MODULE 2
Trees outside of forests

Case study 2.2

Devising options for conservation of two tree species outside of forests

David Boshier

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Module 2
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Devising options for conservation of two tree species outside of forests

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Conservation faces a problem in Central America. The seasonally dry forest is diverse and distinctive, containing many socio-economically important species that have been used in much of the tropics (e.g. *Calliandra calothyrsus*, *Gliricidia sepium*). However, existing protected areas cover a very small fraction of the original forest, and there are few intact dry forests left to conserve. The degree to which *in situ* protected areas are appropriate for conservation depends on a variety of factors, such as forest size, the extent of fragmentation, and the prevailing socio-economic context. Those dry forests that do remain are usually small (e.g. 1 to 500 ha), below a size that might be considered viable. Furthermore, they are highly scattered, so that the ideal of maintaining a single large reserve is often not realistic. Consideration must therefore be given to the biological and social feasibility of managing networks of small forest patches within the current land-use mosaic. Conservation initiatives for such dry forest must examine approaches that depart from the traditional *in situ* conservation paradigm which emphasizes protected "wilderness areas," and focus instead on ways in which the species of an already highly altered forest type can be conserved.

This case study allows you to explore the role that trees outside of forests may play in conserving tree genetic resources. The exercise considers the overall question of '*Can valuable tree genetic resources persist outside of forests and, if so, what measures need to be taken to ensure they persist*?' The case study presents information from ecological, genetic, and socio-economic research conducted in the 1990s in dry forests of Costa Rica and Honduras. It focuses on two timber species, *Pachira quinata*, Bombacaceae, and *Swietenia humilis*, Meliaceae, both of local socio-economic importance, with superficially similar ecology and regarded as being of conservation concern.

Use the information presented here to derive an action plan to ensure effective conservation and use of both species outside of forests. In your group discussions, you need to think about the following:

- What is the mating system of each species? Do trees self and if so under what circumstances? How do the pollen and seed dispersal vectors respond to fragmentation/isolation?
- Does maintenance of the species in agroecosystems lead to reduced levels of genetic variation and if so what management strategies can be used to avoid such a reduction?
- What are the factors and threats limiting maintenance of *P. quinata* and *S. humilis* (short-term/long-term) in the fragmented farm landscape? Are they the same or different for each species? Think of problems by type such as ***genetic*** (e.g. selfing), ***ecological*** (e.g. lack of regeneration), ***social*** (e.g. land tenure, use).
- Is any other information needed to allow more definitive conclusions?

In your action plan you should cover the following:

- Main biological features of the species.
- Factors limiting maintenance of the species in fragmented farm landscapes – the differences between the species.
- Specific actions to ensure both use and conservation of both species in this agroecosystem (including maintenance of genetic diversity). Should they be the same or different for each species and if different, in what way(s)?
- How will you implement the action plan? ***Who*** will do ***what***, **w*here*** and ***how*** will you pay for it?

Introduction

The southern Honduran lowlands are mainly used for cattle pasture and export agriculture (cantaloupe, watermelon, sugarcane), and characterized by a subtropical climate with a distinct dry season (October-May). The foothills comprise a fluctuating mosaic of land uses, with a predominance of maize and sorghum production (*milpas*), alternating with fallows plus some low-density cattle grazing and, in more humid areas, low-intensity coffee production. Lack of mechanized tillage and control of livestock movement typically allow natural regeneration of a highly variable range of tree species from soil seed banks, stumps, and new seed. Reflecting a desire to make the best use of available resources, many farmers actively protect a subset of these tree species that they value for a range of products (e.g. firewood, timber). Thus some trees become, and remain, reproductively mature in *milpas* or pasture. Another subset of species remains as resprouting stumps (up to 17 000 per ha) simply because the removal cost is not thought to produce sufficient benefits. Many of these trees also reach reproductive maturity in fallow periods. These lowlands therefore contain patchy forest within a surrounding forest-agriculture interface, which along with the socio-economic circumstances are suited to multi-disciplinary research.

Case study species

Pachira quinata (syn: *Bombacopsis quinata*) is a medium- to large-sized deciduous tree from Central America, Colombia, and Venezuela. It is hermaphroditic, largely self-incompatible and principally bat-pollinated (*Glossophaga soricina*). Its seeds are loosely attached to kapok (a fluffy cotton-like fibre) which facilitates wind dispersal. Its timber is much in demand and has led to investment in large plantations, as well as to planting by farmers within Central America. The tree grows well in plantations when established in the open, with nursery stock raised from seed. It can also be propagated by stakes and is used for living fences in parts of its range. Selective felling, deforestation, and destructive agricultural practices have left this once common species largely limited to isolated forest remnants, with some populations considered endangered.

Swietenia humilis is a monoecious, medium-sized deciduous tree found along the Pacific watershed of Central America and Mexico. It is pollinated by small butterflies, bees and other insects, while its fruits contain large, wind-dispersed seeds. Under controlled pollination, it is self-incompatible. Its sawn timber is highly valued, but commercial reforestation within its native range is hindered by the high incidence of attack by the shoot borer *Hypsipyla grandella*. Where populations of *S. humilis* and *S. macrophylla* are sympatric, hybridization is known, and their distinctness as species has been questioned. Populations over much of the species' range have been reduced and fragmented, leading to its listing in 1973 on Appendix 2 of CITES and classification as "vulnerable" by IUCN.

Patterns of distribution at the species level

Two rapid botanical surveys (a plotless sampling technique) were undertaken to determine tree and shrub species composition of southern Honduran agroecosystems. A first, village-level survey consisted of species inventories in four rural communities that reflect regional variation across socio-economic and environmental gradients. Within each community, 20 households were selected along a socio-economic gradient and a random subset of land units selected for inventory from amongst those farmed by these families. Land unit categories were based on definitions given by householders. In each land unit, species were scored as present or absent, a species being considered present if it could be identified as a woody individual, and so this included live stumps. A second, forest level survey inventoried tree diversity in a subset of forest patches in southern Honduras. Forests were selected non-randomly to maximize geographic spread and biased towards the few remaining, relatively large forest areas (i.e. > 50 ha). All forests appeared to be largely, if not completely, composed of secondary regeneration of varying ages. Primary dry forest apparently no longer exists in southern Honduras, although it is probable that some older trees are remnants of much older forests. The forest cover that does remain is composed of stands of trees of as little as 2 ha in area and rarely greater than 20 ha, areas usually considered too small to be of value for conservation.

The species differ in where they occur. *S. humilis*, one of the most commonly found species (only 7 of >250 woody species were found more often), occurred as frequently in farmland as in forests (Table 1). In contrast, *P. quinata* was found less often than *S. humilis*, but far more often in forests than on farmland. Compared to home gardens and orchards, where planting is more typical, both tree species were more common in fallows, fields, and pastures (Table 1), all of which are systems where natural regeneration typically occurs. Both species also showed considerable variation in occurrence between the four communities (Table 1), probably owing to a combination of biological and human factors.

Two of the larger forests in southern Honduras suggest that both species show similar levels of occurrence in mature forest. In relatively undisturbed forest on Cerro Guanacaure, *P. quinata* is common, as is *S. humilis*. On Cerro Las Tablas, in one of the most mature secondary forests in the area, many mature *P. quinata* and *S. humilis* trees occur (densities up to 17.0 and 9.6 trees per ha, respectively). In Costa Rica, both species occur at similar levels in more undisturbed areas of protected dry forest (e.g. Lomas Barbudal, Playa Nancite mature forest; Table 2). Thus, there are grounds to believe that in southern Honduras the relatively low occurrence of *P. quinata* on farms results partly from unfavourable management practices (see later) rather than a natural tendency toward low densities.

The common on-farm occurrence of *S. humilis* cannot be explained simply by farmer preference (see section “Patterns of Management of *P. quinata* and *S. humilis* in Southern Honduras”), given that natural regeneration has to occur before farmers can aid its recruitment. *S. humilis*, like its close relative *S. macrophylla*, undoubtedly thrives in conditions of heavy disturbance such as occurs with traditional agriculture in southern Honduras. Once established, it can survive for decades in the closed forests that may form when fallows are abandoned. Germination of *S. macrophylla* in Guanacaste was not affected by differences in light levels and could establish equally well in pasture and young secondary forest. A study with seedlings in pasture and secondary and mature forest, showed zero survival of *P. quinata* at three years of age in both Costa Rica and Honduras, compared with 15-60% for *S. humilis*. This pattern is repeated at Playa Nancite (Santa Rosa National Park), where *S. humilis* regeneration in adjoining areas of abandoned and degraded pasture is abundant and that of *P. quinata* non-existent (Table 2). In contrast to other predictions and some studies, seed production of *S. humilis* was also more reliable and higher in disturbed environments than in closed forest whereas that of *P. quinata* showed no difference by forest type, except at Playa Nancite where seed production was low in all four fruiting seasons (Table 3). During this period, 13% of *P. quinata* trees at Playa Nancite died from apparent old age, creepers or wind. Given the lack of any regeneration, the future of *P. quinata* at this site seems insecure, despite it being within a protected area. Indeed, fires and tree felling evident over four years (Table 2) confirm threats to both species, even within protected areas.

Table 1. Occurrence of *P. quinata* and *S. humilis* by land-use and community in southern Honduras

Land use	Total number of samples	Percentage containing *P. quinata*	Percentage containing *S. humilis*
Forest	48	27	52
Farm	105	11	56
Fallow, field and pasture	58	16	67
Home garden and orchard	47	4	36
Community/Department			
San Juan Arriba, Choluteca	25	12	4
Agua Zarca, Valle	38	5	74
San Jose de las Conchas, Choluteca	24	17	46
Los Coyotes, Choluteca	25	16	64

Table 2. Mortality of trees greater than 10 cm dbh over a four year period, through natural causes or human intervention, at sites in Costa Rica and Honduras

Species	Site	Country	Site type	Area studied (ha)	No of trees	Mean dbh[3] in cm (s.d.)	Percentage of trees cut/ dead
P. quinata	Lomas Barbudal Biological Reserve	Costa Rica	protected area	25	61	69.2 (25.5)	0/6.6[2]
	Playa Nancite, Santa Rosa National Park	Costa Rica	protected area/ mature	28	62	71.6 (42.8)	0/12.9
	Playa Nancite, Santa Rosa National Park	Costa Rica	protected area / regeneration	3	0		
	Punta Ratón, Choluteca	Honduras	private forest/ farm	240	172	54.2 (20.9)	8.1/5.8[2]
S. humilis	Lomas Barbudal Biological Reserve[1]	Costa Rica	protected area	25	57	47.4 (17.0)	0/14.0[2]
	Playa Nancite, Santa Rosa National Park	Costa Rica	protected area/ mature	28	156	46.7 (16.0)	0/5.8
	Playa Nancite, Santa Rosa National Park	Costa Rica	protected area / regeneration	3	23	20.3 (3.7)	0/0
	Cerro Las Tablas, Choluteca	Honduras	private forest/ farm	68	105	41.9 (14.0)	25.7/1.9
	Punta Ratón, Choluteca	Honduras	private forest/ farm	240	75	37.9 (14.1)	5.3/5.3

[1] possibly *S. macrophylla* or *S. macrophylla* x *S. humilis* [2] killed by 1994 fire [3]dbh = diameter at breast height

Table 3. Percentage of trees per year with moderate to heavy seed production at various sites

Species	Site [a]	Sample size[b]	1994 %	1995 %	1996 %	1997 %	1998 %
P. quinata	Lomas Barbudal	>45	70.6	66.7		68.9	
	Playa Nancite	>30	61.5	56.4	55.2	31.5	
	Punta Ratón	>105	76.4	61.9	73.3	90.1	
S. humilis	Lomas Barbudal	>46		12.1	0.0	16.3	20.8
	Playa Nancite	>143		32.9	11.0	18.4	17.2
	Cerro Las Tablas	>61		48.7	12.6	29.5	44.6
	Punta Ratón	>45	28.0	36.1	42.2	49.1	33.3
	Comayagua	30	66.7		60.0	83.3	76.7

Note: Moderate to heavy seed production for *P. quinata* is > 20 seed capsules; for *S. humilis* > 10 seed capsules.

[a] Sites are ranked for increasing degree of disturbance: Lomas Barbudal, a relatively undisturbed area within a reserve; Playa Nancite, area of National Park with disturbance; Cerro Las Tablas, forest with remnant trees and secondary regeneration; Punta Ratón, remnant trees and secondary regeneration in small fragments and pasture; Comayagua, planted trees by roadside

[b] Sample size varies from year to year owing to mortality

The study concludes that species are likely to occur non-randomly in the various land-use types of an agroecosystem and that these distribution patterns must be known for *circa situm* conservation options to be assessed and to devise and implement strategies. The fact that 76% of species identified in the surveys were found in agroecosystems (i.e. not limited to forest) emphasizes the potential for on-farm trees to make a contribution to conservation. Assuming greater occurrence means greater conservation potential, the potential for different sites as foci of successful *circa situm* conservation will vary. For example, from just the distribution data, the Agua Zarca community has a high potential for conservation of *S. humilis* but very little for *P. quinata* (Table 1). *S. humilis* appears ecologically suited to *circa situm* conservation through use on the farms, where tillage is minimal, livestock movement controlled, and fallows sporadically allowed. *P. quinata*, however, appears less suited, being far more susceptible to removal of forest cover. However, even for such species that appear to be predominantly "forest species", the relatively few individuals on farms may facilitate gene flow between forests and maintain population sizes across landscapes. Evidently, conservation strategies for the two species need to be different.

Patterns of management of *P. quinata* and *S. humilis* in southern Honduras

A study in the same communities where species inventories were taken, shows that in addition to differences in reproductive biology, ecology, and local distribution, *P. quinata* and *S. humilis* differ in management by local people. In general, within these communities, people mentioned that many of the tree species under active protection are also used for timber, although there was a marked contrast between the frequency of active protection for *S. humilis* and that of *P. quinata* (Table 4).

A focal group meeting at Los Coyotes rated species for present and past use, revealing marked differences in the way the two species have been regarded socio-economically. "*In our grandfathers' era*" *P. quinata* was almost the only species used for timber. However, its exploitation to supply furniture workshops in the town of El Triunfo led to a large decrease of its numbers in the area. Farmers now use a broad range of previously little-used species, including *S. humilis*, some others of which (e.g. *Guazuma ulmifolia*) have far inferior timber value. Farmers also described previous management practices during field clearance, whereby many valuable timber trees were felled and burned on-site or used for firewood. By contrast, in current practices, valued trees are protected and only timber off-cuts used as firewood.

Apparently due to a scarcity of forest resources resulting from high human population densities, many farmers favour certain tree species during clearance, protecting and managing these trees within their fields to help meet their subsistence needs and provide a naturally regenerated cash crop. Stumps and seeds also survive regardless of felling because stump removal is difficult and mechanical tillage is rarely practised owing to topographical constraints. Farmers are also adept at controlling grazing which is necessary for successful maize cultivation, so livestock do not necessarily prevent tree regeneration and indeed may facilitate it (e.g. stimulating germination of some species). Despite their small sizes, patches of fallow and forest within the mosaic continue to be propagule sources of many of the species found in these fields.

Table 4. Principal tree species mentioned by farmers as used for timber or actively protected within agricultural areas as sources of timber or posts in four communities in southern Honduras

Species used	% of interviewees[a]	Species protected	% of interviewees[a]
Cordia alliodora	84.8	*Cordia alliodora*	38.0
Pachira quinata	20.3	*Swietenia humilis*	22.8
Enterolobium cyclocarpum	19.0	*Lysiloma* spp.	20.3
Albizia saman	16.5	*Enterolobium cyclocarpum*	10.1
Lysiloma spp.	16.5	*Albizia saman*	10.1
Swietenia humilis	16.5	42 other tree species, including *Pachira quinata*	1.3 - 6.3 each
Calycophyllum candidissimum	15.2		
Cedrela odorata	15.2		
Conocarpus/Rhizopora spp. (mangrove)	15.2		
Simarouba glauca	11.4		

Note: The four communities were San Juan Arriba, Agua Zarca, San Jose de las Conchas and Los Coyetes
[a] Figures given as a percentage of 79 interviewees

Up to a limit, the benefits of keeping trees outweigh the negative effects (e.g. shade) that farmers perceive some trees to have on crops. Such management represents a rational response to resource scarcity rather than a desire to conserve biological diversity *per se*. The relatively low frequency of protection of *P. quinata* in fields (Tables 1 and 4) is not apparently due to its being less valued than *S. humilis* or from differences in farmers' perceptions of tree/crop interactions (no important negative interactions were reported by farmers between either species or crops). A more probable explanation is the relative scarcity and patchy distribution of *P. quinata* natural regeneration, particularly in fields. Farmers do protect *P. quinata* but it is found much less frequently than *S. humilis*. The current scarcity of *P. quinata* appears to stem, in part, from its ecological characteristics and past over-exploitation, prior to self-imposition of tree management controls by farmers as a response to its scarcity. *S. humilis* differs in that it appears to have been rather less valued than *P. quinata* and as a result largely escaped over-exploitation. *S. humilis* now benefits from the current practice of active protection of the remaining valued species and its ease of regeneration. However, despite farmers' clear preference for both species and their promotion by extension agencies, neither species is commonly planted. This probably reflects the cost of planted trees, compared with 'free' natural regeneration and possibly the greater risks to planted trees from cattle that are periodically allowed into *milpas* to eat crop residues.

Both *P. quinata* and *S. humilis* also occur in forest patches and pastures within larger estates (e.g. in the Cerro Las Tablas area), although management systems and socio-economic conditions are very different from those in the small farmer communities. In both pasture and forest remnants on these estates, there appears to be a continued decline due to sporadic felling (Table 2), possibly as the landowners do not face the same conditions of overall resource scarcity that motivate small farmers to nurture natural regeneration. Compared to subsistence production systems on steeper land, conditions in many pastures of these larger estates are less favourable for tree regeneration; they are normally destumped on clearing and then periodically burned to encourage grass growth.

Genetic diversity and its maintenance

Reproductive biology, genetic diversity and gene flow, were studied within the native range of both species in southern Honduras and north-west Costa Rica (Fig. 1). Remnants of secondary dry forest, confined principally to hillsides, and remnant pasture trees were used, along with control plots in more continuous forest. Fragments varied in size (1 to 150 trees) and spatial isolation (1.0 to 4.5 km). For both species, direct measurements of mating patterns, using microsatellite molecular markers, gave higher levels of between-fragment pollen flow over longer distances. Common to forest and fragments was a predominance of near-neighbour mating (<300 m between trees) in both species. A large proportion of pollen donors were, however, from outside each fragment, indicating an extensive network of gene exchange at this spatial scale (16 km^2). So, for *S. humilis* in two fragments (22 and 44 trees), 62% and 53% respectively of pollen donors were from within the fragment, whereas 24% and 34% were from distances greater than 1.5 km and 3.6 km, respectively (Fig. 2 and Table 5). Thus, at the degree of isolation studied, fragmentation did not impose a genetic barrier.

There was no evidence for increased inbreeding in fragments, with both species continuing to show high levels of outcrossing even in small fragments. In contrast, outcrossing patterns of isolated pasture trees varied between species. A single *S. humilis* tree, isolated by 1.4 km from the nearest flowering trees, showed 100% external pollen sources, more than 70% of which came from trees in the main area of forest more than 4.5 km away (Tree 501, Fig. 2; Table 5). This corresponds to a strong self-incompatibility mechanism in *S. humilis* and is in contrast to predictions that spatially isolated trees are more likely to deviate from random mating and receive pollen from fewer donors.

Figure 1. Location of study sites in Central America

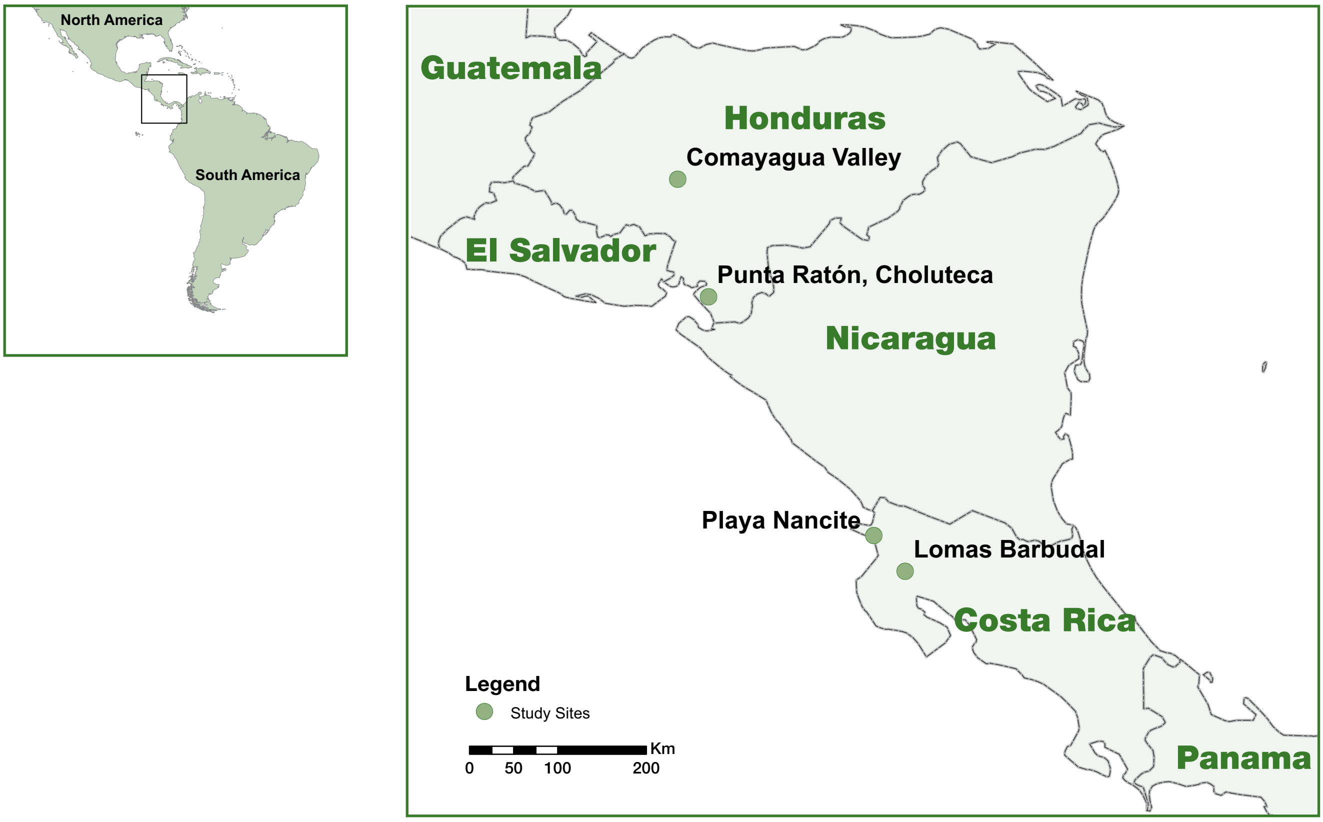


Table 5. Pollen flow in *S. humilis* into fragments and an isolated tree in Choluteca, Honduras. The sample size of each fragment, separation distance from the nearest fragment, mean percentage of external pollen flow and largest minimum distances of pollen flow are shown per fragment

Fragment	Sample size	Separation distance from next fragment (km)	Mean % 'into fragment' pollen flow	Mean largest minimum pollen flow distance (km)
Las Tablas*	97	-	36.0	-*
Butus/Jicarito	44	1.1	47.0	3.1
Jiote	22	1.1	38.3	1.7
Tablas plains	7	1.2	68.4	1.6
Tree 501**	1	1.4	100.0	>4.5

* 'Las Tablas' is a portion of continuous forest and is adjacent to unsampled trees
** 'Tree 501' is an isolated tree

Isolated *P. quinata* trees in pastures did show some increase in selfing for the population as a whole, although this varied between sites, trees and degree of isolation (Table 6). Examination of individual tree outcrossing rates showed that selfing does not increase directly with isolation, with the most isolated trees not always selfing (Fig. 3). Microscope studies of controlled pollinations show that *P. quinata*'s self-incompatibility system is 'leaky'; there is reduced germination of self pollen on stigmas and slower growth rate of self pollen through the style to reach the floral ovaries (Table 7). Controlled pollination also showed a varied ability to self among trees, with 50% of trees failing to self, whereas 12.5%

showed high seed set under selfing. Thus, there is varied capacity between trees to self when availability of cross-compatible pollen is reduced, as may happen with spatial isolation. Increased levels of inbreeding from the leaky self-incompatibility system could lead to reduced fitness of seed collected from isolated *P. quinata* trees in pastures or other agroecosystems.

Figure 2. Relative locations of *S. humilis* trees (represented by a dot) sampled in Choluteca, Honduras. Each fragment is enclosed with a hatched line and labelled. Location of unsampled trees (U) adjacent to Las Tablas site shown by spotted area. Seventeen trees selected for progeny analysis are circled. All trees and progeny were genotyped at four microsatellite loci. Paternity exclusion analysis identified subsets of fathers for each progeny, fractional likelihood of paternity, and distance from the tree

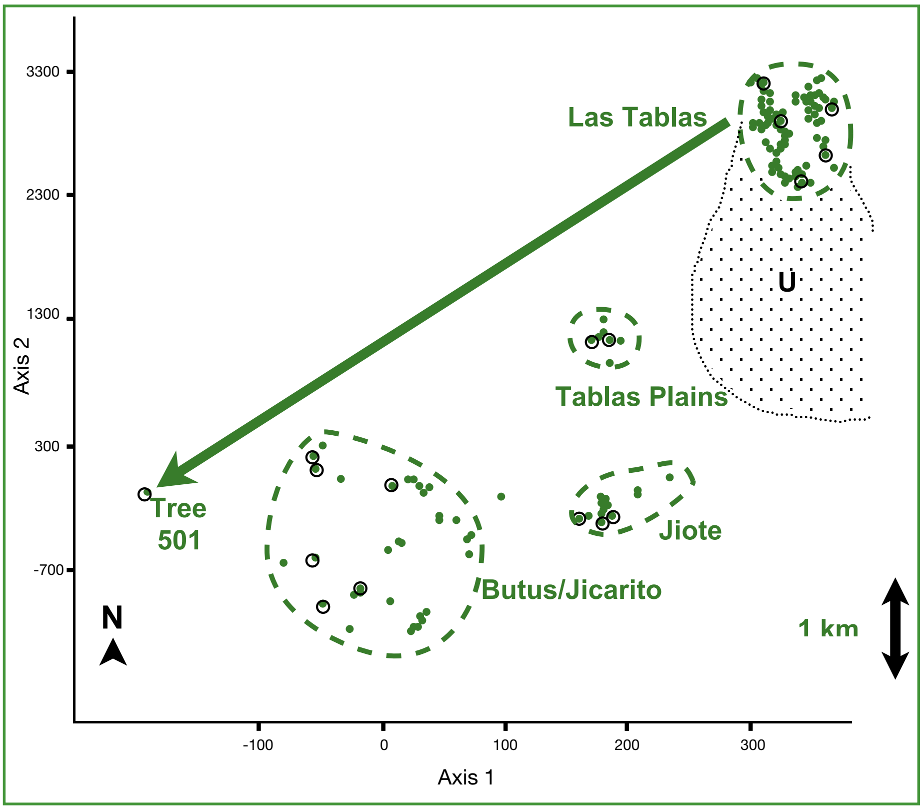


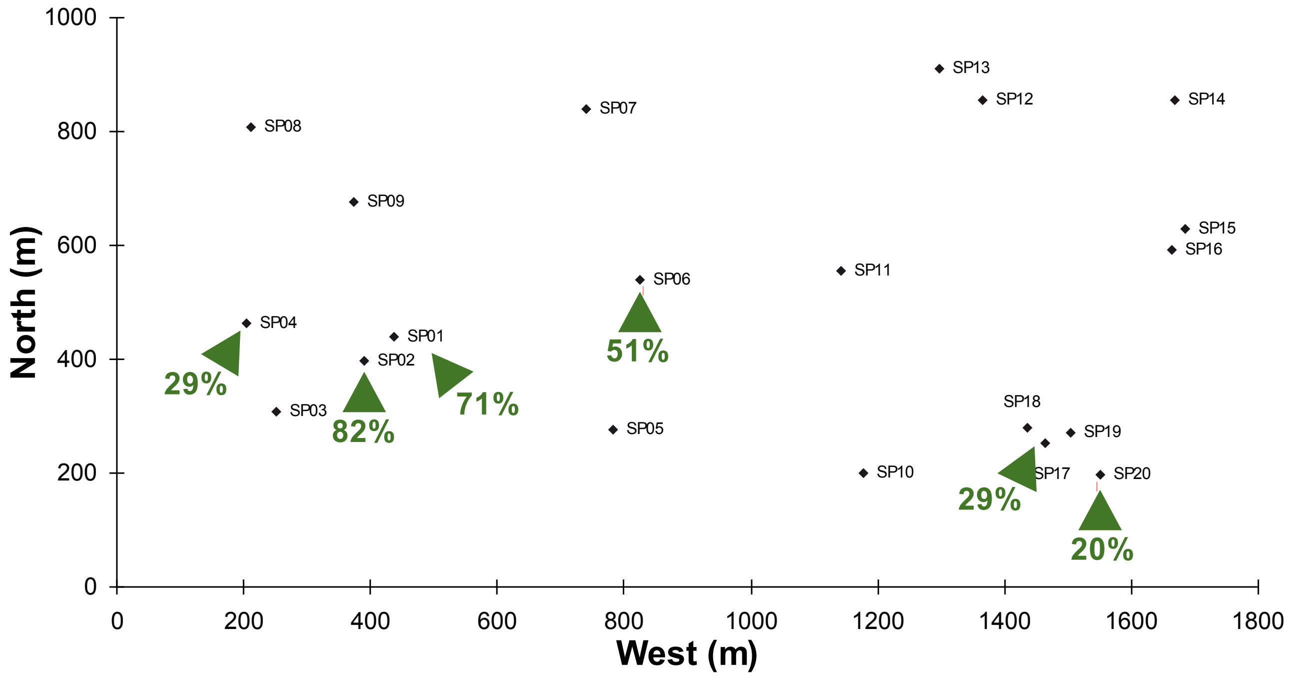
Table 6. Outcrossing rates and dispersal distance of *P. quinata* trees in forest and pasture under differing degrees of spatial isolation. Standard errors in parentheses

Site	Tree isolation distance	Outcrossing rate (SE)	Correlation of tm (SE)	No of sires	Mean dispersal distance
Forest	10-100m	0.926 (0.005)	0.117 (0.045)	3.7-4.6	48m
Forest	10-100m	0.915 (0.043)		1.8-2.6	
Pasture	60-300m	0.828 (0.015)	0.636 (0.148)	3.1-4.1	158m
Pasture	>500m	0.777 (0.114)		1.2-1.6	

Table 7. Percentage of pollen tubes reaching the ovary in relation to the time after pollination, showing differential pollen tube growth rate in controlled pollinations of *P. quinata*

Time after pollination	Self	Cross
48 hours	15%	56%
72 hours	64%	90%
120 hours	89%	90%

Figure 3. Relative locations of *P. quinata* trees sampled in pasture in Guanacaste, Costa Rica. Arrows indicate trees that showed a high selfing rate (% selfing is given next to the arrow)



The enhanced levels of long-distance gene flow into smaller fragments seen for both species will potentially restore or maintain genetic variation in populations of these species within the modified environment. Increased dispersal distances from a large number of sites should maintain genetic variation in fragmented landscapes, though this will depend on the characteristics of the land-use mosaic and the extent to which each land-use facilitates or impedes gene flow. This contrasts with traditional views of the genetic effects of fragmentation whereby increases in spatial isolation and population size reduction have been considered to reduce gene flow between fragments. Although the genetic effects of fragmentation are complex, for some tree species under fragmentation, pollination may occur over much greater distances than previously considered. There will, however, be distances and landscapes for which genetic isolation will occur, with associated problems for population viability and adaptation. Thresholds will vary between species depending on pollinator characteristics and availability, specificity of the tree-pollinator relationship, and the presence and strength of any self-incompatibility mechanism. Self-compatible species that normally show some level of outcrossing are likely to show increased levels of inbreeding at much shorter distances of separation (lower thresholds) than self-incompatible species.

Information sources

The study is based on the following papers and other unpublished work of Boshier and co-workers.

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