Nature Conservation 21: 57–82 (2017)
doi: 10.3897/natureconservation.21.13906
http://natureconservation.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Reconstituting a rainforest patch in southern Benin for the protection of threatened plants

Peter Neuenschwander[1], Aristide C. Adomou[2]

1 *International Institute of Tropical Agriculture (IITA) 08 BP 0932 Cotonou, Bénin* **2** *Université d'Abomey-Calavi (UAC) 01 BP 4521 Cotonou, Bénin*

Corresponding author: *Peter Neuenschwander* (P.Neuenschwander@cgiar.org)

Academic editor: *I. Steffan-Dewenter* | Received 31 May 2017 | Accepted 22 June 2017 | Published 30 August 2017

http://zoobank.org/EA5972AC-5CE9-4B71-AEF9-32DC46043DF2

Citation: Neuenschwander P, Adomou AC (2017) Reconstituting a rainforest patch in southern Benin for the protection of threatened plants. Nature Conservation 21: 57–82. https://doi.org/10.3897/natureconservation.21.13906

Abstract

In a twenty-year effort at Drabo, southern Benin, small remnant forests, young fallow and agricultural fields were linked and rehabilitated to develop a 14 ha forest reserve. Forest regrowth was encouraged by managing the natural growth of the local fallow vegetation and by bringing in seeds and other propagules from forest islands of Benin. The succession to shade-tolerant woody forest species of Guineo-Congolian origin at the expense of extra-regional herbs, the co-existence of species with slightly different requirements, and the fate of exotic trees in this natural forest are described. A quantitative assessment of a homogeneous lot indicated 397 trees per ha, with stem diameters >10 cm, 43.7% of them below 20 cm, and a rich undergrowth of 72600 smaller plants per ha, proof of active rejuvenation. Only 4.2% of all plants resulted from the 1041 introduction events, i.e., species per date, mostly of the 253 plant species that were new to Drabo. A total of 635 species were recorded, but 50 did not survive and four are yet to be identified. In June 2016, the total of 581 known living species included 224 trees. Among all plants, 244 hailed from the Guineo-Congolian zone with 17 of Upper Guinean and four of Lower Guinean origin, 113 from the three savannah zones, and 224 were of extra-regional origin. Overall, 72.8% of all woody plants, such as many climbers, all shrubs and trees, were of forest and savanna origin (GC, SG, SZ and S), whereas 70.4% of all herbs came from other regions (At, PAL and Pt). Only 7.0% of all species from the GC zone were in decline; but the further away the plants originated from, the larger the decline in numbers and vigour, up to 64.6% among plants of pan-tropical origin. Particularly pan-tropical herbs became ever rarer, with 80.0% of them declining and confined to the few open spaces along paths. In 2017 the forest harboured 52 threatened species, with threat categories EW, CR, EN or VU on the Red List of Benin, out of 73 IUCN-listed species that could possibly survive in Drabo. Some of these species occur in only one or two other locations in Benin. The biodiversity richness of the rehabilitated forests of Drabo now rivals that of natural rainforest remnants of the region. As the surrounding landscape becomes

ever more impoverished because of the high human population and its ever increasing impact, the maintenance of such managed islands of biodiversity is critical. By establishing rare local species from other locations we can compensate for direct human destruction and long-term stochastic loss of species in this highly fragmented landscape where natural seed dispersal is difficult.

Keywords
Benin, sacred forest, threatened plants, IUCN Red List, forest regeneration, Guineo-Congolese semi-deciduous forest

Introduction

During the quaternary Ice Ages, West Africa's rain forests receded to two main refuges situated in today's Côte d'Ivoire/Liberia and southern Cameroon (Figure 1). As climate warmed, forests advanced, though with temporary recessions, but never quite closed the so-called Dahomey Gap in Benin-Togo and south-eastern Ghana, which separates the western Upper Guinean from the eastern Lower Guinean/Congolese forest block (Poorter et al. 2004, Giresse 2008). In present-day Benin, Guineo-Congolese closed semi-deciduous humid forests are limited to tiny patches, most of them so-called sacred forests, which are under threat. The fauna and flora of these forests are composed of species originating from one or the other or both forest blocks, as well as species from different savannah zones (Booth 1958, Robbins 1978, UICN 1996, Sinsin and Kampmann 2010, Neuenschwander et al. 2011).

In a highly populated region with sometimes over 250 people per km^2 (INSAE 2013) and embedded in an agricultural landscape and human-induced so-called derived savannah (Paradis and Houngnon 1977, Mama et al. 2014), these forests are islands of high biodiversity. Covering 0.02% of the national territory, they harbour 20% of all plant species and 64% of the highly threatened plants, but are mostly outside established nature reserves (Adomou et al. 2011). Their protection has been described as the highest priority for nature conservation in Benin (Neuenschwander et al. 2011). Many of these forests are severely degraded in terms of structure and species diversity, which calls for rehabilitation measures. Apart from the detailed study of Adomou (2005), only short-term mapping of the flora and rapid surveys through interviews have been conducted (Adjanohoun et al. 1989, Sokpon and Agbo 1999, Nagel et al. 2004, Juhé-Beaulaton 2008, Kokou et al. 2008, Hèdégbètan 2011, Agbani 2012, CERF Bénin 2013).

Here we describe a 20-year effort to link up tiny forest fragments and to rehabilitate them through selective management of former farm and fallow land by encouraging forest regrowth and introducing plants from other forest islands of southern Benin. The management of this reconstituted, biodiversity-rich forest with its most important inhabitants, the critically endangered, endemic red-bellied monkey, *Cercopithecus erythrogaster* (Cercopithecidae) and the interactions with the villagers have already been described and compared with management in other forest sites (Neuenschwander et al. 2015).

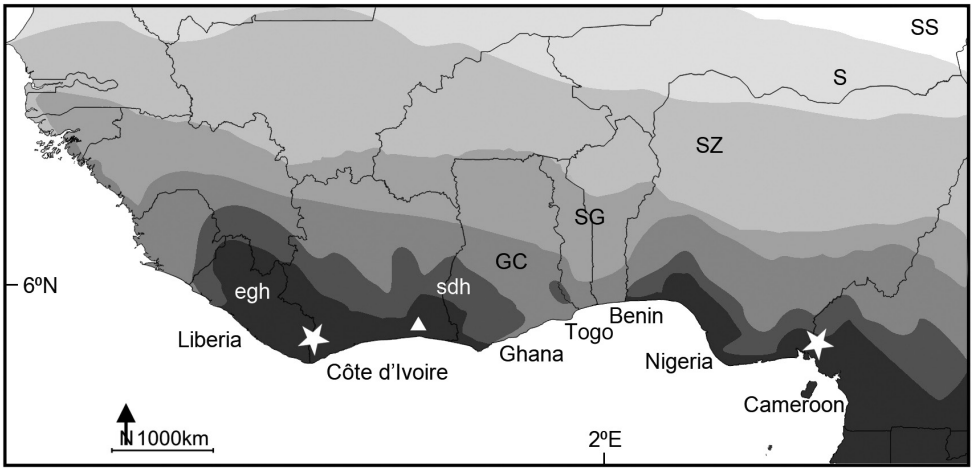

Figure 1. Map of West Africa with ecological zones: SS Sahelo-Sahara, S Sahel savannah, SZ Sudan savannah, SG Guinea savannah, GC Guinea-Congolian forest with closed sdh semi-deciduous forest, egh evergreen forest, asterisks Upper Guinean and Lower Guinean ice-age refuges, triangle Sikensi block. According to Arbonnier (2000), UICN (1996), Chatelain et al. (2004), Hawthorne and Jongkind (2006), and Adomou (2011).

Material and methods

Overall situation

Ecological zones in West Africa (Figure 1) were delimited using Arbonnier (2000) for the north, UICN (1996), Chatelain et al. (2004), Hawthorne and Jongkind (2006) for the south, and Adomou et al. (2006, 2011) for Benin. The main ice age refuges in western Côte d'Ivoire, today Taï National Park, and western Cameroon, today Korup National Park, are marked. In view of the huge human impact in the region, these zones circumscribe the ecological limits for the corresponding vegetation, rather than showing actual forests.

Within the Guinea-Congolese forest zone, the limits for the vegetation and the outer limits of still existing semi-deciduous and evergreen rainforests are therefore given separately. The site of a detailed study of plant cover (Chatelain et al. 2004) in the 20 × 20 km Sikensi block is indicated.

The Dahomey Gap as shown in Figure 1 has a strong gradient of rainfall, with highest rainfall towards the Nigerian border and lowest rainfall in the Accra Plains in Ghana. In Benin, this gradient is reflected in the distinction of phyto-geographical districts within each ecological zone (Figure 2, Adomou 2011). The Guineo-Congolese zone has two widely separated rainy seasons; further north, there is only one rainy season.

Study site

Drabo Gbo (6°30'N; 2°18'E; ca 60 m asl) (Figure 2) is a village of about 500 inhabitants at the southern edge of the Allada plateau, 30 km north of Cotonou, 12 km from

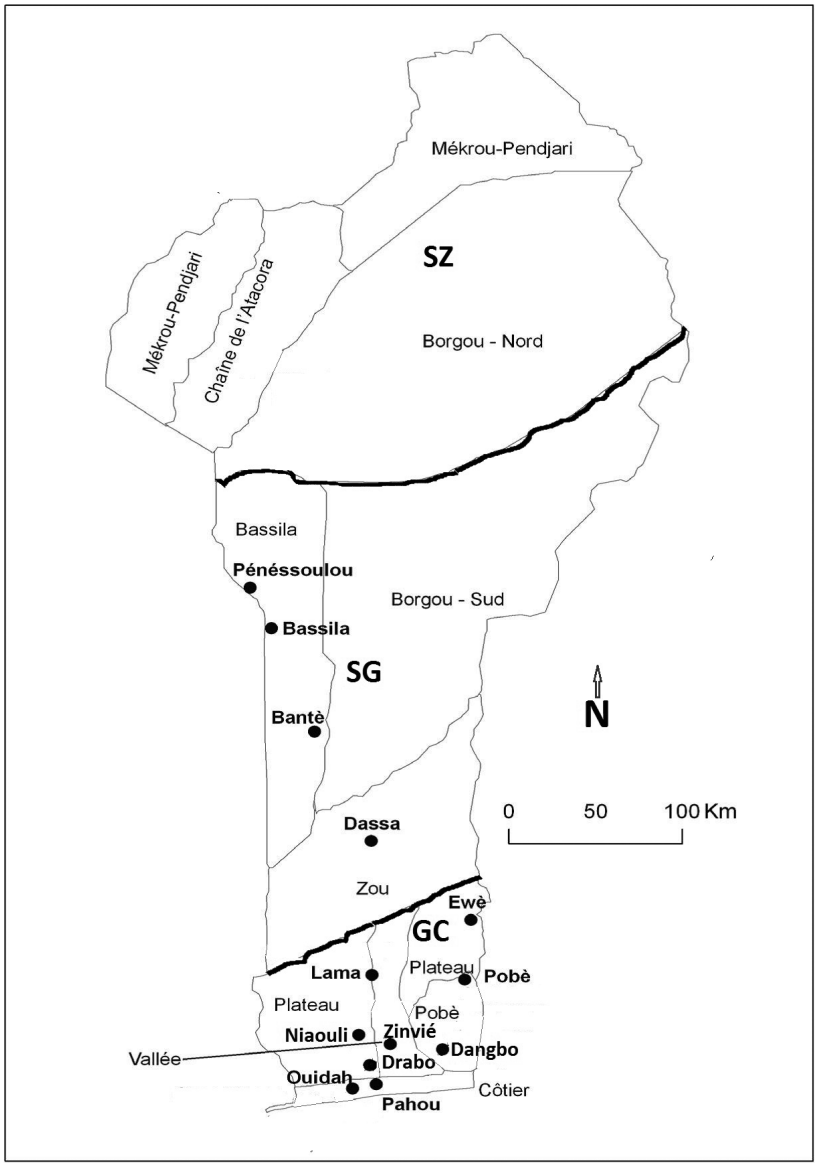

Figure 2. Map of Benin with phyto-ecological zones with GC, SG and SZ as in Figure 1, phyto-geographical districts according to Adomou (2011) in small print.

the spreading town of Calavi. The area has a mean annual rainfall of 1200 mm with two rainy seasons with peaks in May-June and September, and a long dry season from December to February, and a short one from July to August. Variability in rainfall is pronounced. During the period from 1996 to 2016, a maximum of 1815 mm was recorded in 2010 and a minimum of 762 mm in 2000. Daytime temperatures in March-April reach 35 °C, rarely up to 40 °C, and minimum temperatures in January

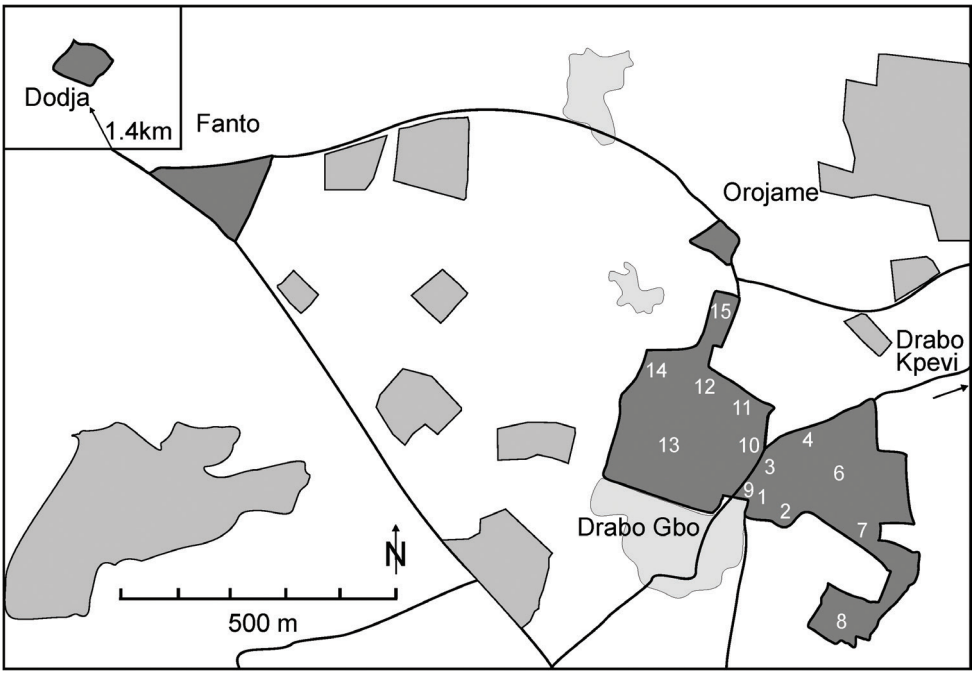

Figure 3. Map of Drabo forests with year of purchase and start of forest management, major clearings: **1** nursery-garden 1997 (house constructed 1997-1998) **2** papa-garage 1999, 2000 **3** Lissanou 1999–2003 **4** mill 2000 **5** Gaston part of Cooun cleared in 2010 **6** Cooun 2001 **7** corridor-Dansou 2004, 2010 **8** Emile 2001–2007 partly cleared 2012 **9** 'Maison de Jeunesse' (MdJ house constructed 2005) 1998, cleared in 2013 **10** Tofinou 1998-2000 **11** Pierre 1999–2001 **12** Kakpo 2004 **13** Grande Forêt 1996, local fire in 2012 **14** AgoXwè 2000–2003 **15** Corridor north 1998, 2002–2003, Orojamè 1998, Fanto 1998–2000, partly cleared 2014, Dodja 2011, partly cleared 2016. Natural forests grey with border line, wood lots light grey with border line, compact villages light grey, unsurfaced roads as lines.

are 20 °C, rarely down to 15 °C during "Harmattan" periods, when a dust-laden wind from the Saharan desert brings cooler night-time temperatures. The study site has a deep lateritic soil. One small lot, called "Emile" in Figure 3, is sandy. The water table throughout is at 25 m depth below the soil surface.

The "Monkey Sanctuary of Drabo Gbo" (Figure 3, centre of map: 6°30.28'N; 2°17.77'E) was founded in 1995 when the first author bought 2.5 ha of teak forest and agricultural land from the elders of Drabo Gbo. The study site was assembled from 25 single lots of different sizes, most of them agricultural fields or recently fallowed land, bought between 1995 and 2005 (for year of purchase of each lot see legend of Figure 3). A small house in the forest and a house for the community called "Maison de Jeunesse" (MdJ), situated on an adjacent triangle of land, were constructed in 1997/98 and 2005, respectively. For some lots, full registration with title deeds has not yet been possible. In January 2014, most of this land was donated by the first author to the International Institute of Tropical Agriculture (IITA) as a site for biodiversity

studies. Today there are 14 ha of land that has been managed for forest regrowth from agricultural fallow or teak plantation over 10 to 20 years, as well as tiny sacred forests, like Orojamè (0.8 ha) and Dodja with its old growth forest (0.7 ha). They are adjacent to the village of Drabo Gbo and the smaller villages of Drabo Fanto and Dodja.

History of the land

Speed, quality and abundance of regrowth depend much on the previous occupation of the land (Stanturf et al. 2012, Chazdon 2014). The first author's residence on this site since twenty years offered numerous opportunities for informal interviews with the elders, most of them illiterate farmers, in order to tap into the oral history, which in most families was very much alive.

Management

A flimsy fence of concrete poles, which support five lines of barbed wire, surrounds most of the forest lots; however, effective protection is provided by the "vodun adogba" , i.e., by traditional cults to which the first author has been initiated. Interactions with the surrounding population were described in detail in Neuenschwander et al. (2015), among others that no gathering of fire wood and medicinal plants is allowed.

Management consists of freeing trees from an excessive burden of climbers and maintaining small paths. Exotic timber species, such as *Cassia siamea, Acacia auriculiformis* and *Tectona grandis* (teak), are cut on demand by villagers, but under the supervision of the owner. Among the indigenous commercially important species, oil palm (*Elaeis guineensis*) is by far the most important. On demand, its fruits are collected where easily accessible. During successive fallow cycles, this indigenous species had been protected and enriched to a degree where in many places areas of up to 0.5 ha were so densely stocked that all other vegetation was suppressed. Cutting these oil palms produced sunlit habitats, which triggered the emergence of pioneer trees and offered open space for planting young trees. These were sometimes shaded by cut palm leaves until full rooting was achieved.

Introducing trees, shrubs and lianas from other forests

During the twenty-year period of establishing the forest, numerous collecting trips were made to other patches of forest in southern Benin. Plant material was collected mainly in the following locations (Figure 2): Forest pockets (<1 ha each) near Drabo Gbo and nearby villages; a community forest in Lanzron (50 ha) east of Zinvié in the Ouémé Valley, which is inundated from August to November; the "Forêt de la Panthère" (1.4 ha) of Zinvié (for management of the Lanzron and Zinvié forests see

Neuenschwander et al. 2015); the forest on the national agricultural research station of Niaouli (170 ha), where collections were made along public paths to the small, local stream and beyond; the "Forêt de Kè" at Dangbo (2 ha) bordering swampland; the forest of Ahozon near Pahou (150 ha natural forest), which is the last remaining coastal forest between Lagos and Accra, now under the supervision of the national forest services; the forest of Pobè (about 115 ha) on land of the national oil palm research institute, with a small river; the forest of Ewè (150 ha), a rich but unprotected forest contested by two rival communities and under threat of disappearing completely; the natural forest of the "Noyau Central" of the Lama forest (2000 ha), which is the largest dry type rainforest of Benin, locally inundated and supervised by the managers of the surrounding teak plantations and the official forest station; the community forest of Tobè near Koko, West of Bantè (350 ha), in the Guinea Savannah, which is controlled by the local community and supported by an NGO; the forest of Pénéssoulou still further north; plus exchanges of plants with the Botanic Garden of the University of Abomey-Calavi. With the exceptions of Tobè and Pénéssoulou, the flora of these sites belongs to different phyto-districts of the Guineo-Congolese semi-deciduous forest zone (Adomou 2011).

Most collecting expeditions were conducted in the main rainy season to benefit from conditions favourable for transplanting. To facilitate establishment at Drabo, plants, seeds, or cuttings were first held in a 50 m^2 nursery in open forest near the house, where they could be provided with additional shade if needed, water, and mulch. Most plants remained there for up to a year, awaiting the next significant rains. Recalcitrant seeds were scarified or treated with hot water. Some plants were planted out directly into particular microhabitats, mostly into 5 ha near the habitation of the owner. Watering and mulching during the first year made it possible that also plants from slightly moister forests could survive in Drabo.

Quantitative assessment of regrowth

On "Cooun" (Figure 3), which has the highest proportion of introduced plants among all rehabilitated forests of this study, a uniform regrowth area of about 4 ha was assessed quantitatively in May 2016 to describe first the general habitus of this 20 year old *Albizia-Antiaris-Blighia* forest with a high proportion of oil palms. Second, the importance of introduced plants was to be estimated. The total number of trees >10 cm diameter on 1000 m^2 (a circle measured out with a string of 17.8 m length) and all species of trees, lianas and herbs on 5 times 10 m^2 (in the centre and on the main circle in all four directions, measured with a string of 1.78 m) were assessed. The procedure was repeated three times from randomly chosen points on the narrow main path. Data about trees from 3000 m^2 and all plants from 150 m^2 were extrapolated to numbers of plants per ha. Tree numbers were grouped in 10 cm-diameter intervals, separately for the three dominant *Albizia* sp., two common *Blighia* sp., *Elaeis guineensis*, all other indigenous trees, and all introduced plants. In the small circles, all plants were deter-

mined to species and counted. Trees with diameters >10 cm were separately noted to check for congruence in the data, since the surface of the 15 small circles is 5% of the surface of the three big circles.

Inventory of the flora

To register all plant species, parts of the forest were inspected since 1998 daily for "Cooun" and surroundings, weekly for "Grande Forêt" and surroundings, and monthly for Drabo Fanto and Dodja by PN and/or a local guide. Unknown plants were marked with a yellow plastic band for later identification by AA. First identifications in 1997 and 1998 had been made by the late Prof. Paul Houngnon of the National Herbarium of Benin. Plants were identified by means of Akoègninou et al. (2006) and Hawthorne and Jongkind (2006) and by comparison with specimens in the National Herbarium. Additionally, dead or withering plants were noted. If this condition concerned all or most specimens this species was registered as 'decreasing'.

A list of all species registered in these forests is given as supplementary file. Species from aquatic, semi-aquatic, coastal-sand, or rocky habitats as well as horticultural species are excluded because they are not part of the natural flora of Drabo and, where present, survived only under special conditions, i.e., in pots or concrete ponds. The supplementary file lists:

- Taxa (Pteridophytes as 1Pteri, Gymnosperms as 2Gym, Monocotyledons as 3Mono, Dicotyledons as 4Dicot, and non-identified as 5nonid.
- Plants are described as parasites/epiphytes, herbs, climbers, shrubs or trees based on the description in Akoègninou et al. (2006) and–where different growth forms exist–with the habitus they show in Drabo. Species that are either new or not included in this flora are marked. Family names follow taxonomic revisions (APG I 1998, for least differences with Akoègninou et al. 2006).
- Chorology according to Adomou et al. (2010, 2011) and Akoègninou et al. (2006): The origin of the species is indicated as follows (Figure 1): GC Guineo-Congo forest species that are distributed across the Upper and Lower Guinean and into the Congolese zone east to Sudan, Uganda, Kenya, GO Upper Guinea forest species from west of the Dahomey Gap with an eastern limit in Benin or nearby Nigeria, GE Lower Guinea forest species from east of the Dahomey Gap with a western limit in Benin, SG Guineo-Sudanian transition zone species, SZ Sudanian savannah species, and S Sahel savannah species. Many species occur in different zones; only their main habitat is indicated. At indicates Afrotropical species with distributions beyond West and Central Africa into Madagascar, PAL Paleotropical and Pt Pan-tropical species, i.e. all species that have penetrated or invaded West Africa from other floral regions, for example Cocos palm. West African species that have similarly spread across the world are indicated by their original zone, for example oil palm.

- The next column indicates the origin of transplanted species (Figure 2, including Ouéga and the IITA campus a few km south of Drabo, Agongbè north of Drabo, Hévié north of Pahou, Avrankou on the Iguidi River near the Nigerian border east of Dangbo, and Tanougou waterfalls outside the Penjari Park in the Sudan savannah) and their location in the study forests (Figure 3), the years of collecting and transplanting, and–separately–in which form, namely seeds, small plants, sticks, they were collected.
- Abundance in 2016 is ranked as follows: 1 = 1–4 plants established; 2 = 5–10 plants; 3 = up to 20 plants; 4 = common species; 5 = abundant species.
- The maximum height of trees of each species was estimated in April-June 2016, taking into account all study forests. For most species, biggest trees were found in Drabo; in addition, especially big specimens from Dodja (Do), Fanto (Fa) or Orojamè (Or) were indicated.
- The population tendency was roughly estimated as s = stable, i = increasing, d = decreasing. Where necessary, Cut or Lost (**L** = lost by July 2016) were indicated.
- Red List status was given according to Neuenschwander et al. (2011) based on IUCN criteria as NT = near threatened, VU = vulnerable, EN = endangered, CR = critically endangered, EW = extinct in the wild in Benin. All other species were considered as Least Concern because they are not threatened or have not been assessed. In the evaluation of threatened species, NT-species were excluded.
- Suspected reasons for difficulty in establishment were given as: - recalcitrant seeds, which were sometimes treated with hot water or by scarifying, - drought, i.e., temporarily too little water, - savannah species, of which we suspect that they do not support transfer to two rainy seasons and are therefore not capable of reaching the coast, - medicinal use, e.g., roots harvested for increasing male potency.
- The number of samples, which include one to maximum 10 plantlets or seeds per species and date, was indicated.
- Plants originally found on the 14 ha and in their vicinity of a few hundred meters were marked with x. Some of them, if they were rare, were also reproduced and transplanted to other sites.

Percentages were compared by a two-way Chi-square test with correction for continuity.

Results

History in the 20th century

Even before the village of Drabo Gbo had been founded at the end of the 19th century, the area had been under cultivation probably for hundreds of years out of the village of Gbodjo situated at the lagoon near Calavi, with fallow cycles of 15 years or more. Some forests remained untouched and served as sacred forests, like Dodja, the old-

est forest in this study. Its *Cola gigantea*, *Celtis milbraedii*, *Blighia sapida* and *Antiaris toxicaria* are probably several hundred years old and reach 40 m. The forest was not touched for perhaps 100 years; but gaps with trees of only 10 m height that are heavily encumbered by lianas indicate that big trees had been cut before the present inhabitants of Dodja can remember. Another sacred forest, Orojamè, was created around a big *Cola* tree about 80 years ago and to date is the central site for the "Oro" cult of the entire area. This site of 0.4 ha was bought in 1999 and increased to about 0.8 ha.

In the former teak forest and another fallow lot, two big *Cola gigantea* trees were included in the newly acquired land. Their preservation was due to a courageous action in the late 1970s by the then "délégué" , who refused political pressure to cut them down because they were reputed to be sites of ghosts. They became islands of biodiversity, from where plants, insects, but also mammals spread to the rest of the developing forest.

About 8 ha, among them "Cooun" where the quantitative study was made, were under forest cover about 50–70 years ago, before the forest was cleared and replaced by maize, teak, *Dialium guineense*, which were stunted to harvest the sweet seeds, or cow "pasture", effectively bush regrowth since the local cows eat only broad leaves, no grass. Since no heavy equipment was ever used, seeds and roots of the previous forest vegetation remained alive. When fallow or crop land was purchased it was mostly devoid of trees. Once cultivation ended, shrubs, some up to man's height, developed into big trees within a few years.

In the past, fire in Fanto was ignited along the edge to catch grass-cutters, a large rodent. Moreover, at Drabo Gbo, six big *Albizia* and *Rhodognaphalon* trees were set on fire by igniting a car tyre at their base. In the same vindictive action in 2013 by villagers, who were enraged because of a local murder, all 65 trees on the triangle of the "Maison de Jeunesse" (MdJ), were cut. This action was ordered by the "Bokonon" (seer), who claimed a bad spirit was located there. The garden of the MdJ has meanwhile been transformed into an ethnobotanical garden. At present, the protection of the forest is good, i.e., no trees are debarked or felled, few lianas cut, no fire is laid, and no hunting is observed, except for some digging-out of ground squirrels or Gambian rats.

Status today

The forests of Drabo are embedded in a landscape of farmland with numerous isolated small houses. The section in Figure 3 covers 2.1 km^2 and shows 80 houses in Drabo Gbo, 16 in Drabo Fanto, 16 on AgoXwè, plus 350 isolated houses on 500 m^2 lots. The surrounding vegetation consists of fallow, which during the period of the study was gradually reduced from a few to zero years. Fields are mostly planted with maize, cassava, or pineapple. Up to now, most land has been sold to people from town by the original owners, who eventually install themselves in this area by building modest one-story houses and grow various fruit trees and bananas. Where construction has not yet started the land is often being abused by the original owners without any consideration

to conserve soil fertility. It is therefore often heavily infested with *Imperata cylindrica*. Gradually, big *Cola* and other trees, which were typical of a rich landscape, have been felled and the forest of the present study has meanwhile become an island in an ecologically impoverished surrounding.

Numerous woodlots have been planted with *Cassia siamea, Tectona grandis*, and mostly *Acacia auriculiformis*. The total area of uniform and biodiversity-poor woodlots in Figure 3 is bigger than the 14 ha of forest of the present study. Such lots provide wood for construction and firewood and take the pressure off the reconstituted, biodiverse forest.

Today, trees in Dodja are around 30 m high, with a few up to 40 m. In Orojamè the canopy is at around 20–25 m. In the oldest, selectively managed fallow land, trees reach 20–25 m, but in Drabo Fanto and on "Emile" in Drabo Gbo on sandy soil, the canopy is at only 10–15 m.

In 2016 a quantitative assessment of the vegetation was made in a mixed *Albizia* forest with rich undergrowth on "Cooun ", after 15 years of fallow combined with cow pasture (Figure 4). Among all trees, *Albizia* spp. (half *A. zygia,* ¼ *A. adianthifolia,* ¼ *A. glaberrima*) accounted for 64.7% (N = 119), *Elaeis guineensis* for 13.4%, all other indigenous trees for 19.3%, and the introduced species for only 1.7%. There were 397 trees with diameters >10 cm per ha, resulting in 25.2 m^2 per tree. Young trees with diameters of 10 to 20 cm accounted for 43.7% of all trees. In the small circles, where all plants were identified, a total of 1093 plants were counted, i.e. 72600 plants per ha. Four trees had diameters of >10 cm, which averages out at 267 tree per ha, slightly below the count from the big lots. This rich undergrowth was variously dominated by *Mallotus oppositifolius* (in 5 of the 15 samples), *Chassalia kolly* (in 3 lots) or *Reissantia indica, Macrosphyra longistyla,* and *Brachiaria deflexa* (each dominant in one lot); the rest (4 lots) having a highly mixed undergrowth. Though this part of the forest was particularly well enriched with species from nearby natural forest patches the importance of these species remained still modest, namely 4.2% of all small plants in the small lots.

All above named species are part of the 328 naturally occurring species classified as abundant (category 5), yet they account for only 11.6%. For 64.6% of all local species, less than 20 specimens are known, and for 25.0% only 1–4 specimens could be found despite regular and intensive search. Among the 253 introduced species, only one reached a total population of more than 20 specimens.

Origin of species and successional changes

Identification, particularly of juvenile plants without flowers and fruits, proved to be challenging. Up to 1998 a total of 168 plants of local origin had been identified. By 2004, when the bulk of the land had been acquired, the number increased to 317. Up to 2010 only 7 more species were discovered, and 4 more up to 2016, bringing the total of local species to 328. Another 253 species were introduced from forests from southern Benin (Fig. 2).

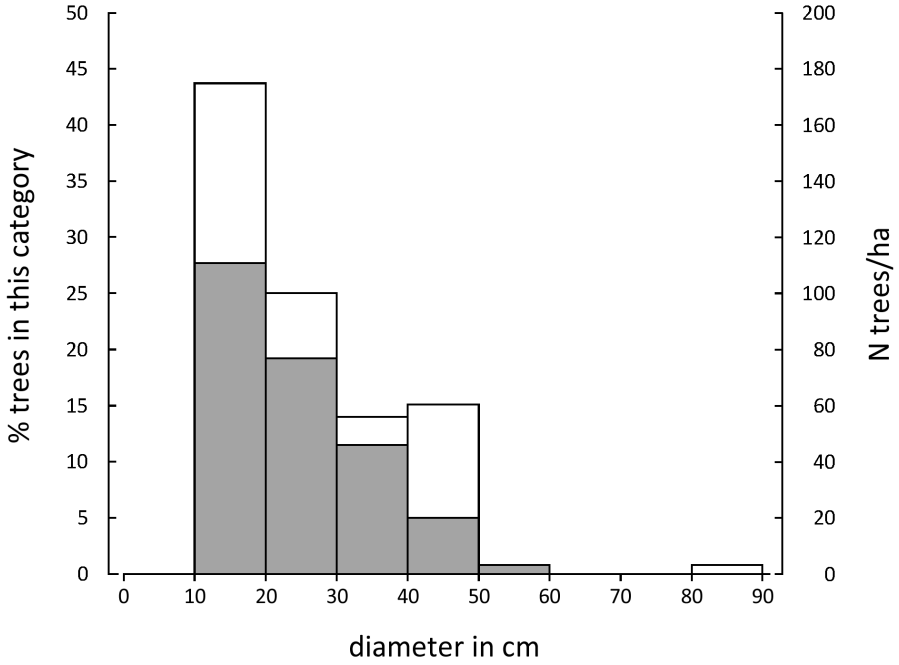

Figure 4. Quantitative assessment. Percentage of trees (N = 119) in classes with diameters of 10 cm differences and estimated numbers per ha. Grey for *Albizia.* Cooun, Drabo Gbo, 2016.

The supplementary file lists 635 plant species, among which four could not yet be identified. Identification or description as a new species will become possible as soon as flowers will be produced. Two have been tentatively attributed to the genus *Monanthotaxis* (Annonaceae).

Among the 631 remaining species, 50 or 7.9% were lost during the last 20 years, 49 of them introduced species. For five of the 10 extra-regional (At, PAL, Pt) and 10 of the savanna (SG, SZ, S) species, loss is attributed to seeds that would not sprout in the forest environment. By contrast, only one out of seven forest (GC) species that had been collected only as seeds failed to produce seedlings.

This leaves 581 species (Table 1) with 244 from Guineo-Congolian forests, among them 17 of Upper Guinean and four of Lower Guinean origin, 113 (81+32) from the three savannah zones, and 224 (80+144) of extra-regional origin. Woody plants, i.e., many climbers, all shrubs and trees, but without parasites and epiphytes, of forest and savanna origin (GC, SG, SZ and S) dominate (72.8%, N = 423) the flora in Drabo, whereas significantly more herbs (70.4%, N = 152) hail from other regions (At, PAL and Pt) (Chi-square = 9139, P<0.001, N = 575).

Since locally occurring rare species were also transplanted to other parts of the forest, the total number of introduction events in the course of the last 20 years was a high 1041, with a maximum of 10 introductions per species with up to 10 individuals from one collection date.

Table 1. Number of species alive and percentage declining (d.) in different ecological zones. Drabo July 2016.

Region	Para. & Epi.		Herbs		Climbers		Shrubs		Trees		Total	
	N	%d.	N	%d.	N	%d.	N	%d.	N	%d.	**N**	**%d**
CG[†]	4	0.0	23	13.0	75	9.3	33	3.0	109	5.5	**244**	**7.0**
SG	0		17	64.7	23	13.0	8	25.0	33	18.2	**81**	**27.2**
SZ and S	0		5	60.0	3	33.3	4	50.0	20	45.0	**32**	**50.0**
At and PAL	0		42	74	17	29.4	6	33	15	27	**80**	**52.5**
Pt	2	50.0	65	80.0	20	65.0	10	70.0	47	42.6	**144**	**64.6**
Total	**6**	**16.7**	**152**	**65.8**	**138**	**21.0**	**61**	**24.6**	**224**	**20.1**	**581**[¥]	**33.0**

[†] including GO (Upper Guinea) 17 spp. and GE (Lower Guinea) 4 spp.

[¥] plus 4 spp. non-identified, 2 of them climbers, 2 shrubs

During the last 20 years, changes in composition were observed. Declines in number of plants and, sometimes, plant vigour were unevenly distributed among growth forms and origins (Table 1). Declines were rare (7.0%) among plants from the GC zone, particularly trees and shrubs. They increased gradually the further away the plants originated from, up to 64.6% among plants of pan-tropical origin. Particularly pan-tropical herbs became rare with 80.0% of all 65 species of this category declining and being confined to the few remaining open spaces and alongside paths.

Change to a more mixed composition of large trees with a larger proportion of evergreen species is reflected in the frequent breaking of large branches of *Albizia* trees during storms, while *Celtis* and *Blighia* spp. resist better and become gradually more important.

The decline in numbers and vigour of particular species in Table 1 indicates the prospective changes in species distribution. Here some examples concerning trees and plants of commercial interest:

A total of 224 tree species are growing on these 14 ha. Among them, 69 are big trees of 10 m height or more. In the Drabo forest under total protection, the number of *Cola gigantea*, which had been largely destroyed in the area, increased steadily. The timber trees *Afzelia africana, Celtis milbraedii*, *Diospyros mespiliformis, Milicia excelsa* and *Triplochiton scleroxylon,* which had all disappeared from Drabo, grew well in the study forest. *Erythrophleum suaveolens* raised from seeds became common and reached 25 m, while *Rhodognaphalon brevicuspe* planted as sticks reached 22 m.

Some formerly rare plants like *Oxyanthus racemosus* and *Pavetta corymbosa*, of which only one plant each could be found in 1995-1996, became common. Similarly, some tree species like *Albizia ferruginea, Borassus aethiopum, Ceiba pentandra, Celtis milbraedii, Parkia biglobosa, Psydrax parviflora, Vepris verdoorniana,* and *Zanthoxylum*

leprieuri existed in only one lot, but grew well when planted elsewhere. Several trees, which were the last ones in the area and were subsequently felled, provided seeds and sticks that were reared in the nursery and then planted out: *Cynometra megalophylla, Elaeophorbia drupifera, Kigelia africana,* and *Pentaclethra macrophylla*.

Some species from the Guineo-Sudanian transition zone or even further north reach the coast and were found in Drabo, like *Adansonia digitata, Crossopteryx febrifuga, Lawsonia inermis, Parkia biglobosa,* and *Tamarindus indica*, of which only a few big trees survived in the area. *Lophira lanceolata* from the isolated population near Pahou survived only on sandy soil.

The following introduced species came from clines in forests with open water like Pobè and Niaouli; they required irrigation and mulching during the first dry season for establishment: *Barteria nigritana, Cleistopholis patens, Dennettia tripetala, Distemonanthus benthamianus, Entandrophragma angolense, Homalium letestui, Mansonia altissima, Monodora myristica, Piptadeniastrum africanum, Pycnanthus angolensis, Tabernaemontana eglandulosa,* and *Trilepisium madagascariense*.

In the course of reforestation of the last 20 years, yearly herbs decreased or disappeared. They resurged, however, immediately wherever an opening provided sunlight habitat. Thus, *Trema orientalis* trees could not be found anymore, until they suddenly reappeared from dormant seed on MdJ in 2013 in the newly opened up area, hundreds of meters away from the original site. Even in places where *Chromolaena odorata* was not cut, the encroaching forest within 10 years shaded it out completely. *Tithonia diversifolia,* another feared invader, appeared only once in 2002 and disappeared the same year, when shaded out.

Commercialized fruits are produced by the following well-established indigenous trees: *Chrysophyllum albidum*, *Dialium guineense, Irvingia gabonensis,* and *Spondias mombin*. Of particular interest is the introduced *Synsepalum dulcificum*, an endangered plant that has potential for commercialization because of its sugar-free sweet fruits. Tropical crops of closed forests like *Coffea canephora*, *Hevea brasiliensis, Theobroma cacao*, and *Vanilla planifolia* needed irrigation to start growth. By contrast, the exotic fruit trees *Anacardium occidentale*, *Azedirachta indica, Mangifera indica*, and *Psidium guajava* did not last in the closed forest and died within 10-15 years. Similarly, field crops like *Ananas sativus*, *Manihot esculenta,* and *Musa* triploid spp. did not produce any commercial product anymore, but persisted in the closed forest for many years even when shaded.

Among the introduced timber species, *Acacia auriculiformis* and *Cassia siamea* grew well in closed forest, whereas *Leucaena leucocephala* was overgrown by climbers and despite abundant seed-set did not reproduce vigorously. Among the original 1 ha of *Tectona grandis* many trees were cut; but the remainder grew well in a mixed forest. The one clump of *Bambusa vulgaris* remains problematic because it is displacing all other plants in the vicinity.

Many medicinal plants, which grow also in the Drabo forest, like *Acanthus montanus, Mondia whitei, Acridocarpus smeathmanii* and *A. alternifolius,* as well as *Heliotropium indicum* are being commercialized and sold on the "juju" markets, without being cultivated or even locally protected.

Endangered plants

Table 2 lists a total of 73 species from the Red List of Benin (EW, CR, EN or VU only), which could possibly survive in the reconstituted forest, among which 52 species are actually growing in Drabo, i.e., 71.2%. Four more species were planted, but could not survive. Ten species were found in Drabo before introductions from other sites started.

Most threatened (CR) are *Acanthus montanus* which was purchased on the market in Calavi, where material from one location near Porto Novo is sold as medicine; *Barteria nigritana* from Ahozon; *Caloncoba echinata* from a moist site in Niaouli; *Entandrophragma angolense,* which originally had only a few trees in Niaouli; and *Dennettia tripetala* and *Nesogordonia kabingaensis* from Ewè, where they are not protected. *Caesalpinia bonduc* is extinct in the wild (EW), but widely maintained (and also stolen!) in the village for its medicinal roots. A few plants of *Garcinia cola* (EW) also grow in the study forests. Of special interest are *Distemonanthus benthamianus* (EN), which exists in Benin only in one small, though protected site in Pobè, and *Mansonia altissima* (CR) from Ewè, where it is not protected. Both species grow as isolated populations at the eastern edge of their continental distribution, and only few trees exist in Benin.

Thanks to 20 years of careful protection and management, many threatened plants could be established and the species richness of the forest now rivals the one of the forests from where these endangered species come from (Table 2).

Discussion

Biodiversity in general, and of tropical forests in particular, is to be preserved for ethical reasons, for agriculture under the headings of plant protection-biological control (Neuenschwander et al. 2003, van Driesche et al. 2010) and varietal selection (Dansi et al. 2013), and for the preservation of water regimes and mitigation of climate change (Corlett 2014) or other eco-services (Martin 1991, Kuyah et al. 2016, Rowland et al. 2016). In an ideal world, nature protection and agriculture are considered complementary and nature reserves a prudent investment (McNeely and Scherr 2001). Though knowledge and understanding of the interactions with agriculture are increasing rapidly (IAAST 2008, Kuyah et al. 2016, Rowland et al. 2016) destruction of forests continues unabated. For Benin, the legal framework for nature conservation is in place (Republic of Benin 2012), but implementation is often insufficient. The protection and restauration particularly of southern forests has therefore been described as first priority in nature protection (Neuenschwander et al. 2011).

Because of their small sizes, Benin forests would not satisfy the criteria for a key biodiversity area (Secretariat of the Convention on Biological Diversity 2002, Brooks et al. 2006, IUCN 2016, RBG Kew 2016); but they show a particularly interesting history. Generally, forests in West Africa have been advancing since the Ice Ages, 10 000 years BP, though this advance has been marked by recessions and, in the area of

Table 2. Distribution of threatened plant species in southern Benin. Only living woody plants (trees, shrubs, lianas) and species on solid ground (i.e., without plants limited to swamp forests, sandy beaches or rocky outcroppings) are considered. Only VU to EW. Presence = x, origin as in Figure 1.

Family	Species	IUCN†	Drabo ¥	Ewè incl. Kétou	Pobè incl. Sakété	Dangbo	Lama	Niaouli	Ahozon (Pahou)	others	Origin§
Acanthaceae	*Acanthus montanus*	CR	x*		x					Bassila, Porto-Novo	GC
Anacardiaceae	*Antrocaryon micraster*	CR+			x[a]						GC
Apocynaceae	*Carissa spinarum*	VU	x	(x)	x	x	x	x	x	coast	PAL
Apocynaceae	*Tabernaemontana pachysiphon*	EN	x*		x	x					At
Apocynaceae	*Voacanga africana*	VU	x*	x	x	(x)	(x)	(x)	(x)	north	At
Annonaceae	*Dennettia tripetala*	CR	x*	x			x				GC
Annonaceae	*Monodora myristica*	EN	x*			x		x		Lanzron	GC
Annonaceae	*Xylopia aethiopica*	VU	x*		x	x		(x)	x	north	At
Arecaceae	*Borassus aethiopum*	VU	x	(x)			(x)			across country	SZ
Aristolochiaceae	*Pararistolochia mannii*	EN	**L**	(x)	(x)			(x)	x	Zinvié	GC
Asclepiadaceae	*Mondia whytei*	VU	x	x	x	(x)	x	(x)			SG
Bignoniaceae	*Kigelia africana*	VU	x	(x)	x	(x)	x	(x)	(x)		SG
Burseraceae	*Canarium schweinfurthii*	CR			x[a]						GC
Capparaceae	*Maerua duchesnei*	EN	x*	x	x						SG
Celtidaceae	*Celtis milbraedii*	EN	x*	x		x		x			GC
Clusiaceae	*Garcinia kola*	EW	x*							Ouidah, Porto-Novo	GC
Clusiaceae	*Pentadesma butyracea*	VU	x*							Bassila, Pénésoulou	SG
Combretaceae	*Terminalia superba*	EN	x*		x		x		(x)*	north	GC
Euphorbiaceae	*Discoglypremna caloneura*	VU			x[a]						GC
Euphorbiaceae	*Drypetes aframensis* Hutch.	CR		x[a]							GC
Euphorbiaceae	*Drypetes gilgiana*	CR		x[a]							GC
Flacourtiaceae	*Caloncoba echinata*	CR	x*					x[a]			GO
Flacourtiaceae	*Homalium letestui*	EN	x*		x	x		(x)			GC
Leguminosae-	*Afzelia africana*	EN*	x*	(x)	x	(x)	x	(x)	(x)	north	S
Leguminosae.	*Albizia ferruginea*	VU*	x	x	x	(x)		x	x	Pénéssoulou	GC
Leguminosae.	*Anthonota fragrans*	CR	x*		x					Bonou	GC

Family	Species	IUCN†	Drabo ¥	Ewè incl. Kétou	Pobè incl. Saképé	Dangbo	Lama	Niaouli	Ahozon (Pahou)	others	Origin§
Leguminosae.	*Caesalpinia bonduc*	EW	x*	(x)*	x*	(x)*	(x)*	(x)*	(x)*		Pt
Leguminosae.	*Detarium senegalense*	VU			x					north	GC
Leguminosae	*Distemonanthus benthamianus*	EN	x*		x[a]						GC
Leguminosae.	*Hymenostegia afzelii*	EN			x						GC
Leguminosae	*Parkia bicolor*	EN	x*		x	(x)		x		Zinvié	GC
Leguminosae.	*Pentaclethra macrophylla*	VU	x		x	(x)		x			GC
Leguminosae.	*Piptadeniastrum africanum*	VU	x*		x	x		x		Zinvié	GC
Leguminosae	*Tetrapleura tetraptera*	VU	x*		x			x	x	north	GC
Leguminosae	*Amphimas pterocarpoides*	EN			x						GC
Leguminosae	*Pterocarpus erinaceus*	EN	x*		(x)		x			north	S
Malpighiaceae	*Acridocarpus alternifolius.*	EN	x*		x		(x)	(x)	x		GC
Malpighiaceae	*Acridocarpus smeathmanii*	EN	x*	(x)	x						GC
Meliaceae	*Carapa procera*	VU			x			x			GC
Meliaceae	*Entadrophragma angolense*	CR+	x*		(x)			x			GC
Meliaceae	*Khaya grandifoliola*	EN+	x*				(x)*			Bassila, Zagnanado	GC
Meliaceae	*Khaya senegalensis*	EN+	x*	(x)	(x)	(x)	(x)	(x)	(x)	Bassila, Zagnanado	S
Meliaceae	*Trichilia martineaui*	CR						x[a]			GO
Meliaceae	*Turraea heterophylla*	EN	x*		x	x	x	(x)			GO
Moraceae	*Milicia excelsa*	EN+	x	x	x	x	x	x	x		GC
Myristicaceae	*Pycnanthus angolensis*	VU	x*		x	x		x	(x)		GC
Orchidaceae	*Angraecum distichum*	EN	x*	x						Djrègbè	GC
Orchidaceae	*Graphorkis lurida*	EN	**L**			x					At
Olacaceae	*Strombosia pustulata*	EN	x*		x	x		x			GC
Oleaceae	*Schrebera arborea*	EN		x						north	GC
Passifloraceae	*Barteria nigritiana*	CR	x*						x		GE
Rubiaceae	*Aidia genipifolia*	EN	x*	x	x	(x)		x	x		GC
Rubiaceae	*Euclinia longiflora*	EN	x*		x	x					GC
Rubiaceae	*Gardenia nitida*	EN	x*	x	x		x				GC
Rubiaceae	*Nauclea diderrichii*	EN+	x*		x			x		Lokoli	GC

Family	Species	IUCN †	Drabo ¥	Ewè incl. Kétou	Pobè incl. Sakété	Dangbo	Lama	Niaouli	Ahozon (Pahou)	others	Origin §
Rubiaceae	*Psilanthus mannii*	CR	x*		x	x					GC
Rubiaceae	*Tricalysia reflexa*	CR				x[a]					GC
Rutaceae	*Afraegle paniculata*	EN					x			north	At
Rutaceae	*Zanthoxylum gilletii*	EN	**L**		x						GC
Rutaceae	*Zanthoxylum zanthoxyloides*	VU	x	x	(x)	(x)	x	(x)	x		GO
Sapotaceae	*Chysophyllum albidum*	VU	x		x	x		(x)	x		GC
Sapotaceae	*Mimusops andongensis*	EN	x*				x[a]				GC
Sapotaceae	*Synsepalum dulcificum*	EN	x*		(x)					Porto-Novo etc.	GC
Sapotaceae	*Vitellaria paradoxa*	VU	**L**	x						north	S
Simaroubaceae	*Pierreodendron kerstingii*	EN+	x*		x			(x)		Zinvié, north	GO
Sterculiaceae	*Mansonia altissima*	CR	x*	x[a]						Calavi*	GC
Sterculiaceae	*Nesogordonia cabingaensis*	CR	x*	x[a]							GC
Sterculiaceae	*Octolobus spectabilis*	CR		x[a]							GC
Sterculiaceae	*Pterygota macrocarpa*	CR		x[a]							GC
Sterculiaceae	*Triplochiton scleroxylon*	EN+	x	(x)	x	x		x		north	GC
Tiliaceae	*Christiana africana*	EN					x				Pt
Violaceae	*Rinorea dentata*	EN	x*	x	x					Bassila	GC
Violaceae	*Rinorea ilicifolia*	CR		x[a]							GC
Total threatened plant species:		**73**	**52**	**30**	**48**	**28**	**20**	**32**	**18**		

† IUCN classification for Benin (Adomou et al. 2011): NT near threatened, VU vulnerable, EN endangered, CR critically endangered, EW extinct in the wild. + also on international Red List. ¥ * introduced; **L** lost; [a] = only known site in Benin where species occurs naturally; (x) new records according to A. Adomou; § origin: GC Guineo-Congolian (GO Upper Guinean, GE Lower Guinean), SG Sudano-Guinean, SZ Sudanian, S Sahelian, At Afro-tropical, PAL Paleotropical, Pt Pan-tropical.

the Dahomey Gap, slowed by sea currents and trade winds. Since 2000 years, advances are regular and little influenced by grazing, slash- and-burn agriculture with long fallow-periods, originally with endemic crop like rice and yams, firewood collection for iron-smelting, and home use by low human populations (Giresse 2008). Because close forests develop at annual rainfalls of >1400 mm and existing forests decline if rainfall drops below 1200 mm the area of the Dahomey Gap, including southern Benin, did not reach total forest cover (Giresse 2008). Under the rapid population increase of 10 to 20 times in Benin observed in the 20th century, tree savannah surrounding the rainforest pockets was further degraded (Paradis and Houngnon 1977, Mama et al. 2014) and gave rise to agricultural land under ever shorter fallows. Rainforest vegetation was confined to the often cited, but little studied sacred forests (lately: Agbani 2012, CERF Bénin 2013), some small communal and government forests, as well as riparian forests further north (Natta and van der Maesen 2003).

These forest islands harbour plant species with origins in the biodiversity centres of the Upper or Lower Guinea forest blocks. Today, large contiguous forest areas in West Africa are confined to western Côte d'Ivoire and eastern Liberia for the Upper Guinea block and extreme eastern Nigeria to southern Cameroon for the Lower Guinea block. In most areas designated as evergreen or semi-deciduous humid forest (Figure 1), deforestation has been so pervasive that actual conditions are not that far removed from what is found in the moister parts of the Dahomey Gap. In southern Côte d'Ivoire in the Sikensi block of 20 × 20 km, well within the evergreen forest zone (Figure 1), for instance, forest cover changed from 182 km^2 in 1958 to 149 km^2 in 1990, to 17 km^2 in 2000. Forests of less than 4 ha represent 64% of the forest area (Chatelain et al. 2004). Similarly high deforestation rates with maxima in the 1980s were reported from Nigeria (14.3%) and Côte d'Ivoire (15.6%) (Giresse 2008), demonstrating the difficulty of assigning phyto-ecological zones.

Because of rapid deforestation eight out of 26 commercial timber species of Côte d'Ivoire and Ghana are listed as threatened (Poorter et al. 2004). Some of these species exist in Benin, where their threat status is even higher (Table 2, Adomou et al. 2011; for a more stringent list see Adomou 2005). Table 2 demonstrates the richness of threatened species that grow in Drabo, rivalling the one of well-established larger forest reserves. It must, however, be noted that Benin forests with locally open water, like Pobè, Dangbo, and Niaouli, harbour several additional threatened plants, namely those requiring much higher humidity than found in Drabo; such species were not collected nor evaluated. Several of the listed species, like *Distemonanthus benthamianus* and *Mansonia altissima,* which are moreover at the edge of their continental distributions, occur in only one locality each, which–in the case of *Mansonia*–is unprotected, yet they grow well in Drabo. Despite similar conditions, none of the listed forests has all threatened species. We conclude that, in this highly fragmented landscape, rare species were either destroyed by man or suffered from stochastic loss in isolated habitats where important seed dispersers, like some birds, bats or rats, are no longer present (Fahrig 2003, Klein et al. 2014). In a situation, where creating corridors (Damschen et al. 2006) is no longer possible, introducing rare species into convenient habitats under

protection counteracts this loss. Our systematic transfer within the same ecological zone, which did not inflict undue harm in the collection sites, thus saved plants that might otherwise disappear from Benin. In Benin, many of these species are at the edge of their ecological and/or geographical distribution and may therefore be genetically different from those in the centre. Such genetic differences could well give them an advantage to face stress from climate change. Special care to ascertain their survival is therefore justified.

The fact that plants from zones with yearly rainfalls 200 mm above the one in Drabo, as for instance *Baissea zygodioides, Dennettia tripetala, Dracaena phryniodes, Gardenia nitida, Landolphia togolana, Pararistolochia goldieana, Tapura fischeri,* and *Turraea heterophylla* from evergreen forest pockets (Holmgren et al. 2004) survive in Drabo, if watered modestly during the first dry season, is testimony to their great plasticity and adaptability.

At the other extreme, these forests harbour also tree species that must be considered remnants of the savannah into which the advancing forests intruded. These include *Lophira lanceolata,* with its isolated population near Pahou (Paradis et al. 1978) as well as *Adansonia digitata*, *Crossopteryx febrifuga, Parkia biglobosa,* and *Khaya senegalensis*, all characteristic trees of the Sudanian savannah, some with occurrence even in the Sahel savannah. They thereby demonstrate their great adaptability to different climates.

The present long-term observations in Drabo describe the succession towards the climax Guineo-Congolese semi-deciduous forest through natural fallow, enriched with plants from other botanical districts of this zone (Adomou 2011). By planting in clearings similar to natural tree fall and without irrigation, traditional forestry practices used for rehabilitation were employed (Sabogal 2007, Stanturf et al. 2012, Chazdon 2014). By planting *Celtis* spp., the natural succession from leguminous pioneer trees like *Albizia* spp. to Celtidaceae, as observed in Dodja, is being accelerated. In contrast to forests on shallow soil as in IITA-Ibadan, where in some places 40 years were not enough to develop a forest (Neuenschwander et al. 2015), Drabo forests develop on deep soil and, by adding species, reach the semblance of a secondary forest within 20 years.

As the tree canopies close herbs–most hail from outside the region–gradually decline. This concerns particularly grasses, so that only two forest species, *Olyra latifolia* and *Oplismenus hirtellus,* remain. The disappearance of herbs is, however, immediately reversed as soon as free soil appears because of natural tree fall or clearance. Because the Drabo forests are of irregular shape with long edges, many light-demanding species can still survive along the fringes.

Except for bamboo, no plant in Drabo has the potential to become invasive and transform the environment. Even *Chromolaena odorata* and *Imperata cylindrica,* two feared weeds, as well as potential invaders like guava or *Leucaena leucocephala* under the conditions of southern Benin just follow the environmental conditions, but do not transform them (Lincoln et al. 2016). They are easily shaded out and cannot stand up to the pressure from the local vegetation except when situated at the very border of the

forest. Moreover, in situations where *C. odorata* becomes an obnoxious climax stage, its biological control is now promising (Prasad et al. 1996, Timbilla 1996, Day et al. 2013).

One cannot step into the same forest twice (paraphrasing Heraclitus); the present text therefore provides only a snapshot. The fact that only a few species were newly detected in the last years indicates that the cumulative list of species has reached a plateau and we can expect only few more discoveries. Since 21 IUCN-listed spp. with good potential for establishment are still lacking (Table 2) some more threatened plants might, however, be introduced in future. Conversely, among the introduced plants, some species are represented only by a few, some even by only one specimen with uncertain survival. Most cultivated plant still present in the forest will disappear altogether, while plants used in traditional medicine will hold steady if sufficiently protected. Due to successional changes, alpha-biodiversity, expressed as the total number of species, will probably decline as seen in other systems (Barlow et al. 2007). It is doubtful that a stable climax will ever be achieved because natural tree fall and edge effects will continue to offer footholds for transient species.

Conclusions

With 585 plant species or about 20% of the Flora of Benin, the Drabo forest have become a sanctuary not only for monkeys but also for rare plants, which themselves again offer the basis for the establishment of rare butterflies and other specialists. The vicinity to big towns and the relatively easy access should allow some eco-touristic development. Since the ownership has been transferred to IITA sustainability should be guaranteed (Neuenschwander et al. 2015).

The present study shows that with relatively modest means, but much patience and perseverance, it is possible to restore, even create de novo, a rainforest. The techniques are available since long time (Dobson et al. 1997, Mansourian et al. 2005). What is needed now is action to create a network of protected forests with exchange of species and local rehabilitation to round up the area of forests and to fill holes created by earlier logging. Most importantly, the local populations have to be involved and see the advantage of such forests or at least not oppose their creation. The 14 ha reserve is not large, but it represents two dozen sacred forests. Contrary to those, it is open to the public. Though it is not "natural" (Willis and Birks 2006) it effectively protects biodiversity in a human-impacted, so-called "gardenized" , landscape.

For the future, the major question remains whether in this densely populated area it will be possible to maintain this sanctuary which has become the best known and fully sampled forest of the entire region, while all other forests are all less well known and probably also less well protected. To assure its sustainability the forest will have to be used for scientific studies and bring benefits to the local population. The present study should thereby serve as a basis.

Acknowledgements

We thank P.O. Agbani (Botanical Garden Université d'Abomey Calavi UAC) and B. Sinsin (rector of UAC), H. Dassou (National Herbarium UAC), M. Tamò (IITA-Bénin), K. Ostertag (Tobè, Bantè) and A. Sessou (forester) and other people, who continue to participate in the protection of these forests, for specimens, encouragement and/or assistance, E. Onasanya (AfricaRice, Cotonou) and G. Goergen (IITA-Benin) for help in literature search and mapping, and G. Kandji and L. Hounguè (Drabo Gbo) for assistance in the field.

References

Adjanohoun EJ, Adjakidjè V, Ahyi MRA, Aké Assi L, Akoègninou A, d'Almeida J, et al. (1989) Contributions aux études ethnobotaniques et floristiques en République Populaire du Bénin. Agence de Coopération Culturelle et Technique, Paris, 895 pp.

Adomou AC (2005) Vegetation patterns and environmental gradients in Benin: Implications for biogeography and conservation. PhD Thesis, Wageningen, Wageningen.

Adomou AC (2011) Phytogeography of Benin. In: Neuenschwander P, Sinsin B, Goergen G (Eds) Protection de la nature en Afrique de l'Ouest: Une Liste Rouge pour le Bénin. Nature conservation in West Africa: Red List for Benin. IITA, Ibadan, Nigeria, 14–20.

Adomou AC, Agbani OP, Sinsin B (2011) Plantes, Plants. In: Neuenschwander P, Sinsin B, Goergen G (Eds) Protection de la nature en Afrique de l'Ouest : Une Liste Rouge pour le Bénin. Nature conservation in West Africa: Red List for Benin. IITA, Ibadan, Nigeria, 21–46.

Adomou AC, Sinsin B, van der Maesen LJG (2006) Phytosociological and chorological approaches to Phytogeography: A study at meso-scale in Benin. Systematics and Geography of Plants 76: 155–178.

Adomou AC, Sinsin B, Akoégninou AA, van der Maesen J (2010) Plant species and ecosystems with high conservation priority in Benin. In: van der Burg X, van der Maesen J, Onanana M (Eds) Systematics of African plants, Royal Botanical Garden, Kew, 429–444.

Agbani OP et al. (2012) Potentiel en diversité biologique des forêts sacrées des Départements de l'Ouémé et du Plateau. Rapport Contrat de Prestation de Service N. 2011/005/ Projet 00076343, 312 pp.

Akoègninou A, van der Burg WJ, van der Maesen LJG [Eds] (2006) Flore analytique du Bénin. Backhuys Publishers, Wageningen, 1034 pp.

APG I (1998) The Angiosperm Phylogeny Group. An ordinal classification for the families of flowering plants. Annals of the Missouri Botanical Garden 85: 531–553. https://doi.org/10.2307/2992015

Barlow J, Gardner TA, Araujo IS, Avilla-Pires TC, Bonaldo AB, Costa JE, Esposito MC et al. (2007) Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. PNAS 104: 18555–18560. https://doi.org/10.1073/pnas.0703333104

Booth AH (1958) The Niger, the Volta and the Dahomey Gap as geographic barriers. Evolution 12: 48–62. https://doi.org/10.1111/j.1558-5646.1958.tb02927.x

Brooks TM, Mittermeier RA, de Fonseca GAB, Gerlach J, Hoffmann M, Lamoreux JF, Mittermeier CG et al. (2006) Global biodiversity conservation priorities. Science 313: 58–60. https://doi.org/10.1126/science.1127609

CERF Bénin (2013) Projet d'intégration des forêts sacrées dans le système des aires protégées du Bénin. Répertoire des forêts sacrées dans les départements de l'Ouémé et du Plateau. Centre d'études de recherches et de formation forestières, Bénin, 1–68.

Chatelain C, Dao H, Gautier L, Spichiger R (2004) Forest cover changes in Côte d'Ivoire and Upper Guinea. In: Poorter L, Bongers F, Kouamé FN, Hawthorne WD (Eds) Biodiversity of West African forests: An ecological atlas of woody plants species. CABI Publishing, Cambridge, 15–32. https://doi.org/10.1079/9780851997346.0015

Chazdon RL (2014) Second Growth. The promise of tropical forest regeneration in an age of deforestation. University of Chicago Press, Chicago, London, 449 pp. https://doi.org/10.7208/chicago/9780226118109.001.0001

Corlett RT (2014) Forest fragmentation and climate change. In: Kettle C, Koh LP (Eds) Global forest fragmentation. CAB International, Wallingford, 69–78. https://doi.org/10.1079/9781780642031.0069

Damschen EI, Haddad NM, Orrock JL, Tewksbury JJ, Levey DJ (2006) Corridors increase plant species richness at large scale. Science 313: 1284–1286. https://doi.org/10.1126/science.1130098

Day MD, Bofeng I, Nabo I (2013) Successful biological of *Chromolaena odorata* (Asteraceae) by the gall fly *Cecidochares connexa* (Diptera: Tephritidae) in Papua New Guinea. In: Wu Y, Johnson T, Singh S, Raghu S, Wheeler G, Pratt P, et al. (Eds) Biological Control of Weeds: XIII International Symposium, Waikoloa, Hawaii. [September 2011]

Dobson AP, Bradshaw AD, Baker AJM (1997) Hopes for the future: Restoration ecology and conservation biology. Science 277: 515–522. https://doi.org/10.1126/science.277.5325.515

Dansi A, Orobiyi A, Dansi M, Assogba P, Sanni A, Akpagana K (2013) Sélection de sites pour la conservation *in situ* des ignames sauvages apparentées aux ignames cultivées: cas de *Dioscorea praehensilis* au Bénin. International Journal of Biological and Chemical Sciences 7: 60–74. https://doi.org/10.4314/ijbcs.v7i1.6

Fahrig L (2003) Effects of habitat fragmentation on biodiversity. Annual Review of Ecology and Evolutionary Systematics 34: 487–515. https://doi.org/10.1146/annurev.ecolsys.34.011802.132419

Hawthorne W, Jongkind C (2006) Woody plants of Western African forests: A guide to the forest trees, shrubs and lianes from Senegal to Ghana. Royal Botanical Garden, Kew, 1023 pp.

Hèdégbètan GC (2011) Etude écologique de l'îlot forestier Bahazoun dans la Vallée du Sitatunga, arrondissement de Kpanroun (Commune d'Abomey-Calavi), Bénin. Licence Professionnelle. GEn/EPAC, Université, Abomey-Calavi.

Holmgren M, Poorter L, Siepel A (2004) What explains the distribution of rare and endemic West African Plants. In: Poorter L, Bongers F, Kouamé FN, Hawthorne WD (Eds) (2004)

Biodiversity of West African forests: An ecological atlas of woody plants species. CABI Publishing, Cambridge, 73–389. https://doi.org/10.1079/9780851997346.0073

IAAST (2008) International assessment of agricultural knowledge, Science and technology for development. Summary approved by governments attending the IAASTD Intergovernmental Plenary in Johannesburg, South Africa. [April 2008]

INSAE (2013) Recensement général de la population et de l'habitat. MDAEP, INSAE, Cotonou, Bénin, 1–8.

IUCN (2016) A global standard for the identification of key biodiversity areas, version 1.0, 1–37.

Juhé-Beaulaton D (2008) Sacred forests and the global challenge of biodiversity conservation: the case of Benin and Togo. Journal for the Study of Religion, Nature and Culture 2: 351–372. https://doi.org/10.1558/jsrnc.v2i3.351

Klein AM, Boreux V, Bauhus J, Chappell MJ, Fischer J, Philpott SM (2014) Forest islands in an agricultural sea. In: Kettle CJ, Koh LP (Eds) Global forest fragmentation. CAB International, Wallingford, 79–95.

Kokou K, Adjossou K, Kokutse AD (2008) Considering sacred and riverside forests in criteria and indicators of forest management in low wood producing countries: The case of Togo. Ecological Indicators 8: 158–169.

Kuyah S, Öborn I, Jonsson M, Dahlin AS, Barrios E, Muthuri C et al. (2016) Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa. International Journal of Biodiversity Science, Ecosystem Services and Management. https://doi.org/10.1080/21513732.2016.1214178

Lincoln TR, Schmidt-Jeffris RA, Del Pozo-Valdivia AI (2016) Management strategies–solutions to grand challenges. American Entomologist 62: 98–107. https://doi.org/10.1093/ae/tmw033

Mama A, Bamba I, Sinsin B, Bogaert J, De Cannière BC (2014) Déforestation, savanisation et développement agricole des paysages de savanes-forêts dans la zone soudano-guinéenne du Bénin. Bois et Forêts des Tropiques 322: 1–11. https://doi.org/10.1079/9781780642031.0079

Mansourian S, Vallauri D, Dudley N [Eds, in cooperation with WWF International] (2005) Forest restoration in landscapes: beyond planting trees. Springer, New York, 437 pp. https://doi.org/10.1007/0-387-29112-1

Martin C (1991) Die Regenwälder Westafrikas. Ökologie, Bedrohung und Schutz. Birkhäuser, Basel, 235 pp.

McNeely JA, Scherr SJ (2001) Common ground, common future: How ecoagriculture can help feed the world and save wild biodiversity. IUCN (Gland); Future Harvest, Washington, D.C., 24 pp.

Nagel P, Sinsin B, Peveling R (2004) Conservation of biodiversity in the relic forest in Benin–an overview. Regio Basiliensis 45: 125–132.

Natta AK, Sinsin B, van der Maesen LJG (2003) A phytosociological study of riparian forests in Benin (West Africa). Belgian Journal of Botany 136: 109–128.

Neuenschwander P, Bown D, Hèdégbètan GC, Adomou A (2015) Protecting rain forest patches in West Africa. Nature Conservation 13: 21–46. https://doi.org/10.3897/natureconservation.13.6539

Neuenschwander P, Langewald J, Borgemeister C, James B (2003) Biological control for increased agricultural productivity, poverty reduction and environmental protection in Africa. In: Neuenschwander P, Borgemeister C, Langewald J (Eds) Biological control in IPM systems in Africa. CABI Publishing, Wallingford, 377–405.

Neuenschwander P, Sinsin B, Goergen G (Eds) (2011) Protection de la nature en Afrique de l'Ouest : Une Liste Rouge pour le Bénin. Nature conservation in West Africa: Red List for Benin. IITA, Ibadan, Nigeria, 1–365.

Paradis G, Houngnon P (1977) La végétation de l'aire classée de la Lama dans la mosaïque forêt-savane du Sud-Bénin (ex Sud-Dahomey). Bulletin di Muséum National d'Histoire Naturelle 503: 169–196.

Paradis G, de Souza S, Houngnon P (1978) Les stations à *Lophira lanceolata* dans la mosaïque forêt-savane du Sud-Bénin (ex Sud-Dahomey*).* Bulletin Musée Naturelle et Histoire Naturelle, Paris, Botanique 35: 39–58.

Poorter L, Bongers F, Kouamé FN, Hawthorne WD (Eds) (2004) Biodiversity of West African forests: An ecological atlas of woody plants species. CABI Publishing, Cambridge, USA, 1–521. https://doi.org/10.1079/9780851997346.0000

Prasad UK, Muniappan R, Ferrar P, Aeschlimann JP, de Foresta H (Eds) (1996) Distribution, ecology and management of *Chromolaena odorata*. Proceedings of the third Int. Chromolaena Workshop (Abidjan, Côte d'Ivoire), November 1993. University of Guam, Publications 202: 1–213.

RBG Kew (2016) The State of the World's Plants Report. Royal Botanic Gardens, Kew, 1–80.

Republic of Benin (2012) Interministerial Order N°0121/MEHU/MDGLAAT/DC/ SGM/ DGFRN/SA Setting the conditions for the sustainable management of sacred forests in the Republic of Benin.

Robbins CB (1978) The Dahomey gap. A reevaluation of its significance as a faunal barrier to West African high forest mammals. Bulletin of the Carnegie Museum of Natural History 6: 168–174.

Rowland D, Ickowitz A, Powell B, Nasi R, Sunderland T (2016) Forest foods and healthy diets: quantifying the contributions. Environmental Conservation 1–13. https://doi.org/10.1017/S0376892916000151

Sabogal C (2007) Site-level restoration strategies for degraded primary forests. In: Rietbergen-McCracken J, Maginnis S, Sarre A (Eds) The forest landscape restoration handbook. Earthscan, London, 83–95.

Secretariat of the Convention on Biological Diversity (2002). Review of the status and trends of, and major threats to, the forest biological diversity. Montreal, SCBD, CBD Technical Series 7: 1–164.

Sinsin B, Kampmann D (Eds) (2010) Atlas de la biodiversité de l'Afrique de l'Ouest, Tome I: Bénin. Cotonou and Frankfurt/Main, 1–726.

Sokpon N, Agbo V (1999) Sacred groves as tools for indigenous forest management in Benin. Annales des Sciences Agronomiques du Bénin 2: 161–175.

Stanturf J, Lamb D, Madsen P (Eds) (2012) Forest landscape restoration integrating natural and social sciences. World Forest. Springer Science and Business, Dordrecht, 1–330.

Timbilla JA (1996) Status of *Chromolaena odorata* biological control using *Pareuchaetes pseudoinsulata*, in Ghana. In: Moran VC, Hoffman JH (Eds) Biological Control of Weeds: Ninth International Symposium, Stellenbosch. [January 1996]

UICN (1996) L'atlas pour la conservation des forêts tropicales d'Afrique. Editions Jean-Pierre de Monza, Paris, 310 pp.

Van Driesche RG, Carruthers RI, Center T, et al. (2010) Classical biological control for the protection of natural ecosystems. Biological Control Supplement 1: 2–33. https://doi.org/10.1016/j.biocontrol.2010.03.003

Willis KJ, Birks HJB (2006) What is natural? The need for a long-term perspective in biodiversity conservation. Science 314: 1261–1265. https://doi.org/10.1126/science.1122667

Supplementary material 1

Table A. Comprehensive list of all plant species of Drabo Gbo, Benin.

Authors: Peter Neuenschwander, Aristide C. Adomou

Data type: species data

Explanation note: Status July 2016. Explanations in Materials and methods.

Link: https://doi.org/10.3897/natureconservation.21.13906.suppl1