentation due to upgrading and construction of new roads. Loose cattle, goats and donkeys roam the island and damage the habitat through trampling and grazing. Natural disasters are a current and on-going threat e.g., hurricanes and coastal inundation (Clubbe et al. 2003; Smith-Abbott et al. 2002; Proctor and Fleming 1999; D'Arcy 1971).

### **2.1.9 St. Helena**

*Trochetiopsis erythroxylon* (Redwood) is a tree endemic to St. Helena and is extinct in the wild. After settlers arrived, the species was extensively exploited for its excellent timber and bark which was used for tanning hides. By 1718, the species was already extremely rare. Further losses occurred when flax plantations began in the late 1800s. By the mid of the twentieth century, only one redwood individual

survived and this single tree is the source of all the St. Helena's Redwoods known in cultivation today. Inbreeding depression and a depauperate gene pool are the most serious threat to the future survival of this species.

*Trochetiopsis ebenus*, called Saint Helena Ebony, is a critically endangered shrub found only on this island. The species declined sharply in the eighteenth century, mainly due to overgrazing by goats, and was once thought to be extinct. In 1980, two shrubs were rediscovered on the island. All existing material in cultivation is derived from these two individuals. This species was previously burned to produce mortar. The wood was also used in the nineteenth century for turnery and ornament making and was introduced to British gardens around 1800.

The hybrid of cultivated plants of *Trochetiopsis erythroxylo* × *ebenus* may provide the only chance of survival for this part of the gene pool (Cairns-Wicks 2003).

Also *Mellissia begoniifolia* is a critically endangered shrub found on St. Helena Island. The wild population currently numbers some 16 individuals. The size of this population fluctuates year by year, largely depending on weather conditions, but also on predation pressure. Currently only one plant in the population can be considered mature and it is from this that the majority of seeds has been collected to establish plants in cultivation. Threats include attacks from aphids and caterpillars, mice and rabbits. Growing in such a dry environment, the plants are also prone to drought ([www.iucnredlist.org](http://www.iucnredlist.org)).

*Nesiota elliptica* was a small endemic tree on St. Helena that grew on the highest parts of the island's eastern central ridge. It became very rare in the nineteenth century and by 1875 only 12–15 trees were recorded. The species had been thought to become extinct until a single tree was discovered in 1977. This tree was found to suffer from fungal infections which might have been exacerbated by damage sustained during attempts to conserve it. Because cuttings were difficult to root, because the species very rarely set good seed as it was almost completely self-incompatible, and because of fungal infections the species died in the wild in 1994 and became globally extinct in 2003. No other live material, plants, seeds or tissues, remain in local or international collections. The extinction of this plant has been attributed to habitat loss through felling for timber and to make way for plantations.

### 2.1.10 Germany

*Oenanthe conioides* is an annual or biannual pioneer herb living at the Elbe river in and nearby Hamburg. The number of individuals is fluctuating from year to year; normally some hundred individuals are counted. A serious problem for the survival of this species is the destruction of habitat including alteration of water depth, currents and tides, caused by governmental authorities of the harbour of Hamburg and river traffic. Different neophytes inhabit the remaining natural habitats which in this case obviously do not cause any problem to *Oenanthe conioides*. Fortunately, the species is building a soil seed bank in muddy substrates (Below et al. 1996).

### 2.1.11 *Alborán, Spain*

The annual herb *Diploaxis siettiana* was last seen in 1974 in the wild. At that time seeds were fortunately collected on the island of Alborán, south of Spain's mainland, where the plant was growing in a tiny area around a helicopter platform. The seeds were multiplied at the University of Madrid, and distributed to some botanical gardens. Under cultivation conditions high germination rates can fortunately be achieved. A re-introduction programme has been started and has become more and more successful since 1999 (Montmollin and Strahm 2005).

### 2.1.12 *Sicily Archipelago, Italy*

Some 30 trees of *Abies nebrodensis* grow at an altitude of 1,500 m altitude on limestone soil. The Madonie Mountains, Sicily, rising to 1,980 m, were once covered by *Abies nebrodensis*. Degraded natural habitat, the poor health of specimens propagated in tree nurseries, the limited population size, and threat from fire represent the biggest threats to the species. Hybridization with non-native firs results in genetic contamination.

Foresters immediately initiated conservation measures. However, soil degradation in the natural habitat has made re-introduction difficult. Researchers from Palermo University are currently investigating the species' ideal growth conditions. The species has grown well in several European botanic gardens. An EU LIFE-financed project is being carried out to conserve the existing population. The project includes implementing an action plan which would include forest management, conservation, and the gradual elimination of non-indigenous fir species. The goal is to stabilize the current population and improve the survival rate based on natural reproduction. Their location within the Madonie Regional Park guarantees some level of protection. In 1978, following seed collection, the forestry service cultivated 110,000 young trees in a nursery. Since the survival rate in nature is extremely low, an adoption programme was set up in parallel. 40,000 young plants have been planted in the Botanical Garden of Palermo, Sicily, as well as in gardens and second homes in the Madonie Mountains, slightly away from their natural area of distribution. Several mature trees also grow in botanic gardens and arboreta elsewhere in Europe. For *ex situ* cultivation of *A. nebrodensis*, areas should be selected that are not home to other fir trees to prevent genetic contamination (Farjon et al. 2006; Montmollin and Strahm 2005; Virgilio et al. 2000; Ducci et al. 1999).

*Bupleurum dianthifolium*, a small shrub, is endemic to the island of Marettimo, part of the Egadi archipelago, west of Sicily, Italy. It grows in only a few locations on the northern side of the island in an area of 5 km<sup>2</sup>. It is estimated that approximately 300–500 individuals remain. The small, cushion-shaped perennial shrub grows on calcareous cliffs at an altitude of 20–600 m, preferring north-facing slopes and growing in the cracks of limestone rock faces.

This species is considered to be an old, paleoendemic taxon, which means that it was once much more widely distributed than today, and probably grew throughout the mountains of the Mediterranean when the region had a tropical climate. The plant reproduces from seeds only, a common characteristic of plants growing in such habitats. Mist is probably its main source of water (Gianguzzi and La Mantia 2006; Gianguzzi et al. 2003; Fabbri 1969). In this case global warming might help this species to survive.

### **2.1.13 Malta Archipelago**

*Cheirolophus crassifolius* has a patchy distribution along the northwestern and southern cliffs of the islands of Malta. The total wild population is estimated at a thousand individuals. This perennial shrub is confined to coralline limestone of seaside cliffs and scree, growing in full sun. The so-called Maltese Rock-centaury is the National Plant of Malta. The species displays some ancient traits in its habitat preference and flower morphology, and is considered to be paleoendemic, which means that it speciated in the distant past and may have been much more widely distributed than today.

The species is threatened by a number of factors. First, it is rare to find juvenile plants of this long-lived species, possibly due to the larvae of an unidentified moth observed attacking the developing fruits. Second, the habitat is under threat from quarrying, as fragile boulder cliffs collapse from the pressure wave of nearby dynamite explosions. Third, a number of sites have been affected by human disturbance, especially those most easily accessible (Stevens and Lanfranco 2006; Lanfranco 1996, 1995).

### **2.1.14 Cyprus**

*Scilla morrisii* is found only in three locations on Cyprus. Less than 600 individuals are known to exist and the survival of the species depends on conservation of the remaining oak forests. Logging for timber, road construction and expansion of farmland has considerably reduced these forests and large, old oak trees have become rare and scattered where there used to be a closed forest cover. Currently the *S. morrisii* population does not seem to be declining. The species entered the 2006 Red List as critically endangered (Kadis and Christodoulou 2006; Montmolin and Strahm 2005; Meikle 1977, 1985).

*Centaurea akamantis* is only found on the Akamas peninsula in the northwestern part of Cyprus. There are only two small fragmented subpopulations covering an area of less than 1 km<sup>2</sup>, and the extent and quality of its habitat is declining. One subpopulation has only 50 individuals, and the other approximately 500. The subpopulations are geographically isolated from each other and if one of them disappears it is unlikely to be recolonized from the other.



This semi-woody herbaceous plant colonizes steep and humid limestone cliffs in the Avakas and Argaki ton Koufon (“Stream of Snakes”) Gorges. *Centaurea akamantis* is characterized by an extremely long flowering and fruiting period.

The number of mature individuals has remained stable since 1993, when the species was first described, although the increasing number of visitors to the Akamas peninsula is contributing to a decline in habitat quality. Grazing poses a serious threat, even though it is not permitted in these areas (Kadis and Christodoulou 2006).

### 2.1.15 *Other Extremely Rare Plants on Mediterranean Islands*

Montmollin and Strahm (2005) published a booklet about the so-called “Top 50 Mediterranean Island Plants: wild plants at the brink of extinction, and what is needed to save them”. Many of the plants listed are restricted to a few or single populations with countable numbers of individuals. Examples are *Silene hecisiae* (Aeolian Islands, c. 430 individuals), *Apium bermejoi* (Minorca, <100 ind.), *Arenaria bolosii* (Majorca, <200 ind.), *Euphorbia margalidiana* (Ses Margalides, Balearic Islands, <200 ind.), *Ligusticum huteri* (Majorca, <100 ind.), *Bupleurum kakiskalae* (Crete, c. 100 ind.), *Convolvulus argyrothamnos* (Crete, c. 30–35 ind.), *Horstrissea dolinicola* (Crete, a few dozen ind.), *Allium calamarophilon* (Euboea, a few ind.), *Minuartia dirphyia* (Euboea, <250 ind.), *Ribes sardoum* (Sardinia, c. 100 ind.), *Bupleurum elatum* (Sicily, c. 400–600 ind.), *Zelkovia sicula* (Sicily, c. 200–250 ind.).

### 2.1.16 *Algeria and Tunisia*

The orchid *Serapias stenopetala* is found in small, scattered populations of less than 250 individuals in total in Algeria and Tunisia ([www.iucnredlist.org](http://www.iucnredlist.org)). This critically endangered species is threatened by the destruction of its habitats through building of new roads, trampling and grazing by livestock, and the creation of an Animal Park in Brabtia, Algeria. Trade of all orchids is regulated under Annex B of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and a specific policy of protection and conservation is urgently needed (De Bélair 2009; De Bélair et al. 2005; De Bélair and Boussouak 2002).

### 2.1.17 *South Africa, Namibia*

*Aloe pillansii* is a critically endangered tree aloe occurring primarily in the mountainous area of the Northern Cape, South Africa and southern Namibia. A decline in the population has reduced the numbers to less than 200 mature individuals. No recruitment has been recorded at any of the main sub-populations probably due to

the impacts of grazing by goats and donkeys, and the older plants are dying. Today, the species is the focus of a new survey and possible reintroduction programme by members of the IUCN/SSC Southern African Plant Specialist Group (Loots and Mannheimer 2003; Hilton-Taylor 1998; Williamson 1998; Menne 1992).

Two collections were made of *Kniphofia leucocephala* in 1970 near Lake Msingazi in northern KwaZulu-Natal, South Africa. The plant grows in coastal wetlands (Bajinaith 1992). No further plants were collected until 20 years later when a new population was discovered in a wetland that was being planted to timber trees. By that time the habitat had almost completely been transformed into commercial forestry plantations and urban expansion. Hence it is impossible to guess what the past range and population size have been. The population discovered in 1990 is still the only known living population, and the wetland where it grows is owned by a forestry company and is completely surrounded by plantations (cf. Scott-Shaw 1999). In 1991 there were about 70 plants, a number declining to about 21 individuals in 1998. Fortunately, the forestry company developed a strong conservation focus, the wetland was declared a natural heritage site, considerable effort has been put in since 2000 to rehabilitate the wetland and the forestry company implemented a conservation management plan. The result is that the *K. leucocephala* population is now thriving and numbers have increased to around 350 individuals (www.platzafrica.com and www.iucnredlist.org, downloaded 21st of September 2010).

Only a single individual of the Cycad *Encephalartos woodii* – now extinct in the wild – was ever found in South Africa. Its extinction in the wild may have been hastened by over-exploitation for medicinal purposes by local people. There is no likelihood of ever reintroducing the species back into the wild as there are only male plants in existence, and the risk of theft would be too great (Donaldson 2009; Baillie et al. 2004). Unless a female plant is found, *E. woodii* will never reproduce naturally. However, the next best thing has been accomplished. *Encephalartos woodii* forms fertile hybrids with *E. natalensis*. If each offspring is subsequently crossed with *E. woodii* and the process is then repeated, after several generations, the female offspring will be close to a female of *Encephalartos woodii*. Genetic analysis of chloroplast DNA of F1 hybrids between *E. woodii* and *E. natalensis* showed that all chloroplasts are inherited from the female *E. natalensis*, indicating that multigenerational hybrid offspring would have *E. natalensis* chloroplasts and could never be pure *E. woodii* (Cafasso et al. 2001; Osborne 1986; Giddy 1984).

### 2.1.18 Tanzania

*Toussaintia patriciae* is an endangered species known from less than 30 trees in the Udzungwa Mountains National Park and West Kilombero Nature Reserve (Deroin and Luke 2005). The plant occurs in very low numbers where found, though it is cryptic when not flowering and hopefully may be more common than is currently known. It is considered relatively secure at present, as the population is present

in protected areas and occurs above the altitude at which firewood collectors are allowed to operate. However, this species could become threatened very quickly if human activities, especially wood collection, increase (Eastern Arc Mountains & Coastal Forests CEPF Plant Assessment Project Participants 2006).

*Aloe pembana* is another example of an endemic plant of Tanzania with few individuals. The species is confined to a small area on Pemba Island (Misali Island Conservation Area). The total population numbers between 50 and 250 mature individuals which grow in scrub vegetation right on the beach. It is threatened by fishermen through trampling and collecting for medicinal purposes. There is also increasing tourism on the island which may have an impact (Eastern Arc Mountains & Coastal Forests CEPF Plant Assessment Project Participants 2006; Carter 1994).

### 2.1.19 Kenya

*Afrothismia baerae* is confined to Shimba Hills National Reserve, Kenya. A single population of seven plants (Cheek 2003) was recorded only from a tiny area less than 0.5 m in diameter. The parasitic plant is growing in an evergreen coastal forest remnant on the roots of *Zanha golungensis* (Sapindaceae). Species in this parasitic genus are often very hard to find because of their scarcity, diminutive stature and the fact that unless flowering the plants are invisible above ground. Flowering only lasts for a month or so and plants may not flower every year. The area was logged in the past by the Forestry Department but meanwhile that has been stopped and the impact of elephants was being reduced (Eastern Arc Mountains & Coastal Forests CEPF Plant Assessment Project Participants 2006; Cheek 2003).

### 2.1.20 Madagascar

Recent surveys revealed only a few individuals of the orchid *Grammangis spectabilis* in its habitat in SE Madagascar. The species lives on large trees, in seasonally dry, deciduous forest or woodland (Cribb and Hermans 2009).

A few individuals of two other orchids have been recorded in the plateau region of the same island. *Erasanthe henrici* var. *isaloensis* inhabits humid forests at 800–1,000 m. *Angraecum longicalcar* is living in xerophytic vegetation and in gallery forest at 1,000–2,000 m on trachyt rock (Cribb and Hermans 2009). Pressure on the relating vegetation types means extinction risk for these orchids.

Only few adult specimens have been recorded in a couple of other plant taxa in Madagascar, including e.g. *Dalbergia bathiei*, *Delonix velutina*, *Phylloxylon xiphoclada* (cf. Labat & Moat in Goodman and Benstead 2003). Fortunately, in some cases there is hope to find other populations of these and other rare plants in regions where botanists or biogeographers have not been before.

### 2.1.21 *Mauritius*

On the island of Mauritius most native plant communities – almost all forest – have been destroyed and converted to sugar-cane plantations or else they are badly degraded. The remaining forests are strongly influenced by different neobiota such as rat, deer, pig, tenrec, macaque monkey, mongoose, man and different neophytes. The decline of some tree species may be due to habitat destruction, timber harvesting, introduced pigs and macaques which disturb and eat the fruits, and introduced plants. As a result, in 1973 there were only 13 very old *Sideroxylon grandiflorum* specimens recorded, a tree endemic to the island. Fortunately, to aid the seed in germination, botanists and foresters now know to use turkeys and gem polishers to erode the pericarp of the fruits to allow germination (Hershey 2004; Rouillard and Guého 1999; Walter and Gillett 1998; Davis et al. 1994; Staub 1993).

*Hibiscus fragilis* is another example of the many critically endangered plant species unique to the island of Mauritius. There are only c. 40–60 mature plants left at the two known localities and they are not regenerating because of introduced alien species. Although the species is easy to propagate from cuttings, long-term maintenance in botanic gardens is problematic because the species hybridizes easily with the introduced garden plant *Hibiscus rosa-sinensis*. The only hope for the continued survival of the species is management of the wild populations, clearance of the alien invaders and restocking from known cultivated sources (Bachraz and Strahm 2000; Bosser et al. 1987).

### 2.1.22 *Sri Lanka*

*Cryptocoryne bogneri* is an aquatic plant still living on Sri Lanka. The species was believed to be extinct as it had not been recorded since 1900. However, in 1999 a researcher discovered a new population of this species ([www.iucn.org](http://www.iucn.org), downloaded 21 September 2010). More than 250 individual plants were recorded in a very small area of a 75 ha patch of swamp forest on the edge of an extensive rubber estate. This species is not commercially exploited and the present owner of the site location is conserving the land as the area contains many other endemic species. The water level at the site fluctuates naturally but it is not known that there is regular fluctuation in the numbers of mature individuals. Expanding agricultural activities and human settlements have impacted the other sites where this species was previously recorded (cf. Jacobsen 1987; De Wit 1975).

### 2.1.23 *China*

*Abies beshanzuensis* and *Abies yuanbaoshanensis* are two critically endangered species of China, the first living in Baishanzu Mountain, Zhejiang, the second in

Yuanbao Mountain, Guanxi. Both species occur outside the general range of fir species. Only five living specimens of *Abies beshanzenensis* have been recorded in a mixed forest in the wild. Major threats are expansive agriculture and fires, coupled with poor regeneration. These are thought to have largely been responsible for the decline of the species (Conifer Specialist Group 1998; Fu and Chin 1992). The number of individuals of *Abies yuanbaoshanensis* is estimated at ~100. Young trees of this plant are very rare and regeneration is hampered by long coning intervals, seed predation by squirrels and competition with *Sinarundinaria* species. Fortunately, effective protection of the population is given by the Forest Department (Hilton-Taylor 2000; Fu and Chin 1992).

### 2.1.24 *Philippines*

*Rafflesia magnifica* is among the group of plants that produce the largest single flowers in the world. Only a few individuals of *R. magnifica* have been recorded, all of them male. The species is listed as critically endangered because of its very small population size and restricted range. Construction of a national highway in the area has facilitated easier human access and disturbance poses a threat to this rare plant as its unusual flowers are often treated as visitor attractions. Parts of the forest are also being converted into banana plantations (Madulid et al. 2008, 2005).

### 2.1.25 *New Caledonia*

First discovered in 1988, *Pittosporum tannianum* from New Caledonia was thought to have gone extinct in the 1990s. But, in 2002 the species was rediscovered. Three individuals are known to exist in the wild today giving this species the opportunity to avoid extinction. Loss and degradation of its sclerophyllous forest habitat is the main threat to the species (Baillie et al. 2004; Tirel and Veillon 2002).

### 2.1.26 *Vanuatu*

*Carpoxydon macrospermum* occurs on the islands Aneityum, Tanna and Futuna of the Vanuatu Archipelago. Approximately 40 individuals exist in lowland rainforest and another 120 mature trees are cultivated around villages. Regeneration is moderate. This palm tree is of ornamental interest (Dowl 1998).

### 2.1.27 *New Zealand*

There are only two species in the genus *Chordospartium*, both endemic to New Zealand. *Chordospartium muritai* is confined to a site in Clifford Bay in Marlborough. Only 12 wild plants have been counted in a remnant of coastal forest (Oates and Lange 1998; Hunt 1996; Purdie 1985).

### 2.1.28 *Fiji Islands*

*Acmopyle sahniana* is a critically endangered species of Central Viti Levu, Fiji. Very few individuals are still living on forested mountain ridges. There is only little evidence of regeneration (Conifer Specialist Group 2000; Oldfield et al. 1998; Smith 1979).

### 2.1.29 *Hawaii Islands*

Listed as critically endangered, the forest tree *Caesalpinia kavaiensis* is found only on the islands of Hawaii and O'ahu. Only some 60 individuals are known, however, many of them are old and probably non-reproductive. Threats include pigs, cattle, deer, goats, introduced plants, rats, fire, volcanic eruptions, sheep, black twig borer and collection by humans (Brueggemann and Caraway 2003; Wagner et al. 1999).

*Hesperomannia arbuscula*, listed as critically endangered, is a small shrubby tree known only from the Hawaiian islands of Maui and O'ahu. There has been an observed population decline of 25–50 % over the last years and the number of known individuals is less than 25. Main threats to the species are habitat degradation by pigs, predation by rats, and trampling or collecting by humans (World Conservation Monitoring Centre 1998; Oldfield et al. 1998).

The whole genus *Hibiscadelphus* is endemic to the Hawaiian Islands. Seven species have been described. Three of them have become globally extinct, the other four species are listed as critically endangered. One of them is *Hibiscadelphus distans*. Occurring as a shrub or small tree, the species is known from a single population on Kauai. Fewer than 20 individuals are recorded in a patch of dry forest (World Conservation Monitoring Centre 1998; Wagner et al. 1990, 2005; Gentry 1986).

Gentry (1986) reported on a couple of species in the tropics which are known from a single to a few individuals only. At least some 100 vascular plant taxa worldwide are known to have become extinct in historical times and more than 1,500 are classified as extinct in the wild or critically endangered. Unfortunately, and in contrary to the goals of CBD, the number of extinctions is still increasing (Baillie et al. 2004; [www.iucnredlist.org](http://www.iucnredlist.org)).

## 2.2 Number of Endemic Taxa (E)

The species is regarded as a fundamental unit of biodiversity, species richness as the fundamental dimension of biodiversity, and richness of endemic species in a region as one of the fundamental characteristics of Biodiversity Hotspots and value to nature conservation policies. A severe but frequently ignored complication when counting the number of species or measuring the richness of endemic species is the lack of a universally applied definition of what a species is. For any given assemblage, the numbers of species may potentially differ, dependent on the species concept (cf. Gaston 1996a; Mallet 1996). In practice, one can find counts of endemic species and subspecies or varieties for many regions in the world on the internet, in books and scientific journals. What we normally do not know is if these various numbers are comparable and if the taxa have been split into many, or lumped to fewer, species or subspecies. As an interim result we have to accept that comparing numbers of endemic taxa in different geographical regions might result in biased conclusions; the number of endemic subspecies in one geographical region may be comparable with the number of endemic species in another one.

If we ignore such systematic biases and if we use the number of endemic vascular plant taxa – including very often endemic species and subspecies – then China (15,000–18,000 endemics), Indonesia (17,500), Colombia (15,000), Australia (14,000), Mexico (12,500), Venezuela (8,000), Madagascar (6,500), India (5,000), Peru (5,400), Ecuador (4,000), Bolivia (4,000), and the USA (4,000) are the countries with the highest numbers of endemic plant species (numbers rounded, see Huang et al. 2011 for China, and Groombridge and Jenkins 2002 for all these countries).

## 2.3 Proportion of Endemics (E/S)

Regional endemism is often characterised by the proportion of endemics: the number of endemic taxa (E) divided by the total number of taxa (S) [as a percentage:  $(E \times 100 \%) / S$ ]. Many islands have higher proportions of endemics than any mainland region, e.g. Madagascar, Hawaii Islands, New Caledonia, New Guinea, New Zealand, St. Helena, etc. (cf. overview in Hobohm 2000).

In the biogeographical context, one has to be very careful when comparing proportions (Magurran and McGill 2011; Ungricht 2004; Hobohm 2000, 2008). For example, 15 % of the whole vascular flora of Vanuatu Island is endemic whereas the rate for Corsica is 6 %. But on their own, these numbers do not allow any conclusion concerning the richness of endemic taxa in the two regions. Both islands are inhabited by nearly the same number of 150 endemic taxa, but the size of Vanuatu (14,763 km<sup>2</sup>) is almost twice the size of Corsica (8,723 km<sup>2</sup>). This means that the density of endemic taxa (the number of endemic species per unit area) is higher on Corsica than on Vanuatu. The densities of endemic plant species on the Madeira Islands (11 % of the vascular flora is endemic), Balearic Islands (7 %) or Crete (7 %)

are also higher than or similar to concentrations on Hawaii (47 %), St. Helena (80 %) or New Zealand (82 %; cf. Hobohm 2000, 2008). Therefore, when a high percentage of the vascular flora of an area is endemic, this does not necessarily indicate a high density of endemics or a centre of endemism. If a single species is living on an island and if this taxon is endemic to the island then rate of endemism is 100 % and the density also is maximal. It is thus important to clearly distinguish between total number of endemics, rate (or proportion) of endemism and endemic density.

## 2.4 Bykow's Index of Endemism (BI)

Based on available empirical data about the proportions of endemics found in different regions, as well as the consideration that on the scale of the entire globe, all taxa are endemic, Bykow (1979) developed a regression equation describing the relationship between area and the expected proportion of endemics in that area. The formula for this equation is:

$$\log e_n = 0.373 \times \log a - 1.043,$$

where  $a$  = size of the area in  $\text{km}^2$ ,  $e_n$  = expected endemism (as percentage value). The residuals can be calculated as  $i = |e_f/e_n|$ ; with  $i$  = index of endemism,  $e_f$  = proportion of endemics as a percentage of the whole species composition (empirical value for a region). According Bykow's Index, 1 % endemics can be expected in an area of  $\sim 625 \text{ km}^2$ , 2.8 % endemics in an area of  $10,000 \text{ km}^2$ , 6.6 % in  $100,000 \text{ km}^2$ , and 15.7 % endemics in a region of  $1,000,000 \text{ km}^2$ .

This measure is used as a simple and quite good predictor of endemism that results from a combination of both isolation and ecological continuity of a region (cf. Bruchmann 2011; Georghiou and Delipetrou 2010). The authors calculated high Bykow-values for the Canary Islands, Madagascar, Chile, South Africa and California. Hobohm (1999) compared different regions within Europe and found an extraordinarily high value for a small Balearic islet called Ses Margalides. *Euphorbia margalideana*, discovered in 1978 by Heinrich Kuhbier (1978) and endemic to this islet, is living together with only seven other vascular plant species.

## 2.5 Density, Endemic Species Diversity in Space (E/A)

The density of endemics in a region (number of endemics over area, E/A) describes how many endemic taxa per unit area occur. It is a measurement of the concentration of endemics. In general, the density of endemics is used as indicator for the duration of uninterrupted evolution and/or evolutionary speed in a region.

The number of endemic species divided by area gives a very simple measurement that roughly indicates high or low degrees of endemism. This method is valid for areas of similar sizes, but it is extremely difficult to compare density values calculated



for regions with different area sizes in a mathematically correct way (Magurran and McGill 2011). For example, say we want to compare the concentration of endemics on the endemic-rich island Madagascar with that of the Cape Verde Island Brava (55 km<sup>2</sup>), which with a single endemic species seems to be relatively endemic-poor. 7,750–8,160 endemic vascular plant species inhabit Madagascar (585,000–587,000 km<sup>2</sup>; Gillespie and Clague 2009; Burga and Zanola 2007; Hobohm 2000; Davis et al. 1994). If we divide these numbers by the size of the area – which is not in fact a valid method (see literature cited for EARs) – to get the number of endemics per km<sup>2</sup> or 10,000 km<sup>2</sup> – we would find higher values for Brava (0.018 endemic species per km<sup>2</sup> or 182 endemics per 10,000 km<sup>2</sup>) compared to Madagascar (0.032–0.039 endemics per km<sup>2</sup> or 132–139 endemics per 10,000 km<sup>2</sup>). This is the consequence of attempting to directly compare areas of different sizes.

If we are only taking areas of the same size into account we can compare absolute numbers of endemics (E) directly (Table 2.1), and the interpretation of E then is similar to the interpretation of density (concentration) measures of endemic taxa. For regions of different sizes, a different method is necessary (EARs, Sect. 2.6).

According to Table 2.1, Mauritius has a density of endemic vascular plant species three times higher than Tenerife, Canary Islands, while endemism of Tenerife is slightly higher than endemism of Sierra Nevada, Spain mainland, but much higher than endemism of Cuatro Cienagas, Mexico mainland. The numbers of Tenerife and Sierra Nevada are quite well comparable because they share important parts of the flora and biogeographers (Izquierdo et al. 2004; Castroviejo et al. 1986 ff.). The tables also give some geographical numbers which could be relevant. Distance to mainland means also reduction of dispersal opportunities. Altitude is used as indicator for the diversity of climate zones and habitats (environmental heterogeneity). Latitude is related to albedo, warmth and influence of former glaciation periods.

We can also compare regions with the same E and different A directly (Table 2.2). In this case the locality with the smaller size of area represents the higher concentration (density) of endemics.

In Table 2.2 we list areas with approximately the same number of endemic species in their vascular floras. But according to the numbers in Table 2.2, the highest density of endemics goes to Amistad which is higher than Polynesia-Micronesia and Cuba, much higher than SW Australia, and very much higher than the Himalaya Mountains. How can we explain these differences? If we take the environmental parameters of Table 2.2 into account we easily can come to the conclusion that these numbers (and area) alone cannot properly explain the differences in endemism between the regions. Other factors must be taken into consideration including the geographical position of Amistad which is located between two oceans (W-E) sandwiched by climate-stabilising currents, and two continents with dispersal abilities from two different floristic subcontinents to the North and South. A complete explanation must take three types of processes and conditions into account: global and continental evolutionary processes (due to climate constancy or change and geological activity or quiescence) which generates the continental species pool (i), regional dispersal opportunities (ii) and the history

**Table 2.1** Regions with a similar size of area in declining order of concentration in endemic vascular plant species

Region (km <sup>2</sup> )	No. of endemic species	Latitudes (degrees)	Climates/annual precipitation/Pleistocene	Altitudes (m asl.)	Distance to mainland (km)	No. of vascular plant species in total
Mauritius, Indian Ocean (1,940)	300	20S	Wet tropical/1,000–4,000 mm/not glaciated	826	1,800	900
Tenerife, Canary Islands, Atlantic Ocean (2,050)	106	28N	Dry Mediterranean to orogenic dry/100–1,000 mm/not glaciated	3,718	280	1,367
Sierra Nevada, Spain, Europe (2,000)	80	36/37N	Mediterranean to orogenic cool/358–2,500 mm/glaciated above 2,500 m	600–3,479	–	2,100
Cuatro Cienagas, Mexico (2,000)	23	27N	Dry subtropical to orogenic/c. 200–?/not glaciated	740–2,500 (–3,000)	–	860

Data from Burga et al. (2004), Nau (2003), Hobohm (2000), Davis et al. (1997)

**Table 2.2** Regions with a similar number of endemic vascular plant species in declining order of concentration

Region	Size of area (km <sup>2</sup> )	Latitudes (degrees)	Recent climate annual precipitation rate Pleistocene	Altitudes (m a.s.l.)	Minimum distance to mainland (km)	Total no. of vascular plant species
La Amistad Costa Rica, Panama, Middle America (c. 3,000 endemics)	c. 10,200	8–10N	Wet tropical to tropical alpine, 2,800–6,840 mm, not glaciated during Pleistocene	3,819	–	c. 10,000
Polynesia-Micronesia (3,074 endemics)	47,000	25S–30N	Dry to wet tropical, 400–15,000 mm, not glaciated	0–4,205	c. 2,000	c. 6,600
Cuba Caribbean Islands (c. 3,100 endemics)	108,722	19–22N	Warm tropical with a winter-dry period, 800–3,000 mm, not glaciated during Pleistocene	1,994	500	6,375
SW Australia (2,948 endemics)	356,717	26–36S	Mediterranean, 300–1,500 mm, not glaciated during Pleistocene	1,110	–	5,571
Himalaya Asia (c. 3,100 endemics)	741,706	20–35N	Warm wet tropical to extremely cold and dry, wintery or summer-rain in almost all altitudes, 150–12,000 mm, large parts glaciated during Pleistocene	100–8,848	–	c. 10,000

Data from Mittermeier et al. (2005), Burga et al. (2004), Nau (2003), Beard et al. (2000); Hobohm (2000); Davis et al. (1997, 1995)

of the landscape ecology (iii) including all the local biotic and abiotic interactions, processes controlling vegetation structures, biomass, productivity, destruction of vegetation and reduction of biomass.

## 2.6 Endemics-Area Relationships (EARs)

One of the best fit laws in ecology and biogeography is the *power law* or *Arrhenius-equation* (see e.g. Magurran and McGill 2011; Dengler 2009; Arrhenius 1921; and many other ecologists and biogeographers). This equation describes Species-Area Relationships (SARs) in many cases better than other equations.

$$\log S = z \times \log A + \log c \text{ or } S = cA^z$$

where  $S$  = total species number of an area,  $A$  = area size,  $z$  and  $c$  = empirical constants. This equation describes the increase in the number of species with increasing size of area surveyed. It can be reformed for the analysis of the endemics, in terms of  $E$  instead of  $S$ .

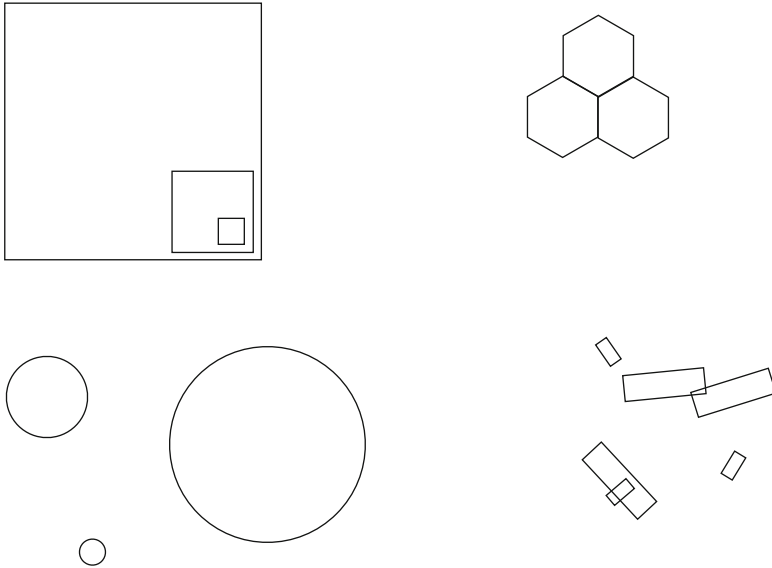
$$\log E = z \times \log A + \log c \text{ or } E = cA^z$$

The curve and mathematical description of the relationship between area and richness depends on the dispersion of the species in space and the design of analysis, e.g. on the spatial extent and size and position of the plots surveyed (Fig. 2.2).

From the definition of the term *endemic*, the  $z$ -value in a nested plot design – every small plot is included in a larger one (Fig. 2.2) – should be as high or higher than 1 because the number of endemics should increase at the same rate or more rapidly than the total number of species (i.e. when area doubles, on average the number of endemics will at least double as well). Recently Storch et al. (2012) found that different curves (for amphibians, birds and mammals) collapse into one universal power law with a slope ( $z$ -value) close to 1 after the area is rescaled by using the range sizes of the taxa.

If we assume that the terrestrial area on earth is  $\sim 147,930,000 \text{ km}^2$  ( $\log A = 8.17$ ) and the number of endemics is 300,000 ( $\log E = 5.477$ ; cf. Baillie et al. 2004) and then extrapolate beyond this point, we predict that the average sized area in which there is a single endemic species ( $\log E = 0$ ) should be greater than or equal to  $493 \text{ km}^2$ . Hence Brava (1 endemic species,  $55 \text{ km}^2$ ) represents an area with higher than average endemism.

We can compare the values of  $\log E$  and  $\log A - 2.7$  as a simple heuristic to determine if observed values of density ( $E/A$ ) are below or above the trendline (regression) for the whole world. The formula results from the assumption that the total number of vascular plant species on earth is 300,000, that the terrestrial area is c.  $147,930,000 \text{ km}^2$ , that  $z$  in the power law is 1 (nested plot design), and that the power law describes the relationship between species number and area in an adequate way. Because of these complex assumptions the formula can only be used as a very rough short-cut analysis.



**Fig. 2.2** Nested plots (*quadrats*), split plots with shared flanks (*hexagons*), dispersed, independent plots (*circles*), and randomly dispersed, particularly overlapping plots (*rectangles*); for discussion of different designs of multiscale sampling and how the design is controlling the result see Dengler (2009), Stohlgren (2007)

If the value of  $\log E$  is higher than  $\log A - 2.7$ , then the density (concentration) of endemics is above average (for example, Brava, 55 km<sup>2</sup>, 1 endemic plant species:  $\log A = 1.74$ ,  $\log E = 0$ ; 0 is higher than  $1.74 - 2.7 = -1.04$ , Madagascar, 585,000 km<sup>2</sup>, 8,000 endemics:  $\log A = 5.77$ ,  $\log E = 3.9$ ; 3.9 is higher than  $5.77 - 2.7 = 3.07$ ).

If the  $z$ -value for the regression is higher than 1 then the slope becomes steeper and the distance to the trendline from each residual above the trendline is increasing. Recall that the only fixed point of the regression in this nested plot design is the residual for the whole earth (300,000 endemics, 147,930,000 km<sup>2</sup>) and the reason for  $z > \text{or} = 1$  is the definition of endemism, the logic of EARs in a nested design and few empirical data (cf. Storch et al. 2012).

If we wish to analyse empirical data for dispersed and independent plots such as islands or archipelagos rather than nested plots, and try to find a regression for this design in  $\log E$ - $\log A$  space (referred to as either type IV according to Scheiner 2003, 2004, ISARs according to Whittaker and Fernandez-Palacios 2007, and dispersed, independent plots in Stohlgren 2007) then the  $z$ -values are often lower than 1 (cf. Georgioui and Delipetrou 2010; Werner and Buszko 2005; Hobohm 2000). This is not in conflict with the assumptions above because those assumptions are valid for nested plot designs only (Fig. 2.2).

Regardless of the assumptions, with different types of regressions it is possible to find whether a residual is located close to or distant from the trendline, and if

the concentration of endemism in a region is higher or lower than average. The numerical procedure has been developed independently by different authors (cf. Groombridge and Jenkins 2002; Hobohm 2000; Thomasson 1999). In every case the regression equation has to be checked not only mathematically but also with regards to biogeographical plausibility. The z-value can even become negative (!) if too many residuals represent large and cold or arid regions with little endemism and many small islands in warmer or wetter regions with higher endemism (which is the case e.g. in Europe). We found a negative relationship between the number of endemic vascular plant taxa and the size of regions in Europe in a log-log space (unpublished). This example shows that it can be difficult to find a meaningful regression equation, especially for the islands design (dispersed plots). Further, there are many theoretical discussions concerning the correct empirical design or relevance of a regression equation (cf. Dengler 2009; Stohlgren 2007; Scheiner 2003, 2004), and it is difficult at the moment to conclusively determine the biological or biogeographical meaning of the residuals, of z or c, or which processes they reflect, respectively.

EARs have been used to estimate the number of species that will go extinct after suitable habitats in a region are destroyed (cf. Kinzig and Harte 2000). Recently, He and Hubbell (2011) published a paper titled “*Species-area relationships always overestimate extinction rates from habitat loss*”. Recent controversy about calculating extinction rates using Species-Area Relationships (SARs) versus EARs or via comparison of SARs and EARs is surprising, given the lack of data about real extinction events (i) and the discussion about the “correct” numerical procedures, designs and curves when calculating such relationships (cf. Dengler 2009; Whittaker and Fernandez-Palacios 2007; Scheiner 2003, 2004) (ii). It seems to be more useful at the moment to focus less on calculating former extinctions or the risk of extinction by using SARs or EARs or both, given the scientific discussion that is ongoing, and better to concentrate on real threats faced by concrete rare and endemic organisms.

## 2.7 Range-Size Rarity (RSR) and Weighted Endemism (WE, CWE)

The range size of a taxon is often calculated as the sum of geographical grid cells or unit areas in which a taxon occurs. Growing attention is being paid to latitudinal and altitudinal gradients in the mean (or median) geographic range size of species in an area. The mean range size has been found to increase towards higher latitudes in a sufficient variety of higher taxa (Rapoport’s Rule, cf. Rapoport 1982; Gaston 1996a, b) although one can find exceptions of the rule.

Range-Size Rarity can be measured as the sum of the inverse range sizes per grid cell or area unit (cf. Lovett et al. 2000). Slightly different modifications of this methodology have also been published (cf. Crisp et al. 2001; Linder 2001; Laffan and Crisp 2003).

$$RSR = \sum (1/C_j)$$

with  $C_j$  = number of grid cells in which the taxon  $j$  occurs. Thus, a species restricted to a single grid cell would be scored as 1 for the cell where it occurs and with 0 for the other grid cells where it doesn't occur. A species occurring in two grid cells would be scored as 0.5 for each of the two cells. RSR is the sum of all inverse range sizes (= 1/number of grid cells) for all plant taxa that occur in a grid cell. This method was also applied for geographical units of different size which is statistically questionable.

RSR can be used as a simple measure of the distribution of species endemism in space. For the measurement of RSR for endemic species it is not necessary to analyse the whole vascular plant species composition of every site. This method makes it possible to identify centres of endemism over large areas. In many cases the RSR values are calculated only for a single genus, family or order (cf. Kessler 2002). The value of RSR for each grid cell depends on the extent of the species composition and total number of grid cells. This means that any modification in the database will change the values of many or all grid cells. Similar to the measure of the proportion of endemics, a high value can result for different reasons. In general, two explanations are possible for all species groups which confirm Rapoport's Rule: a decreasing (1) or increasing (2) number of species with large ranges towards higher latitudes, in combination with an increasing (1) or decreasing (2) number of species with small ranges in relation to latitude. If we find a great number of species with small ranges (endemics) in the tropics and only a few at higher latitudes then the absolute number of species with large ranges can theoretically also be higher in the tropics; for a confirmation of Rapoport's Rule only an increasing mean (or median) of the range sizes with latitude is important.

Weighted endemism (WE) is calculated as the sum of the reciprocals of the total number of cells each species is found in. Weighted endemism is correlated with richness, and so a better measure, Corrected Weighted Endemism (CWE) (Crisp et al. 2001) removes this richness effect. To do so, WE is divided by the total number of species in each cell. For example, let us presume the existence of three species in a single grid cell, which has four immediate neighbouring cells to the North, East, South and West. One of the species is highly range-restricted and occurs in three of the five grids in our sample area and in four grids in total (one outside our sample area). The second species is weakly range-restricted with two of 30 and the third species is relatively widespread with four of 3,100. The calculation of the CWE for this grid cell is

$$CWE = (3/4 + 2/30 + 4/3,100) / 3 = 0.473$$

This differs from RSR in that the values can be computed for different clusters (packages) of grid cells (so called "sample windows"; Laffan and Crisp 2003). In our example the sample window is five grid cells.

## 2.8 Parsimony Analysis of Endemism (PAE)

The possibility of applying a parsimony method to delimit areas of endemism was developed by Rosen (1988; see also Giokas and Sfenthourakis 2008; Santos 2005; Garcia-Barros et al. 2002). Comparable to RSR analyses, PAE basically unites areas based on their shared taxa.

As described in Morrone (1994) the method comprises the following five steps: Draw quadrats or other unit areas of the same size on a map of the region to be analysed (1), construct a data matrix where columns represent the species and rows represent the sample units (quadrats) with 1 if a species is present and 0 if it is absent (2), perform a parsimony analysis (3), e.g. as described in Rovito et al. (2004), delimit the groups of quadrats defined by at least two or more species (4), and finally, superimpose the groups delimited in the cladogram onto the quadrats and map the areas of endemism (5).

To identify areas of endemism or conservation priorities, the method often was modified or combined with different more or less complex modeling procedures (cf. Rovito et al. 2004).

The method often was criticized, especially when it was used to detect biogeographic histories involving dispersal (Brooks and Veller 2003; Peterson 2008). However, similar to analyses of RSR the method can be useful to identify and describe centres of endemism.

## 2.9 Phylogenetic Measurements of Endemism (PE)

With the rapid development of DNA-sequencing technologies, there has been a phylogenetic revolution in biology. There has been great diversification in phylogenetic metrics meant to measure diversity, as well as large advances in the amount and quality of information encoded by phylogenies. Phylogenetic trees quantify the evolutionary information represented in groups of taxa. Their structure – both degree of relatedness and age (branch lengths) of taxa – can be used as measures of taxonomic distinctiveness and time since evolution of biological features or genetic isolation (Huang et al. 2012; Nipperess et al. 2010; Rosauer et al. 2009; Sechrest et al. 2002; Vane-Wright et al. 1991). Moreover, with genetic information and information about recent distribution patterns of a taxon, it is possible to reconstruct historical colonization routes (Dixon et al. 2009; Erkens et al. 2007). For example, based on geographical distribution data and information about the genetic diversity within populations of *Saponaria bellidifolia*, Csergö et al. (2009) suggested that the Romanian populations of this plant – which have relatively low genetic diversity – have most likely originated from a Holocene range expansion from the glacial refugia in Bulgaria or Italy where the populations are genetically more diverse.

Combining phylogenetic analyses with biogeographical parameters such as endemism is of interest for nature conservation policies as well. The term *phylogenetic diversity* originates with Faith (1992), and represents the sum of the branch lengths



of a phylogenetic tree representing a certain taxon (e.g. genus, family) in a region (Faith and Baker 2006). This value is high if there are many old taxa (e.g. species) represented by the cladogram. It is lower if the taxa are younger and/or if the number of taxa is smaller. This also means that the measurement has to be standardised to capture differences in area or other variables of interest. Recently Rosauer et al. (2009, cf. also Sechrest et al. 2002) introduced a new metric, *phylogenetic endemism* (PE). This value is high if a small region captures a large fraction of a clade's evolutionary diversity. The value is smaller if the region is larger or if the fraction is smaller (Cadotte and Davies 2010; Rosauer et al. 2009). Using another metric of phylogenetic endemism, Tucker et al. (2012) showed that the distribution of high phylogenetic endemism was different for the Proteaceae of the South African fynbos as compared to the distribution of overall species diversity. This has important implications, since current reserves capture species richness well, but endemic richness poorly.

Calculating these or other values which combine evolutionary distinctiveness with geographical diversity of endemism measurements can require empirical data from the field and laboratory that is not always readily available (Huang et al. 2012). Because this scientific approach is rather young it is clear that for many regions in the world we are – at the moment – far away from having the necessary information.

## 2.10 Habitat Preferences (E/H)

Most likely Rikli (1943, 1946) was the first biogeographer to include chapters in his books about endemism in vascular plants in relation to habitat and ecological conditions. For Mediterranean endemics he emphasizes the meaning of rocky habitat, garigue, steppe, coastal and desert habitats. The publications of Pawlowski (1969; Alps and Balcanic Mountains), Gamisans and Marzocchi (1996; Corse), Tan and Iatrou (2001; Peloponnese, Greece), Petrova (2006; Bulgaria), and Rabitsch and Essl (2009; Austria) are further important examples focusing on endemism and characterizing habitat and environmental conditions.

Independent of the distributional range, every taxon is more or less strongly related to one or more habitat types. *Rhizophora mangle* is an example of a widely distributed plant which almost only occurs in mangroves (cf. Bailey 1998; Huston 1994); compared to other habitats such as *grassland* or *shrubland* this habitat type is relatively well defined (influence of tides, salt or brackish water, sand or muddy soil, tropical/subtropical climate, coastal and estuarine areas). Other plant taxa are less strongly connected to a single habitat type or narrow habitat conditions. In contrary to *Rhizophora mangle*, e.g. *Cirsium hypopsilum* represents a narrow geographical range in combination with a wider habitat specificity. This species is endemic only to the Mountains of Peloponnesus, Stera Ellas, S Pindhos and Evvia in Greece, where the main habitats and ecological conditions are deforested rocky slopes and screes, and ravines in open *Pinus nigra* and *Abies cephalonica* forest, *Pinus halepensis* woodland, and spiny *Astragalus* thorncushion communities, on calcareous marl, limestone or schist, between 300 and 2,350 m (Tan and Iatrou 2001). Another

**Photo 2.1** *Saussurea pseudotilesii*, endemic to Kamchatka Peninsula and Commander Islands in the Russian Far East, NE Asia, in pioneer vegetation on tephra (Photographed by Dietbert Thannheiser, Kamchatka Peninsula)



example of a geographically restricted species which occurs at different altitudes between sea level and up to c. 1,000 m, on different soil types and in different habitat types such as ruderal vegetation, coastal dunes, megaforb communities, or tundra is *Saussurea pseudotilesii* on Kamtchatka peninsula. We assume that the dispersal mode of hydrochory in the marine environment and ecological conditions promote the wide geographical distribution in the case of *Rhizophora mangle* whereas dispersal or pollination mode and/or the marine environment limits the ranges of *Cirsium hypopsilum* and *Saussurea pseudotilesii* (Photo 2.1).

These examples also show that it might become complicated to quantify a strong or weak habitat preference. If we want to explore which and how many endemics in a region are related to a certain habitat type or vegetation structure we first have to do it in a descriptive or qualitative manner.

The second step can be to count endemics in a certain region which are recorded in predefined habitat categories (E/H, cf. Bruchmann 2011). Normally endemics in a region are not absolutely restricted to a single habitat type. For a numerical procedure this means that the same endemic taxon can be listed in different habitat types. However, this metric underlines the meaning of certain habitats for conservation priorities.

According to the IUCN Red List ([www.iucn.redlist.org](http://www.iucn.redlist.org); downloaded 9/2011) 421 vascular plant species of the categories EW (extinct in the wild) and CR (critically

endangered) are living or should live in forests. The second largest group (145 species) is associated with shrublands, followed by plants of rocky areas (109), wetlands (61), grassland (46), marine coastal, supratidal (43), desert (21), savanna (16) and other habitat types (21). Most of these species are restricted to very small areas. In this case the habitat types are not strictly defined. E.g. the term *desert* is related to obviously different habitat types with different precipitation regimes and vegetation structures.

## 2.11 Perception of Endemics

Since the term *endemic* was defined by De Candolle in (1820), endemic species have received growing interest. However, we assume that the general perception of different endemic species by the public varies, depending on the range size, threats, and also on many other circumstances. The perception might also be dependent on questions such as if the endemic plant is beautiful or charismatic, where it occurs, or if the species is economically valuable.

The IUCN Red List, first published in 1966 as Red Data Book, was one of the first Red Lists worldwide. Conceived in 1963, this system set standards for species listing and nature conservation assessment efforts. Today many thousands of rare and threatened species are named in a huge number of Red Lists, appendices of national or international laws, or they are labeled as flagship species, keystone species, umbrella species or target species to underline their meaning for nature conservation activities. Red Lists, the concept of target species (cf. Ozinga and Schaminée 2005) and laws are the result of scientific work and political processes including legislation. The resulting attributes – Red List species, protected species, target species – can be used as indicators for the political, conservational, and social perception of rarity or threats.

To test this we first posed a null hypothesis and alternative hypothesis (i). Second, we searched regions of comparable size (ii): a single region on the one hand and a region of the same size which is composed by two or more regions as defined in Flora Europaea (cf. Tutin et al. 1996a, b, c, d, e), on the other. And then (iii) we compared the lists of endemic vascular plants of these regions (EvaplantE; last updated version) with lists of vascular plants which are named in the IUCN Red List (version 2011.1, downloaded 1/2012), which are protected by the Bern Convention (Appendix I; revised 2002) and European Habitats Directive 92/43 (2003, Annex II), and finally with the list of vascular plant species which are characterised as target species in Europe (Ozinga and Schaminée 2005).

We assume that the real ranges of the endemics within these pairs of regions are normally much smaller than the regions themselves, that they on average are comparable in size and that they together represent a similar frequency distribution of range sizes at local to regional scales. However, the discussion what range size of a taxon exactly means and how it can be measured is actually a long and ongoing discussion (cf. Gaston 1996a, b, c).

**Table 2.3** Numbers of endemic vascular plant species in two regions of comparable range size (Italy vs. Greece plus Albania and Bulgaria), number of the relating protected species (Bern Convention and/or European Habitats Directive), of species named in the IUCN Red List, and of the species characterised as target species (Ozinga and Schaminée 2005). \*\* $p < 0.01$

Region (km <sup>2</sup> )	No. of endemics (vascular plant species)	No. of protected species	No. of species named in IUCN Red List	No. of target species
Italy (250,631)	145	19 (13.1 %)	31 (21.4 %)	127 (87.6 %)
Greece, Albania, Bulgaria (261,245)	91	5 (5.5 %)	7 (8 %)	22 (24.2 %)
Significance of differences (chi-square)		n.s.	**	**

Our null hypothesis in this context is that the perception of endemics results from national/political delimitations and global threats in equal measure. We assume that the opposite is more likely and that the perception of endemics is geographically biased (alternative hypothesis). We guess that the perception of endemics restricted to a single country is stronger than the perception of endemics which occur in two or more countries even if these countries together cover the same range. Furthermore, the perception and appreciation of island endemics is probably stronger than the perception of mainland endemics in regions of the same size.

For Europe we examined a few pairs of regions which are of similar area size. France is comparable with Portugal plus Spain, Italy with Greece plus Albania and Bulgaria, France with Poland plus Czech Republic, Slovakia and Hungary, European Northern Russia with Scandinavia plus Baltic Countries. Sicily is a little bit smaller than the Krim Peninsula which again is only a little bit smaller than Albania. The area of Great Britain is comparable to the Czech Republic plus Slovak Republik or to Bulgaria, respectively. Unfortunately, the northern regions and small countries with low numbers of endemic vascular plants do not meet the criteria of the relating statistics (Chi-Square Test for Homogeneity).

Thus, only two pairs of regions could numerically be analysed. The following two tables show the results.

All differences of the perception indicators for endemics in a single country are higher than those for combined countries (i.e. endemics which occur in two or more regions). However, only the differences for the numbers of species listed in the IUCN Red List and in the list of target species (in Ozinga and Schaminée 2005) are highly significant (Tables 2.3 and 2.4).

These results clearly are not enough to understand whether there is a global trend. Further studies should be undertaken with a higher number of comparable regions. At the very least we can conclude that the perception of endemics in different regions may be biased and we assume that these differences depend on the impact of geographically different scientific, economic and political efforts.

The photographs 2.2, 2.3, 2.4, 2.5, and 2.6 show images of very attractive plant species from Australia.

**Table 2.4** Numbers of endemic vascular plant species in two regions of comparable range size (France vs. Portugal plus Spain), number of the relating protected species (Bern Convention and/or European Habitats Directive), of species named in the IUCN Red List, and of the species characterised as target Species (Ozinga and Schaminée 2005).  $**p < 0.01$

Region (km <sup>2</sup> )	No. of endemics (vascular plant species)	No. of protected species	No. of species named in IUCN Red List	No. of target species
France (539,527)	77	10 (13 %)	18 (23.4 %)	63 (81.8 %)
Spain, Portugal (582,626)	191	12 (6.3 %)	15 (7.9 %)	28 (14.7 %)
Significance of differences (chi-square)		n.s.	**	**

**Photo 2.2** *Anigozanthus rufus* in species-rich kwongan (Fitzgerald River National Park, some 600 km SE of Perth, near the south coast of Australia; photographed by Marinus Werger). Kwongan is the general Australian term for Mediterranean type woody scrub vegetation. This perennial plant is endemic to dry sandy, silicious regions. The species and other members of the genus are grown commercially in many parts of the world





**Photo 2.3** *Helipterum splendens* in a dense spring carpet community together with a few other annuals, near Cue, some 450 km NE of Perth (photographed by Marinus Werger). This plant is also commercially grown for gardening



**Photo 2.4** *Swainsona formosa* (*Cianthus formosus*) at Coral Bay, Western Australia (photographed by Marinus Werger). The annual plant species is native to the arid regions of central and north-western Australia



**Photo 2.5** *Banksia hookeriana* and *Xylomelum occidentale* on sandplain shrubland near Enneaba, Western Australia (photographed by Marinus Werger). Both species belong to the Proteaceae; this family is very species-rich and mainly distributed in Australia, South Africa and southern South America



**Photo 2.6** *Banksia menziesii* in Kwongan near Cataby, Western Australia (photographed by Marinus Werger). All but one *Banksia* species are endemic to Australia. Western Australia is the centre of the diversity of banksias

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