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Natural vs. Plantation Forests: A Case Study of Land Reclamation Strategies for the Humid Tropics

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ABSTRACT / Biomass and productivity were compared in two plantations and in one stand of natural regeneration on similar sites in a premontane moist forest region of Puerto Rico. While initial growth rates of plantation species were higher, after four decades productivity of the natural regeneration plots was equal to or greater than productivity of the plantations. For the first 44 years, aboveground biomass of natural regeneration increased at an average annual rate of 3.8 $t \cdot ha^{-1} \cdot yr^{-1}$, but the last year of the study it was 14.7 $t \cdot ha^{-1}$. Biomass increment of a pine plantation averaged between 8 and 10.5 $t \cdot ha^{-1} \cdot yr^{-1}$ except for one year when the rate was much lower, possibly because of hurricane damage. A tropical hardwood plantation averaged close to 4 $t \cdot ha^{-1} \cdot yr^{-1}$ for 41 years. It is suggested that in countries where funds for land reclamation are limited, intensive plantations may not always be the best strategy. Natural regeneration or shelterbelt plantations may be suitable alternatives.

A serious problem faced by land managers and foresters throughout the tropics is how to reforest land that has been cleared for wood products, agriculture, or pasture. Because of the increasing demand for wood throughout the world, as well as for other services of forests such as soil retention and water purification, land managers are under pressure to re-establish forests as quickly and as cheaply as possible. Often the land manager will choose plantation establishment because it is perceived as the cheapest and most rapid method of reforestation. In many cases, however, plantation establishment is cheap only because it is subsidized by the government or by foreign aid. An alternative, allowing natural secondary succession to occur, is often not considered or is even considered undesirable.

During field surveys in Guatemala, while we were preparing an Environmental Profile for the United States Agency for International Development, we became aware of several problems that arose as a result of a belief that plantation forestry is the only suitable method of land reclamation. The native forests on many of the lower mountain slopes in Guatemala consist primarily of angiosperms (broad-leaved hardwoods). Many of these forests have been cleared for agriculture, but erosion problems have forced abandonment after several years. The Guatemalan Forestry Department has been charged with reforestation. The approach often is to establish pine plantations, with individuals planted in rows and spaced at 2 to 3 m intervals. There is a major problem with this approach. Vigorous, woody, secondary successional vegetation, some of it leguminous (nitrogen fixing species), invades plantations and overtops the pine seedlings. To combat this problem, rewards are given to the crew that achieves the highest survival success in plantations. To achieve high survival of seedlings, crews clear competing hardwood vegetation from around the pine seedlings. As a result, not only is there the initial cost of plantation establishment, there is the cost of this clearing, which continues for five or more years.

KEY WORDS: Land reclamation strategies; Natural regeneration; Plantation forests

The purpose of this report is to suggest that in some cases natural regeneration can be an alternative to plantation forestry. Plantation foresrs are not always necessary for land reclamation purposes. If it can be recognized that under some conditions land reclamation and reforestation can be achieved without the expense of plantation forestry, the money saved could be used in other ways to promote land reclamation. A second objective of this paper is to suggest an alternative land reclamation technique.

Methods

Our objective was to compare natural regeneration and plantation forestry as land reclamation strategies in a subtropical moist forest (Holdridge 1967), an important forest type rapidly being cleared. Because logistics in Puerto Rico are relatively uncomplicated, and because the Institute of Tropical Forestry in Puerto Rico offered to assist us with this study, the work was done in Puerto Rico.

For the study, we required sites that were physically similar, but that had undergone contrasting land reclamation strategies. Suitable sites were found in the western section of Luquillo Experimental tract of the Caribbean National Forest in Puerto Rico. The region

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had been coffee plantations through the early 1930s, and then was abandoned due to economic conditions and to lowered production resulting from depletion of soil nutrients. Aerial photographs and records at the Institute of Tropical Forestry in Rio Piedras indicate that the site was abandoned about 1935 and incorporated as part of the National Forest.

Ideally, we needed sites that had been planted in plantation forests at the same time that similar sites were abandoned to natural regeneration. The best that we were able to find was a plantation of Maria (*Calophyllum brasiliense* Camb.) planted in 1940. We also wanted a pine plantation, because pines are a favored plantation species in Latin America. The oldest plantation on a comparable site was one of *Pinus caribaea* (Morlet) planted in 1962.

Site Description

Field work was carried out on the Cubuy Tract of the Luquillo Experimental Forest in eastern Puerto Rico, latitude 18° 15′ N, longitude 65° 52′ W. The tract is on mountainous terrain about 500 m altitude. The area receives about 2000 mm of rain annually. The tract is classified as subtropical premontane moist forest (Holdridge 1967). The soil is similar to the Los Guineos clay described by Edmisten (1970). Three sites with north to northeast facing aspects and about 40° slopes were chosen for productivity measurements. One site was the stand of Caribbean pine, the second was the Maria plantation, and the third site was a natural regeneration forest that had never been planted and had been allowed to regenerate naturally following abandonment from agriculture. At the time of sampling, the most common species in the natural regeneration site was Ausubo [*Manilkara bidentata* (A.DC.) Chev.]. The natural regeneration area contained emergent and understory trees with vigorous crowns interspersed in the mainly co-dominant canopy, while the plantations were much more uniform. There was a heavy ground cover of ferns in the pine plantation, while ground cover in the other stands was less dense. Naturally regenerating trees and shrubs had been weeded out of the plantations, but seedlings and a few saplings were present at the time of the survey.

In each site one plot was selected for detailed study. The natural regeneration plot, bounded by two ravines and a road, had an area of 0.28 ha, and contained 165 trees greater than 10 cm diameter. In each of the plantations, plots containing 100 trees were laid out. All trees had diameters greater than 10 cm. The pine plot had an area of 0.11 ha, and the Maria plantation had an area of 0.08 ha.

Estimating Biomass and Productivity

Perhaps the most straightforward and best overall indices to compare success of natural regeneration and plantation forests are standing crop and productivity. We measured standing crop of aboveground biomass in the three plots in August 1979, August 1980, and August 1981. Difference between standing crops was annual productivity for the respective years.

Standing crop of pine and Maria was measured as follows: biomass and diameter were measured for selected destructively sampled trees outside of the detailed study plots; allometric equations relating diameter and biomass were derived; diameters of all trees on each plot were measured; biomass of all trees on each plot were determined; biomass per plot was calculated and extrapolated to a per hectare basis. The same procedure was used for the natural regeneration forest, except that already published equations were used for biomass calculations.

Biomass Regressions: To determine biomass as a function of diameter, six pines and six Maria were cut at ground level. Diameters were measured at 1.5 m above base level. Leaves and branches were removed and wet weight was determined with portable field scales. For small trees, total leaves and branches were dried and weighed. For medium and larger trees, 4 to 6 subsamples were dried and weighed. Trunks were cut into sections of approximately 2 m, wet weight was determined, and one section from each segment was cut for dry weight determinations. Natural logarithm of biomass was then regressed on logarithm of diameter using least square procedures.

For natural regeneration, biomass was predicted by regressions (1) and (2) for tropical hardwoods developed by Jordan and Uhl (1978) in a Venezuelan rain forest. The slope and Y-intercept of the regressions did not differ significantly from the slope and Y-intercept of regressions for tropical hardwoods in Thailand (Ogawa and others 1965), and, consequently, it was felt that the same regressions were general enough to be suitable for the native hardwood forest in Puerto Rico. The regressions predict dry weight biomass as a function of diameter squared times height times specific gravity of the wood of the trees. Diameter squared is used instead of diameter because diameter alone is a better predictor of biomass than height alone. Squaring gives more weight to the diameter measurement. For wood biomass

$$\ln \text{biomass} = 0.9982 \ln (d^2 \cdot h \cdot s\cdot) - 3.080. \quad (1)$$

Standard error of the estimate was 0.19 (Jordan and Uhl

1978). For total above ground biomass

$$\ln \text{biomass} = 0.9906 \ln (d^2 \cdot h \cdot s) - 2.9678. \quad (2)$$

Standard error of the estimate was not determined. In the equations, d is the diameter in cm, h is the height in m, and s is the specific gravity of wood.

Diameter Increments: We measured diameters of all trees greater than 10 cm diameter in our study plots. Diameters had to be measured very precisely, since annual changes in diameter are small relative to size of trees (Dawkins 1956). To improve precision, it is important to make a series of diameter measurements on each tree at each measurement period, instead of just one, and to measure each diameter in exactly the same place each measurement period. Our method consisted of placing a metal circumference tape around the tree at about 1.5 m height. Depending on tree diameter, three or four 40 cm lengths of metal measuring tape were placed under the circumference tape, equidistant around the bole and parallel to the tree axis. The tape lengths were hung on nails driven in the tree. Six circumference measurements were made at 5 cm intervals, by placing the circumference tape accurately at the 5 cm marks of the vertical measuring tape lengths. The first diameter was 5 cm below the nails. The measurement offset avoids a measuring bias from tree swelling in response to the nails. After measurement, the vertical measuring tape lengths were removed. Replacement of these lengths on the nails each successive year ensured that each diameter was measured exactly in the same place. Tests for precision were carried out by replacing the guides and remeasuring the circumference. Six measurements per tree resulted in a precision of ± 0.2 percent of diameter.

Height and Specific Gravity: For the natural regeneration equations, it was necessary to know height and specific gravity of the wood. It was not possible to make tree height measurements with sufficient precision to detect significant changes over an interval of one or two years. Our procedure to determine change in tree height was to make initial tree height estimates with a Haga altimeter, correlate height with diameter, and then predict the change in height based on change in diameter. Specific gravities of the naturally regenerating species were taken from Little and Wadsworth (1964) and Little and others (1974).

Biomass Increments: Standing crop on each plot for each year is the sum of the biomasses of all the individual trees. Annual biomass increment for each plot is the difference in the standing crops between successive years. Biomass for each plot was converted to a hectare basis by dividing biomass per plot by area of plot.

Since the age of the plantations and age since abandonment of the natural regeneration were known, it was also possible to calculate the average annual growth by dividing the biomass by the age of the plot. This average, however, does not accurately represent biomass dynamics throughout the age of the stand, since the first few years of growth were undoubtedly considerably less than average, and later years were greater than average.

Merchantable Lumber: Standing crop of merchantable lumber is another index of the relative success of plantations and natural regeneration. To compare merchantable lumber in the three study stands in 1979, we calculated board footage and value of the lumber for the pine, Maria, and six native species which have a market in Puerto Rico.

The following regression equation developed by Parker (1972) was used to calculate board feet volume by the International 1/4-in Rule of the natural regeneration forest and the Maria plantation. This broadly applicable equation was developed by Parker from the Mesavage and Girard (1946) form class tables and is the best approximation of board feet volume

$$V = \frac{d^2}{3.27127 + 2.17474 \frac{1}{\text{MH}} 3.81697 \text{ FC}} \quad (3)$$

where d is the dbh in inches, MH is the merchantable height in 1/2 logs where each log is 16 ft to a merchantable limit of 6 in, and FC is the form class (a measure of the taper of the tree).

Board feet content of logs was calculated using height of merchantable logs determined by an expandable pole, and diameter from pentaprism measurements. The canopy of the natural regeneration stand occupied 20 percent of the height of tree on the average, hence merchantable height was assumed to be 80 percent of the total height. We used a form class of 85 for all species based on the average of the field measurements. For *Calophylum brasiliense* the canopy occupied approximately 26 percent of the total height of the tree, therefore, we based the merchantable height limit on 74 percent of the height. An average form class of 80 was determined through field measurements.

To determine board feet for the *Pinus caribaea* plantation, we employed the regression equation developed by Bennet (1959) for the International 1/4-in Rule for slash pine plantations in Georgia. Caribbean pine and slash pine have similar growth form

$$V = .012876\, d^2 h + 1.342631 \text{ FC} - .801619\, h - 83.91 \quad (4)$$

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Table 1. Dry weights of trees harvested for biomass regressions and regressions to predict biomass as a function of diameter.

Pine

Tree number	Diameter cm	Kg dry weight: Bole	Kg dry weight: Twigs and branches	Kg dry weight: Total wood	Leaves	Total tree
1	13.9	38.05	4.49	42.54	2.48	45.02
2	20.1	83.83	6.52	90.35	6.23	96.58
3	15.2	56.06	4.67	60.75	3.55	64.28
4	23.5	141.17	11.91	153.08	14.02	167.10
5	37.5	576.82	21.09	597.91	21.83	619.74
6	33.2	438.04	11.82	449.86	26.99	476.85

ln biomass = $a + b$(ln diameter)

Total above ground biomass	Wood only
$a = -3.149088688$	-3.246442465
$b = 2.637133461$	2.649056121
$r^2 = .98$	$r^2 = .98$

Maria

Tree number	Diameter cm	Kg dry weight: Bole	Kg dry weight: Twigs and branches	Kg dry weight: Total wood	Leaves	Total tree
1	11.0	26.59	8.10	34.69	.87	35.56
2	12.1	42.42	12.90	55.32	1.47	56.79
3	19.9	120.52	36.78	157.30	4.77	162.07
4	21.3	103.01	45.52	148.53	6.35	154.88
5	32.2	202.77	259.98	462.75	15.58	478.33
6	28.9	202.64	216.52	419.16	12.67	431.83

ln biomass = $a + b$(ln diameter)

Total above ground biomass	Wood only
$a = -1.99694032$	$a = -2.005395317$
$b = 2.36051098$	$b = 2.352922463$
$r^2 = .98$	$r^2 = .98$

where d is the dbh in inches, h is the total height in feet, and FC is the form class (form class of 71 was used based on field measurements).

Results and Discussion

Biomass Regressions and Biomass Increments

Diameters and dry weights of the trees harvested for biomass regressions are given in Table 1 and Figure 1. Dry weight biomass per hectare of the plantation forests in 1979, 1980, and 1981, determined by the regressions in Table 1, are given in Table 2, along with dry weight biomass of the natural regeneration calculated from equations 1 and 2. Differences between the 1979, 1980, and 1981 values are the current annual increments in biomass (Table 2). Biomass in 1979, divided by the age of the stand in 1979, is the average annual wood biomass increment over the life of the stand. Actual annual growth rates during this interval of course varied around the average.

Table 2 shows that for biomass and productivity through 1979, natural regeneration was comparable to the plantation of Maria. Pine appears to have grown more rapidly than Maria or natural regeneration. Al-

Table 2. Dry weight and weight increment of aboveground biomass of trees greater than 10 cm diameter in plantation and natural regeneration forests in 1979, 1980, and 1981.

	Natural regeneration ($kg \cdot ha^{-1}$)		Pine ($kg \cdot ha^{-1}$)		Maria ($kg \cdot ha^{-1}$)	
	Wood	Total	Wood	Total	Wood	Total
1979	157877	165330	128257	136131	145869	150344
1980	161800	169406	130568	138621	151408	156071
1981	175970	184125	140428	149127	155551	160357
Age 1979	44		17		39	
$\bar{x}\Delta$/yr to 1979	3588	3757	7554	8008	3740	3855
Δ79-80	3923	4076	2310	2490	5539	5727
Δ80-81	14170	14719	9860	10506	4143	4286

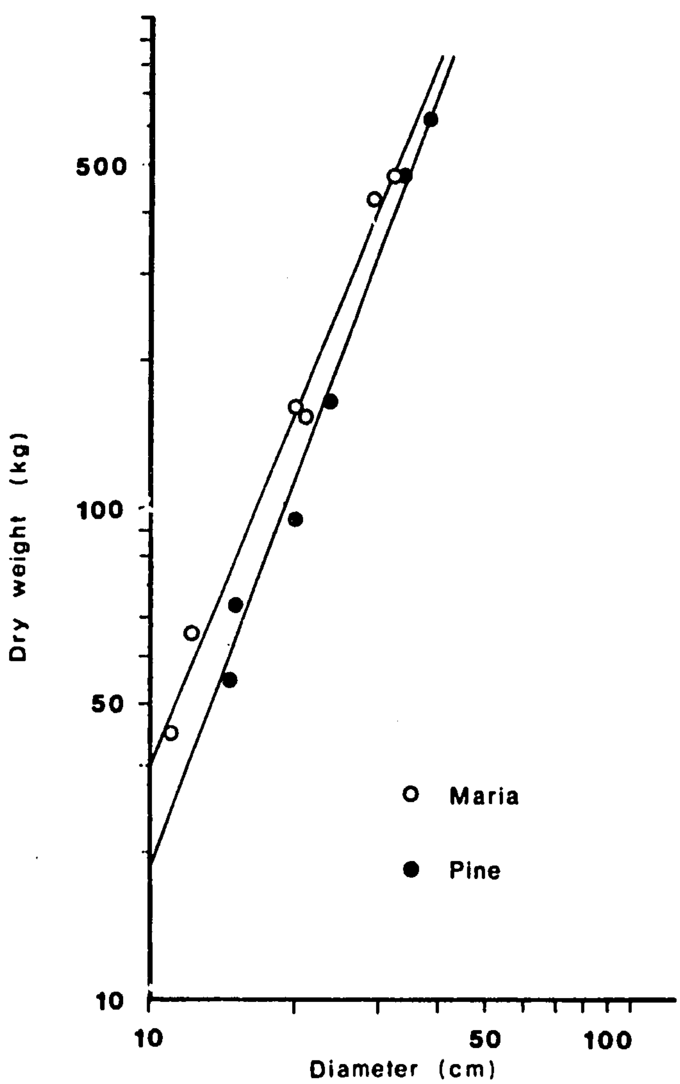

Figure 1. Dry weight of total aboveground biomass of harvested trees as a function of diameter and regression lines resulting from least squares fit. The r^2 for the log transformations is 0.98 for both species.

though pine was only 39 percent of the age of the natural regeneration in 1979, the total biomass was 82 percent of that of the natural regeneration. However, pine might be expected to slow down as its canopy closes, while the more heterogeneous canopy of the natural regeneration may prevent stagnation of that forest.

During 1979-1980, there appeared to be a dramatic slowdown of pine growth, but the next year growth was high again. There was also a very large difference in growth rates of the natural regeneration between the two study years. A tropical storm passed near Puerto Rico two weeks before our initial survey. During that survey, we found freshly fallen leaves and branches on all sites. The loss of leaves may have affected growth rates of the pine and natural regeneration during the first year of the study. The difference in growth rates of Maria was much less between the two years. Maria did not show a big increase in growth the second year, as did the pine and natural regeneration.

Figure 2 illustrates the percent departure from normal (long term average) rainfall in eastern Puerto Rico (NOAA 1979–1981). The 1979 diameter measurements were carried out during a period with substantially more rain than normal, while the 1980 measurement period had less than normal rainfall. However, because the soil is very porous and drains quickly even after heavy rains, we believe that the physical damage caused by the tropical storm in 1979 may have influenced growth more than differences in rainfall.

Rates of biomass increment in Table 2 are comparable to results of other studies. In a survey of rates of wood production of natural forests in moist areas of the world, Jordan (1982) found that wood accumulation averaged 7.34 ± 2.75 (n = 10) $t \cdot ha^{-1} \cdot yr^{-1}$ in tropical zones, and 7.58 ± 2.90 (n = 3) $t \cdot ha^{-1} \cdot yr^{-1}$ in subtropical zones. Lugo and others (unpublished manuscript), in a survey

Table 3. Density, board feet volume, and board feet value of plantation and natural regeneration forest stands in the Cubuy Tract, Luquillo Experimental Forest, Puerto Rico. Calculations were based on September 1979 measurements.

Forest	Age (yr)	Density (ind/ha)	Volume (bd ft/ha)	Value (dollars/ha) Per Mbdft[1,2]	Value (dollars/ha) Total
Plantation					
Pinus caribaea	17	919	24,865.8	400	9,946
Calophyllum brasiliense	39	1270	43,024.1	800	34,419
Natural regeneration (Total)	44	728	60,964.9		
Manilkara bidentata			18,097.5	500	9,048
Ormosia krugii			5,821.9	200	1,164
Ocotea spp.			5,399.8	1000	5,400
Byrsonema coreacea			1,214.2	500	607
Tabebuia heterophylla			3,019.1	800	2,415
Cecropia peltata			10,714.4	300	3,214
	Total of 6 spp.		44,266.9		21,848

[1]Timber values communicated by Mr. Muñoz, Institute of Tropical Forestry, Rio Piedras, Puerto Rico.
[2]Timber values available only for the six natural regeneration species listed. These species represent 73 percent of the total board feet volume.

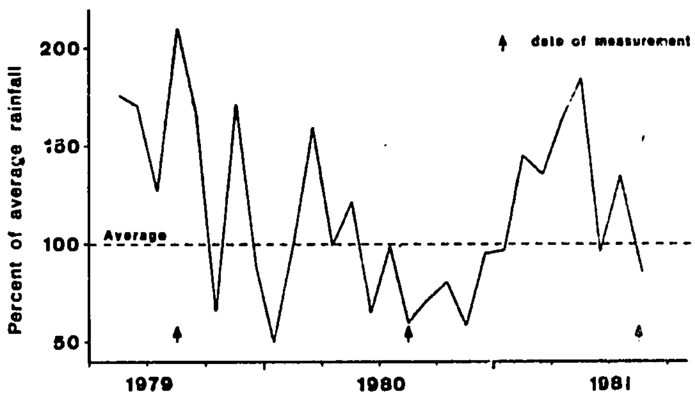

Figure 2. Percent departure of monthy rainfall totals from long-term average rainfall. One hundred percent represents long-term average or normal.

of stemwood accumulation in tropical tree plantations, found that subtropical moist forest zone plantations of *Pinus caribaea* averaged 6.09 ± 2.57 $t \cdot ha^{-1} \cdot yr^{-1}$ ($n = 56$). They also found three reports of growth of *Calophyllum brasiliense* (Camb.) [*Calophyllum calaba* (Jacq.)] in tropical moist forests, with biomass accumulation rates averaging 2.5 ± .3 $t \cdot ha^{-1} \cdot yr^{-1}$, and one stand in a subtropical wet forest with a rate of 6.4 $t \cdot ha^{-1} \cdot yr^{-1}$.

Merchantable Lumber

One argument for plantation forestry as a land reclamation strategy is that in the event the forests are ever to be harvested for lumber or pulp, native hardwoods are sometimes more difficult to use than plantation species. With improved wood processing methods, however, many tropical hardwoods now have a market (Collardet 1976).

Merchantable board footage of *Calophyllum* was approximately equivalent to that of the merchantable natural regeneration, but value of the lumber was greater (Table 3). The pine plantation contained 56 percent of the merchantable board footage and 41 percent of total board footage of that in the natural stand, while the age of pine was 39 percent of the natural regeneration. Plantations produce merchantable lumber more rapidly than natural regeneration, but if lumber production is the primary goal, costs of establishment must be determined and compounded over the life of the plantation until the time the lumber is sold in order to determine the profitability of plantations.

Plantation Costs

Costs of plantation establishment are not negligible. Salazar (1978) in a study of the costs in man hours and dollars, found that the costs of establishing a 260-ha caribbean pine plantation in Turrialba, Costa Rica in 1977 was $228 per hectare. This cost includes labor, materials, equipment, supervision, transportation, and roads, but not land. Salazar estimated costs of maintenance for the first eight years to be $348/ha (43.50/ha/yr) on plantations that were originally in pasture and $668/

ha (83.50/ha/yr) for plantations that were established on luxuriant growth areas.

Land Reclamation

If land reclamation rather than timber production is the primary objective, our study shows that after several decades, there is no clear advantage in plantations over natural regeneration. Although natural regeneration has a lower initial rate of productivity due to slower establishment of seedlings, after four decades the productivity is comparable to that of plantations. In addition, natural regeneration has the advantage of no establishment costs. On the basis of a floristic study in Costa Rica, Fournier and Herrera (1977) also concluded that natural regeneration could be an efficient means of forest recovery.

An Alternative

We suggest that in situations where land reclamation is the primary objective, and where there are funds but they are limited, intensive plantation forestry may not be the best strategy, at least in humid life zones such as the one studied here. Since natural regeneration will eventually occur in these zones, extensive plantations that will assist natural regeneration may be a better strategy. Further, we suggest that when extensive plantings are carried out, seedlings be placed where they might be the most effective in assisting natural regeneration. In some situations, this might be in naturally occurring depressions in the terrain, where the tree would grow rapidly and serve as cover for birds and animals that carry seeds of natural vegetation into the area. In other areas, trees can be planted as windbreaks or shelterbelts where mulch can accumulate and serve as seedbeds for natural vegetation. If sheet erosion is a problem, one or two rows of planted trees can be just as effective as an entire plantation in stopping the surface flow.

Conclusions

Although plantations may be more productive than natural regeneration for a few years, or even decades, eventually natural regeneration gains an advantage. After several decades in a moist forest of Puerto Rico, plantations had no clear advantage over natural regeneration, and they had the disadvantage of initial costs of planting and maintenance. In some regions, a more efficient strategy of reforestation for land reclamation than plantations may be extensive but judicious planting of seedlings to facilitate natural regeneration.

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