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# Ecological prospective for tropical Latin America

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## 1 Introduction

The Latin American tropics and subtropics contain many unique ecosystems of high biological diversity, many endemic species, and a great potential in terms of renewable natural resources. The ecosystems have evolved under climatic regimes of relatively low variability, characterized by high temperatures and precipitation, resulting in very complex and intricate ecological interrelationships. On the other hand, the ecosystems exhibit a high degree of fragility in face of human perturbations, particularly those associated with the indiscriminate application of modern technologies originating in the industrialized countries and generated under quite different climates and social settings.

However, indigenous pre-Hispanic cultures and civilizations had reached a rather sophisticated level of technology in the management of complex ecosystems, which proved to be sustainable over long spans of time. Different civilizations, such as the Maya, the Inca, and the hydraulic cultures of Brazil, Bolivia, Colombia, Ecuador, and Mexico, maintained sustainable agricultural production for centuries, developing original and efficient solutions for managing the environmental resources without destroying the ecological base of production, at relatively high population densities and often including metropolises of considerable size (Gallopín, 1985; Gligo and Morello, 1980; Vitale, 1983).

The fragility of the Latin American tropical ecosystems, therefore, must be considered in relation to the technology utilized, and not necessarily as an intrinsic attribute precluding any kind of human intervention.

It is clear, however, as will be discussed later, that the current trends in the region are characterized by very high and accelerated rates of ecological deterioration, expressed as deforestation, desertification, soil erosion and depletion, agricultural, industrial, and domestic pollution, accumulation of wastes, and increased vulnerability to catastrophic landslides, droughts, and floods (CEPAL/PNUMA, 1983a; Damascos et al., 1989; Doureojeanni, 1982; Sancholuz et al., 1989; Sunkel and Gligo, 1980). A large proportion of those changes occur in the tropical and subtropical areas of the region, where the advance of the agricultural frontier is most dynamic.

The problem lies not in the transformation or alteration of the natural ecosystems (transformations that in principle could be positive), but in the actual modality and results of these transformations, implying an accelerated degradation of the ecological basis of production, a veritable impoverishment and destruction of the region's renewable natural resources and vital ecological processes. It should be emphasized that many alterations, such as desertification and soil erosion, are irreversible in practical terms.

The destruction of the Latin American tropical ecosystems, and particularly of the tropical forests, is cause for serious concern. From the regional and local viewpoints, the destruction of forests, besides representing a waste of resources for development, has serious ecological impacts, generating micro- and mesoclimatic changes, through variations in the albedo and residence time of rainwater, increases in surface runoff, reductions in evapotranspiration, increases in maximum temperatures and daily thermal amplitudes, and reductions in precipitation (Salati et al., 1989), as well as soil erosion, floods, and other effects. From the global viewpoint, tropical deforestation is a significant contributor to the greenhouse effect, and might possibly affect the regulation of the planetary atmospheric circulation; tropical deforestation is also considered one of the major current causes of species extinction.

In the face of this situation, it is worth investigating the potential for a sustainable management of the major tropical ecosystems in

Latin America. While a number of studies are available around the world, addressing the issue of sustainability at the micro-level and examining alternative technical solutions for the sustainable use of natural resources by a particular human community, or for a given specific ecosystem, studies at the macro-level (regional or global) are very scarce. This paper presents the results of an investigation of sustainability for the whole of tropical Latin America, centred on an ecologically and technically feasible prospective scenario. This scenario is defined as an alternative to the ecologically degrading trajectory being followed in the region.

## 2 The current condition of the tropical Latin American ecosystems



Latin America is a region where tropical (including subtropical) ecosystems predominate. They cover about 85 per cent of the total surface area of the region, including dense forests (55 per cent), open forests and savannas (33 per cent), and deserts and semi-deserts (12 per cent).

By 1980, 23.5 per cent of the surface of the tropical ecosystems was exploited for ranching and 7 per cent for crop agriculture; 0.6 per cent was under urban uses and 0.3 per cent under plantations. The original (virgin or semi-virgin) ecosystems represented 46 per cent of the total tropical area; the altered ecosystems accounted for 20.5 per cent, and the wastelands (irreversibly desertified or degraded lands) amounted to 2 per cent (see table 2.1).

The tropical portion of Latin America is relatively well endowed with natural resources. It includes 46 per cent of the tropical forests of the world, containing an estimated minimum of 40 per cent of the tropical plant and animal species. It has important reserves of fresh water and minerals, and the highest untapped hydroelectric potential in the world. About 10 per cent of its lands are suited for intensive agriculture and ranching, and another 32 per cent are suitable for agroforestry, agro-silvo-pastoralism and ranching.



However, owing to the advance of the agricultural frontier, as well as the inappropriate management of pastures and agricultural lands associated with high rates of soil erosion and desertification, the degradation of productive lands, deforestation, and land reconversion are advancing at accelerating rates.

The contribution of Latin America to the emissions of carbon dioxide by 1988 has been estimated (Gallopín et al., 1991) as roughly

Table 2.1 **Surface area ($10^3$ km$^3$) under each category for the major life-zones of tropical Latin America in 1980 (percentages of total life-zone area appear in parentheses)**

| | Natural | Agricultural | Grazing | Altered | Plantations | Urbanized | Wasteland | Total |
|---|---|---|---|---|---|---|---|---|
| T & ST moist forests | 5,795 (71.3) | 583 (7.2) | 683 (8.5) | 1,023 (12.5) | 20 (0.2) | 17 (0.2) | 3 (0.1) | 8,124 |
| T & ST montane moist forests | 158 (12.6) | 178 (14.2) | 473 (37.8) | 390 (31.2) | 6 (0.5) | 41 (3.2) | 5 (0.5) | 1,251 |
| T & ST dry forests | 1,068 (22.5) | 377 (7.9) | 1,612 (33.9) | 1,557 (32.8) | 21 (0.5) | 20 (0.5) | 92 (1.9) | 4,747 |
| Tropical savannas | 423 (39.7) | 32 (3.0) | 485 (45.5) | 125 (11.7) | 0 (0) | 1 (0.1) | 0 (0) | 1,066 |
| T & ST mangrove forests and deltas | 52 (28.0) | 8 (4.3) | 42 (22.6) | 82 (44.0) | 0 (0) | 2 (1.1) | 0 (0) | 186 |
| Paramo and puna | 173 (18.8) | 23 (2.5) | 422 (45.8) | 253 (27.4) | 0 (0) | 6 (0.5) | 45 (5.0) | 922 |
| T & ST deserts and dry scrub | 354 (30.5) | 79 (6.8) | 392 (33.7) | 146 (12.6) | 0 (0) | 26 (2.2) | 165 (14.2) | 1,162 |
| Tropical Latin America | 8,023 (46.0) | 1,280 (7.3) | 4,109 (23.5) | 3,576 (20.5) | 47 (0.3) | 113 (0.6) | 310 (1.8) | 17,458 |
| Latin America | 8,287 (40.5) | 1,562 (7.6) | 5,476 (26.8) | 4,505 (22.1) | 58 (0.3) | 136 (0.7) | 393 (2.0) | 20,417 |

Source: Winograd, 1989a.

Key: T & ST = tropical and subtropical.

14 per cent of the world total, of which about 2.9 per cent is due to the burning of fossil fuels and the rest is mainly from biomass burning associated with tropical deforestation. By contrast, the developed countries contribute more than 70 per cent of the total carbon emissions (Holdgate et al., 1989).

Deforestation is certainly the most pressing ecological problem of the region in terms of land use and the loss of renewable natural resources. In the 1980s,[1] the destruction of tropical dense forests (including both natural and already altered forests) amounted to 4.34 million hectares per year, or 0.59 per cent per year, and the elimination of tropical open forests added another 1.37 million hectares per year.[2] If only natural (virgin and semi-virgin) forests are considered, dense forests are being depleted at a rate of 0.63 per cent per year, and open forests at a rate of 1 per cent per year. Mangrove forests, deltas, and savannas are also diminishing fast. On the other hand, only 0.5 million hectares per year were reforested during the same period, implying an average reforestation to deforestation ratio of 1:11, ranging from 1:7 in the mountain and dry forests to 1:15 in the lowland moist forests (tables 2.2 and 2.3).



Deforestation in tropical Latin America is mainly caused by commercial and subsistence ranching, shifting agriculture, and land speculation. Shifting agriculture accounts for 35 per cent of the deforestation in tropical and subtropical moist forests, and 15 per cent in the tropical dry forests (FAO, 1981; Lanly, 1985; Winograd, 1989a). Peasant and shifting agriculture together generate more than 50 per cent of the agricultural products for final consumption. On the other hand, the expansion of pastures and commercial ranching exhibited sharp increases in the 1960s in Central America and in the 1980s in South America. In the Brazilian Amazon, for instance, this activity is responsible for about 80 per cent of the deforestation in its tropical moist forests. Despite the allocation of important subsidies to this activity, commercial ranching accounted for less than 0.1 per cent of the Brazilian gross internal product in 1981 and employed only 1 per cent of the labour force in the Amazonian agricultural sector (Browder, 1989).



Besides the waste of valuable natural resources, tropical deforestation is a major engine of species extinction. Recent calculations (Lugo, 1988), although lower than other previous figures, suggest that from 30,000 to 100,000 species could disappear irreversibly by the year 2000 in tropical Latin America.

In the dry forests and woodlands, deforestation is also affecting a

Table 2.2 **Deforestation by life-zone in tropical Latin America in the 1980s**

| | Natural ($10^3$ km$^2$) | Altered ($10^3$ km$^2$) | Deforestation: On natural (km$^2$/yr) | Deforestation: On altered (km$^2$/yr) | Deforestation: Total (km$^2$/yr) | Annual rate (%/year) |
|---|---|---|---|---|---|---|
| TF | 5,588 | 752 | 30,350 | 4,000 | 34,350 | 0.54 |
| STF | 207 | 271 | 3,300 | 1,200 | 4,500 | 0.94 |
| T&ST F | 5,795 | 1,023 | 33,650 | 5,200 | 38,850 | 0.57 |
| TSTMF | 128 | 283 | 3,000 | 450 | 3,450 | 0.84 |
| TLMF | 30 | 108 | 850 | 290 | 1,140 | 0.83 |
| T&ST MF | 158 | 391 | 3,850 | 740 | 4,590 | 0.84 |
| TDF | 393 | 632 | 6,800 | 1,700 | 8,500 | 0.83 |
| TVDF | 496 | 311 | 2,380 | 535 | 2,915 | 0.36 |
| STDF | 179 | 614 | 1,885 | 450 | 2,335 | 0.29 |
| T&ST DF | 1,068 | 1,557 | 11,065 | 2,685 | 13,750 | 0.52 |
| TS | 423 | 125 | 1,280 | 200 | 1,480 | 0.27 |
| D&M | 52 | 82 | 450 | 150 | 600 | 0.45 |
| Total | 7,496 | 3,178 | 50,295 | 8,975 | 59,270 | 0.56 |



Source: Winograd, 1989a.

Key: TF = tropical moist forests
STF = subtropical moist forest
T&ST F = tropical and subtropical moist forests
TSTMF = tropical amd subtropical montane forests
TLMF = tropical lower montane moist forests
T&ST MF = tropical and subtropical montane moist forests
TDF = tropical dry forests
TVDF = tropical very dry forests and thorn woodlands
STDF = subtropical dry forests
T&ST DF = tropical and subtropical dry forest
TS = tropical savannas
D&M = tropical and subtropical deltas and mangrove forests



growing number of people. It is estimated that in 1980 about 26 million persons were suffering from acute fuelwood deficits (Lanly, 1985; Lugo, 1987).

Soil erosion and desertification are also a problem in tropical Latin America. In 1980, about 226 million hectares of tropical and semi-arid lands were suffering from desertification, affecting primarily productive lands (pastures and rainfed and irrigated croplands), and 50 to 75 per cent of the productive lands in the mountain areas were exposed to soil erosion (Doureojeanni, 1982; Masson, 1987; Winograd, 1989a).

Table 2.3 **Forest losses and gains in tropical Latin America in the 1980s**

| | Forest area[1] ($10^3$ km$^2$) | Annual deforestation rate (%/year) | Annual deforestation (km$^2$) | Annual reforestation (km$^2$) | Reforestation/deforestation ratio |
|---|---|---|---|---|---|
| T&ST F | 6,818 | 0.57 | 38,850 | 2,600 | 1:15 |
| T&ST MF | 549 | 0.84 | 4,590 | 700 | 1:7 |
| Total dense forests | 7,367 | 0.59 | 43,440 | 3,300 | 1:13 |
| T&ST DF | 2,625 | 0.52 | 13,750 | 2,050 | 1:7 |
| Total dense and open forests | 9,992 | 0.57 | 57,190 | 5,350 | 1:11 |
| TS | 548 | 0.23 | 1,480 | 0 | — |
| D&M | 134 | 0.45 | 600 | 0 | — |
| Tropical Latin America | 10,674 | 0.56 | 59,270 | 5,350 | 1:11 |



Source: Winograd, 1989a

Key: (1) Natural + altered
T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forests
T&ST DF = tropical and subtropical dry forests
TS = tropical savannas
D&M = tropical and subtropical deltas and mangrove forests

The human population in the tropical and subtropical areas reached about 280 million (80 per cent of the total for Latin America) in 1980. Per capita agricultural land in 1980 amounted to 0.46 hectares per person. However, this average hides large disparities in the availability of agricultural land, as well as in the destiny of agricultural products. For instance, in the same year, agricultural land amounted to 1.17 ha/person in the tropical and subtropical moist forests, where a large part of the production is directed towards export. On the other hand, in densely populated zones such as the tropical and subtropical mountain moist forests, and the paramo and puna, per capita agricultural land reaches only an average of 0.19 and 0.14 ha/person, respectively. There, subsistence crops (corn, beans, potatoes, etc.) dominate (table 2.4).



In general terms, inappropriate modalities of land use in tropical Latin America translate into low grain production, insufficient har-

Table 2.4 **Current (1980) and anticipated (simulated for 2030) per capita availability of agricultural land in the Latin American tropics**

| | 1980 | | 2030 | | | |
|---|---|---|---|---|---|---|
| | | | Reference | | Sustainable | |
| | ha/person | PIL | ha/person | PIL | ha/person | PIL |
| T&ST F | 1.17 | L | 0.73 | L–I | 0.96 | I |
| T&ST MF | 0.19 | L–I | 0.13 | I | 0.084 | H |
| T&ST DF | 0.88 | L–I | 0.46 | I | 1.1 | I–H |
| TS | 1.6 | L | 0.79 | L–I | 1.5 | I |
| D&M | 0.17 | L | 0.08 | L–I | 0.09 | I |
| P&P | 0.14 | L | 0.11 | L–I | 0.11 | I |
| T&ST DDS | 0.11 | L | 0.06 | L–I | 0.08 | I–H |
| Total | 0.46 | L–I | 0.27 | I | 0.32 | I–H |



Source: Winograd, 1989a.

Key: PIL = predominant input level: L = low; I = intermediate; H = high
T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forest
T&ST DF = tropical and subtropical dry forests
TS = tropical savannas
D&M = tropical and subtropical deltas and mangrove forests
P&P = paramo and puna
T&ST DDS = tropical and subtropical deserts and dry scrub

vests of roots and tubers, and the decline and even disappearance of traditional food crops; alternatively, the latter are produced to satisfy external demand (Winograd, 1989a).

In 1980, livestock amounted to 270 million animal units (AU) in tropical Latin America; that represents an average of 0.96 AU/person. However, the efficiency of ranching is very low, average meat production being about 45 kg/ha/year. Ranching is essentially extensive, with low animal loads: in ten-year-old pastures they may diminish to 0.2 AU/ha (Hecht et al., 1988).



## 3 Modelling ecological changes

For the purpose of exploring alternative ecological futures for tropical Latin America it was necessary to choose a land classification system capable of including the ecological characteristics of the region and its potential and limitations, and adaptable to the type and quality of the available information. The life-zone approach (Holdridge,

1967) was considered appropriate, subdivided into specific categories (e.g. savannas, mangrove forests) according to the criterion of actual vegetation.

The spatial extent of the tropical zone was adjusted by taking into account the ecological and productive characteristics of the different areas (Brown and Lugo, 1980; Winograd, 1989b); as a consequence, some ecological units exceed the geographical limits (23°27′ South to 23°27′ North) of the strict definition of the tropics. A total of twelve tropical and subtropical life-zones were identified for the region, aggregated into seven major zones for the purposes of the present paper (figs. 2.1 and 2.2).

Simulation models were implemented (Gallopín and Gross, 1989; Winograd, 1989a) for each of the twelve zones. Each zone is modelled as a set of compartments representing different ecological categories or conditions and with different structural, functional, and productive characteristics. The following seven categories were defined:



(1) "Natural": virgin areas, and areas with past alteration but currently similar to the original ecosystems; (2) "Altered": denotes a mosaic of patches of land under production coexisting with patches of original and secondary vegetation, and areas with slight to moderate soil erosion; (3) "Agricultural": annual, permanent, and non-traditional (i.e. coca, marijuana) crop areas, including fallow from permanent agriculture;[3] (4) "Grazing": ranching areas in natural or artificial pastures; (5) "Plantations": reforested areas used for forestry and watershed protection; (6) "Wastelands": unproductive lands irreversibly transformed by extreme soil erosion and desertification (natural deserts are not included here); and (7) "Urban": urbanized areas (mainly cities).



Every year, land shifts from one category to others according to the intensity and nature of the human activities (defined by an assumed scenario) and of the natural processes occurring on it (fig. 2.3). Simulations span the period 1980–2030. A simple compartment model was used. Each compartment represents the surface of a land category, for each life-zone, and it changes according to the following equation:

$$S^i_{t+1} = S^i_t + \sum_{j \epsilon J} Inflows^{ij}_{t,t+1} - \sum_{k \epsilon K} Outflows^{i,t}_{t,t+1}$$

$$J \subseteq I, K \subseteq I \qquad 0 \leq S^i_t \leq S^i_{max}$$

where $S$ = surface of a given land category (km$^2$); *Inflows* = surface of land of other categories converted into the considered category in

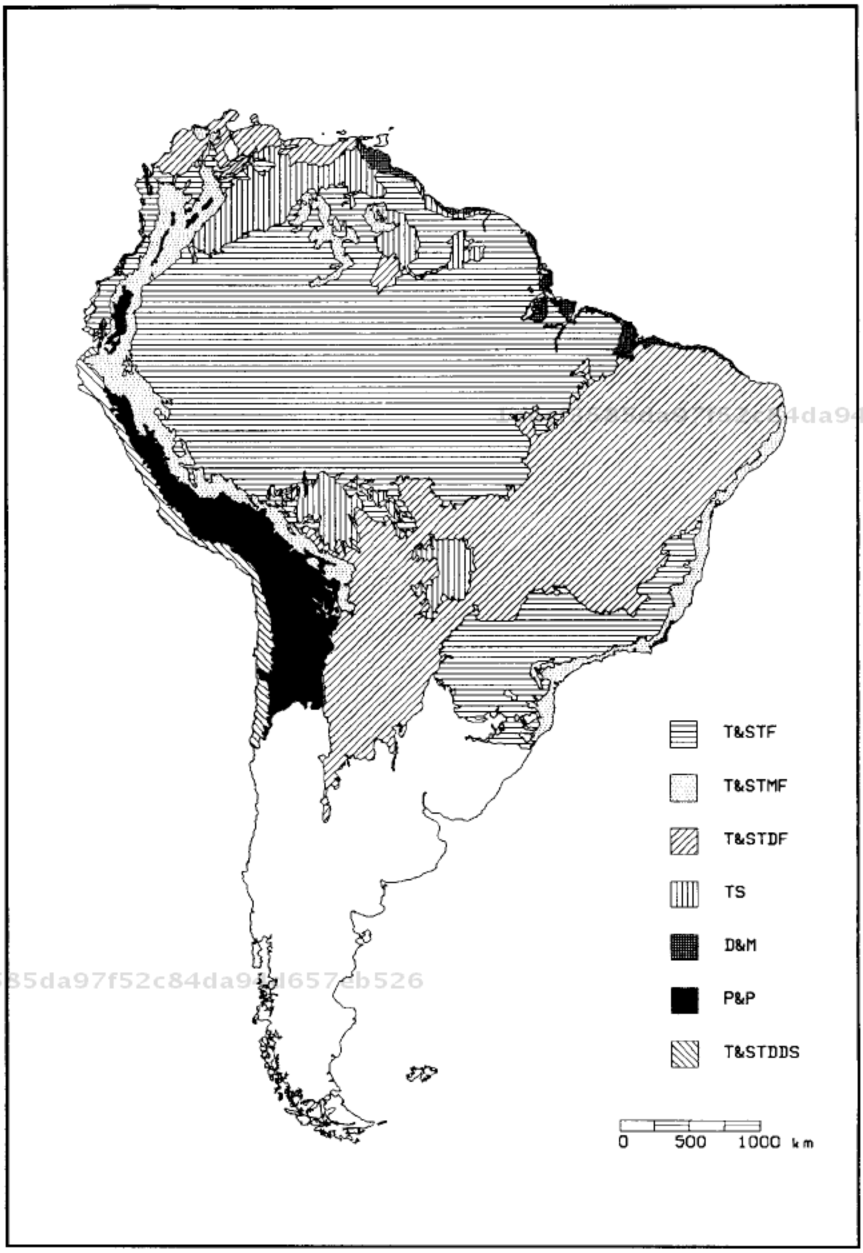






Figure 2.1 **The major tropical and subtropical life-zones of South America. T&ST F = tropical and subtropical moist forests; T&ST MF = tropical and subtropical montane moist forests; T&ST DF = tropical and subtropical dry forests; TS = tropical savannas; D&M = tropical and subtropical deltas and mangrove forests; P&P = paramo and puna; T&ST DDS = tropical and subtropical deserts and dry scrub.**

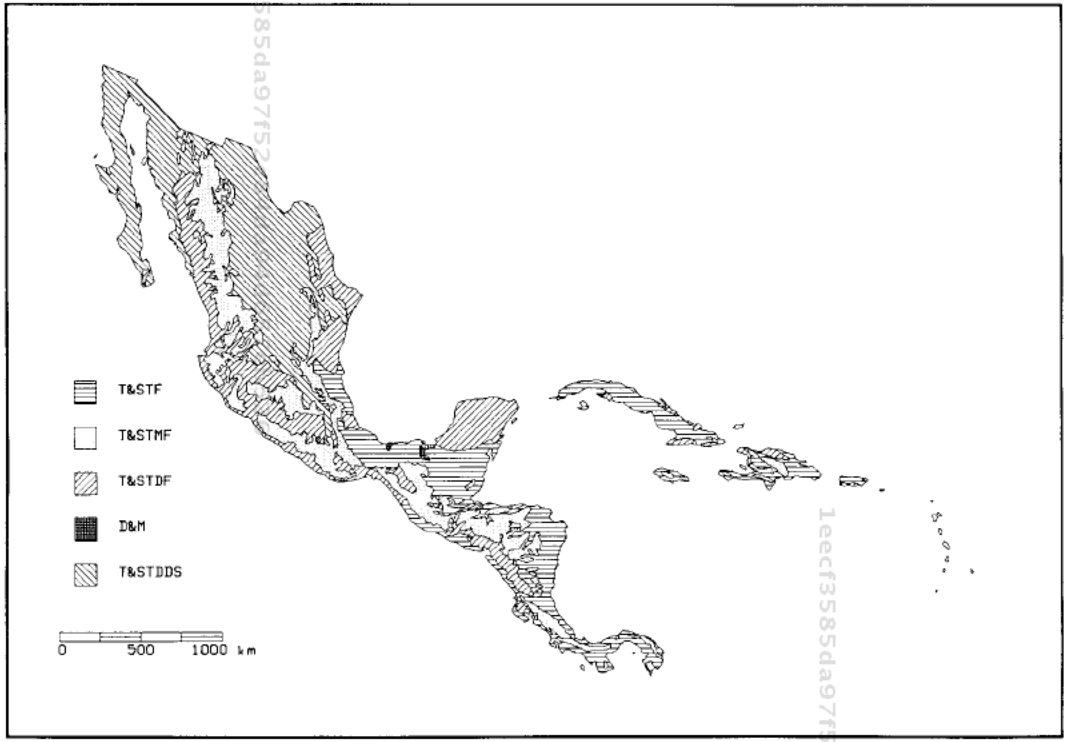


Figure 2.2 **The major tropical and subtropical life-zones of Central America and Mexico. T&ST F = tropical and subtropical moist forests; T&ST MF = tropical and subtropical montane moist forests; T&ST DF = tropical and subtropical dry forests; D&M = tropical and subtropical deltas and mangrove forests; T&ST DDS = tropical and subtropical deserts and dry scrub.**

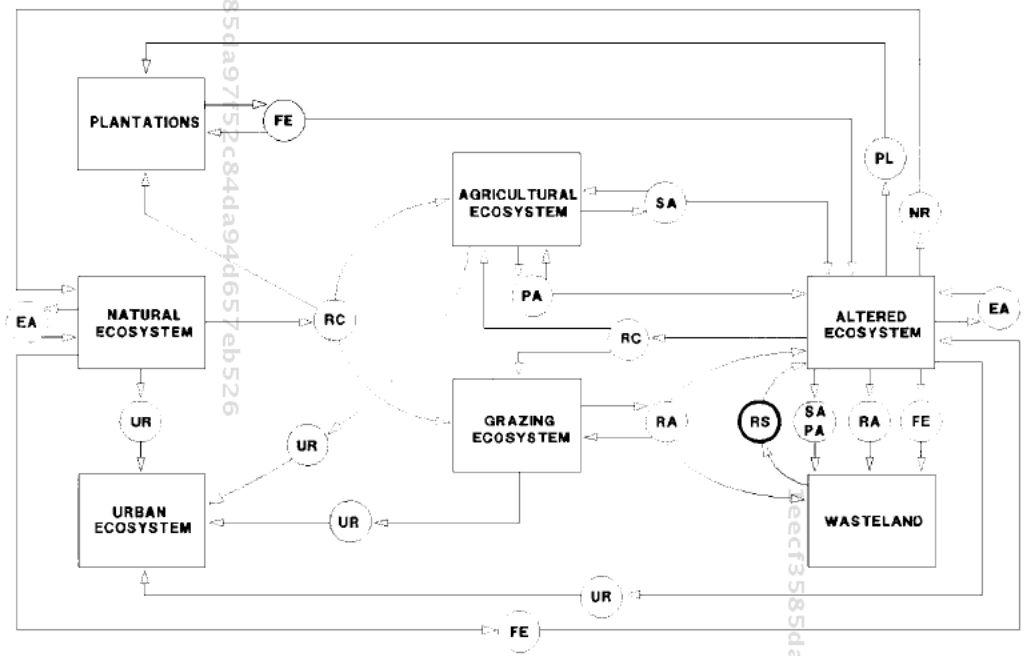


Figure 2.3 **Potential transitions of land between ecological categories, simulated for each major life-zone of Latin America. Boxes indicate land categories; circles indicate processes generating the transitions; arrows denote the transitions. The thick circle operates in the sustainable scenario only. SA = shifting agriculture; PA = permanent agriculture; FE = forest exploitation; EA = extraction activities; RA = ranching; PL = plantation; RC = reconversion; NR = natural regeneration; RS = restoration; UR = urbanization.**

a given year ($km^2$/year); *Outflows* = surface of land of the considered category converted into other categories (including itself) in a given year ($km^2$/year); $S_{max}$ = maximum potential surface of the category ($km^2$); $I$ = set of all land categories. The scenario yearly defines the process generating the transformations (human activities or natural regeneration; see fig. 2.3) for each category and life-zone, specifying the portion of the category affected by the activity and the rates of conversion to other categories. The scenario is exogenously defined, taking into account the current situation, the assumed rate of growth of the activity, and the availability of land. Models were run under both a reference and a sustainable development scenario (see next section).



While the simulation models, in their present state, do not calculate production, but only the surfaces of land under different categories and production systems, the estimates of production are based upon the expected improvements in agricultural yields (compatible with the historic changes within the region and probably underestimating the future increases).

## 4 The reference scenario

Based on the current situation and the trends already visible, the expected reference scenario of changes in the region in the next forty years has been specified (Furtado, 1984; Gallopín, 1986, 1989a; Winograd, 1989a). The scenario implies a partial continuation of the current stagnation followed by a moderate increase in economic growth, but at a level lower than before the current crisis. The pattern of development would be fundamentally unchanged, with an expanding influence of transnational corporations. The regulating role of the state will diminish and market forces will become increasingly dominating. The current social disparities and income concentration would be maintained or increased. Environmental policies will continue to be weak and little enforced, and additional pressures on the ecological base will arise. These will originate in the increasing emphasis on exports for the servicing of external debt, for compensating for the deteriorating terms of trade, and for occupying a niche in the changing world economy. The major dynamic factor in the economy will continue to be industrial production oriented towards the internal market of consumer goods, but with an increasing preponderance of the export sector (raw materials and industrial goods). The new and emerging technologies will enter essentially exogenously, with the region maintaining its current passive attitude, and generating a number of ecological (as well as social) impacts (Gallopín, 1988). At the international level, closer cooperation between the industrialized countries is expected, leading to a higher coordination of their economic policies. The external debt of the third world would be reformulated, eventually reversing the current net capital flow from the South to the North.

A number of general hypotheses regarding variables directly related to land use have been specified for each scenario, and adjusted for each of the life-zones, by taking into account the current pattern of use, the potential availability of land, the ecological limitations, and the expected pressures for exploitation. The basic reference scenario has been subdivided into a pessimistic and an optimistic subscenario (table 2.5).[4] Besides the hypotheses, a gradual decrease in the rate of advance of the agricultural frontier in tropical zones, and a general increase in the intensity of land and inputs use, is assumed for the reference scenario.



The aggregated results from the simulation runs under the reference scenario appear in table 2.6, and the results for each life-zone in table 2.7.

For the whole region, the figures imply the transformation of 4.7 million hectares per year (as an average for the fifty years) of virgin and semi-virgin ecosystems. As much as 80 per cent of the surface will come from the tropical areas, and 20 per cent from the subtropical areas. As much as 45 per cent of this transformed area will become agricultural (30 per cent under shifting agriculture, 15 per cent under permanent agriculture); 30 per cent will be used for grazing and 22 per cent for forest exploitation (timber, charcoal, and fuelwood).



Two major driving forces account for a large part of the dynamics: (1) the advance of the agricultural frontier, translating into a decrease of the natural ecosystems and the growth of the agricultural, grazing, and altered areas; and (2) the intensification of land use, which in the dry zones increases the wastelands at the expense of the altered ecosystems, and in the humid zones increases the area of altered ecosystems, within which subsistence agricultural activities intensify.

The loss of natural forests will reach from 3.7 to 6.8 million hectares per year, in the optimistic and pessimistic scenarios respectively (table 2.8).

Soil erosion problems originating from deforestation, inappropriate agricultural techniques, overgrazing, and overexploitation will

Table 2.5 **General hypothesis of the simulation scenarios for tropical Latin America**

| Variable | Pessimistic reference subscenario | Optimistic reference subscenario | Sustainable scenario |
|---|---|---|---|
| Population growth | From 2.2%/yr in 1980 to 1.2% in 2030 | From 2.2%/yr in 1980 to 1.2% in 2030 | From 2.2%/yr in 1980 to 1.2% in 2030 |
| Average growth of per capita agricultural production | Within the range 0 to 0.5%/yr | 0.5%/yr | Within the range 0.5 to 1%/yr |
| Average growth of crop yields | 0.5%/yr | 1%/yr | Within the range 1.5 to 2%/yr. |
| Animal carrying capacity (animal units) | From 0.6AU/ha in 1980 to 0.9AU/ha in 2030 | From 0.6AU/ha in 1980 to 1.2AU/ha in 2030 | From 0.6AU/ha in 1980 to 1.5AU/ha in 2030 |
| Annual harvested area | 65% of the agricultural land | 65% of the agricultural land in 1980; 75% in 2030 | 65% of the agricultural land in 1980; 85% in 2030 |
| Land allocation | Emphasis on export crops | Emphasis on export crops; secondarily, on crop diversification for internal consumption and export | Emphasis on crop diversification for internal consumption and export; secondarily, on export crops |



Source: Gallopín, 1989a; Winograd, 1989a.



Table 2.6 **Simulated total changes in land categories for tropical Latin America 1980–2030, under the reference scenario**

| | 1980 | 2030 | Total change (%) |
|---|---|---|---|
| Natural | 46.0 | 33.5 | −27.1 |
| Altered | 20.5 | 19.2 | −5.6 |
| Agricultural | 7.3 | 11.2 | +52.4 |
| Grazing | 23.5 | 30.2 | +28.2 |
| Plantations | 0.3 | 1.5 | +459.6 |
| Urban | 0.6 | 1.3 | +96.5 |
| Wastelands | 1.8 | 3.1 | +72.9 |
| Total | 100.0 | 100.0 | |

Table 2.7 **Evolution of land use under the reference scenario ($10^3$ km$^2$)**

| | Natural | | | Agricultural | | | Grazing | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 |
| T&ST F (8,124) | 5,795 | 5,193 | 4,436 | 583 | 744 | 849 | 683 | 745 | 1,040 |
| T&ST MF (1,251) | 158 | 98 | 48 | 178 | 273 | 319 | 473 | 472 | 550 |
| T&ST DF (4,747) | 1,068 | 884 | 678 | 377 | 486 | 576 | 1,612 | 1,861 | 2,183 |
| TS (1,066) | 423 | 367 | 286 | 32 | 46 | 51 | 485 | 543 | 627 |
| D&M (186) | 52 | 43 | 34 | 8 | 8 | 8 | 42 | 50 | 53 |
| P&P (922) | 173 | 145 | 112 | 23 | 43 | 49 | 422 | 437 | 487 |
| T&ST DDS (1,162) | 354 | 309 | 252 | 79 | 92 | 99 | 392 | 366 | 328 |
| Tropical L. America (17,458) | 8,023 | 7,042 | 5,845 | 1,280 | 1,692 | 1,951 | 4,109 | 4,474 | 5,268 |
| Latin America (20,417) | 8,287 | 7,286 | 6,071 | 1,562 | 1,995 | 2,284 | 5,476 | 5,806 | 6,597 |



Source: Winograd, 1989a.

Key: T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forests
T&ST DF = tropical and subtropical dry forests
TS = tropical savannas
D&M = tropical and subtropical deltas and mangrove forests
P&P = paramo and puna
T&St DDS = tropical and subtropical deserts and dry scrub



particularly affect the tropical and subtropical mountain rain forests and the subtropical rain forest of Central America, the Andean countries, and Brazil.

Watershed degradation due to deforestation and damming will affect mainly the tropical and subtropical mountain and lowland rain forests in Central America, the Andean countries, parts of South America, Brazil, and Mexico.

Floods due to watershed degradation, deforestation, and natural processes will mainly affect the tropical and subtropical mountain and lowland rain forests in Central America, the Andean countries, and Brazil, and some of the savannas and subtropical forests of the Andean countries and Brazil.

| Plantations | | | Urban | | | Altered | | | Wastelands | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 2000 | 2030 | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 |
| 20 | 62 | 122 | 17 | 26 | 39 | 1,023 | 1,350 | 1,634 | 3 | 4 | 4 |
| 6 | 16 | 31 | 41 | 45 | 53 | 390 | 338 | 235 | 5 | 9 | 15 |
| 21 | 58 | 110 | 20 | 31 | 47 | 1,577 | 1,310 | 1,001 | 92 | 117 | 152 |
| 0 | 0 | 0 | 1 | 2 | 3 | 125 | 109 | 99 | 0 | 0 | 0 |
| 0 | 0 | 0 | 2 | 3 | 4 | 82 | 81 | 84 | 0 | 1 | 3 |
| 0 | 0 | 0 | 6 | 9 | 12 | 253 | 238 | 202 | 45 | 50 | 60 |
| 0 | 0 | 0 | 26 | 42 | 64 | 146 | 132 | 119 | 165 | 223 | 302 |
| 47 | 136 | 263 | 113 | 158 | 222 | 3,576 | 3,558 | 3,374 | 310 | 404 | 536 |
| 58 | 165 | 316 | 136 | 187 | 264 | 4,505 | 4,467 | 4,217 | 393 | 511 | 688 |



Desertification associated with overgrazing, excessive extraction of fuelwood, and cyclic droughts will advance mainly in the puna, the dry tropical forests, and the tropical and subtropical desert shrublands in the Andean countries, Brazil, Peru, Mexico, and Central America.

Agricultural pollution will continue in many parts of the cultivated lands in the whole region, and agricultural, industrial, and urban pollution will increase in the deltas and mangrove forests of Central America, the Caribbean, and parts of South America.

The fuelwood deficit will continue to increase in most of the ecosystems. It is anticipated that, by the year 2030, not less than 50 million people will suffer from an acute fuelwood deficit in the western dry areas, the Andean plateau, and in densely populated zones.

The results from the models suggest that agricultural land will become critically scarce by the year 2030 in tropical Latin America, being reduced from 0.46 to 0.27 hectares per person on average. A total of 710 million people (90 per cent of the projected total population of Latin America) will be living in the tropical areas. In order to produce enough food for the population, agricultural inputs will have

Table 2.8 **Anticipated losses of natural forests in tropical Latin America according to two reference sub-scenarios (figures in parentheses indicate percentages of total surface of the corresponding life-zone)**

| | 1980 | 2000 | | 2030 | |
|---|---|---|---|---|---|
| | | O | P | O | P |
| T&ST F | | | | | |
| Natural condition ($10^3$ $km^2$) | 5,795 (71) | 5,193 (64) | 5,035 (62) | 4,436 (55) | 3,512 (43) |
| Annual deforesation ($km^2$/year) | 33,650 | 30,100 | 38,000 | 25,550 | 50,750 |
| Deforestation rate (%/year) | 0.58 | 0.58 | 0.75 | 0.58 | 1.40 |
| T&ST MF | | | | | |
| Natural condition ($10^3$ $km^2$) | 158 (13) | 98 (8) | 80 (6) | 48 (4) | 0 (0) |
| Annual deforestation ($km^3$/year) | 3,850 | 3,000 | 3,900 | 1,700 | 0 |
| Deforestation rate (%/year) | 2.4 | 3.0 | 4.8 | 3.5 | 0 |
| T&ST DF | | | | | |
| Natural condition ($10^3$ $km^2$) | 1,068 (22) | 884 (19) | 793 (17) | 678 (14) | 274 (6) |
| Annual deforestation ($km^3$/year) | 12,950 | 9,200 | 13,750 | 7,000 | 17,300 |
| Deforestation rate (%/year) | 1.2 | 1.0 | 1.7 | 1 | 6.3 |



Key: O = optimistic reference sub-scenario.
P = pessimistic reference sub-scenario.
T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forests
T&ST DF = tropical and subtropical dry forests



to increase from the current low to an intermediate level, or to an intermediate to high level (the latter is comparable to the level applied today in the industrialized countries) (Gómez and Gallopín, 1989a, and table 2.4, above). The situation will be worst in the mountainous areas; the results indicate that agricultural land availability will be reduced to 0.13 hectares per person in the tropical and subtropical mountain forests, and to 0.11 ha/person in the paramo and puna.

Species extinctions could range from 100,000 to 350,000 species in the next forty to fifty years, considering only those existing in dense tropical forests (Lugo, 1988; Winograd, 1989a).

Table 2.9 **Carbon contents of forest biomass in Latin America (tons C/ha)**

| Life-zone | Natural | Altered fallow | Altered exploited |
|---|---|---|---|
| T&ST F | 164 | 63 | 119 |
| T&ST DF | 40 | 19 | — |
| T&ST MF | 133 | 51 | 97 |

Sources: Brown and Lugo, 1982, 1984; Fearnside, 1987; Detwiler et al., 1985.

Key: T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forests
T&ST DF = tropical and subtropical dry forests



Table 2.10 **Calculated carbon emissions ($10^6$ tons of C) due to deforestation in Latin American tropical forests under three alternative scenarios**

| | 1980 | 2000 | | | 2030 | | |
|---|---|---|---|---|---|---|---|
| | | P | O | S | P | O | S |
| T&ST F | 599.3 | 676.5 | 536.4 | 354.0 | 903.4 | 455.4 | 46.0 |
| T&ST MF | 31.1 | 31.5 | 24.3 | 9.4 | 0.0 | 13.7 | 5.5 |
| T&ST DF[1] | 35.2 | 43.0 | 30.3 | 19.2 | 52.5 | 24.0 | 3.6 |
| Total | 665.6 | 751.0 | 591.0 | 382.6 | 955.9 | 492.7 | 55.1 |

Key: P = pessimistic reference scenario; O = optimistic reference scenario; S = sustainable scenario
T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forests
T&ST DF = tropical and subtropical dry forests

[1] Including tropical savannas.
Note: it is assumed that all the carbon in the biomass is converted into $CO_2$ during forest burning.



By using the estimated contents of carbon in forest biomass presented in table 2.9 and the detailed simulated changes in land use, it is possible to anticipate that carbon emissions associated with deforestation could change from 665.6 × $10^6$ tons of carbon (1980) to between 493 × $10^6$ tons and 956 × $10^6$ tons in the year 2030 (table 2.10).

## 5 The sustainable scenario

A possible and desirable scenario for the sustainable development of the region was identified (Furtado, 1984; Gallopín, 1986, 1989b; Winograd, 1989a). This scenario emphasizes the satisfaction of the needs of the population, a better distribution of wealth, and a participatory and decentralized approach. It assumes the implementation of national and regional environmental policies and an active strategy for research and development (R&D) focused upon regional problems and opportunities; the implementation of social and economic reforms; land use zoning and regulation of the agricultural frontier; policies for the reinforcement of the industrial sectors associated with renewable and non-renewable natural resources and agriculture; the development of local energy sources (mainly hydroelectricity and biomass); promotion of technological innovations in relation to the revalorization of the renewable natural resources and to the development of new sustainable productive uses and internal and international market ‘‘windows of opportunity,’’ particularly in relation to tropical forests and agricultural production.



In terms of environmental sustainability, the issues of **technological pluralism** (complementary use of traditional, modern, and high technology) and of **technological blending** (constructive integration of new and emerging technologies into traditional or modern technologies) will assume paramount importance, requiring new forms of social organization and an integrated strategy for technological development and diffusion. The re-evaluation and upgrading of traditional technology and of the empirical knowledge existing in the region will be specially important for the medium and small-scale sectors of the rural areas. While many of the traditional technologies are extensive rather than intensive, they are often well adapted to the local ecological and social characteristics. They represent a good basis for building new, efficient, high-yielding, and ecologically sound production systems. A number of already tested systems of forestry, agroforestry, and agro-silvo-pastoralism support this point (Hecht, 1981).



Special emphasis will be given to the development of new systems of production based on the utilization of the ecosystems already altered, including the ‘‘neo-ecosystems’’ generated by past human activities on virgin and abandoned lands, and to modernization and yield improvements in the high-quality lands that are already being exploited.

Strategies will be developed concerning the allocation of ecological areas for protection (and in some cases management) of large-scale ecological functions and processes (i.e. watershed regulation, bio-geo-chemical cycles, etc.), often requiring cooperation among different countries.

Regarding the major rural productive activities, integrated production systems will be favoured when appropriate. Particular emphasis will be placed upon the development of productive activities according to ecological suitability zoning (see table 2.11). A general criterion is the maintenance (at least during a transition period) of **productive pluralism**, with the coexistence of different types of agriculture, integrated through subnational, national, and regional policies (Gallopín, 1988). Structural reforms and technological innovations directed towards the transformation of the present subsistence agricultural sector into an efficient and sustainable peasant agriculture will be required. New forms of high-technology diversified agriculture will be developed, directed towards the selective exploitation of the local genetic resources for food, medicine, industry, and so on. It will imply the development of technologies for a new efficient agriculture in diversified ecosystems, as well as new ranching and wildlife management systems, viewing ecological diversity, heterogeneity, variability, and singularities as resources rather than as hindrances or constraints. Forestry will emphasize the re-evaluation of the forests as multi-purpose producers (wood, energy, wildlife, special products, ecological functions).



The scenario was derived using the following conclusions from the EPLA project:

1. There are no important **ecological constraints** (at the regional level) to the satisfaction of human needs and to sustainable development, including food production. It is not necessary to sacrifice conservation areas needed to maintain essential ecological functions and services (Coutou, 1988; Gómez and Gallopín, 1989a, 1989b; Higgins et al., 1982; Morello et al., 1989).
2. There is no **lack of available technologies** impeding the sustainable management of Latin American ecosystems. Even where more research is needed and knowledge of the management of some ecosystems is seriously incomplete, there exist many socially, economically, and ecologically sustainable management techniques for a wide variety of ecosystems (Fuentes Godo, 1989; Gligo, 1989; Winograd, 1989a, 1989b).
3. Regarding **new and emerging technologies**, the following broad regional priorities for R&D will be emphasized (Gallopín, 1987): (i) the fertility limitations of tropical red soils (covering 50 per cent of South America) for traditional agriculture; (ii) sustainable use of deserts and semi-deserts (covering 15–20 per cent of South America and 35–40 per cent of Central America and Mexico) and of superficial and underground freshwater; (iii) sustainable management of tropical forests and their ecological functions; (iv)

Table 2.11 **Land use suitability for the tropical life-zones of Latin America (surface area in $10^3$ $km^2$; percentages in parentheses)**

| | T&ST F | T&ST MF | T&ST DF | TS | D&M | P&P | T&ST DS | Total |
|---|---|---|---|---|---|---|---|---|
| Protection | 4,358.5 (54) | 312.5 (25) | 1,542.0 (33) | 374.0 (35) | 74.0 (40) | 323.0 (35) | 930.0 (80) | 7,914.0 (45) |
| Ranching | 480.0 (5) | 148.5 (12) | 1,019.5 (21) | 533.0 (50) | 0.0 (0) | 184.5 (20) | 116.0 (10) | 2,481.5 (14) |
| Agro-silvo-pastoralism | 147.5 (2) | 227.5 (18) | 1,162.5 (24) | 53.0 (5) | 0.0 (0) | 184.5 (20) | 58.0 (5) | 1,833.0 (10) |
| Agroforestry | 886.0 (11) | 187.5 (15) | 94.5 (2) | 53.0 (5) | 19.0 (10) | 92.0 (10) | 0.0 (0) | 1,332.0 (8) |
| Forestry | 1,551.0 (19) | 187.5 (15) | 335.0 (7) | 0.0 (0) | 84.0 (45) | 46.0 (5) | 0.0 (0) | 2,203.5 (13) |
| Internsive agriculture and ranching | 701.0 (9) | 187.5 (15) | 593.5 (13) | 53.0 (5) | 9.0 (5) | 92.0 (10) | 58.0 (5) | 1,694.0 (10) |
| Total | 8,124.0 (47) | 1,251.0 (7) | 4,747.0 (27) | 1,066.0 (6) | 186.0 (1) | 922.0 (5) | 1,162.0 (7) | 17,458.0 (100) |

Source: Winograd, 1989a.

Key: T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forests
T&ST DF = tropical and subtropical dry forests
TS = tropical savannas
D&M = tropical and subtropical deltas and mangrove forests
P&P = paramo and puna
T&ST DDS = tropical and subtropical deserts and dry scrub

management and protection of regional germplasm and wildlife; (v) sustainable increment of agricultural yields and sustainable livestock management; (vi) evaluation and use of the regional empirical cultural experiences in agro-ecological management; (vii) management and conservation of fragile ecosystems; (viii) management, rehabilitation, and restoration of degraded or overcharged regional environments;[5] (ix) management of the stabilized "neo-ecosystems" generated by human actions; (x) treatment of regional and sub-regional bio-geo-chemical cycles and intercountry coordination of human activities affecting them. (The general hypothesis for variables directly affecting land use appears in table 2.5, above.)



Under the sustainable scenario, the simulations indicate that the region is capable of satisfying the agricultural, livestock, fishing, and forestry internal requirements in a sustainable manner within the considered time-horizon of the next forty years, with a substantial surplus for exports.

Three major processes account for a large part of the dynamics in this scenario: (1) implementing science and technology and economic policies emphasizing the productive rehabilitation of deteriorated and altered ecosystems, which cover 20 per cent of the total land area; (2) implementing policies favouring integrated rural production systems (agriculture–animal husbandry–forestry–aquaculture) whenever appropriate; and (3) actively implementing policies directed to integrating the new technologies into traditional and modern technologies.

The results from the simulation runs under the sustainable scenario appear in aggregated form in table 2.12, and for each life-zone in table 2.13.



Table 2.12 **Simulated total changes in land categories for tropical Latin America 1980–2030, under the sustainable scenario**

| | 1980 | 2030 | Total change (%) |
|---|---|---|---|
| Natural | 46.0 | 40.9 | –11.0 |
| Altered | 20.5 | 19.3 | –31.8 |
| Agricultural | 7.3 | 13.1 | +78.8 |
| Grazing | 23.6 | 20.2 | –14.4 |
| Plantations | 0.3 | 3.6 | +1,253.2 |
| Urban | 0.6 | 1.2 | +85.8 |
| Wastelands | 1.8 | 1.7 | –31.6 |
| Total | 100.0 | 100.0 | |

Table 2.13 **Evolution of land use under the sustainable scenario ($10^3$ km$^2$)**

| | Natural | | | Agricultural | | | Grazing | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 |
| T&ST F (8,124) | 5,795 | 5,325 | 5,100 | 583 | 852 | 1,118 | 683 | 667 | 568 |
| T&ST MF (1,251) | 158 | 126 | 165 | 178 | 255 | 206 | 473 | 432 | 316 |
| T&ST DF (4,747) | 1,068 | 949 | 999 | 377 | 623 | 686 | 1,612 | 1,742 | 1,396 |
| TS (1,066) | 423 | 372 | 356 | 32 | 69 | 95 | 485 | 515 | 486 |
| D&M (186) | 52 | 47 | 54 | 8 | 10 | 9 | 42 | 35 | 44 |
| P&P (922) | 173 | 153 | 157 | 23 | 64 | 50 | 422 | 430 | 416 |
| T&ST DDS (1,162) | 354 | 319 | 312 | 79 | 97 | 125 | 392 | 336 | 292 |
| Tropical L. America (17,458) | 8,023 | 7,291 | 7,143 | 1,280 | 1,970 | 2,289 | 4,109 | 4,157 | 3,518 |
| Latin America (20,417) | 8,287 | 7,548 | 7,424 | 1,562 | 2,288 | 2,662 | 5,476 | 5,490 | 4,780 |



Source: Winograd, 1989a.

Key: T&ST F = tropical and subtropical moist forests
T&ST MF = tropical and subtropical montane moist forests
T&ST DF = tropical and subtropical dry forests
TS = tropical savannas
D&M = tropical and subtropical deltas and mangrove forests
P&P = paramo and puna
T&St DDS = tropical and subtropical deserts and dry scrub



In addition to the quantitative differences with the pattern derived from the current trends, the qualitative changes in the modality of rural production imply a drastic reduction of the ecologically degrading processes exhibited by the reference scenario. For the whole region those figures imply the transformation of 2.2 million hectares per year of virgin and semi-virgin ecosystems. Protected areas represent 45 per cent of the remaining natural ecosystems. Altered ecosystems will cover 19 per cent of the area, the same figure as in the reference scenario. However, in this case most of the altered lands become productive lands (13 per cent under sustainable forestry and 6 per cent in rehabilitation). Cultivated lands increase to 13 per cent (10 per cent under intensive agriculture and 3 per cent under shifting cultivation). Rangelands decrease because of increments in carrying

| Plantations | | | Urban | | | Altered | | | Wastelands | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 2000 | 2030 | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 | 1980 | 2000 | 2030 |
| 20 | 88 | 214 | 17 | 25 | 34 | 1,023 | 1,163 | 1,088 | 3 | 3 | 1 |
| 6 | 24 | 130 | 41 | 44 | 50 | 390 | 361 | 378 | 5 | 8 | 6 |
| 21 | 83 | 254 | 20 | 31 | 44 | 1,557 | 1,217 | 1,285 | 92 | 102 | 83 |
| 0 | 2 | 10 | 1 | 2 | 3 | 125 | 105 | 116 | 0 | 0 | 0 |
| 0 | 2 | 12 | 2 | 3 | 4 | 82 | 89 | 63 | 0 | 1 | 1 |
| 0 | 2 | 16 | 6 | 9 | 13 | 253 | 219 | 234 | 45 | 45 | 35 |
| 0 | 0 | 0 | 26 | 41 | 62 | 146 | 169 | 202 | 165 | 200 | 169 |
| 47 | 201 | 636 | 113 | 155 | 210 | 3,576 | 3,323 | 3,366 | 310 | 359 | 295 |
| 58 | 249 | 818 | 136 | 184 | 249 | 4,505 | 4,206 | 4,113 | 393 | 452 | 371 |



capacity (14 per cent is under intensive and semi-intensive grazing systems and 10 per cent is integrated with forestry). Eight per cent of the land will be under agroforestry. As a consequence of the rehabilitation and restoration activities, wastelands are reduced.

The ecological and technical feasibility of the sustainable scenario is supported by a number of additional considerations. By conservative estimates, not less than 15 per cent of the territory of tropical Latin America is suitable for crop agriculture (7.5 per cent for intensive agriculture and 7.5 per cent for agroforestry, agro-silvo-pastoralism, and shifting agriculture) (Winograd, 1989a). The requirement of agricultural lands in order to nourish the total projected population of Latin America by the year 2030 is estimated as 4 per cent of the total land surface under a high level of agricultural inputs, 7 per cent if an intermediate level is used, and 19 per cent with a low input level agriculture (Gómez and Gallopín, 1989a). The major constraint to food production (at the regional level) is thus not the absolute scarcity of agricultural land, but the low effectiveness of its utilization. Only 65 per cent of the tropical agricultural lands are harvested annually (FAO, 1986); however, this figure can be increased to at least

85 per cent. This implies a large potential increase in agricultural production by the improvement of this single factor.

On the other hand, the agroclimatological conditions in 75 per cent of the tropical areas of the region permit up to 2.5 annual harvests of short-cycled crops. The yields of those crops can be duplicated just by applying currently known technological systems (FAO, 1981, 1988).

Taking all those factors into account, it can be estimated that average food production could be multiplied by four within a relatively short period, merely by introducing known technical improvements in the allocation and utilization of agricultural land.

Agricultural land availability will reach 0.32 hectares per person in the year 2030 (table 2.7, above).



Important improvements are also feasible regarding tropical ranching, which currently exhibits a very low efficiency. By using existing techniques (Hecht et al., 1988), production can be increased from the present 45 kg/ha/year to 90–120 kg/ha/year and animal loads from 0.6 AU/ha to 1.5 AU/ha. This would allow increased production while reducing by 30 per cent or more the extent of pasture lands, land that could be allocated to more sustainable uses (Winograd, 1989a).

Other major opportunities for sustainable development are associated with the richness and diversity of the flora and fauna of the Latin American tropics, a potential much underutilized so far. It is estimated that 36 per cent of the 250,000 known species of flowering plants live in the region. About 1,000 plant species have a clear economic potential (Myers, 1984; Tosi, 1980). About 250 plant species and 45 animal species of the Andean mountain areas are appropriate for cultivation or domestication (Patiño, 1982). The tropics of the region possess areas with the capacity to provide unique products: in the puna, for instance, more than 30 potato varieties are grown, and a large economic potential exists for the production of fine wool from camelids such as alpaca, vicuña, and llama (CEPAL/PNUMA, 1983b). These alternative production systems can be not only ecologically but also economically better suited than the prevailing ones (see table 2.14 for some illustrative examples).



In the sustainable scenario, it is anticipated that carbon dioxide emissions from biotic sources would be reduced by 90 per cent from the 1980 level, to about $55 \times 10^6$ tons of carbon per year (table 10, above) by the year 2030. This is associated with the strong reforestation emphasis embodied in the scenario, aiming at a reforestation rate of 1.3 million hectares per year. This would result in 64 million

Table 2.14 **Some examples of alternatives systems of production for tropical areas of Latin America**

| | Prevailing | | | Alternative | | | References |
|---|---|---|---|---|---|---|---|
| | Activity | yield of main product | Other products | Activity | yield of main product | Other products | |
| T&ST moist forests | Cattle ranching | 0.1 ton/ha/yr of meat | Leather | Iguana breeding | 1.2 ton/ha/yr of meat | Skins | Cohn, 1989; Hecht et al., 1988 |
| T&ST moist forests | Selective forest exploitation | 100 to 120 $m^3$ of timber | — | Natural forest management | 150–200 $m^3$ of timber | Fruits, wildlife | Harshorn et al., 1987 |
| T&ST montane moist forests, puna | Monoculture | 1 to 2 ton/ha of wheat | — | Agriculture in terraces | 40 ton/ha of potatoes | Vegetables | Masson, 1987 |
| T&ST montane moist forests | Sunny coffee cultivation | 0.65 to 2 ton/ha | — | Shade coffee cultivation | 0.5 to 0.65 ton/ha | Fruits, wood | Carrizosa, 1987 |
| Tropical savannas and tropical dry forests | Cattle ranching | 15 kg/ha/yr of meat | Leather | Capybara breeding | 64 kg/ha/yr of meat | Leather | González-Jiménez, 1979 |
| Tropical deltas and mangrove forests | Monoculture | 2 tons/ha of rice | — | Chinampa agriculture | 3 to 4 tons/ha of corn | Vegetables, fishes, manure, wood, livestock | Jiménez Osornio et al., 1987 |
| Puna | Sheep ranching | 0.5 kg/yr of wool | Leather | Camelid ranching | 1.5 to 5 kg/yr of wool | Leather | CEPAL–PNUMA, 1983 |

hectares reforested by the year 2030. This represents 14 per cent of the new reforested area that could compensate the excess atmospheric carbon due to human activities (Sedjo, 1989). This value should be compared with the present estimated regional biotic emission of between 8.5 and 10.4 per cent of the world total.

## 6 Conclusions

The elements presented in this paper suggest the technical and ecological feasibility of an environmentally sustainable scenario for the region. While its economic feasibility has not been investigated in depth, our preliminary estimates of the costs specifically associated with the necessary changes in land use range between US$ 2,300 and 3,500 million per annum for the whole region (Winograd, 1989a) – not an exorbitant figure.



As a general conclusion, it can be stated that the ecological future of Latin America, and the possibilities of benefiting from the ecological opportunities while minimizing the constraints, are much more directly tied to the great social options adopted in the region than to the search for new knowledge and new ecosystem management techniques. Unfortunately, the more recent trends in the region are going in the direction of the reference scenario, with a disordered abandonment of the regulating role of states (rather than true modernization) and increasing pressures to produce for export, neglecting internal social needs.

The prospects of a sustainable scenario for Latin America will depend also to a large degree upon the attitudes adopted by the industrialized countries, and their willingness to assume their full share of the responsibility for the reversal of the worldwide ecological degradation and social impoverishment.



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## Notes

1. Based on data for the period 1980–85, which, after examining partial data available for later years, are considered approximately valid for the whole decade.
2. Estimates of deforestation in tropical Latin America are polemic, although all imply very significant rates. For instance, estimates for the "Pan-American" Amazon (covering about 7 million km$^2$) range from not less than 20,000 km$^2$ per year (Salati, 1989) to 23,000 km$^2$ year (Freitas, 1989). For the Brazilian Legal Amazon (an area of 4.9 million km$^2$), Fearnside (1982) estimated that 44% of the Legal Amazon would be deforested by the end of the 1980s. However, the same author (Fearnside, 1989) corrected his calculations, estimating a deforestation rate of 35,000 km$^2$ year for 1989, with a cumulative deforestation of 352,000 km$^2$ (7.2% of the Legal Amazon) for the decade. Those figures yield an average rate of some 25,000 km$^2$ per year for the period 1975–1989. Recent studies, based on the analysis of satellite images (Landsat-TM) made by INPE (Brazil), indicate an average rate of 15,649 km$^2$ per year for the period 1975–78, and of 17,678 km$^2$ per year for the period 1978–1988. Those figures yield a cumulative figure of 251,500 km$^2$ per year for the period (Pereira da Cunha, 1989). It should be noted that the Legal Amazon includes tropical moist forests (84%), tropical dry forests or *cerrado* (11.5%), and tropical moist savannas or *campos* (4.5%). Later estimates (Fearnside, 1990) indicate that, in the period 1960–1988, 6.4% of the tropical moist forests and 9.6% of the dry tropical forests were eliminated. Deforestation rates for 1988 reached 20,000 km$^2$ per year in the Amazon moist forests and 18,000 km$^2$ per year in the dry forests. This implies a total deforestation rate of 38,000 km$^2$ per year and a total cumulative figure of 459,734 km$^2$ (9.2% of the Legal Amazon) in 1988. The range of figures discussed here is compatible with our estimates (not limited to the Amazon forests) presented in table 2.1 and table 2.2. The often-cited figures of the World Bank (Mahar, 1989), giving a cumulative deforestation of 600,000 km$^2$ or 12% of the Legal Amazon by the year 1989, should be discarded. They do not represent estimates, but are mere extrapolations assuming exponential growth based on data from 1975, 1978, and 1980. Other extreme estimates (Setzer and Pereira, 1991) suggesting a deforestation rate of 1.6% per year for 1987 are probably unreliable (Cunha, 1989; Goldemberg, 1989).
3. Note that, contrary to other authors' definitions, fallow from shifting and peasant agriculture within forest areas in included in "Altered."
4. The run of the models for the initial period 1980–1990, for which independent estimates are available, show that the optimistic reference sub-scenario results in a better reproduction of the real trends for that period than the pessimistic sub-scenario. Unless otherwise stated, simulation results presented for the reference scenario refer to the optimistic sub-scenario.
5. E.g. Andean zone, coastal and island areas, deforested, desertified, and overgrazed areas.

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