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State-of-knowledge on *Astronium fraxinifolium* Schott (Anacardiaceae) for genetic conservation in Brazil

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Abstract

This study explores the basis for conservation action on *Astronium fraxinifolium* Schott (Anacardiaceae). This is a wide-ranging forest species occurring in Brazil and other South American countries, and typical of gallery forest along watercourses in the Cerrado region. Information about this species is scanty and scattered. This paper aims to provide a structured review of available knowledge of its biology, ecology, silviculture and management. Widely-scattered published reports have been critically considered and efforts made to highlight and resolve contradictions and inconsistencies. Because little effort has been applied to its domestication and improvement, knowledge of silviculture and management of *Astronium fraxinifolium* is particularly meagre. Gaps in current knowledge relevant for conservation are identified and steps to fill them proposed. Where in situ conservation was considered appropriate, recommendations are made for the location of additional protected areas. Complementary ex situ and enrichment conservation action is suggested for specific parts of the range where resource losses are already so extensive that in situ measures alone are insufficient. Provision for refining the limited management and conservation knowledge is made through highlighting priorities for study of the taxon. Finally, future action is discussed in the context of the infrastructure of the national conservation sector of Brazil.

Key words: Brazilian savanna, Cerrado, conservation, forest genetic resources, research

Introduction

It is understandable that in situ conservation efforts usually focus upon ecosystems. There is, however, a need to complement these efforts with attention directed at particular target species. This approach is developed here for *Astronium fraxinifolium* Schott (Anacardiaceae), a forest species which is typical of – although not necessarily restricted to – a distinctive but threatened habitat in central Brazil, the Cerrado. This taxon is included in the listing of 23 priority species for Brazil drawn up by the Brazilian Agricultural Research Organization through its Genetic Resources and Biotechnology Research National Centre (Embrapa-Cenargen, unpubl. data) in connection with the Brazilian government's national conservation strategy. Criteria for selection were those recommended by the FAO Panel of Experts on Forest Gene Resources: restricted ecological distribution, low population densities, heavy exploitation for wood and other products,

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unknown or deficient silviculture and threatened habitat (Roche 1987).

Efforts to apply a robust but flexible standard system for acquiring, collating and organising information on named neotropical tree species have not hitherto been successful. The reasons reside in problems of standardisation of taxonomic and systematic nomenclature, in the regional variability of taxa (particularly a problem for widely-distributed woody species), as well as in the generally scattered nature and insufficient information about these species. For example, in the *Forestry Compendium* of CAB International (2000) *A. fraxinifolium* is only briefly mentioned without offering substantial information. However, Lorenzi (2000) provides an instructive account of this species including nice figures. Reference to World Conservation Monitoring Centre (WCMC-Kew 1990) indicates that this situation is no different for other tropical areas. Since species are the targets of gene resource conservation, a structured review of existing knowledge has great appeal when conservation strategies are to be formulated. Accordingly, this paper offers a framework for such action, with *A. fraxinifolium* serving as a case study.

The form and distribution of knowledge about tropical tree species introduce complications in information retrieval. Unprocessed 'raw data' (for example, those recovered from herbarium holdings, ecological literature and species listings) need to be thoroughly reviewed and critically incorporated into the progressing study. In an uncollated state, published information is often very dispersed, much of it (notably early references) being in obscure or little-circulated documents. Records may be in many different languages, and references may be made under obsolete names which reflect broader or narrower concepts of the species than those accepted today. For many wide-ranging species these problems are acute, making the preparation of a unifying account a taxing, time-consuming and sometimes laborious process. The exercise is nevertheless important as the basis for an authoritative conservation planning.

Few can claim familiarity with all aspects of the existing knowledge of a wide-ranging species. Information about a species covers many fields of enquiry, each with its own specialists and technical language: foresters, ecologists, geographers and botanists. Geographical spread also complicates matters greatly, since concern about the status of species is often restricted to the national level rather than considering the full species range. Obviously, differences in the circumscription and in the nomenclature of species need to be recognized (and perhaps reconciled) and taken into account as the information is integrated. Whether or not this can be achieved in a single step depends on the species in question, the quantity of published and archival information (including herbarium material), and on the resources and time available to the investigator.

The present study, which is aimed at producing a current state-of-knowledge account for *A. fraxinifolium* to support genetic conservation programmes in Brazil and other South American countries, has three objectives: (1) to review available information on the biology, ecology, silviculture and management of *A. fraxinifolium* relevant to its genetic conservation as a sustainable resource; (2) to create a comprehensive and authoritative monographic account of the species by a critical analysis of available information, highlighting in the process unresolved misinterpretations and inconsistencies which need clarification; and (3) to identify the major gaps in current knowledge of the taxon and recommend positive research actions to fill them.

Material and methods

The fragmented and unsatisfactory species information for many species in the Neotropics requires today's monographers to invest more thought, effort and time to taxonomic circumscriptions and their geographical implications than their counterparts in Africa, Asia or Australia. In the present research, a retrospective picture of the taxonomic chronology was a necessary preliminary to an overview of the knowledge base. The first step in producing such overview is to summarize in tabular form where studies have been carried out and on which aspects of the taxon. A model used by Aminuddin bin Mohamad (1990) for integrating what was known about rattans (Arecaceae: Calamoideae) was adapted for this study. The literature base is specified, with code numbers denoting particular references as cell entries in 2-way tables; these can either be for different aspects of a taxon (geographical unit × aspect) or for comparisons of taxa (taxa × geographical unit; taxa × aspect). With such a framework established for a taxon, the references located for different aspects of its study are the basis for unified comment, taking account of geographical variation as necessary.

More specific comments on the importance of knowledge of the different aspects of a species have been given by Hall (1993, in press). Hall (1993, in press) reports the general need for monographic accounts on both multipurpose tree species and traditional forestry trees rather than only lists, brief profiles, data-sheets and bibliographies. Fewer than 20 forestry species have been covered in depth in this way. Monographs represent the most authoritative and comprehensive documents of the state of knowledge on any species. However, it is important that they are based as a sound framework in the form of a set of headings covering all aspects of the tree's biology and resource potential, including taxonomy, morphology, distribution, ecology and silviculture/management. Critical assessment of the information gathered is important, and nomenclatural contradictions and differences of opinion need to be explained and resolved as far as possible. Hall (1993, in press) stresses the prominent role that distribution maps should play among these headings. The necessary data come from five distinct sources: herbaria, taxonomic literature (basically in the form of floras), inventories, ecological literature and personal observations. Distributions can then be related to complementary data sets such as terrain, climate and soils. Hall (in press) also discusses the potential combined role of such information sets in distinguishing genetically determined variation from ecologically determined variation in a wide-ranging species, using all relevant available information. A critical approach to these issues is essential if conservation programmes are to be successful.

Unification of information about a species into a structured and authoritative monograph has been achieved for the African dry zone tree *Balanites aegyptiaca* (L.) Delile (Balanitaceae) by Hall & Walker (1991). This study serves as a useful model for a monograph, though it must be adapted for other species. In the present case, prominence has been given to conservation; this aspect was excluded by Hall & Walker (1991) although separately considered at some length elsewhere (Hall 1992).

The present work is based on diverse sources of information. For Brazil these are published and unpublished material at Embrapa and Cenargen, National Parks management plans, and lists and maps of current protected areas at the Brazilian Institute for the Environment and Renewable Natural Resources (Ibama). Paraguayan Conservation Data Centre data sheets on the target taxa were also obtained. In Britain, WCMC's database information on protected areas and assessment of conservation status of the target species were consulted and information assembled through visits to and correspondence with the Royal Botanic Garden, Kew (both herbarium and library). Electronic data banks (DIALOG, CAB, BIDS), traditional abstracting facilities (Forestry and Biological Abstracts) and a range of periodicals – particularly *Forest Ecology and Management, Forest Genetic Resources Information, Threatened Plants Newsletter* and *Silvae Genetica* – were also consulted. For less readily available recent documents, Inter-library Loans were used. Further information was collected in discussions and correspondence with experts, both in Britain and abroad (Brazil, Paraguay, Switzerland).

Results

Systematic position and circumscription

The genus *Astronium* is composed of ten (Rizzini 1978) to twelve species (Record & Hess 1972) or, according to Barkley (1968), thirteen species:

A. balansae Engl.
A. concinnum Schott
A. conzattii Blake
A. conzattii var. *lundellii* Barkl.
A. conzattii var. *standleyi* Barkl.
A. fraxinifolium Schott
A. fraxinifolium var. *glabrum* Engler
A. gardneri Mattick
A. glaziovii Mattick
A. gracile Engler
A. gracile var. *acuminatum* (Chodat & Hassler) Barkl.
A. graveolens Jacq.
A. graveolens var. *dugandii* Barkl.
A. graveolens var. *inodorum* Triana & Planchon
A. lecointei Ducke
A. lecointei var. *tomentosum* (Matt.) Barkl.
A. mirandai Barkl.
A. obliquum Friseb.
A. ulei Mattick
A. urundeuva (Fr. All.) Engl.
A. urundeuva var. *candollei* (Engl.) Hassl. ex Mattick

Astronium fraxinifolium and *A. graveolens* are closely related species in *Astronium* section *Euastronium* with almost identical ranges (Barkley 1968; Record & Hess 1972). Muñoz (1990) stressed that the distinction between the two was based only on the number of leaflets and on differences in pubescence; neither of these is a satisfactory taxonomic feature for separating such closely related species particularly where, as in Colombia, their ranges overlap. The existence of infraspecific varieties within *A. fraxinifolium* – the typical and var. *glabrum* – complicates the matter even more. Phytochemical and cytogenetic studies might help resolve the uncertainty but have not yet been undertaken.

Rizzini (1978) regards *A. fraxinifolium* as a vicariant of *A. lecointei* – the latter from Venezuela and upper Amazon River – from which it differs in being smaller and having thicker leaflets (which are also larger and less acuminate) with conspicuous reticulate venation. The lamina is usually more or less velvet-like on the adaxial blade. The calyx is also smaller in the former species.

The taxonomic history of *A. fraxinifolium* and *A. urundeuva*, including synonymy is summarized in Table 1. The references for this were after Schott (1827), Engler (1881), Barkley (1968) and Santin & Leitão Filho (1991).

Table 1. Taxonomic history: *Astronium fraxinifolium* Schott and *A. urundeuva* (Fr. All.) Engl.

Year	Authority	Event
1760	Jacquin	*Astronium* described with the type species being *A. graveolens*
1827	Schott	*Astronium fraxinifolium* described
1862	Fr. Allemão	*Myracrodruon* described with the type species being *M. urundeuva*
1876	Engler	*Astronium graveolens* var. *brasiliensis* described
1879	Grisebach	*Astronium juglandifolium* described, with Lorentz & Hieronymus *394* and *sn* from Tabacal, Argentina (at G, CORD) nominated as type specimens
1881	Engler	*Myracrodruon* moved down into *Astronium*, but retained at level of section. *Astronium fraxinifolium* referred to Section *Euastronium* with two infraspecific taxa: var. *fraxinifolium* and var. *glabrum*. *Astronium candollei* described, the type specimen being nominated as *Balansa 2528*, from Cerro-Hú, Paraguay, at G
1883	Engler	*Astronium fraxinifolium* var. *glabrum* described, with *Glaziou 12542*, from Rio de Janeiro, at G, as the type specimen
1934	Mattick	Revised circumscription of infraspecific taxa within *A. fraxinifolium*: f. *mollissimum* , f. *subglabrum*, f. *glaberrima*, f. *pilosum*; within *A. urundeuva* distinguished var. *urundeuva* and var.*candollei*, the latter name a validation of a proposal by Hassler which eventually had *A. candollei* as synonym. *Blanchet 2765*, collected on the River São Francisco, Brazil, at G, designated the isotype of f. *pilosum*
1968	Barkley	Re-instatement of Engler's circumscription of *A. fraxinifolium*. In this review Barkley nominated *Blanchet 2765* as the isotype for *A. fraxinifolium*. *Astronium graveolens* var *brasiliensis*, *A. fraxinifolium* ff. *mollissimum* and *pilosum* became synonyms of *A. fraxinifolium*. *A. fraxinifolium* ff. *subglabrum* and *glaberrima* were brought into synonymy under *A. fraxinifolium* var. *glabrum*. *Euastronium* and *Myracrodruon* raised from sectional to subgeneric rank with subgenus *Myracrodruon* divided into two sections: *Eumyracrodruon* (which contained *A. urundeuva*) and *Macrocalyx*
1990	Santin	Proposal to restore generic rank to *Myracrodruon* for *A. urundeuva*

Vernacular names of Astronium fraxinifolium

Portuguese: gonçalo-alves, guarita, gibatan, ubatan, chibatan, aratanha, aranta, batão, cubatan-vermelho, guaritan, guarabu, jejuira, gonçalo, gomável, gonçaleiro, aderno, camboatá, quebracho, aroeira-do-campo, aroeira-preta, aroeira-vermelha, maçarandubinha, sete-cascas, pau-gonçalo, gibatão-rajado, guarubu-rajado, jequira-preto, guaritan-rajado, aroeira-da-mata, brito, gonsalavia, aroeira-d'água, aroeira, gonçalo-do-mato, gonçaleiro-branco (Barkley 1968; Record & Hess 1972; López 1987; Salomão, unpubl.).
Spanish: gusanero, quebracho, quiebrahacha, almendro-macho, cuchi-blanco, urunday, urunday-para, urundei para, alemandro macho (Barkley 1968; Record & Hess 1972; López 1987; Salomão, unpubl.).
English: zebra wood, Brazilian kingswood (Titmuss 1971; Salomão, unpubl.).
French: bois de courbaril (Salomão, unpubl.).
Guarany: urunde'y para (López 1987).
Maskoy: nempeena (López 1987).

Description

Seedling: There is very little information available on the morphological features of the seedlings. I have observed dense groupings of seedlings, recently germinated, beneath a number of parent trees in gallery forest in the National Park of Brasília. Jesus et al. (1986) cited by Salomão (unpubl.) found transplanting of seedlings resulted in restricted growth.

Habit, size and form of mature tree: *Astronium fraxinifolium* is a medium to large tree, depending on soil conditions. In Colombia it is reported to reach 12–15 m in dry forests below 365 m elevation (Barkley 1968). López (1987) reported, however, individuals from 20 to 30 m and diameter between 45 and 100 cm. The bole is straight and yields commercial logs 6–15 m long. The branches are cylindrical and pubescent when young. The primary branches are large and tortuous, leading to a flat crown with thick branchlets. There is little ramification. The base of the trunk is sometimes expanded (López 1987). The bark is greyish-brown to whitish (due to the presence of lichens), devoid of hairs, rough but not fissured, and thick (10–15 mm). López (1987) described the outer bark as having numerous small lenticels. It is thin (1–3 mm), smooth and with rounded thick scales, which leave white spots when removed. The blaze is brown whilst the inner bark is pinkish and rather thick (10–16 mm).

In a review of the genus *Astronium*, Barkley (1968) noted how poorly documented the species were in terms of habit: "apparently forest trees of considerable size, but information in regard to size and shape of tree and type of root system is remarkably scanty."

Foliage: The leaves (Fig. 1) are compound, alternate, imparipinnate and petiolate. There are 7–11 leaflets which are opposite and short-petiolate, ovate in shape, acute to acuminate at the apex and subcordate to rounded at the base. Their margins are entire to slightly serrate. The central and lateral veins are conspicuous. They are pubescent on the adaxial blade, particularly over the central veins. They measure 7–12 cm in length and 3.5–6.0 cm in width (López 1987; Muñoz 1990; Salomão, unpubl.). The variety shown in Fig. 1 has glabrous leaflets that give off a characteristic mango smell when crushed (López 1987).

Flowers and fruits: The inflorescence is composed of terminal or lateral panicles which are slightly pubescent. The flowers, borne on pedicels 1 mm long, are exclusively male or female (Barkley 1968) and numerous. However, Salomão (unpubl.) also reports the presence of hermaphrodite flowers. The calyx is ca. 1 mm in diameter and composed of five suborbicular, glabrous sepals. The corolla is pentamerous, each petal being white to yellowish-green in colour and obovate in shape, measuring ca. 1 mm in width and 1.5–2.0 mm in length. These obtuse, glabrous petals persist with the mature fruit. There are five stamens with ovate anthers. The ovary is of three carpels. The stigma and the style are minute and persistent. The fruit is an oblong-fusiform, one-seeded striated drupe, 13–15 mm long. It is surrounded by ample light brown 'wings' – sepals from the pistillate flowers – which measure ca. 10–2 × 3–4 mm (López 1987; Muñoz 1990). The pericarp is smooth, with pits and the mesocarp is resinous and oil-bearing (Salomão, unpubl.).

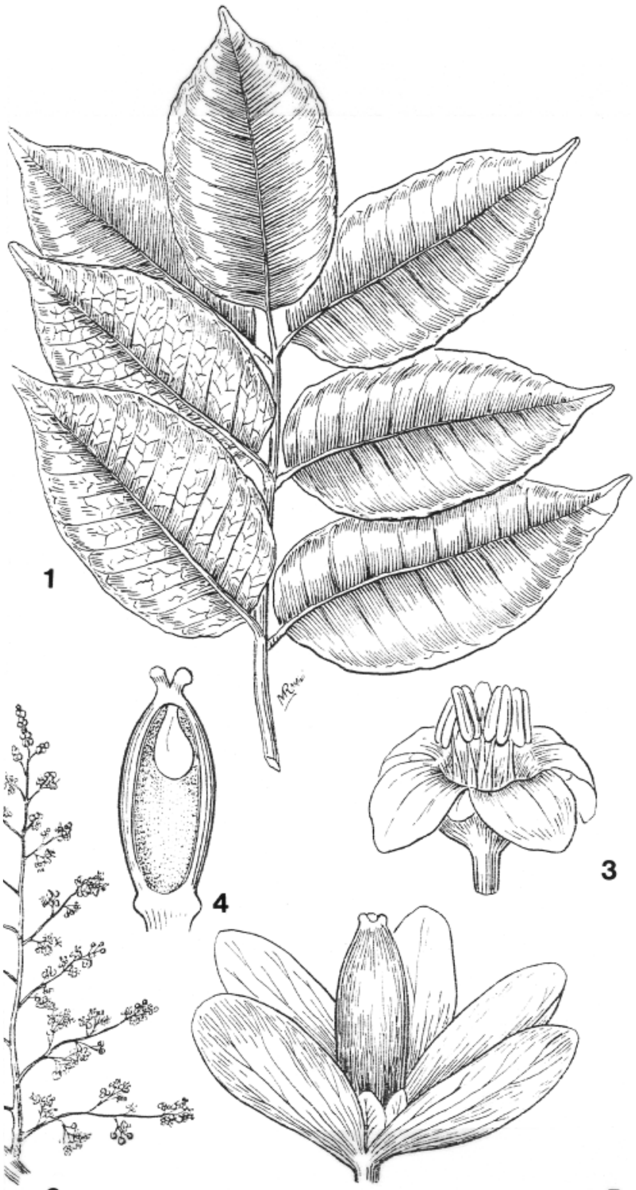

Fig. 1. Branchlet of *Astronium fraxinifolium* var. *glabrum*, 1; inflorescence, 2 (× 0.3); staminate flower, 3 (× 1.8); longitudinal section of the gynoecium, 4 (× 7.5); and fruit with the large persistent sepals, 5 (× 3) (after Muñoz 1990).

Systematic anatomy: Virtually nothing has been reported on the anatomical features of the species apart from mention of the presence of schizolysigenous canals (spaces formed by the separation of cells) in the phloem which extend to leaves and flowers. No specific function is reported for these structures. Their contents are said to be non-toxic (Barkley 1968).

Reproductive biology

Phenology: Information on the phenology of the species is summarized in Table 2. According to Barkley (1968), the fact that in several species of the genus, the flowering and/or fruiting periods are not synchronized with the presence of leaves on the trees complicated attempts to sort out the taxonomy.

Pollination and dispersal: Barkley (1968) gives the following account of the nature of *Astronium* flowers with respect to pollination: "The plants have either only pistillate or only staminate flowers. The stami-

Table 2. Phenological events for sections of the range of *Astronium fraxinifolium* Schott.

Location	Event	Period
Central Cerrado	Flower	Jun–Aug
Amazonia	Flower	Jun–Oct
	Fruit	Oct–Dec
Atlantic coast forest	Flower	Jun–Oct
	Fruit	Sep–Nov
Paraguay	Flower	Aug–Oct
	Fruit	Sep–Dec

Sources: López (1987), Cavallari & Gripp (1990), Muñoz (1990), Salomão (unpubl.), Silva *et al.* (1990).

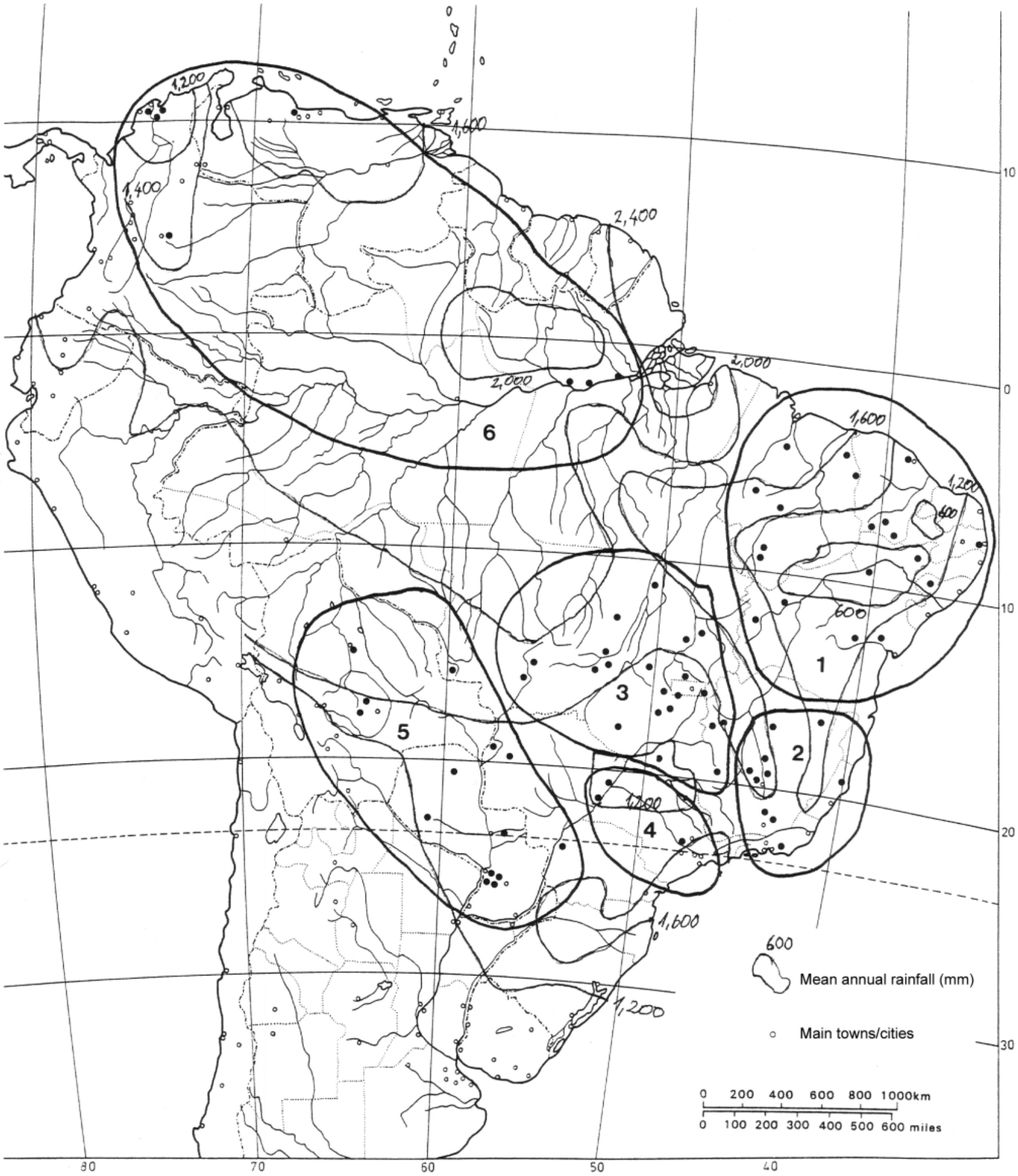

Fig. 2. Distribution of *Astronium fraxinifolium* Schott in South America. Numbers denote sub-regions and countries as follows: 1, northeastern Brazil; 2, southeastern Brazil; 3, central Brazil; 4, southern Brazil; 5, western Brazil, Bolivia and Paraguay; and 6, northern Brazil, Colombia and Venezuela.

nate flowers have small orbicular sepals, well developed stamens, and the ovary is extremely rudimentary; the pistillate flowers have obovate large sepals, which grow very rapidly after pollination, becoming the 'wings' of the fruit, small sterile stamens, and the well developed ovary that enlarges very rapidly after pollination."

Seed biology in natural conditions: Seed dispersal is apparently anemochoric but there appears to be no information on the distances travelled by the winged seeds. Data provided by Salomão (unpubl.) lets us estimate that the number of seeds in one kilogram as 4,290–6,450.

Distribution and ecology

Distribution

Present distribution: Occurring mainly in Brazil, *A. fraxinifolium* extends into Bolivia, Colombia, Paraguay and Venezuela (Salomão, unpubl.). López (1987) reports its occurrence in northern Argentina, but there are apparently no collections to support this claim.

Range: The species occurs in most northeastern Brazilian states (1), in the Amazonian State of Pará (6), in all central southern states. Some of the southernmost reported occurrences in Brazil are in Paraná State (2,3,4), just on the Tropic of Capricorn (Salomão, unpubl.). Outside Brazil the range extends to its northernmost and westernmost limits in Colombia, just north of latitude 10° N and at about 75° W longitude (6). The southernmost occurrence is in Paraguay, south of the Tropic of Capricorn (5). From the analysis of the distribution range in Fig. 2, it is clear that there is a core distribution area from the northeast of Brazil, through the centre-south with extensions towards the centre-west of the South American continent as far as Bolivia and Paraguay. In Paraguay the species is found mostly between the basins of the two most important rivers, the Paraguay and the Paraná (López 1987). In the north there are at least two disjunct occurrences – one in the Brazilian Amazonia and one at the north end of the continent in Colombia and Venezuela. It is probably that the two varieties of *A. fraxinifolium*, the typical and the one with glabrous leaflets, overlap in their distributions in Brazil, particularly in the centre and northeast, as well as in eastern Bolivia. The glabrous variety may also reach Colombian territory to the north, and Paraguay to the south. The immense gap between these extremes (cf. Fig. 2) is probably due to the very low number of collections of the species throughout its range (Campbell & Hammond 1989).

Ecology

Elevation: Evidence from herbarium information and from Barkley (1968) indicates that the species occurs over an elevational range from ca. 50 to 800 m a.s.l. It is obvious, though, that the upper limit is actually higher; it is found for example in the Central Plateaux of Brazil on terrain above 1,000 m (E.J. Leite, pers. observ.).

Climate: Comments relate to a detailed mean annual rainfall map of South America (WMO et al. 1975) and association with the distribution map (Fig. 2). The amplitude of rainfall where the species is present is very large, ranging from 600 mm in northeastern Brazil to 1,600 mm in more rainfed areas in the southeast of that country. It has also been reported in Amazonia, however, where the rainfall exceeds 2,000 mm. This pattern is consistent with the mesophytic character of the species.

Soil: In the Cerrado region the species has been recorded mainly on acid soils of low fertility in gentle landscapes. Noteworthy, however, are the occurrences on fairly rich soils, luvisols, mainly in the Brazilian northeast and the deep sandy planosols (López 1987), restricted to the southwestern part of the range. The species seems to develop well and with good form even in the poor soils of the Cerrado in the State of São Paulo (Garrido & Poggiani 1979). The species is abundant in gallery forests, despite the rather poor, acidic soils and seasonal climate. The occasional presence of the species in the upper canopy in tall forests is attributed by López (1987) to the occurrence at these sites of well-drained soils.

Community context of *Astronium fraxinifolium*

Associated species: From extensive lists of species occurring with *A. fraxinifolium*, an attempt has been made to identify those species with which it is positively associated (Table 3).

Relations with the natural fauna: No information is available on this aspect of the ecology of the species.

Relations with forest disturbance: The only report of the species being present in secondary vegetation comes from an exsiccatae label at Kew Herbarium; it indicates an origin in low secondary gallery forest in the transition between the Cerrado and Amazonia in the State of Maranhão, Brazil.

Silviculture and management

Experience with artificial regeneration

Propagation: Reported experience is limited to propagation by seed, although propagation by cuttings may be feasible. Germination reaches 80% within 7–14 days under laboratory conditions. Salomão (unpubl.) draws attention to a rapid loss of viability. Reis et al. (1980) reported total deterioration of the seeds during a 285-day germination test in the dark in a germinator at 30 ºC.

Outplanting and establishment: Seedlings seem to adapt badly to transplanting (Jesus et al. 1986, cited by Salomão, unpubl.) and direct sowing has been recommended. Garrido & Poggiani (1979) found that this pioneer species developed a good form when planted in the Cerrado in the state of São Paulo. There are planted stands in the form of silvicultural trials in the states of Minas Gerais and São Paulo (Garrido & Poggiani 1979).

Table 3. Woody species associated with *Astronium fraxinifolium* Schott.

Associated species	Part of the range
Hymenaea courbaril var. *courbaril*	C*, A*, Ca*
H. courbaril var. *stilbocarpa*	C, S*
Himatanthus obovatus	C
Caryocar brasiliense	C
Genipa americana	C
Sterculia striata	C
Dipteryx alata	C
D. odorata	A*
Copaifera martii	C*
C. langsdorffii	C*, S*
C. multijuga	A*
Jacaranda cuspidifolia	C*
J. brasiliana	C*, Ca*
Tabebuia impetiginosa	C*, A*
T. alba	C*, S*
T. caraiba	C*
T. serratifolia	Ca*, S*
T. avellanedae	Ca*
T. rigida	A*
T. cassinoides	S*
Cordia trichotoma	C*, S*
C. verbenacea	C*
C. bicolor	A*
Cariniana estrellensis	C*, S*
C. legalis	S*
Didymopanax morototoni	C*, A*
Astronium gracile	S*
A. urundeuva	C*
Bowdichia virgilioides	Ca, C*
Melanoxylon brauna	S
Schizolobium parahyba	S
Aspidosperma polyneuron	S*
A. olivaceum	S*
Cedrela fissilis	S*
C. angustifolia	S*
Ocotea pretiosa	S*
O. organensis	S*
O. suaveolens	C*

Key to symbols: A, Amazonia; C, Cerrado; Ca, Caatinga; S, South
* Denotes that the species is found in at least one sampled area within that region, while the absence of an * denotes that the species is found in several sampled areas within that region.
Source: Salomão (unpubl.)

Utilization

Wood properties

Macro- and microscopic features: According to Titmuss (1971) the grain of the species is normally straight, with a texture both fine and uniform; in contrast, Salomão (unpubl.) reported the grain as being irregular. The sapwood, which is light-coloured, is also thick – up to 8 cm according to Salomão (unpubl.). The heartwood, which is readily distinguished from the sapwood, ranges from a lightish-brown to a reddish tint with darker stripes. These bands, variably spaced, produce a very striking and beautiful figure which, together with the texture, bears some resemblance to golden ebony or coromandel (*Diospyros* sp.); however, the tone is warmer in *A. fraxinifolium*. A mottled figure approaching that of Brazilian rosewood (*Dalbergia nigra*) is sometimes evident (Record & Hess 1972). Salomão (unpubl.) reports the fibres as straight.

Physical and mechanical features: Table 4 shows physical and mechanical properties of the wood of this species.

Use as timber

Seasoning and preservation: Titmuss (1971) reports generally very satisfactory seasoning qualities of *Astronium* wood. No information has been seen on preservation apart from a reference to a good response to polishing and varnishing (Salomão, unpubl.).

Durability and workability: Record & Hess (1972), Salomão (unpubl.) and López (1987) draw attention to the durability of this wood. López (1987) stresses resistance to fungal attack, although Titmuss (1971) points out that the natural resistance to decay is not very important because the timber is mainly used for internal construction. Record & Hess (1972) and Titmuss (1971) report that the wood usually works fairly easily but is rather difficult on occasions. A smooth finish which takes a high natural polish can be achieved.

Table 4. Physical and mechanical features of wood of *Astronium fraxinifolium* Schott.

Feature	Value	Unit	Source
Density	849–1281	kg m^{-3}	a,b,c
Retractability coefficient	0.7		d
Parallel compression	67.9	N mm^{-2}	b
Modulus of elasticity	116.8	N mm^{-2}	a,b
Parallel shear	14.4	N mm^{-2}	a,b
Janka hardness	91.5	N	d
Cleavage	1.6	N mm^{-2}	a,b
Modulus of rupture	9.5	N mm^{-2}	a,b

Sources: a, Titmuss (1971); b, Record & Hess (1972); c, López (1987); d, Salomão (unpubl.).

Uses: The wood is extensively used in civil and naval buildings, luxury furniture making, sleepers, bannisters, doors and veneer (Salomão, unpubl.). Titmuss (1971) noted the rarity of the timber, despite its popularity for use in high-class furniture. When cut into veneer it takes an excellent polish, particularly the softer grades, with attractive figures for fine furniture. The denser and more deeply coloured material, especially in specimens containing a large proportion of black wood, can be used for knife handles as an alternative to cocobolo (*Dalbergia retusa*).

Other uses

Popular medicine: The tannin-rich bark is used in popular medicine against bronchitis and tuberculosis, while the roots and leaves are used to treat ulcers, bronchitis, colds and rheumatisms (Salomão, unpubl.).

Industry: The bark is used in the leather industry for tanning (Salomão, unpubl.).

Conservation status

Present conservation status

Astronium fraxinifolium is listed by the FAO Panel of Experts as a priority species for genetic conservation (Roche 1987). Cenargen has listed the species in Priority I for in situ conservation and in Priority II for ex situ conservation (Salomão, unpubl.). The FAO Panel of Experts assess the need of operational conservation measures, breaking it down in four sub-operations – in situ, ex situ, collections and seed storage – with a rating of 1 indicating the highest priority. The other operations, alongside conservation, are exploration, evaluation and utilization. This approach has also been followed by Cenargen. Strangely, there is no indication of the conservation status of *A. fraxinifolium* in the IUCN Red Data Book (C. Sharpe, WCMC, pers. comm. 1992).

Present conservation priorities

Most of the gallery forests where the species is found lack effective protection to prevent unauthorized felling of important timber trees. These areas are normally of limited size and any loss of individuals impoverishes the population and increases the risk of its disappearance.

The limited size of reserves set aside for conservation that contain this species leaves it vulnerable to catastrophic loss of genetic variability in the event of major perturbation. The small local reserves established to conserve the species in the Cerrado, in the Atlantic coast forest and in the Pantanal (Salomão, unpubl.) illustrate this problem.

Discussion

This paper deals with the conservation issue from a species-oriented rather than from the more common community-centred viewpoint. The approach followed draws on current conservation theory adapted to the circumstances peculiar to the taxon in question. Biological and genetic conservation frameworks for the species are then presented, together with suggestions of priority conservation action.

Success in conserving the genetic variation of widely distributed taxa depends upon sampling enough of the overall genetic diversity within such taxa. This means that the protected populations must include a sufficient spectrum of genetic variability and therefore also an adequate spectrum of ecological variability. The importance of clinal variation, which is common in wide-ranging tropical species, has become increasingly understood through comparative provenance trials (Roche 1984). For species-oriented programmes of genetic conservation it is essential that intraspecific genetic variation takes precedence over interspecific variation (Roche 1984).

For successful implementation of genetic conservation, there must be a clear strategy reflecting the character of the species. Tropical woody species such as *A. fraxinifolium* have long life cycles, are normally allogamous, have large individuals and mostly survive in a wild state. Consequently, relevant objectives for the strategy are a refinement of biological knowledge and development of a capability to introduce and breed the species where and as required. Such objectives also define which method of conservation suits a given species and, theoretically, dictate the sizes of populations that must be conserved.

In view of our chronic lack of knowledge of many aspects of tropical species biology and ecology, in situ conservation measures merit the greatest investment of effort. This is because the in situ approach provides for the maintenance of dynamic genetic variability more effectively than the ex situ. Whilst a level of management intervention may be needed to 'stabilize' populations, our ability to achieve this is usually greater than our ability to create ex situ stands containing an adequate representation of the gene pool.

The appeal of ex situ conservation in recent years has been heavily based on theoretical considerations which do not apply for most tropical high forest species. Implementation of this approach appears most practicable for species which are not part of climax forests; this includes species of more open tropical formations, and particularly those that are aggressive, light demanding and widely distributed (e.g. *Balanites aegyptiaca,* Hall 1992). For the majority of species from the most humid tropical environments,

Box 1. Type of information required for conservation	**Current knowledge relevant to the conservation of *Astronium fraxinifolium***
1. Population status and structure Reflect mainly levels of stocking (individuals ha^{-1}), and prominence represents distinctiveness of the species among constituents of the habitat.	Stocking levels unreported. Less than 2 trees > 15 cm dbh^{-1} (this study). Prominent mostly in Brazilian centre-south and northeast.
2. Resilience (a) Physical The importance of resilience to physical disturbance agents, normally natural (fire, browsing, drought) or 'management' activities (selective logging, clear-felling, girdling) is in the definition of methods of protection and intervention to favour the species.	No available information on this aspect.
(b) Herbivores and/or pathogens The role of herbivores and/or pathogens is important to consider when commercial species are involved.	No available information on this aspect.
3. Level of exploitation Exploitation of the resource relates to the degree to which the species is seen as economically important and under pressure in the current context.	Wide-ranging uses as timber but restricted to local market.
4. Level of rehabilitation Level of rehabilitation and resource creation cover capability in securing regeneration as desired and in controlling agents antagonistic to establishment.	Few efforts to establish plantations through some silvicultural trials.
5. Quantification and characterization of genetic variability Quantification and characterization of genetic variability are achieved through careful examination of collected material within the range of the species looking for variation at an infraspecific level, mainly by observation of phenotypic traits such as shape and size of leaves, fruits, seeds and bark. The assessment of provenance trials within the range of the species, these being dependent on sound appraisal of the total range and how growing conditions vary within it, is also of primary importance.	Infraspecific varieties: *typical* and *glabrous*, but with overlapping distributions. No information on formal attempts to establish different provenance trials.
6. Site Site represents the small-scale environmental variation (e.g. soil texture and composition and topographic features).	Well-represented on acid soils of Cerrado gallery forests.
7. Breeding system and reproductive biology (a) Sexual system Breeding systems and reproductive biology are important to ascertain by which type of reproductive system species populations are perpetuated. (b) Pollination and dispersal Important is insight into agents responsible for pollination and seed dispersal.	No available information on this aspect for this dioecious species. Little information on pollination; winged fruit leads to anemochoric seed dispersal.
8. Seed biology Seed biology knowledge, involving phases subsequent to fertilization (seed crop, pre-dispersal predation and dormancy patterns) is important for prediction of how much is produced and the proportion likely to germinate successfully. (a) Seed crop (b) Seed pre-dispersal predation (c) Seed dormancy	No information on seed crop; variation in seed weight ranges: 4,290–6,450 seeds kg^{-1}. No reported predation of seed. No apparent dormancy. Germination fairly quick in laboratory.
9. Nursery technology Nursery technology, involving raising planting stock both as selected seedlings and as cuttings, is important for enrichment planting and intervention in a management scheme. (a) Seedling production (b) Clonal production	Good response in germination tests. Seedling transplanting problematic. Indication of possibility of planting cuttings.
10. Forest policy to curb threats The forest policy aspect relates to the extent of involvement of the legal authority and how actively it promotes law enforcement regarding conservation matters for the species and how threats to it are curbed.	In situ conservation in protected areas more emphasised than ex situ conservation stands elsewhere. Small size of reserves, however, is a problem to conserve its genetic variability.

however, very little has been achieved towards the development of reliable methods of storage because of seed recalcitrance (FAO 1990). Additionally, lack of research restricts our understanding of the extent to which seed storage is a safe method of conserving tropical woody species (Roche 1975). Alternative approaches such as tissue culture remain unproven as realistic, practical methods for facilitating ex situ conservation.

Efforts have been made to link needed key genetic conservation research areas presented by Roche (1975) and National Research Council (1991) with current knowledge on the target taxa. Gaps in our knowledge, such as those revealed in this study, were given particular attention. Despite these gaps, the available information can be used as a foundation for offering practical suggestions on potentially rewarding conservation approaches, following Hall's (1992) model for *Balanites aegyptiaca*.

The types of information needed to develop a conservation strategy are presented in Box 1, together with the appropriate data for *A. fraxinifolium*. A good deal is known about the wood properties of *A. fraxinifolium*, and about its taxonomy and morphology. However, the taxonomic circumscription of the species remains disputed and clarification is needed. The available information about the distribution of the species could be used as a basis for locating potential in situ conservation areas or for planning germplasm collections for provenance trials. However, to pinpoint precise locations to conserve the genetic variability of this taxon requires further refinement of the maps; this must be based on visits to previous collection points as well as to new areas, in order to assess more fully the level of infraspecific variation. It is possible that taxonomic revision of the species will lead to changes in these maps. Our ecological knowledge about the species, despite the relatively high number of sources, is inconsistent and incomplete. Although there are no indications of stocking densities, unverified reports suggest that *A. fraxinifolium* is a rather gregarious pioneer species. Our present information on the reproductive biology of the taxon is also unsatisfactory. If seed production or seedling establishment are irregular events, it may be quite normal that there is no regeneration for several years. Comparison of the distribution of the species with major soil units was made using the FAO-UNESCO (1971) soil map. At the resolution of the map, the species showed a weak association with fertile soils.

Information concerning artificial regeneration and the influence of management on the species is poor. This is also true for conservation status, since information is very limited. More noteworthy, however, is its consistent association with several other target taxa on the FAO Panel of Experts on Forest Gene Resources list (Roche 1987). This was the basic document used by Cenargen to choose target species for the national programme of genetic conservation in Brazil. The main priorities of this programme are to promote in situ conservation by the establishment of genetic reserves wherever possible and particularly in existing protected areas. Additionally, ex situ conservation is sought through setting up germplasm banks and provenance and progeny trials. In situ genetic reserves should, however, be as large as possible to minimize problems of genetic drift and consequent depression of genetic variability that can be expected in the existing small reserves. Both in situ and ex situ methods require management.

In summary, despite our limited knowledge about *A. fraxinifolium*, we conclude that it is typical of many thinly dispersed, outcrossing, tropical forest trees which are at risk as forest disturbance levels increase and individuals, unisexual in this case, become increasingly isolated.

Of the recognized protected areas (C. Sharpe, WCMC, pers. comm. 1992) in Brazil, few appear to be adequate both in size and legal status for the long-term goals of conservation of forest genetic resources. A more practical listing of potentially viable protected areas is one according with Ibama's definition (J.C. Gonchorosky, pers. comm. 1992) of conservation units of indirect use (national parks, biological reserves, ecological stations) and direct use (national forests and extractive reserves). It is important to establish as far as possible to what extent *A. fraxinifolium* is distributed within such protected areas. Consideration of the species and its distribution within Brazil in relation to the WCMC map of protected areas (C. Sharpe, WCMC, pers. comm. 1992) can be done only on a very tentative basis at present because of limited information about the species present in many protected areas (IBGE 1993). Figure 3 shows a map where the species may occur within protected areas. Three regions correspond to the core of its distribution: the central Cerrado, the northeastern Caatinga and the centre-south. The National Parks of Ubajara (12), Serra da Capivara (10), and Chapada Diamantina (5) represent samples of the thorny scrub vegetation of the Caatinga and fall within the distribution of the species. The National Parks of Brasília (3), Araguaia (2), Emas (6) and Pantanal (9) are potentially important conservation areas in the Cerrado region. In the centre-south region, however, due to unrelenting pressure sustained since the turn of the century on the original tropical/subtropical seasonal forest for agricultural land there are few extensive protected areas. There are, however, a number of smaller ones. The taxon is found in the National Parks of Serra do Cipó

Fig. 3. Distribution of existent protected areas with *Astronium fraxinifolium* Schott: the National Parks of Ubajara (12), Serra da Capivara (10), and Chapada Diamantina (5) in the Caatinga; the National Parks of Brasília (3), Araguaia (2), Emas (6) and Pantanal (9) in the Cerrado; and the National Parks of Serra do Cipó (11) and Itatiaia (7), the Ecological Station of Tupinambás (14) and the Biological Reserve of Poço das Antas (15) in the centre-south region. Recommended potential protected areas in Brazil regarding *A. fraxinifolium* conservation: Amazonia (Santarém region), in the State of Pará (A); in the centre-south on the border between Brazil and Paraguay (D); and interior of the State of São Paulo (E). Current protected areas based on IBGE´s (1993) map.

(11) and Itatiaia (7), the Ecological Station of Tupinambás (14) and the Biological Reserve of Poço das Antas (15). There is need for enhanced protection in a number of areas throughout the ranges of the species (cf. Fig. 3). It is at risk in many parts of its distribution: in Amazonia in the Santarém region in the State of Pará (A); in the centre-south on the border between Brazil and Paraguay (D); and in the interior of the State of São Paulo (E). Protection of outlying populations is important due to the likely genetic variability existent in them when compared to the core of the range populations.

Basically, there are three practical options for tackling the conservation problem: traditional in situ reserves, normally in existing protected areas or specifically designated genetic conservation reserves; traditional ex situ stands, mostly provenance and progeny – sometimes silvicultural – trials; a compromise approach which is based on enrichment action to favour the targeted species.

Considering the current situation of protected areas in Brazil, the geographical distribution patterns of the taxon, and the little that is known of its population structure, some recommendations can be put forward for genetic conservation programmes. *Astronium fraxinifolium* is a normal component of typical forest formations. Therefore, particularly for its occurrences in Amazonia, stress should be on in situ methods with any ex situ/compromise action being limited to more degraded areas subject to major pressure for agricultural land in the interior of the State of São Paulo. Management action for compromise and ex situ approaches – priorities in the latter area – have to involve first of all firm commitment to safeguard the areas chosen from encroachment, particularly because they will be mostly in areas of intense agricultural activity in the centre-south. With our present limited knowledge, the species cannot easily be used in enrichment plantings and planted stands, possessing seed not amenable to nursery work because of poor germination levels and quick loss of viability. Nor is it suited for pure plantings – enrichment stands are more appropriate for it. It is essential to protect seedlings from fire, implying their use within established mixed stands. With so many gaps in the silvicultural/management/conservation picture it is important that new initiatives should be on a planned and focussed basis centred on identified priorities and not merely opportunistic. Detailed studies of the reproductive biology and demography of natural stands of *A. fraxinifolium* are urgently needed.

Those organizations which have a mandate to advise on national conservation policy need to make a convincing case to the legal authorities and decision-makers of the implications of not declaring additional protected areas. As indicated in this paper, these are needed to secure a viable gene pool, and suitable areas are pinpointed in Fig. 3. Other important activities to be promoted are seed collection expeditions and studies of seed storage and germination. These have been successful for two other species of conservation interest and extending these activities to *A. fraxinifolium* should be a priority. In the longer term, more involvement in provenance and progeny trials – as has already started with *Amburana cearensis* and *Astronium urundeuva* – can be foreseen for *A. fraxinifolium*. Teams dealing with reconnaissance surveys or inventories to identify areas (protected or with potential) containing the taxon should also pay special attention to assessing population structure aiming at future rehabilitation (compromise) action. A major role is played by the 'Instituto Florestal' (Forestry Institute) of the State of São Paulo in forest genetic conservation in Brazil. Because most of the actions utilizing ex situ and the compromise (enrichment) approaches are concentrated in a region around that state, it is wise to have their collaboration in these programmes. In Amazonia, programme activities concerning the in situ and compromise conservation of *A. fraxinifolium* (State of Pará) should take advantage of the expertise at Embrapa's Research Centre for the Humid Tropic (CPATU) in Belém and the National Institute for Amazonian Research (Inpa) in Manaus. It is clear, after what has been discussed in this study, that despite the dearth of current knowledge, technical solutions for the conservation of forest genetic resources followed by action are possible. Hopefully, scientific advice will be followed by political will to fulfil expectations.

Conclusions

The effective conservation of *A. fraxinifolium* in Brazil is thwarted by problems related both to our knowledge of the conservation biology of the species and to the institutions responsible for conservation. The distribution and ecology of *A. fraxinifolium* are inadequately known, and there are contradictory reports about its reproductive biology. Over much of the range, it occurs in seasonal conditions where there is increasing pressure to convert forest, including gallery forest, to agricultural land. The recorded disjunct populations in Colombia and Venezuela, as well as its absence in western Amazonia, could be due to low levels of collecting in such areas.

The background level of effectiveness and versatility of the system of protected areas in Brazil is still poor as far as conservation of forest genetic resources is concerned. *Astronium fraxinifolium* is present in only a few protected areas which focus on the conservation and management (national forest and extractive reserve) of the resource through intervention (cf. Fig. 3). Indeed, the majority of existing areas containing the species are in the 'indirect use' categories (national park, biological reserve, ecological station), as shown in Fig. 3. In these areas no management actions will be taken to promote the species, due to the non-intervention policy followed by Ibama. Such management actions are better directed to the conservation problem, in genetic reserves (in situ conservation) and formal planted stands (ex situ conservation) established by the scientific authority, as can be seen in Fig. 3.

There is no initiative concentrating on alternative conservation approaches, such as enrichment planting, to complement traditional ones. There has also been little implementation in the country of conservation options developed over the last few years from the increasing ecological understanding of tropical forest ecosystems. Much current activity takes insufficient account of the high diversity and low population densities of neotropical forest tree species. The vulnerability of the Cerrado formations to conversion for other land use makes application of effective conservation an urgent need. However, important knowledge needed for traditional in situ and ex situ conservation is lacking and, additionally, there is poor legal protection in established areas. Compromise measures, basically through enrichment (e.g. mixture) with local seed source, are therefore urged to compensate for this. Once again, our knowledge of how to achieve this is inadequate.

Recommendations

The following recommendations are made with respect to the conclusions above to assist the national conservation programme in Brazil. The patchy characteristics of forest formations in central Brazil Cerrado and the increasing fragmentation of more populated areas in the northeast and the centre-south, require that conservation strategies should take into account the island-like nature of the habitats. This is because such habitats favour high rates of inbreeding, progressive loss of genetic diversity and, in the long run, extinction of species. To curb this, the establishment of a network of local or, ideally, regional protected areas is recommended; preferably, these protected areas should be of the 'direct' category, but the possibility of creating 'indirect' categories when the opportunity arises should not be disregarded. A significant increase in the number of even small protected areas contributing to a larger network would increase chances of survival of species. This network has to be supported by complementary approaches to favour thinly dispersed forest species such as *A. fraxinifolium* by including sites which serve as links between more widely separated areas. This could involve the use of enrichment techniques with germplasm from nearby sources.

To cater for the needed expansion of protected areas recommended above, surveys of the fragmented gallery forest habitats are necessary. These should include census of woody species, as well as information about recruitment, growth and mortality of the target species. This should be done in all areas within the established conservation network where the species occurs. To refine ecological understanding of the species, emphasis is recommended to be on simultaneous appraisal of populations in replicate areas of gallery forest. This would overcome the problem of limited environmental variation when attention is confined to detailed study at only a single location. Nevertheless, the need for observations to be extensive despite inherently low stocking will remain and the broad sampling strategy of species-focussed census activity should still apply.

Finally, although in situ conservation is to be preferred for *A. fraxinifolium*, ex situ compromise approaches may be the best option in some parts of its range, especially where there is extreme pressure for agricultural land. However, this will require improved knowledge of the reproductive biology of the species.

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