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POTENTIAL COCA GROWING AREAS IN BOLIVIA, COLOMBIA, ECUADOR AND PERU

Analytic Support Paper

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POTENTIAL COCA GROWING AREAS IN

BOLIVIA, COLOMBIA, ECUADOR AND PERU

KEY JUDGMENTS

The determination of potential coca growing areas yields the following major conclusion:

- The current coca cultivation areas of Bolivia, Colombia, Ecuador and Peru represent a very small percentage of the territory in these countries that could (in physical terms) support coca growth--the expansion potential of coca cultivation is high.

This result has significant implications for narcotics monitoring and control programs:

- The availability of land suitable for coca cultivation does not constitute any real constraint upon future coca production.
- The problem of control of coca leaf cultivation will be potentially widespread.
- The large size of the potential growing areas acts to increase the sampling effort required for aerial surveys of potential growing areas--other locational cues (e.g., collateral data) will need to be considered to develop efficient sampling strategies.

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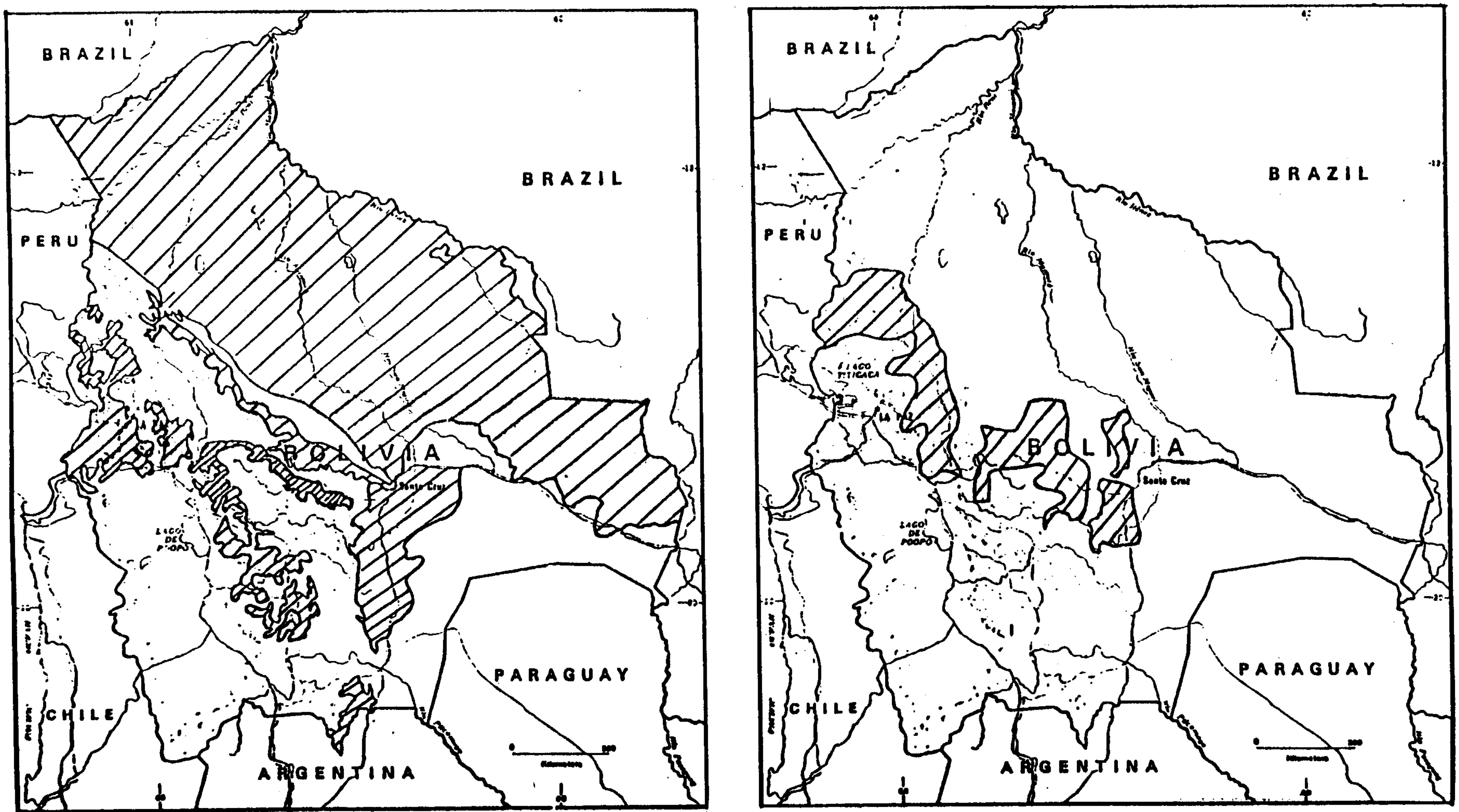
SUMMARY AND MAJOR FINDINGS

The current coca cultivation areas of Bolivia, Colombia, Ecuador and Peru produce quantitites of coca far in excess of legitimate domestic demand and export. However, these cultivation areas represent only a very small percentage of the territory in these countries that could (in physical terms) support coca growth. Estimates of the percentage of the land area where coca cultivation is technically feasible are:

- Bolivia--40%
- Colombia--90%
- Ecuador--65%
- Peru--70%

Figures 1-4 provide a visual comparison of the actual and potential coca growing areas in these countries. In aggregate, the size of the potential coca growing areas in Bolivia, Colombia, Ecuador and Peru is roughly two and one-half million square kilometers, an amount nearly 30% of the land area of the continential United States.

FIGURE 1. A COMPARISON OF ACTUAL AND POTENTIAL COCA GROWING AREAS IN BOLIVIA



Areas of likely coca growth.

Areas of less likely coca growth.

Identified areas of coca cultivation.

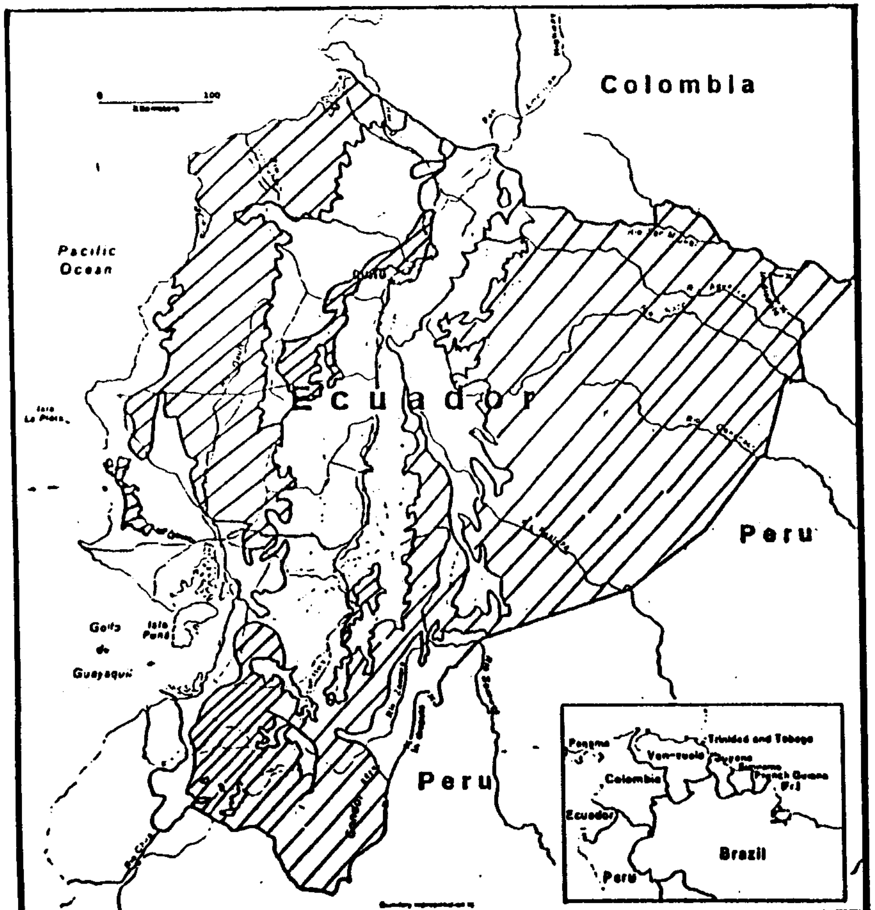
FIGURE 2. A COMPARISON OF ACTUAL AND POTENTIAL COCA GROWING AREAS IN COLOMBIA

Areas of likely coca growth.

Areas of less likely coca growth

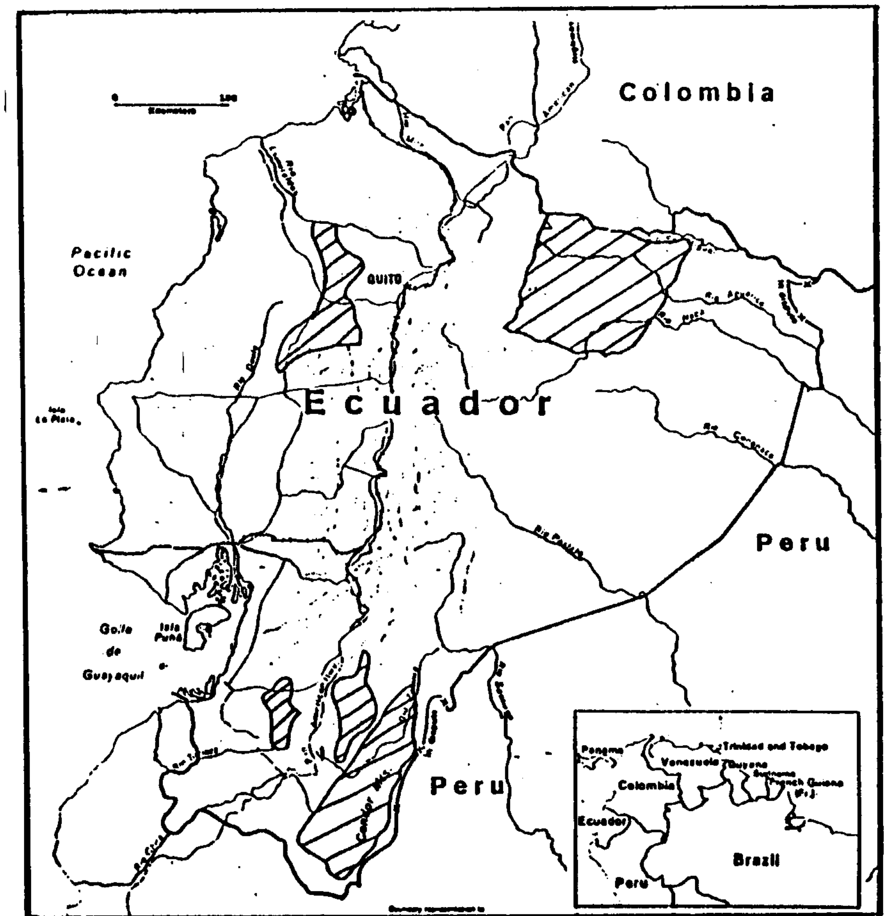
Identified areas of coca cultivation.

FIGURE 3. A COMPARISON OF ACTUAL AND POTENTIAL COCA GROWING AREAS IN ECUADOR



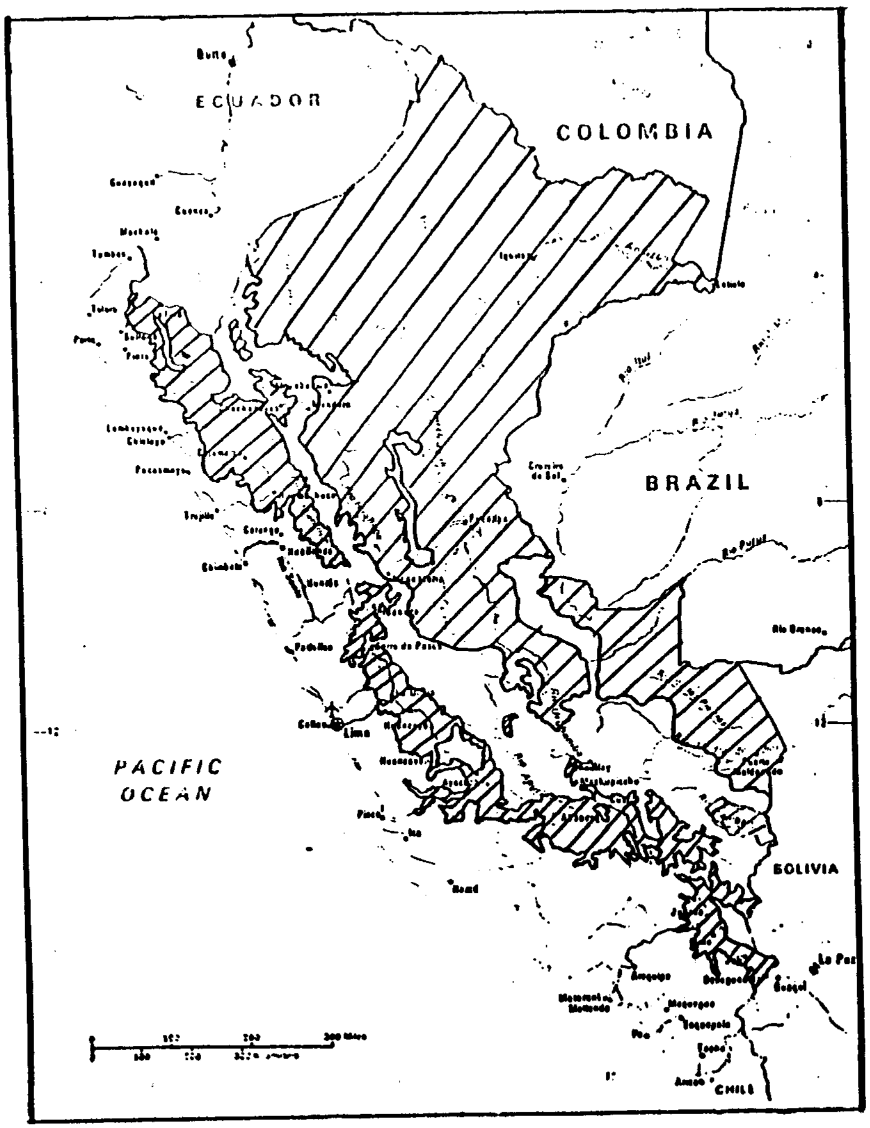
Areas of likely coca growth.

Areas of less likely coca growth.



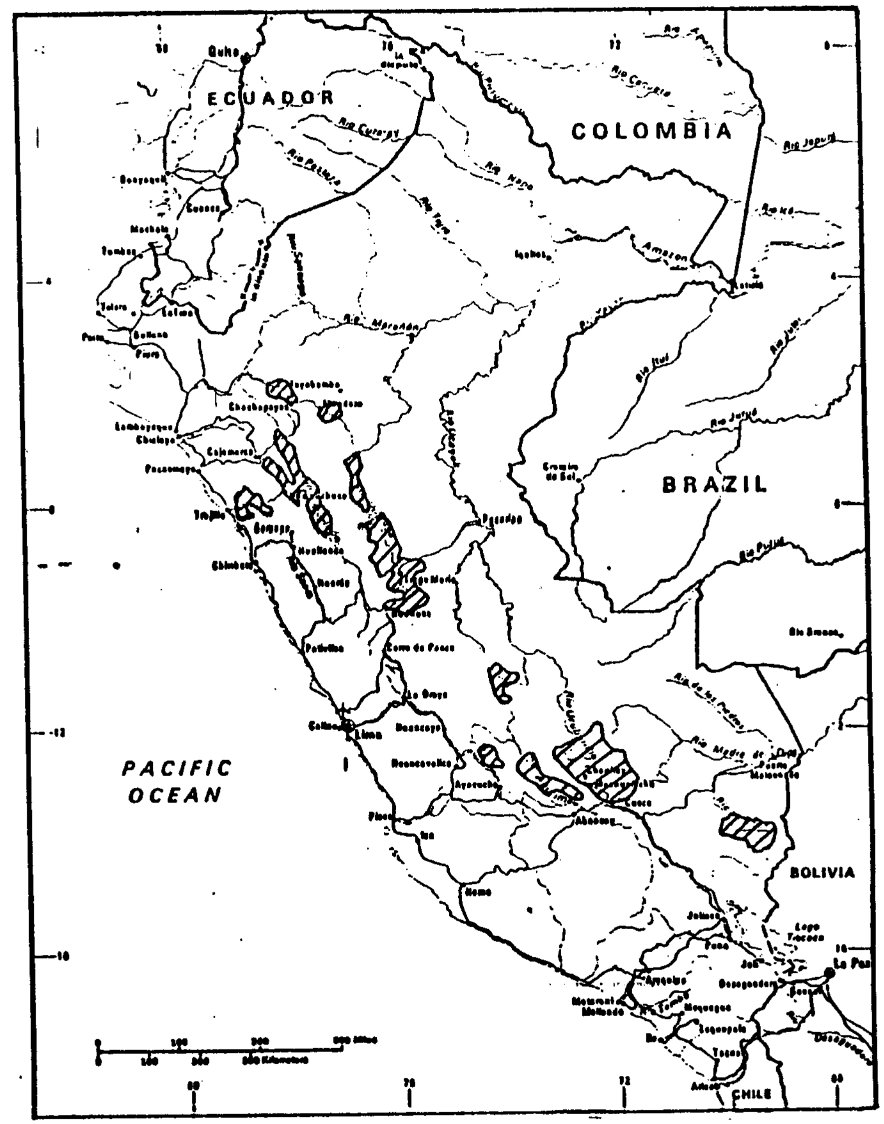
Identified areas of coca cultivation.

FIGURE 4. A COMPARISON OF ACTUAL AND POTENTIAL COCA GROWING AREAS IN PERU



Areas of likely coca growth.

Areas of less likely coca growth.



Identified areas of coca cultivation.

These estimates of potential growing areas have not considered other South American countries where small amounts of coca cultivation have been reported. For example, portions of northwest Brazil which are climatologically similar to contiguous areas in Colombia and Peru were not included in the above estimate, even though historically coca was native to several areas of Brazil. Preliminary analysis also indicates that large sections of Venezuela (about 80% of the national territory) as well as much of the land area in Central America is suitable for coca cultivation--though coca cultivation has not been reported in these countries.

The determination of the potential coca growing areas provides information relevant to future narcotics monitoring and control programs:

- to determine whether the problem of control of coca leaf cultivation will be potentially localized or widespread;
- to determine whether availability of suitable land for coca cultivation is a real constraint that could limit future coca production; and
- to infer possible shifts in current production patterns that may result from the implementation of narcotics control actions (e.g., interdiction, crop eradication or substitution, etc.).

Based on the estimates of the size of potential growing areas, the availability of land suitable (in physical terms) for coca cultivation does not constitute any real constraint upon future coca production. Even a successful coca control program will have to cope with the challenge of the ready availability of such arable land. Coca producers have wide latitude for shifting cultivation sites in response to narcotics control pressures. Such areal shifts are likely to increase the costs of coca production, however, assuming that locations where coca is presently cultivated are economically efficient. Ceteris paribus, increased production costs act to squeeze producer profits, increase prices of intermediates and finished products and ultimately to reduce consumption--all objectives of a coca control program. But these results are far less dramatic than would have occurred if potential growing areas were more limited in extent and production were directly reduced.

The large size of the potential growing areas has another unfortunate aspect. It acts to increase the sampling effort required for aerial surveys of potential growing areas. Indeed, the large size of the potential growing areas implies that other locational cues (e.g., collateral data) will need to be considered to develop efficient sampling strategies.

Specific country details include:

- Bolivia: In climatological terms, an estimated 40% of the national territory can support coca growth. The largest area of potential cultivation includes virtually the entire northern and eastern sections of the country, stretching northward and eastward from the eastern slopes of the Andes to Brazil. Smaller sections of potential coca cultivation are found in the Yungas of La Paz, the Chapare of Cochabamba, and in the areas extending southward from Santa Cruz.

- Colombia: Nearly all (90%) of Colombia is suitable in physical terms for coca cultivation. Areas that are not naturally suited for coca cultivation extend along the Atratro and Cauca Rivers and in the mountainous areas running the length of the country.

- Ecuador: Coca can potentially be grown on an estimated 65% of the national territory of Ecuador. The largest area of potential growth lies east of the Andes extending to the borders with Colombia and Peru. A second major area of potential growth extends along the western Andean slopes in the area between the coast and the mountains.

- Peru: Approximately 70% of Peru can be designated as a potential coca growing area. This region extends along the western and eastern slopes of the Andes. In the case of the latter, the area extends eastward to (and presumably across) the border with Brazil.

These area estimates were made using a methodology based upon "ecological life zones" (combining average temperature and annual rainfall) and frost-free areas to define a climatological "envelope" to delimit potential cultivation areas. Though not exact, this procedure summarizes the available information on coca plant tolerance and makes efficient use of available climatological data. Refinements to the estimation methodology are possible, but likely to be expensive to implement. These refinements are unlikely to affect materially the above findings.

TECHNICAL DISCUSSION

The determination of areas of potential coca cultivation in the current producer countries of Bolivia, Colombia, Ecuador and Peru provides information relevant to future narcotics monitoring and control programs:

- to determine whether the problem of control of coca leaf cultivation will be potentially localized or widespread;
- to determine whether availability of suitable land for coca cultivation is a constraint that could limit future coca production;
- to infer possible shifts in current production patterns resulting from the implementation of control or eradication measures.

To underscore coca's high potential for expansion and/or relocation in the event of control actions, it is useful to make a comparison of the actual and potential coca growing areas. Figures 1-4 show both actual and potential coca growing areas in Bolivia, Colombia, Ecuador and Peru, respectively.

Maps designating actual growing areas were prepared from a composite of data from sources of varying reliability. In some instances--for example, the Chapare region of Bolivia--aerial surveys were used to detect and identify areas of coca cultivation and the maps are highly accurate. In other areas, such as that shown in Colombia near the border with Venezuela, only unconfirmed reports were available. These maps should, thus, be viewed with some degree of skepticism.

Maps designating potential coca growing areas were produced on the basis of the Holdridge Life Zone Classification System and information provided by several investigators, including Dr. James Duke--USDA, Washington (references 1 and 4); Armando Sandagorda--former Chief of the Division of Regional Control of Coca, La Paz, Bolivia (reference 7); and Ruben Horna Ramirez--Ministry of Agriculture, Lima, Peru (reference 6), who have identified life zones suitable for coca cultivation.

A country-by-country analysis is presented later in this report, but the following general comments are noteworthy:

- The potential growing areas are dramatically larger than the zones where coca is currently cultivated. Illicit coca growers have substantial latitude for movement in response to pressure from government narcotics control efforts.

- Coca cultivation control programs of varying intensity are extant in Colombia, Peru and Bolivia. Though only a minor leaf producer at present, Ecuador has a substantial land area suitable for cultivation that is attractive in other respects (access to chemicals, trafficking routes, etc.). It is reasonable to infer that Ecuador would offer attractive locational alternatives to growers in response to increased eradication/control pressures in neighboring Colombia, for example.

- Much of the area of potential cultivation in these countries is found in remote regions--for example, in the llanos area (a vast area contiguous to Brazil) of Colombia. Such regions have low population density, little road infrastructure and only limited government presence or control. In response to the pressure of government anti-narcotics efforts, it is possible that growers might shift cultivation to these remote areas. Logistics difficulties and high transport costs are impediments to such a development, however.

- Considering the accuracy of the inputs to analysis, the correspondence between where coca is reportedly grown and areas of possible cultivation determined by the methodology given in this paper is excellent. There are reported areas of actual cultivation in Bolivia and Peru, however, that are not designated as suitable for cultivation. In part, this discrepancy can be explained by inaccuracies in maps of reported current growing areas. But there are also confirmed areas of cultivation, particularly the Trujillo area of Peru that are not correctly identified by the methodology given here. In this instance Trujillo coca is notably drought resistant and, more importantly, is irrigated in its area of cultivation.[1] The potential growth areas consider "natural" factors only. Thus, these estimates understate the potential growing areas.

Details: The Holdridge System

In essence, the Holdridge System partitions areas of the world into several so-called "life zones" on the basis of regional temperature and precipitation.[2] Insofar as these life zones are correlated with native plant life, these zones can be used as surrogates/predictors of the vegetation types in an area. Although the system has its limitations, (discussed later in the text), it represents the best available means for determining possible cultivation areas from simple climatic data. Moreover, of several ecological classification systems proposed in the literature, the Holdridge System is unique with regard to data availability; with the exception of Brazil, (believed to be a minor producer, but capable of supporting substantially increased amounts of coca cultivation), all the countries where coca is currently cultivated have been mapped into these life zones.

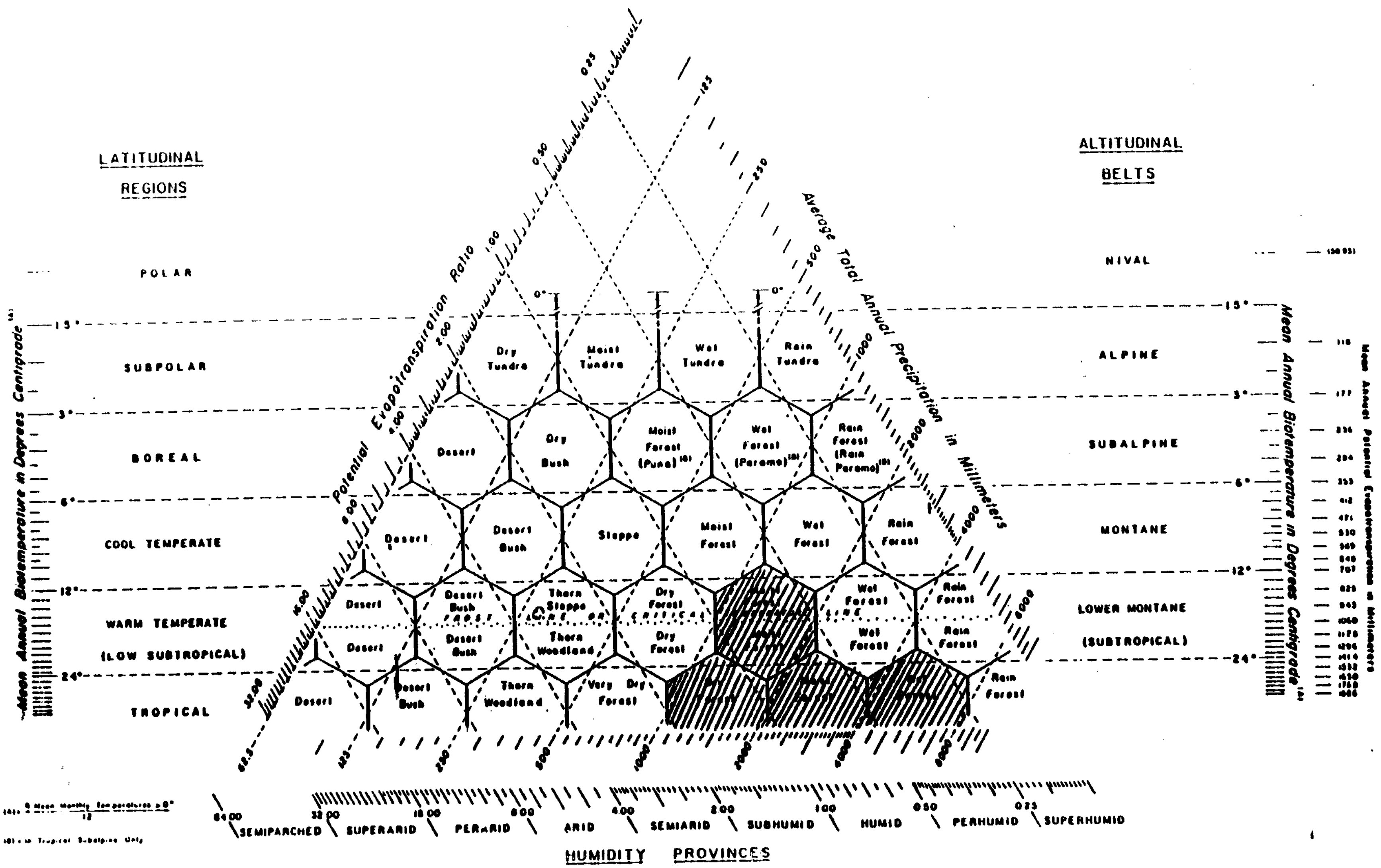
A more detailed description of the Holdridge System is included in appendix A. But briefly, the system divides the world into approximately 30 major life zones on the basis of average total annual precipitation and mean annual biotemperature. Figure 5 shows one rendition of the Holdridge diagram depicting the major zones. The bottom axis displays the average total precipitation in millimeters, while the vertical axis on the right of figure 5 shows the mean annual biotemperature in degrees centigrade. Points on the diagram are divided into homogeneous life zones (e.g., dry tropical forest, wet cool temperate forest, etc.). To illustrate, an area with 2,000 to 4,000 mm average annual precipitation, and with a minimum of 24°C mean annual biotemperature in designated "moist tropical forest" as shown in figure 5. Maps based upon this system, frequently called "ecological maps," typically display the location of these zones in various colors. An illustrative ecological map for Colombia is shown in figures 6 and 7 and discussed in the appendix. These maps have been prepared for all the countries addressed in this report based upon climatic data supplemented with visual observation of extant vegetation and other collateral data.

FIGURE 5

Diagram for the Classification of

WORLD PLANT FORMATIONS OR NATURAL LIFE ZONES

by L. R. Holdridge




REPUBLICA DE
COLOMBIA
MAPA ECOLOGICO
ECUADOR
REPUBLICA DE
COLOMBIA
MAPA ECOLOGICO

FIGURE 7. LEGEND FOR ECOLOGICAL MAP OF COLOMBIA

MAP COLORS	ECOLOGICAL LIFE ZONES
	Tropical Desert Bush
	Tropical Thorn Woodland
	Tropical Very Dry Forest
	*Tropical Dry Forest
	*Tropical Moist Forest
	*Tropical Wet Forest
	Tropical Rain Forest
	Subtropical Thorn Woodland
	*Subtropical Dry Forest
	*Subtropical Moist Forest
	Subtropical Wet Forest
	Subtropical Rain Forest
	Lower Montane Dry Forest
	Lower Montane Moist Forest
	Lower Montane Wet Forest
	Lower Montane Rain Forest
	Montane Moist Forest
	Montane Wet Forest
	Montane Rain Forest
	Paramo
	Rain Paramo
	Cool Temperate
	*Tropical Moist/Wet Forest
	*Tropical Dry/Wet Forest
	*Tropical Dry/Very Dry Forest

*Ecological Life Zones physically capable of supporting coca cultivation.

How Coca Cultivation Areas Are Defined

If the zones capable of supporting coca cultivation are known, it is a simple (if tedious) process to transform an ecological map to one that depicts the locations where coca can be grown. Conceptually, the procedure is as follows. For each "point" or quadrat in the country, the ecological map is consulted to determine if it is a zone capable of supporting coca cultivation. Next a "frost map" is consulted to determine if the location is frost-free. [For a description of the procedure used to determine frost zones see appendix B.] If both conditions are met, the quadrat is assumed to support coca cultivation. In practice, the examination need not be done on a quadrat-by-quadrat basis as the ecological zones tend to be distributed as large areas rather than a pinpoint mosaic (see figure 6 and the discussion in the appendix). With minor modifications to reflect differences in ecological map legends and differences in the definitions of ecological zones (prepared at different times in different countries), and to exclude regions where coca-killing frosts can occur, this procedure was followed in the preparation of all the maps of potential cultivation areas shown in figures 1-4.

Ecological Zones Supporting Coca Cultivation

Several investigators have characterized the ecological life zones capable of supporting coca growth. Broadly, the limits that serve to define the life zone "envelope" are threefold:

- A moisture constraint--if the ecological zone is "too wet," coca cultivation is not favored because of competition with better-adapted species and the incidence of certain plant diseases.
- A second moisture constraint--if the ecological zone is "too dry," coca will not have sufficient moisture (absent irrigation) to survive.
- A temperature constraint--coca cannot thrive in zones where the temperature is "too low."

Taken together, these three constraints define a series of zones, shown as the cross-hatched area in figure 5, where coca can be grown. Slight country-to-country variations are detailed later. Though the coca producing zones are relatively few in comparison to those depicted in figure 5, these zones are concentrated in the tropical and subtropical areas of Central and South America.

Limitations of this Methodology

Table 1 highlights the assumptions and limitations of this procedure. For the most part, the entries are self evident. Three points are especially worthy of elaboration, however.

First, the methodology is based upon defining areas where coca can be "naturally grown." Manual intervention in the form of modern agronomic techniques can reduce the impact of the constraints and expand these zones. For example, the "dryness" constraint can be altered by the practice of irrigation (rain-fed or pumped). While irrigation is not extensively employed in coca cultivation, it is used in some areas, notably in the Trujillo area of Peru. Likewise the "wetness" constraint can be relaxed by appropriate cultivation practices. Considering the possibility of man-made environmental changes (at least technically possible, if not economically efficient), estimates made by this procedure understate the potential coca growing area.

Second, the methodology does not explicitly address questions of the economics of production. The phrase "physically capable of supporting coca production" embraces a wide spectrum of possible plant biomass

TABLE 1. CAVEATS AND DISCLAIMERS ASSOCIATED WITH THE USE OF THE HOLDRIDGE LIFE ZONE CLASSIFICATION SYSTEM

LIMITATIONS	REMARKS/CONSEQUENCES
1. Considers climate as fixed, rather than a controllable variable.	1. While climate *per se* is not (in this context) controllable, techniques such as irrigation can alter the suitability of land for coca cultivation.
2. Addresses the technical feasibility of cultivation from a climatic perspective only.	2. Other variables may preclude or limit cultivation--e.g., insects, plant diseases. While these can often be controlled by use of herbicides or insecticides for example, it may not be optimal or efficient to do so.
3. Is not sufficiently specific to capture the "fine structure" of economic feasibility.	3. Existing regions where coca is grown exhibit wide variability in reported yield and cocaine content--important determinants of economic viability. These differences are not captured in the Holdridge System.
4. Holdridge System maps do not exclude urban areas, roads, etc. or other micro-features which could limit coca cultivation.	4. This limitation acts to overstate possible cultivation areas. Corrections can be made but are of lesser importance than other sources of error.
5. Maps are not exact. Weather stations do not exist at every point in the area to be mapped. Data interpolation, use of surrogates such as visual observation of vegetation types and, ultimately, judgment are necessary to fill in lacunae in data.	5. Regions should be thought of as approximate--maps present a synoptic picture only.
6. Life zones designated apply only to species of E. coca.	6. Other coca species, e.g., Trujillo, may be adapted other life zones.
7. Life zone concept is not sufficiently disaggregated to predict exact soil types.	7. Coca may not grow in very rigorous soil conditions, e.g., bare rock, coarse sand, waterlogged soils (without modification) and saline soils. These soils are not depicted explicitly on Life Zone Maps. The consequence is that growing areas will be somewhat overstated.
8. Holdridge System based upon average annual temperatures--frost not explicitly addressed.	8. Coca cannot survive frost conditions--does not grow above frost line. Frost-free zones have been included in this analysis.

yields, cocaine content, etc., that, in turn, affects the economic viability of the coca field. Other purely economic factors--such as regional variations in the delivered prices of processing chemicals subject to wide variability in the remote areas included in these maps, availability of labor in low population density areas, extent of government control and anti-narcotics emphasis, etc.--are relevant in determining where coca is (or will be) grown rather than where it could be grown.

Third, the methodology based on the Holdridge system makes several commission errors, i.e., areas deemed suitable for coca cultivation where no cultivation is possible (e.g., limitations 4 and 7 in table 1). Examples include built up or urban areas, paved roadways, bare rocks, free standing water, rivers, ponds and lakes etc. Failure to exclude these areas acts to overstate the potential coca growing area. In principle, a detailed analysis could be conducted from small-scale maps, imagery, etc. to estimate the magnitude of this connection. In practice such analysis would be extremely time consuming, face problems of missing data (e.g., much of Peru has not been mapped at small scale) and unlikely to be of material benefit considering the other uncertainties of analysis. In Colombia, for example, in one of the most urbanized and industrialized of those countries considered, urban land is estimated at only 3% of total land area, while inland water covers as much as 6% of the land area (World Factbook, National Foreign Assessment Center); small corrections at most.

Country-by-Country Results:

Bolivia

Figure 1 depicts potential coca growing areas in Bolivia. It was produced using an ecological map and information provided by Duke and Sandagorda identifying life zones that support coca cultivation. On the basis of annual biotemperature, annual precipitation, soil pH, number of warm wet months, and the actual classification system used in preparation of the Bolivian ecological map, Duke designates the following life zones as capable of supporting coca cultivation:[3]

(1) Tropical Dry Forest

(2) Tropical Moist Forest

(3) Tropical Wet Forest

(4) Subtropical Moist Forest

(5) Subtropical Dry Forest

(6) Subtropical Low Montane Dry Forest

(7) Warm Temperate Moist Forest without frost

Another investigator, Armando Sandagorda, though not referring explicitly to life zones, has described the Yungas and Chapare coca growing regions in climatological terms. In terms of the Holdridge System, the Yungas corresponds to Subtropical Moist Forest and the Chapare to both Tropical Wet Forest and Subtropical Rain Forest.[4] Only the latter represents an addition to the list of life zones designated by Duke.

Pooling estimates from both investigators, eight life zones can support coca production in Bolivia. These zones constitute an estimated 40% of the land area of Bolivia--about 440,000 km^2. (More accurately, the geographical boundaries of the coca cultivation zones enclose an area amounting to 40% of the land area of Bolivia.) In the main, this area is concentrated in the tropical and subtropical lowlands of Bolivia, though the higher Yungas is a commercially important area at present. Actual production zones differ somewhat from the potential zones designated in figure 1, but in terms of reported production, the discrepancy is small. Both the Yungas and Chapare regions, each an important area and together accounting for virtually all reported production, are included in the potential cultivation areas shown in figure ~~1.~~ Note also that the current cultivation areas are all concentrated along a northwest-southeast axis that subtends the potential growing area. This is no doubt due to economic/infrastructural factors--there is an economic penalty for producers to move to remote, largely uninhabited areas and, in view of the limited anti-narcotics efforts of the Government of Bolivia (GOB) to date, they have no motivation to do so.

Colombia

Figure 2 shows potential coca growing areas in Colombia and was developed in a manner similar to the procedures outlined for Bolivia. Based on information provided by Duke, life zones conducive to coca are:

(1) Tropical Dry Forest

(2) Tropical Moist Forest

(3) Tropical Wet Forest

(4) Subtropical Moist Forest

(5) Subtropical Dry Forest

(6) Tropical Dry/Moist Forest

(7) Tropical Moist/Wet Forest

(8) Tropical Dry/Very Dry Forest

Unlike Bolivia, the ecological map of Colombia has no Warm Temperate Moist Forest Zone. Life Zones (6), (7) and (8) represent transition zones. It has been assumed that any transition area between two life zones where one or both support coca cultivation should itself be designated as a potential growing zone.[5]

Nearly all (90%) of Colombia is estimated to be capable of supporting coca production, an area slightly larger than 1 million km^2. In this instance, it is more straightforward to describe the areas that are not naturally suited for coca cultivation. As can be seen in figure 2, these coca-free areas extend along the Atratro and Cauca rivers in the higher portions of the mountainous areas extending the length of the country.

Of particular policy interest--according to these findings, the entire llanos area (vast flat plains located east of Bogota) is climatologically suited to coca production. In recent years, actual coca production from this area has increased substantially--depending upon the source, estimates of current coca cultivation range from about 3,000 to over 10,000 hectares in this area. This analysis indicates that land available for coca cultivation will not constrain future growth of production in this area.

Ecuador

Figure 3 designates potential coca cultivation in Ecuador. It was produced using a Holdridge ecological map provided by the Instituto Geografico Militar (Ecuador) and data provided by Duke. The following life zones were assumed to support coca cultivation in Ecuador:

(1) Tropical Dry Forest

(2) Tropical Moist Forest

(3) Tropical Wet Forest

(4) Subtropical Moist Forest

(5) Lower Montane Moist Forest without frost

(6) Pre Montane Dry Forest

Life zones (5) and (6) are designated in terms of altitudinal belts rather than latitude regions. However, inasmuch as Lower Montane corresponds to Warm Temperate and Pre Montane to Subtropical, both have been included in the list of potential coca growing zones.

Approximately 65% of Ecuador (ca. 175,000 km^2) is suitable for coca cultivation. Note that in the distant past, Ecuador was a major producer of coca. Little coca is reportedly grown in Ecuador today, however, so the designation of actual coca zones is more speculative. In the future, Ecuador may have a much more important role in coca cultivation. This could become a reality if Colombia were to increase crop eradication programs. The northeastern area of Ecuador adjacent to Colombia might offer one viable locational alternative to llanos producers. Ecologically, the area is similar to the llanos, implying a minimal need to alter present agronomic techniques and, moreover, the region has little government presence or control. Finally, this area offers somewhat better access opportunities (i.e., simpler logistics) than other areas in Brazil or Peru that are also contiguous to the llanos.

Peru

Lastly, figure 4 depicts areas of potential coca cultivation in Peru. It was produced using an ecological map and data provided by Duke and Ruben Horna Ramirez. The ecological map of Peru is by far the most complex of the four maps utilized in this report. It defines life zones in terms of latitude regions, altitudinal belts, and transition zones in a (bewildering?) variety of combinations. The following life zones defined on the Peruvian ecological map are assumed to support coca cultivation:

(1) Tropical Dry Forest

(2) Tropical Dry Forest-transition zone to Tropical Moist Pre Montane Forest

(3) Tropical Dry Forest-transition zone to Subtropical Moist Forest

(4) Tropical Dry Pre Montane Forest

(5) Subtropical Dry Forest

(6) Tropical Dry Pre Montane Forest-transition zone to Tropical Dry Forest

(7) Subtropical Dry Forest-transition zone to Subtropical Moist Forest

(8) Tropical Dry Lower Montane Forest

(9) Subtropical Dry Lower Montane Forest

(10) Tropical Moist Forest

(11) Tropical Moist Forest-transition zone to Tropical Wet Forest

(13) Tropical Moist Forest-transition zone to Tropical Moist Pre Montane Forest

(14) Tropical Moist Pre Montane Forest

(15) Subtropical Moist Forest

(16) Tropical Moist Pre Montane Forest-transition zone to Tropical Moist Forest

(17) Subtropical Moist Forest-transition zone to Tropical Moist Forest

(18) Tropical Moist Lower Montane Forest

(19) Subtropical Moist Lower Montane Forest

(20) Tropical Moist Montane Forest

(21) Subtropical Moist Montane Forest

(22) Tropical Moist Forest

(23) Tropical Wet Forest-transition zone to Tropical Pre Montane Rain Forest

(24) Tropical Wet Pre Montane Forest

(25) Tropical Wet Pre Montane Forest-transition zone to Tropical Moist Forest

(26) Tropical Wet Pre Montane Forest-transition zone to Tropical Pre Montane Rain Forest

(27) Tropical Wet Lower Montane Forest

(28) Tropical Wet Montane Forest

Life zones (2), (3), (6), (7), (11), (12), (13), (16), (17), (23), (25), and (26) represent transition areas where at least one of the life zones has been designated as conducive for coca growth. Life zones (4), (8), (9), (14), (18), (19), (20), (21), (24), (27), and (28) represent potential coca growing zones with the addition of an altitude specification. Through conversations with Duke, it was determined that altitude specifications generally do not disqualify life zones as potential growing areas. Consequently, these were added to the list.

Ruben Horna Ramirez of the Peruvian Ministry of Agriculture adds Subtropical Wet Forest to the list of potential coca growing life zones.[6] This addition is based on the actual observation of coca cultivation in this area of Peru.

Note that the 29 zones above do not conflict with the zones reported in other countries; the large number of these zones reflects the level of disaggregation used for preparation of Peru's ecological map. In aggregate, these zones are exactly equivalent to zones in Colombia, Bolivia and Ecuador.

It is estimated that 70% of the area of Peru is suitable for coca cultivation--about 910,000 km^2. In the main, there is excellent correspondence between reported coca growing locations and potential growing locations. As noted earlier, the Holdridge system methodology fails to correctly identify the area surrounding Trujillo as a potential growing area. Another discrepancy--thus far unexplained--can be found in the region north of Cusco. Cusco is an important growing region for licit coca in Peru and the map designating the actual growing area is believed accurate in this region.

As with each of the other countries studied, the actual growing area in Peru is only a small portion of the area that could theoretically support coca. The largest potential growing area is in the northeast Amazon region of Peru bordering Ecuador, Colombia and

Brazil. There is no reported cultivation in this area at present--presumably reflecting demographic and economic realities.

Concluding Comments

As a result of comparing actual and potential coca growing areas in current producer countries, it is clear that the expansion potential of coca cultivation is high. Thus, the availability of land suitable for coca cultivation does not appear to be a constraint on production. Estimates of the percent of land available for potential coca cultivation are:

- Bolivia--40%
- Colombia--90%
- Ecuador--65%
- Peru--70%

In the event more effective control and/or eradication measures are implemented, coca cultivation is likely to shift to other areas--making the problems associated with control actions widespread. Due to the large availability of suitable land located on or near established transportation routes, cultivation will not necessarily shift to extremely remote areas. Although preliminary analysis to date has revealed potential coca growing areas and some actual cultivation in the jungle areas of northwest Brazil, it is believed unlikely that coca cultivation will shift to such areas in the near term.

Similar analyses has also indicated potential areas of cultivation in Venezuela and in Central America--further evidence of the wide geographic latitude of the coca plant. Indeed, one agricultural expert has ventured the comment, only half in jest, that coca "can be grown anywhere in the frost-free regions of South or Central America that isn't solid rock or in free-standing water."

A final point of note is the implication of these findings for the design of aerial surveys. Unfortunately, the extent of areas of potential cultivation is so large as to be of little value in the design of aerial survey sampling plans. Efficient survey designs will need to be based on other locational cues (e.g., reported cultivation) rather than agronomic feasiblity.

APPENDIX A

THE HOLDRIDGE LIFE ZONE CLASSIFICATION SYSTEM

As one of many schemes for ecological classification, the Holdridge Life Zone Classification System proposes to determine plant formations (life zones) from simple climatic data, i.e., temperature, precipitation and moisture values. It was initially developed in 1947 by Leslie R. Holdridge after several years of forestry work in the Caribbean area. Its original purpose was to depict the relations existing between mountain and lowland vegetation in Haiti. Since then, however, it has been widely used to determine potential growing areas of selected plants, as in this instance of coca in Bolivia, Colombia, Ecuador and Peru, and to define potential alternative crops for specific regions.

Life zones, in their truest sense, are not units of vegetation but climatic divisions specifically and precisely defined by ranges of the three climatic factors stipulated above. However, inasmuch as life zones are correlated with living organisms, whether they be plant or animal, the distinction becomes blurred.

Moreover, if life zones are to be used in ecological classification they must be thought of in terms of natural units. Definitions of some life zones as established by L. R. Holdridge are given explicitly in table 2 and implicitly in figure 5.

The Holdridge system is predicated on the idea that major vegetation units (life zones) are characterized solely by average temperature, precipitation and moisture regimes. [See_Life Zone Diagram (figure 5)]. Other factors which have appreciable influences on plant physiognomy, e.g., other climatic factors such as the seasonal distribution of rainfall, wind speeds, frost conditions, soil conditions, etc., are not considered in the Holdridge System. Given sufficient additional data, e.g., soils maps, the effects of these factors can be accounted for--but often these data are not available, or not sufficiently accurate for the countries of interest.

Thus, it is appropriate to consider use of the Holdridge System as a screening method, capable of producing a rapid, but "first-order" profile of potential growing areas. In the years since its development, numerous refinements or alternatives to the

TABLE 2. DEFINITION OF LIFE ZONES ON BASIS OF TEMPERATURE AND PRECIPITATION PARAMETERS [After L.R. Holdridge]

LIFE ZONE	PARAMETERS	
	TEMPERATURE	PRECIPITATION
Tropical Desert Scrub	>24°C	125-250mm
Tropical Thorn Woodland	>24°C	250-500mm
Tropical Very Dry Forest	>24°C	500-1,000mm
Tropical Dry Forest	>24°C	1,000-2,000mm
Tropical Moist Forest	>24°C	2,000-4,000mm
Tropical Wet Forest	>24°C	4,000-8,000mm
Tropical Rain Forest	>24°C	>8,000mm
Subtropical Desert Scrub	18-24°C	150-250mm
Subtropical Thorn Woodland	18-24°C	250-500mm
Subtropical Dry Forest	18-24°C	500-1,000mm
Subtropical Moist Forest	18-24°C	1,000-2,000mm
Subtropical Wet Forest	18-24°C	2,000-4,000mm
Subtropical Rain Forest	18-24°C	>4,000mm
Warm Temperate Desert Bush	12-18°C	150-250mm
Warm Temperate Thorn Steppe	12-18°C	250-500mm
Warm Temperate Dry Forest	12-18°C	500-1,000mm
Warm Temperate Moist Forest	12-18°C	1,000-2,000mm
Warm Temperate Wet Forest	12-18°C	2,000-4,000mm
Warm Temperate Rain Forest	12-18°C	>4,000mm
Cool Temperate Desert Scrub	6-12°C	125-250mm
Cool Temperate Steppe	6-12°C	250-500mm
Cool Temperate Moist Forest	6-12°C	500-1,000mm
Cool Temperate Wet Forest	6-12°C	1,000-2,000mm
Cool Temperate Rain Forest	6-12°C	>2,000
Boreal Desert	3-6°C	<125mm
Boreal Dry Scrub	3-6°C	125-250mm
Boreal Moist Forest (Puna)	3-6°C	250-500mm
Boreal Wet Forest (Paramo)	3-6°C	500-1,000mm
Boreal Rain Forest (Rain Paramo)	3-6°C	>1,000mm
Subpolar Dry Tundra	<3°C	<125mm
Subpolar Moist Tundra	<3°C	125-250mm
Subpolar Wet Tundra	<3°C	250-500mm
Subpolar Rain Tundra	<3°C	>500mm

Holdridge System have been proposed and evaluated on a limited scale. In many cases, there are normative reasons (partially supported by data) why these alternatives are superior to the Holdridge System. Nonetheless the Holdridge System is unique among these because several areas of the world--including many countries in South and Central America--have been mapped into Holdridge ecological life zones. It is this simple fact that reduces debate on the relative merits of alternative systems to consideration of moot points.

Still, it is important to understand the limitations of the Holdridge System in order to evaluate, at least in qualitative terms, the likely precision and/or bias of the estimates. As noted earlier, table 1 summarizes these limitations and their consequences.

The three climatic factors utilized in the Holdridge System are described in some detail below:

- Temperature. Temperature values found on the diagram approximate those of the growing season and are designated in terms of mean annual biotemperature, expressed in degrees Centigrade. Mean annual biotemperature values are derived by adding the average monthly temperature readings greater than 0°C and dividing by the number of months in a year. They are used because they reflect more accurately the temperature range within which plant life is active. It has been noted that once the temperature falls below 0°C physiological plant responses are often similar regardless of how far the temperature drops. As seen in the diagram, temperature values are shown (from top to bottom) in a partial geometric progression of 1.5, 3, 6, 12 and 24°C.

- <u>Precipitation</u>. For purposes of the Holdridge System, precipitation is defined as the total amount of water falling from the atmosphere as rain, snow, sleet and hail. Water that condenses on the ground or vegetation is not included, though it, in some cases, may have a significant impact on plant growth. The specific reason why such water is not included is that most standard meteorological stations do not tabulate it in their records. The precipitation values designated represent mean annual total precipitation in millimeters. On the diagram these values are shown (diagonally left to right) in a geometric progression of 62.5, 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 millimeters.

- <u>Moisture</u>. The Holdridge System utilizes yet a third parameter, i.e., moisture (humidity), to define life zones. However, insofar as the moisture factor is solely determined from temperature and precipitation data, it is redundant and serves only to complicate life zone diagrams such as that shown in figure 5. As seen in table 2, life zones are defined solely in terms of temperature and precipitation ranges.

  Holdridge designates moisture values in terms of potential evapotranspiration ratios (division of the mean annual potential evapotranspiration by the mean annual precipitation) which he believes are definite measures of humidity since potential evapotranspiration is the total amount of water that could be utilized by the vegetation of a given area and precipitation the amount of water available for both transpiration and evaporation. Inasmuch as Holdridge fails to describe how in fact he determines potential evapotranspiration, a hypothetical quantity not amenable to direct measurement, the utility of having a third parameter is unclear. More precisely, if potential evapotranspiration is determined from temperature and precipitation data alone (a likely assumption since Holdridge worked with only the simplest of climatic data) the third parameter is clearly extraneous as both components of the evapotranspiration relation are already represented.

Moreover, it is generally agreed that potential evapotranspiration is not solely related to temperature and precipitation. Other factors, e.g., wind speed, day length, cloud cover, and ultimately the nature of the vegetation itself, are important considerations. Holdridge apparently neglects to consider them here.

Holdridge (1947) himself has indicated that the evapotranspiration lines depicted on the diagram are not essential. These evapotranspiration values, he speculated, represent the number of times the actual precipitation could be evaporated during the course of one year at sea level atmospheric pressure, though he offered no data or rigorous analysis to support this claim.

One consequence of having a third parameter, i.e., a third set of lines on the life zone diagram, is that life zones appear hexagonal rather than rectangular in shape--giving a characteristic "chicken wire" shape to the life zone system diagram. In figure 5, the life zone is represented as a hexagonal figure surrounded by six perimeter triangles. These triangular areas represent transition zones. Their designation would differ somewhat if only two parameters, i.e., two sets of lines were used. As seen in figure 5, potential evapotranspiration ratio values are shown (diagonally left to right) in a geometric progression of 32, 16, 8, 4, 2, 1, 0.50 and 0.25.

An Illustrative Ecological Map: Colombia

Figure 6, the ecological map of Colombia, and figure 7, the accompanying legend, are presented as a specific example of a Holdridge map. This map shows the approximate locations of each of the major life zones (if present) identified in figure 5.

The dark green areas of this map, for example, correspond to the tropical wet forest, one of the life zones where coca can be grown. Reference to figure 6 shows this zone to be widely distributed throughout Colombia--in portions of the coastal lowlands, some of the valleys between the mountain chains and further eastward in large areas of the llanos stretching to Brazil. All of this area of Colombia is suitable (in physical terms) for coca cultivation. Likewise the areas colored gold (tropical dry forest), cross-hatched gold and green (a transition zone--tropical dry/moist forest), etc., are suitable for coca cultivation. The boundaries of the aggregate of the coca producing zones are easily traced onto a working map similar to that shown in figure 2. A final refinement in the preparation of the map depicting potential coca cultivation zones is the exclusion of areas where frosts are expected to occur. "Frost-maps" are not generally available for these countries, but can be approximated by noting the lowest elevation where frost can be expected--in Colombia, an estimated 8,000 ft. With this approximation, a conventional contour (or terrain) map serves as a surrogate. Deletion of these areas results in the final map given in figure 2.

The same procedure was used to designate potential coca growing areas in the other countries as well (figures 1, 3 and 4) with only some variation as to number of life zones reported. This variation is due to the development of ecological maps more complicated than the one for Colombia. Such maps differentiate countries into as many as one hundred subzones rather than the thirty aggregated life zones given in figure 5. In general terms, however, life zones in Colombia correspond to those in Bolivia, Ecuador and Peru.

It is important to note that the life zone boundaries are only approximate--in technical terms, the life zone map is said to be highly generalized. Contours have been smoothed, small occlusions have been omitted, etc., partially because of lack of available data and partially to suppress unwanted clutter.

Ecological life zone maps have been prepared for all the countries in Central America together with many South American countries including Bolivia, Colombia, Ecuador, Peru and Venezuela. These maps have been prepared by Holdridge and his co-workers in concert with national mapping agencies of the respective governments. If accurate data on temperature and rainfall were available for all locations in these countries, the task of map preparation would be reduced solely to arithmetic computation, registration and contour determination. Such is not the case for these countries, however, particularly in the more remote areas. Mapmakers use a variety of surrogates in these regions. Holdridge, in particular used visual observation of natural vegetation patterns to determine the life zone--working the problem in reverse as it were. Thus, ecological maps are a mixture of recorded numerical data, visual observation and other surrogates. It is precisely these surrogates, however, that make the Holdridge System most viable according to some experts. They argue that many of the theoretical limitations of the basic life zone concept are removed if actual vegetation patterns are used to determine the life zones. Holdridge is a respected observer with "a fine drawing hand" and some believe these skills are responsible for the quality of the maps. As Duke quips, "only Holdridge can make a Holdridge map."

Ecological maps of the various countries have been prepared over a period spanning roughly two decades. During this time, several (though generally minor) changes have been made to the system and, of course, new climatological data stations have become available. In consequence, the maps are of varying quality and slight adjustments to interpretation are necessary.

APPENDIX B

THE DETERMINATION OF FROST ZONES

Frost lines in Bolivia, Colombia, Ecuador and Peru were determined by plotting the locations of weather stations which reported year-round extreme minimum temperatures of 38 degrees Fahrenheit or less. Instrument shelters at these stations are normally two meters above ground level and, at this height, temperatures are likely to be as much as six degrees higher than on ground level. Hence, for plotting purposes, frost lines were established at 38 rather than 32 degrees Fahrenheit.

In Colombia, the frost line is located at 8,000 feet and at 9,000 feet in Bolivia, Ecuador and Peru. It is unlikely that the frost lines are located at elevations higher than those plotted because extreme minimum temperatures rather than average temperatures were used. Any growth that will not withstand frost has almost no chance for survival above these altitudes.

Due to the small scale of the maps used, the areas depicted are imprecise, e.g., there are many small steep-sided river valleys below the frost lines which are not shown. Large scale maps depicting frost lines more precisely, however, are not presently available.

The areas of potential coca cultivation eliminated by the introduction of a frost or elevation constraint are indeed small. Moreover, they do not significantly alter the maps of potential coca growing areas based solely on the Holdridge System.

ENDNOTES

1. Timothy Plowman, "Botanical Perspectives on Coca" in Cocaine 1980, edited by F.R. Jeri, Pacific Press, Lima, Peru, 1980, p. 90.

2. L.R. Holdridge, "Determination of World Plant Formations from Simple Climatic Data," Science (April-June 1947), p. 367.

3. In 1975, Duke designated Tropical Dry Forest, Tropical Moist Forest, Tropical Wet Forest, Subtropical Moist Forest and Warm Temperate Moist Forest as potential coca growing areas. See A.B. Park and W.G. Brooner, "A Program Design for the Inventory of Coca," Earth Satellite Corporation, Washington, DC, 1975, p. 13. In more recent personal correspondences, however, he delineated Subtropical Dry Forest as an additional coca growing zone, stipulated no major distinction between Subtropical Dry Forest and Subtropical Low Montane Dry Forest as coca growing areas and added the qualitative provision "without frost" to the Warm Temperate Moist Forest Zone.

4. Armando E. Sandagorda, "Coca Production in Bolivia," in Cocaine 1980, edited by F.R. Jeri, Pacific Press, Lima, Peru, 1980, pp. 167-168.

5. J.A. Duke, personal correspondence, 21 July 1982.

6. Ruben Horna Ramirez, "Coca Production in Peru," in Cocaine 1980, edited by F.R. Jeri, Pacific Press, Lima, Peru, 1980, p. 202.

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6. Ramirez, Ruben Horna. "Coca Production in Peru," Cocaine 1980, Pacific Press, Lima, Peru, 1980, pp. 202-205.

7. Sandagorda, Armando E. "Coca Production in Bolivia," Cocaine 1980, Pacific Press, Lima, Peru, 1980, pp. 165-169.