Original article

Impact of habitat type on the conservation status of tamarind (*Tamarindus indica* L.) populations in the W National Park of Benin

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Impact of habitat type on the conservation status of tamarind (*Tamarindus indica* L.) populations in the W National Park of Benin.

Abstract — **Introduction**. The conservation status of many wild fruit tree species that support rural people in Africa remains poorly documented despite its importance for their management. We compared the viability of tamarind (*Tamarindus indica*) populations, a dry land species that has nutritional, medicinal and cultural importance for rural communities, under different human-pressure levels. **Materials and methods**. The data relative to the tree diameter and height as well as the number of adults and stems were collected in plots of inventory and made it possible to calculate the dendrometric parameters for each targeted population, and to establish their diameter distribution. The dendrometric characteristics were analyzed by using nonparametric tests and the diameter distribution was adjusted to a truncated normal distribution. **Results and discussion**. Numbers of mature tamarind trees per hectare and regeneration (expressed as stem·ha^{-1}) were relatively low, suggesting tamarind populations may not be self-rejuvenating. Nonetheless, significant variation occurred between habitat types ($P < 0.001$). Mature tree density in gallery forests [(18.2 ± 10.1) trees·ha^{-1}] was three to eight times higher than that of savannah woodlands [(5 ± 4.5) trees·ha^{-1}] and farmlands [(2.5 ± 0.4) trees·ha^{-1}]. Young plants followed the same trend, with (11.2 ± 9.3) plants·ha^{-1}, (1.1 ± 0.6) plants·ha^{-1}, and 0.00 plants·ha^{-1}, respectively. Diameter size class distributions departed from normality ($P < 0.0001$) and coefficient of skewness was positive irrespective of habitat type, indicating declining populations. However, median diameter values would suggest the species' populations in farmlands and savannah woodlands to be more vulnerable than those occurring in gallery forests. These findings would suggest that gallery forests best suit tamarind *in situ* conservation. The observed severe reduction of trees and juveniles in farmlands and woodlands may negatively impact the long-term viability of tamarind populations. Juveniles' introduction into farmlands may be needed to ensure conservation in agroforestry systems.

Benin / *Tamarindus indica* / resource conservation / habitats / stand characteristics / forest inventories / anthropic influence

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Impact du type d'habitat sur la conservation des populations du tamarinier (*Tamarindus indica* L.) dans le parc national du W au Bénin.

Résumé — **Introduction**. Le statut de conservation de nombreuses espèces fruitières sauvages dont dépendent les populations rurales en Afrique demeure mal documenté en dépit de son importance pour la gestion de leurs populations. Nous avons comparé la viabilité des populations de tamariniers (*Tamarindus indica*), espèce ayant une importance alimentaire, médicinale et culturelle pour les communautés rurales, sous différents degré de pression humaine. **Matériel et méthodes**. Les données relatives au diamètre et hauteur des arbres ainsi que le nombre d'adultes et de juvéniles ont été collectées dans des placettes d'inventaire et ont permis de calculer, pour chaque population ciblée, les paramètres dendrométriques et d'établir la distribution des diamètres. Les caractéristiques dendrométriques ont été analysées en utilisant des tests non paramétriques et la distribution des diamètres a été ajustée à une distribution normale tronquée. **Résultats et discussion**. Le nombre de tamariniers adultes et la régénération (exprimée en nombre de tiges·ha^{-1}) ont été relativement faibles, suggérant que les populations de tamariniers ont une faible capacité à se régénérer. Néanmoins, une différence significative est apparue en fonction du type d'habitat ($P < 0{,}001$). La densité des arbres adultes dans les forêts de galerie [(18,2 ± 10,1) arbres·ha^{-1}] a été trois à huit fois plus élevée que dans les savanes boisées [(5 ± 4,5) arbres·ha^{-1}] et dans les terres cultivées [(2,5 ± 0,4) arbres·ha^{-1}]. Les jeunes plants ont exprimé la même tendance avec (11,2 ± 9,3) plants·ha^{-1}, (1,1 ± 0,6) plants.ha^{-1} et 0 plant·ha^{-1}, respectivement. La distribution des diamètres s'est écartée de la distribution normale ($P < 0{,}0001$) et le coefficient d'asymétrie a été positif quel soit le type d'habitat, indiquant des populations en déclin. Cependant, la valeur médiane des diamètres suggèrerait que les populations de *T. indica* dans les terres cultivées et dans les savanes boisées sont plus vulnérables que celle des forêts galerie. Ces résultats indiquent que les forêts galerie conviendraient le mieux à la conservation *in situ* du tamarinier. La diminution critique des arbres et jeunes plants observée dans les terres cultivées et les savanes boisées pourrait influencer négativement la viabilité à long terme des populations de tamariniers. L'introduction de jeunes plants dans les zones de culture pourrait être nécessaire pour assurer la conservation de *T. indica* dans des systèmes d'agroforesterie.

Bénin / *Tamarindus indica* / conservation des ressources / habitat / caractéristique du peuplement / inventaire forestier / influence anthropique

1. Introduction

Many tropical fruit trees are not the objects of large world markets, but still have considerable importance in local and national economies, being harvested by rural populations for local consumption and commercialization on a small scale [1]. Interest in these species has reached a peak with new initiatives in agroforestry. These initiatives seek to integrate, into tropical farming systems, indigenous trees whose products have traditionally been gathered from natural forests [2], in order to provide marketable products from farms that will generate cash for resource-poor rural households. To sustain this goal, many studies have addressed morphometric, genetic variabilities among and within populations and fruiting potential (for example, baobab [3, 4], *Sclerocarya* [5], *Vitellaria* [6], *Irvengia* [7], *Detarium* [8]). However, efforts in this direction are limited by lack of information about the conservation status of populations of most of these important multipurpose trees.

Like most other tropical countries, Benin ecosystems are full of multipurpose tree species [9]. *Tamarindus indica* L. is a semi-evergreen multipurpose tree species of the Fabaceae family. The species occurs in most tropical countries in a wide range of habitats ranging from natural stands to anthropogenic areas. It is a tree species that has nutritional, medicinal and cultural importance for rural communities [10, 11]. To date it has shown a high economic value and has been chosen as a model species to be domesticated in Sub-Saharan Africa [12]. Studies on the species in Asia and Africa have documented its domestication potential in terms of socio-cultural and nutritional values, and aptitude for seed and vegetative propagation [11]. The species' distribution in Africa has been mapped [13]. Although not exhaustive, it has given evidence of the species' plasticity under tropical areas.

Recent work based on neutral molecular-genetic markers [14] has highlighted a high genetic diversity in West African populations, indicating no immediate risk of genetic erosion in this region, as long as ecological conditions continue to permit regeneration. In West Africa, the maintenance of regeneration in tamarind populations has been reported as being not assured at all [1] but, to date, very few studies have directly addressed tamarind populations' structure nor the causes underlying lack of regeneration using dendrometric characteristics and diameter size distribution. Thus, the population status of *T. indica* remains poorly documented and understood, as for many wild fruit trees that support rural populations in Africa [15]. There is therefore a need to document *T. indica* current populations' conservation status, in order to generate information that would allow guiding the design of comprehensive intervention strategies for the species' conservation and enhanced utilization.

Our study was therefore initiated with the aim of examining the impact of different habitat types, farmlands, savannah woodlands and gallery forests with different land use models (that is, human pressure), on the conservation status of *T. indica* populations, using dendrometric characteristics and diameter size class distributions of the trees as indicators of populations' viability. The research was undertaken posing the following questions: is the population structure of *T. indica* independent of habitat type and human pressure? Which habitat type may best suit *T. indica in situ* conservation?

2. Materials and methods

2.1. Study area

Our study was carried out on a number of tamarind populations established within the W national park of Benin and around, where the species has been documented to occur in different habitats [16]. The sampled region is located in the sudanian climatic zone between lat. 11° 40' N to 12° 23' N and long. 2° 2' E to 3° 2' E, coinciding with up to 80% of the W National Park of Benin (*figure 1*). The mean annual rainfall is about 950 mm and soils are mainly ferruginous [16].

The study was undertaken in three different vegetation types; gallery forests, savannah woodlands and farmlands. In both gallery forest and savannah woodland habitats, *T. indica* is associated with *Grewia* *bicolor* Juss., *Cissus quadrangularis* L., *Capparis sepiara* L., *Feretia apodanthera* Del., *Anogeissus leiocarpa* (D.C.) Guill. et Perr. and *Balanites aegyptiaca* (L.) Del., while, in farmland, it is commonly seen with *Vitellaria paradoxa* Gaertn. f., *Adansonia digitata* L., *Sclerocarya birrea* (A. Rich.) Hochst. and *Balanites aegyptiaca* L. [16].

Gallery forests are characterized by a longer period of soil water availability due to the proximity of water courses. In these forests, the species faces lower drought stress conditions compared with the situation in farmlands and savannah woodlands. This also results in more litter on the soil and thus offers better conditions for seed germination and seedling survival even during drought periods (personal field observations). Other important characteristics of tamarind habitats are the termite mounds and ant hills that occur under mature tamarind individuals, most frequently in savannah woodlands and farmlands. The localization of most of the surveyed gallery forests (well-protected zones of the W national Park), the density of their canopies, topographic conditions along water courses and the presence of some feared snakes such as *Python sebea* Gmelin limit and make tamarind resource harvesting and other human disturbances difficult (field survey). In contrast, the savannah woodlands as well as farmlands are more open, close to surrounding villages, and as a result subject to intensive extractive uses of tamarind [16]. In the two latter habitats, tamarind mature trees and juveniles are subject to seasonal fire. On top of this, farmlands are characterized by land clearing and tree removal for agricultural purposes. Regarding the aforementioned characteristics the investigated habitats were categorized as follows: gallery forests (less human pressure), savannah woodlands (medium human pressure) and farmlands (high human pressure).

Figure 1.
Area prospected for studying the conservation status of tamarind (*Tamarindus indica* L.) populations in the W National Park of Benin and location of sampled sites [16].

2.2. Inventory approach and data collection

The indicators of viability were: mature tree density, young plants (expressed as stems·ha^{-1}), diameter size class distribution and its coefficient of skewness (g_1), and median diameter (D_m). As a result of the differences in the vegetation structure, management systems and size in the different habitat types, plot outlines and layout were fulfilled differently to ensure easy data collection and enhance accuracy in the estimation of the variables under investigation. Finally, in each natural habitat type (gallery forests and savannah woodlands), seventeen circular plots of 5 000 m^2 were laid out along four azimuthal transects. In farmlands, the entire farm of a given household was taken as a plot. This was done because

T. indica's niche on a farm is farmer-controlled and not random in distribution as is always the case for natural habitats. Randomization of natural habitat plots was achieved by laying out plots at 1-km intervals, while farm plots were laid out at 500-m intervals. To make the on-farm data representative, two to three plots were laid out in each of the 18 villages surrounding the W National Park, which is a total of 39 plots. Parameters recorded in each plot were: all individuals above 25 cm height, diameter at 130 cm height (D_{130}) using a forest tape, number of mature trees (trees with $D_{130} \geq 5$ cm), and their height using a clinometer. We considered as young plants all individuals simultaneously fulfilling the following conditions: height above 25 cm and D_{130} inferior to 5 cm.

2.3. Computation of dendrometric parameters

2.3.1. Stem density

Stem density (N), that is, the average number of tamarind individuals per hectare of a given stage (here, mature trees and young plants), was expressed as individuals·ha^{-1}: $N = n / s$, where n is the overall number of individuals of a given stage in the plot and s is the plot surface (ha). Comparison between habitats was made using the Kruskal-Wallis test for k independent samples and the Mann-Whitney test.

2.3.2. Stem diameter class distribution

Stem diameter structures were established by grouping D_{130} data into size classes of 10 cm in width. A histogram showing tree density according to diameter classes was established for each habitat type, using the Minitab statistical package. The obtained structures were subsequently adjusted to a truncated normal distribution. The limit considered for the truncated distributions was 5 cm and was related to the inventory design, that only took into account trees of at least 5 cm in D_{130}. Log-linear analysis was then performed with SASv9 software to check models' adequacy.

To discuss population trends within habitats, the coefficient of skewness (g_1) was used. This coefficient, which describes the evenness of truncated distribution, is a measurement of the relative proportion of small *versus* large stems in a population [17] and is defined as follows: $-g_1 = n \sum_i (x_i - \bar{x}_i)^3/(n-1)(n-2)s^3$, where n is the number of stems; x_i and $\overline{x}$ are the $\log(D_{130})$ of stem i and the mean of x_i, respectively; s is the standard deviation of x_i; $g_1 > 0$ for size distributions with relatively few small stems and many large stems (that is, declining population); and $g_1 < 0$ for distributions with relatively few large stems and many smaller sized stems (that is, increasing population) [17].

The median value of the diameter size class distribution (D_m) was computed to discuss the population trends between habitats and is defined as $D_m = L_1 + [((n/2) - (\Sigma f)_1)/f_m] \times c$, where D_m is the median value of the diameter size class distribution; L_1 is the lowest class boundary of the median class (that is, the class containing the median); n is the number of stems; $(\Sigma f)_1$ is the sum of frequencies of all classes lower than the median class; f_m is the frequency of the median class; and c = size of median class interval.

For a given site, a population with a lower median diameter (that is, relative to smaller stems) tends to increase in abundance more rapidly than at other sites [18].

3. Results

3.1. Impact of habitat type on dendrometric characteristics

The findings of this study indicated significant variations in the number of mature trees per hectare between habitats (H = 43.54; $P < 0.001$). It was three to eight times higher in gallery forests than, respectively, in savannah woodlands and farmlands (*table I*). Comparing the regeneration, the density obtained in gallery forests was above 10 times higher than that of savannah woodlands (H = 54.82; $P < 0.001$). No regeneration was found in farmlands. The ratio

Table I.
Mean and standard deviation of dendrometric characteristics of *Tamarindus indica* in three habitat types of the W National Park of Benin.

Habitat types	Mature trees (trees·ha^{-1})	Regeneration (stems·ha^{-1})	Ratio [mature trees / regeneration]	Diameter at breast height or D_{130} (cm)	Total height (m)
Gallery forest	18.2 ± 10.06 a	11.2 ± 9.3 a	1.63	28.9 ± 1.4 b	10.7 ± 0.5 a
Tree savannah	5.0 ± 0.9 b	1.1 ± 0.6 b	4.64	29.0 ± 2.4 b	10.5 ± 0.8 a
Farmland	2.5 ± 0.4 c	0 c	–	47.9 ± 1.9 a	12.8 ± 0.4 a

Means in a column followed by the same letter are not significantly different.

[mature trees / regeneration] also differed with habitat type and increased with higher human pressure.

The mean diameter significantly differed between habitats, ranging from 47.9 cm in farmlands to 28.9 cm in gallery forests (H = 45.41; $P < 0.001$). In contrast, differences among values of the mean height were found to be not significant, ranging from 12.8 m in farmlands to 10.5 m in savannah woodland (H = 4.86; $P = 0.088$).

3.2. Impact of habitat type on stem diameter class distributions

In savannah woodlands and farmlands, the size structure of trees was bell-shaped with a small proportion of young stems, but departed from the normal distribution, that is, the characteristic distribution of the stem-diameter structure of a population, and is skewed to the right (respectively, $P < 0.0001$; $g_1 = 0.55$; $D_m = 28.2$ and $P < 0.0001$; $g_1 = 2.18$; $D_m = 43.7$). In gallery forests, in contrast, the size structure was more similar to the inverse J-shape with an apparently high proportion of small stems, and departed from the normal distribution, but is also skewed to the right ($P < 0.0001$; $g_1 = 0.34$; $D_m = 25.2$). The values obtained of the coefficient of skewness (g_1) are all positive, meaning that the size distributions showed relatively few small stems and many large stems irrespective of habitat type. However, the median diameter (D_m) value was lower in gallery forests than that in savannah woodlands, farmlands having the highest value (*figure 2*).

4. Discussion

4.1. Habitat type impact on *T. indica* populations

Measuring conservation status is straightforward [19]. But investigating anthropogenic influence on plants requires long-term monitoring data on population trends, which is extremely complicated when addressing long-living slow-growing trees such as tamarind. In the absence of long-term data, a single survey of size class distribution is a rapid and useful approach to assess population structure [20]. Factors that may affect the size class distribution of a plant species are light tolerance, life form [21], habitat type [22], climate, anthropogenic activities [23], agroforestry uses [24] and individual species survival strategies [25]. In the present study, the investigated populations experience the same conditions except for habitat type, anthropogenic activity pressure (fire and land clearing for agricultural purposes) and agroforestry uses (harvesting pressure).

The findings of our study clearly show that tamarind mature trees and regeneration decline from gallery forests to farmlands and tend to be critically reduced in habitats of higher human pressure and drought stress, that is, farmlands. The differences may be due to the different behavior of regeneration shown by the species according to its habitats: seed- and root sucker-originated seedlings were observed. Root suckers were observed in gallery forests only and are probably one of the reasons underlying the gregarious spatial repartition shown by the

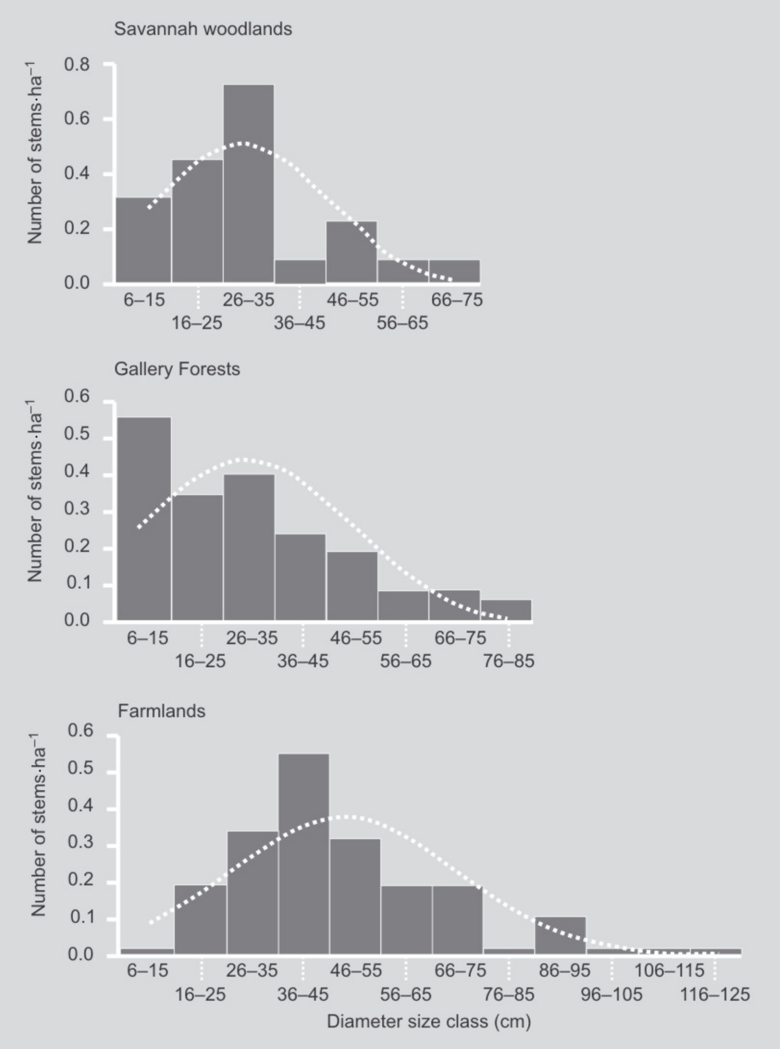

Figure 2.
Diameter size class distribution of *Tamarindus indica* trees in three habitat types (savannah woodlands, gallery forests and farmlands) of the W National Park of Benin.

species in that habitat type. The relatively high aptitude of tamarind trees to make root suckers has been documented. Even if it is not explicit it depends on habitat type [26]. Contribution of human harvesting pressure to the low rate of regeneration is complicated and still not well documented [27]. However, a recent study on *Pentadesma butyracea* Sabine has suggested overextraction of the reproductive structures (fruits, seeds, flowers and stamens) to be a partial consequence of low regeneration [28]. Thus, the harvesting of seeds or fruits needs to be undertaken with caution, since heavy harvesting could lead to long-term detrimental effects on recruitment of new individuals [29]. In the specific case of tamarind, if not extracted, fruits may remain on the trees for one to two years after ripening and generally most of the seeds are destroyed and eaten by insects before the pods fall (field observation). Seedlings that originated from seeds might then be naturally very few and, thus, harvesting pressure influence on the regeneration might be of less importance. In contrast, land clearing, fire and tree density reduction for agricultural purposes [30] may significantly affect seedling establishment and threaten the species. Little attention has been given, despite the need for it, to the evaluation of *T. indica* in its habitats [31]. In Kenya, it was reported that *T. indica* population structure showed low regeneration, while mature trees revealed a higher density along water courses than that of farmlands and savannah woodlands [32]. It is required ecologically that an adequately high abundance of individuals of a given species occurs in the different reproductive stages (seedlings, juveniles and mature trees) in habitats, for continuity [33]. Species occurring in low densities in populations are vulnerable to extinction under human use pressure and other internal and external disturbances [34]. In this regard, reduction of mature tree density linked with scarcity of regeneration of *T. indica*, especially in farmlands, might indicate the absence of any process of systematic sparing or recruitment favoring as is the case in the Sahel zone [1], and thus indicates nonself-rejuvenating populations.

The average diameter is significantly lower in natural habitats compared with that in farmlands. This may be attributed to lower growing rates in the former due to a more intense interspecific competition, which is naturally lower in woodlands and artificially eliminated in farmlands. Such results have been mentioned for other species, especially *Sclerocarya birrea* in South Africa [35] and *Quercus ilex* in Spain [24]. In contrast to our expectations, the average height showed the same gradient between habitats. This may be due to an abundance of relatively young trees in gallery forests. However, the tallest trees are found in gallery forests, a possible result of higher competition for light.

In diameter size class distribution, all the obtained curves deviated from the normal distribution. However, the distribution was closer to a bell-shaped type both in savannah woodlands and farmlands, while it was similar to an inverse J-shaped type in gallery forests. Such distributions would suggest that gallery forest populations are extending while savannah woodlands' and farmlands' are declining [36]. Although studies have often relied on the assumption that standing distribution reflects future population changes, studies to directly test this hypothesis have proven that diameter size distribution is not a good predictor of population changes [18, 37]. However, the coefficient of skewness (g_1) of this distribution is able to predict the direction of population change, according to the same authors. In our study, all the distributions show a positive coefficient of skewness ($g_1 > 0$), indicating a distribution with relatively few small stems (that is, juveniles) and many large stems (that is, mature trees) and, thus, vulnerable populations irrespective of habitat type. However, a population with a lower median diameter at a given site tends to increase in abundance more rapidly than at other sites [18]. In this regard, *T. indica*'s population might increase more rapidly in gallery forests than in savannah woodlands and farmlands. Thus, gallery forest tamarind populations might be less vulnerable than those of savannah woodlands and farmlands.

4.2. Implication for conservation and sustainable management

Tamarind is often quoted as a dry ecosystem species but our findings would suggest that the species' populations seem to be more viable in gallery forests and thus under less drought conditions. This habitat type might therefore best suit the species' *in situ* conservation. However, trends in the species population showed no evidence of stability or long-term viability irrespective of habitat type. In farmlands where regeneration failure can clearly be linked to agricultural activities, the low rhythm of expansion noticed may be attributed to anthropogenic interference. Thus, the domestication of the species by means of young plant production and introduction into rural agricultural systems could help ensure rejuvenation and thus long-term *circa situ* conservation and utilization of the species. In contrast, in the natural habitats of the species, particularly in gallery forests, interpreting the ecological status of the species and building effective *in situ* conservation strategies will need better understanding of factors and processes that impact the population dynamics of the species. Whatever the case, silvicultural method building, identification of the best propagation methods and drought tolerance strengthening with regard to specific environments will be necessary for an effective management plan for *T. indica*.

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Impacto del tipo de hábitat sobre la conservación de las poblaciones del tamarindo (*Tamarindus indica* L.) en el parque nacional del W en Benín.

Resumen. — **Introducción**. El estado de conservación de numerosas especies fruteras silvestres, de las cuales dependen las poblaciones rurales en África, permanece mal documentada, a pesar de su importancia para la gestión de sus poblaciones. Comparamos la viabilidad de las poblaciones de tamarindos (*Tamarindus indica*), especie con una importancia alimenticia, medicinal y cultural para las comunidades rurales, bajo diferentes niveles de presión humana. **Material y métodos**. Los datos relativos al diámetro y a la altura de los árboles, así como el número de adultos y de juveniles, se recopilaron en las parcelas de ensayo y permitieron calcular, para cada población determinada, los parámetros dendrométricos así como establecer su estructura en diámetro. Las características dendrométricas se analizaron mediante el empleo de pruebas no paramétricas; y, la distribución de los diámetros se ajustó a una distribución normal truncada. **Resultados y discusión**. El número de tamarindos adultos así como la regeneración (expresada en número de ramas·ha^{-1}) fueron relativamente débiles, lo que sugirió que las poblaciones de tamarindos poseen una capacidad de regenerarse débil. No obstante, una diferencia significativa apareció en función del tipo de hábitat ($P < 0.001$). La densidad de los árboles adultos en los bosques de galería [(18.2 ± 10.1) árboles·ha^{-1}] fue de tres a ocho veces más elevada que en las sabanas arboladas [(5 ± 4.5) árboles·ha^{-1}] que en tierras cultivadas [(2.5 ± 0.4) árboles·ha^{-1}]. Los jóvenes plantones expresaron la misma tendencia con (11.2 ± 9.3) plantones·ha^{-1}, (1.1 ± 0.6) plantones.ha^{-1} y 0 plantón·ha^{-1}, respectivamente. La distribución de los diámetros se separó de la distribución normal ($P < 0.0001$) y el coeficiente de asimetría fue positivo, indiferentemente del tipo de hábitat, lo que indicó así las poblaciones en decadencia. Sin embargo el valor medio de los diámetros sugirió que las poblaciones de *T. indica* en las tierras cultivadas y en las sabanas arboladas son más vulnerables que aquellas de bosque de galería. Dichos resultados indican que los bosques de galería convendrían mejor para la conservación *in situ* del tamarindo. La disminución crítica de los árboles y de los jóvenes plantones observada en las tierras cultivadas y en las sabanas arboladas podría influenciar negativamente la viabilidad a largo plazo de las poblaciones de tamarindos. La introducción de jóvenes plantones en las zonas de cultivo podría ser necesaria para garantizar la conservación de *T. indica* en sistemas de agroforestería.

Benin / *Tamarindus indica* conservación de los recursos / habitat / características del rodal / inventarios forestales / influencia antrópica