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SIMULATION OF METEOROLOGICAL PARAMETERS FOR ESTIMATING HUMAN CARRYING CAPACITY IN BRAZIL'S TRANSAMAZON HIGHWAY COLONIZATION AREA

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Abstract : Stochastic models for the estimation of human carrying capacity in a part of Brazil's Transamazon Highway colonization area near Altamira, Para, require the simulation of meteorological patterns for the study area. Weather affects simulated agricultural production through erosion and burn quality in fields prepared for planting by slash and burn. Three types of rainfall variability are modeled: day-to-day variation, wet and dry years, and early and late rainy seasons. Also modeled are evaporation and insolation; both are related to burn quality and precipitation Rainfall totals in two seasons of the agricultural year, the burning season from September to December and the planting (rainy) seasonal from January to May, are generated from means and standard deviations. The rain in a each month in these periods is calculated by multiplying the season total by a value generated for the proportion of the total represented by that month. Rainfalls for June. July and August are generated separately. Linear regressions on monthly rainfall yield monthly evaporation and insolation. Variability in daily weather parameters as proportions of monthly values can then generate simulated daily weather parameters reflecting the relevant patterns observed in the study area. Values generated by algorithm outlined here represent a part of a larger modeling effort i simulating the colonists' agroecosystem for the estimation of carrying capacity. Crop yield variability, which derives from variation in meteorological and other factors, has been found to be an important factor affecting human carrying capacity.

Resume : L' etablissement de modeles stochastiques destines a evaluer la capacite de charge humaine dans une partie de la zone de colonisation situee le long de la route Transamazonienne, pres d'Altamira (Para), rend nécessaire la simulation des principaux parametres meteorologiques, ceux-ci influent sur la production agricole simulee par leurs effets sur l' erosion du sol et la qualite du bralis dans les champs defirches pour la mise en culture. Trois types de variations pluviometriques sont modelises:variations journaliéres, années seches et pluvieuses, avance ou retard de la saison des pluies. Sont modèlises aussi l' évaporation et l' insolation, toutes deux significativemente reliees à la qualite du bralis et egalement en relation avec les précipitations. Le total des pluies pour chacune des deux saisons de l' annee agricole, celle du bralis, de Septembre à Decembre, et celle de la plantation (saison pluvieuse) de Janvier à Mai, est calcule en utilisant les moyennes et deviations standards du total des precipitations de chaque periode. Les précipitations mensuelles sont calculees en multipliant ces donnees saisonnières par le pourcentage de pluie de chaque sison que represente chaque mois. La pluviosite pour Juin, Juillet et Aôut est calculee separement. Les régressions linéares de totaux pluviomètriques mensules donnent des valeurs pour l' evaporation et l' insolation mensuelles. La variabilitié des parametres meteorologiques en proportion des totaux mensuels, permet de calculer des paramètressimules de temps quotodiens qui reflètent bien les caracteristiques observees dans la zone etudiee. Les valeurs obtenues par l' algorythme ici resume representent une partie d'une etude plus vaste de modèlisation simulant la capacite de charge humaine. La variabilitié des productions agricoles, qui est fonction de la variation des paramêtres meterologiques (entre autres) a été identifiee comme un important facteur affectant la capacite de charge humaine.

Resumen : Modelos estocásticos para la estimativa de capacidad de sosten humano en una parte de la area de colonizachión delacarretrea Transamazonica, cerca a Altamira, Pará, Brasil, necessitan que padrones meteorológicos sean simulados para el area en estudio. Factores meteorológicos afectan la producción agricola simulada a traves de sus efectos sobre la erosión del suelo y la calidad de la quemada en los canucos tumbados y quemados en preparación por a el plantio. Tres tipos de variabilidad pluviometica son modelados: variación de dia en dia, afios secos y lluviosos, y epocas lluviosas tempranas y atrasadas. Tambien son modelados la evaporación y la insolación, ambas significativamiente relacionadas a la calidad de la quemada y corelacionados con la precipitación. Totales pluviometricos en dos epocas del año agricola, el del plantio (lluviosa) de enero hasta mayo yel de la quemada de setiembre hasta diciembre, son generados a partir de las medias y desvios standars del total de precipitaciones en cada periodo. La lluvia en cada mes en estos períodos es calculada a partir de la multiplicatión de estes valores sazionales por la proporción generada para el referido mes, sobre el total de la epoca correspondiente. Pluviosidades para junio, julio y agosto son generadas separadamente. Regressiónes lineales sobre totales pluviometricos mensuales producen valores para la evaporactión e insolación mensual. Variabilidad en parámetros diarios meteorológicos como proporciónes de totales mensuales pueden generar parámetros simulados de tiempo diario reflejanelo los padrones relevantes observados en el area en estudio. Valores generados por el algoritomo esbozado aqui representan una parte de un esfuerzo de modelaje mayor, simulando el agroecosistema de los colonos para la estimativa de capacidad de sosten. La variabilidad en las producciones agricolas, que es derivada de la variación en factores meteorológicos y otros, han sido constatado como un factor importante afectando la capacidad de sosten humano.

Resumo : Modelos estocáticos para a estimativa da capacidade de suporte humano em uma parte da área de colonizaçao ao longo da rodovia Trasnamazônica, perto a Altamira, Pará, Brasil, precisam que padrões meteorológicos sejam simulados para a área em estudo. Fatores meteorológicos afetam a produçado agrícola simulada atraves dos seus efeitos sobre erosao do solo e qualidade de queimada nas rocas derrubadas e queimadas em preparaçao para o plantio. Três tipos de variabilidade pluviomêtric sao modelados: variaçao de dia em dia, anos secos e chuvosos, e epocas chuvosas prematuras e tardias. Tambem sao modelados a evaporaçao e a insolaçao, ambos significativamente relacionados á qualidade da queimada e corelacionados com a precipitaçao. Totais pluviomêtricos em duas pocas do ano agrícola, a do plantio (chuvosa) de janeiro ate maio e o da queimada de setembro ate dezembro, sao estabelecidos a partir das medias e desvios padrões do total de precipitação em cada período. A chuva em cada mes durante estes períodos e calculada a partir da multipicação destes valores sazionais pela proporçao estabelecida para aquele mes sobre o total da epoca correspondente. Pluviosidades para junho, julho e agosto sao estabelecidas separadamente. Regressões lineares sobre totais pluviometricos mensais produzem valores para evaporaçao e insolaçao mensal. Variabilidade em parámetros diários meteorológicos como proporções de totais mensais pode fornecer parametros simulados de tempo diario refletindo os padrões relevantes observados na área em estudo. Valores gerados pelo algoritmo esboçado aqui representam uma parte de um esfoço de modelagem maior, simulando o agro-ecossistema dos colonos para a estimativa de capacidade de suporte. Variabilidade em produções agricolas, que e derivada da variaçao em fatores metero-

lógicos e outros, tem sido constatada como um fator importante afetando a capacidade de suporte humano.

INTRODUCTION

In 1970 the Brazilian government launched an ambitious project to build the 5000 km long Transamazon Highway across the country from the Atlantic Ocean to the Peruvian border, and to establish extensive planned agricultural settlements along the route (Moran 1981; Smith 1982; Fearnside 1978, In press a). Among the factors which can be expected to have a profound influence on the long-term well-being of the colonists is the relation of the population density in the settlement projects to the carrying capacity of these areas. Carrying capacity refers to the maximum population density that can be maintained indefinitely in a given area at a specified standard of living, given appropriate assumptions concerning productive technology, consumption habits, and other factors (Allan 1949, 1965; ee Street 1969; Bayliss-Smith 1980). An investigation of factors affecting carrying capacity, especially variability in crop yields, indicated highly variable agricultural production to be a critical factor (Fearnside 1978, 1979, 1983-a). Variability in meteorological parameters and other factors such as soil quality (Fearnside in press b) and colonists agricultural behavior and human and material resources (Fearnside 1980a) underlies the observed variation in crop yields. Simulations of the agroecosystem used for carrying capacity estmation must therefore include provisions for replicating relevant aspects of the areas weather. The seasonal nature of land use patterns makes the timing of the most intense rainfall important for erosion prediction (Fearnside 1980b). The unpredictable and often inadequate dry spells make poor burns in agricultural fields cleared by slash and burn a major threat to agricultural production at the level of individual colonists, even in those years when aggregate production statistics for an area may give an impression of relative plenty. Burn quality can be predicted from discriminant analysis using precipitation, insolation, and evaporation information in the period between cutting and burning and immediately before burning (Fearnside 1983b). The present paper explains how these meteorological parameters are generated in the simulation in accord with observed patterns.

The study area for the carrying capacity modeling effort comprises 236 km² of land surrounding Agrovila Grande Esperanca, in the Municipio of Prainha in the state of Para, about 180 km south of the Amazon River. The center of the area is at 3° 22′ S. Lat., 52° 38′ W. Long., at an altitude of approximately 100 m. Agrovila Grande Esperanca is located on the Transamazon Highway 50 km west of the town of Altamira (3° 12′ S. Lat. 52° 13′ W. Long. 75 m altitude). Altamira's climate has been classified as Aw in the Koppen system with a mean annual rainfall of 1688 mm in the period 1931-1969 (Pereira and Rodrigues 1971)[1]. The rainfall, however, is extremely variable: examination of the original weather data from the meteorological station at Altamira for the 1931-1976 period revealed that, if mean precipitation totals for each month are summed, the annual total comes to 1296 mm. Data over the 45-

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(1) Although no mention of incomplete data is made by Periera and Rodrigues (1971), this annual mean would appear to be calculated as a sum of monthly means.

year period are very incomplete, with monthly totals being complete for 18 to 30 years during that period for any given month. Only 9 full years are complete; their average precipitation is 2384 mm, indicating that they were wetter than average years. Fortunately, complete years are not essential for the present analysis.

A link has been suggested between variation in annual and monthly precipitation totals in Amazonia and large scale atmospheric circulation anomalies (Kousky and Kagano 1981). Annual rainfall totals for the area were classed by Nimer (1979) as having variability typical of much of Amazonia based on estimated mean deviations between 15 and 20%. Observed monthly totals are highly variable for precipitation at Altamira (Fig. 1) leaving little guarantee that the intensity and timing of wet or dry periods will conform to the needs and expectations of farmers.

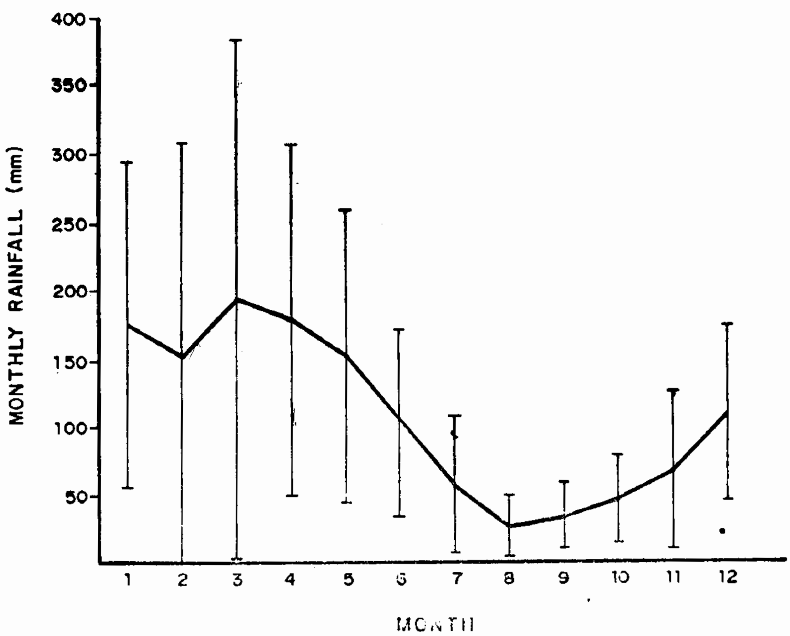

Fig. 1. Means and standard deviations of monthly rainfall totals at Altamira, 1931-1976.

Rainfall and other meteorological parameters in the Amazon vary on a fine scale, as isolated clouds move across the landscape dropping rain in narrow strips on any particular day. Differences in the results of weather stations only a few kilometers apart are evident, for example in information from weather stations maintained by the Brazilian Enterprise for Agricultural and Cattle Ranching Research (EMBRAPA) at km 23 and km 101 west of Altamira since the building of the Trans amazon Highway.

METHODS AND RESULTS

Data for modeling meteorological patterns were obtained from the Altamira weather station of the Brazilian Meteorological Service (50 km from the study area), for the period January 1931—August 1976[2].

In simulating weather on the Transamazon Highway, rainfall is generated first. Precipitation totals are obtained for two periods in the agricultural year, the burning period (September through December) and the planting period (January through May) from normal distributions (truncated at zero) using the means and standard deviations for the period totals (Table 1). This is done by drawing a pseudo-random number from a probability distribution with the specified mean and standard deviation. Any negative values are assigned a value of zero. The rainfall for each month in these periods is obtained by multiplying the calculated season (period) total by the proportion of the seasonal total represented by the month in question (Table 2). The proportions of seasonal totals are generated for each month in the way described above for obtaining seasonal totals. Rainfalls are assigned separately for the months of June, July, and August using the means and standard deviations for rainfall in these months (Table 1). The seasons used correspond to agricultural practices in the area and are confirmed by the existence of significant ($P<0.05$) positive correlations between monthly rainfall totals for a number of months within each season: no significant correlations were found between months in different seasons or between any of the three separately generated months (June, July and August) and any other month.

TABLE 1. *Precipitation in seasons of the agricultural year*

Season	Ranifall (mm)	SD	N (years)
Burning (Sept.-Dec.)	281.7	148.1	12
Planting (Jan.-May)	1396.2	300.9	21
Others			
June	77.5	48.2	30
July	58.5	50.7	28
August	28.1	22.4	27

(2) Due to the need for long periods of record and for maintaining the interrelations between the parameters considered, all data used in the present paper were from this station rather than for the stations closer to the study area which were used for most of the precipitation data in the associated erosion and burn quality prediction studies (Fearnside 1980*b*, 1983b). In the case of the erosion and burn quality studies, rainfall data were from Altamira for the periods January 1, 1972-April 6, 1973 and July 1-August 23, 1976, and from the EMBRAPA station 23 km west of Altamira for all dates between April 7, 1973 and June 30, 1976 with the exceptien of August 25, 1974 and October 26-28, 1974, for which data were used from the EMBRAPA station located 101 km west of Altamira. All insolation and evaporation data were from Altamira in these studies.

TABLE 2. *Monthly rainfall as proportion of seasonal totals*

Season	Month	Rainfall mm mo^{-1}	SD	N (years)
Burning	Sept.	0.1862	0.1099	12
	Oct.	0.1995	0.1075	12
	Nov.	0.1850	0.1377	12
	Dec.	0.4293	0.1026	12
Planting	Jan.	0.1778	0.0588	21
	Feb.	0.2141	0.0880	21
	Mar.	0.2631	0.0502	21
	Apr.	0.2136	0.0505	21
	May	0.1312	0.0522	21

Monthly evaporation is calculated from a regression of monthly totals of daily measurements of pan evaporation and rainfall for the 45 months between January 1972 and August 1976 for which this information is complete for Altamira :

$$Y=102.0-0.150A \quad \text{(Equation 1)}$$

where : Y=Monthly evaporation (mm); A=Monthly rainfall (mm); ($P<0.0001$, $r=0.57$, $SE=32.06$, $N=45$ months).

Monthly insolation is then calculated using a similar regression on monthly rainfall. Insolation is recorded daily at Altamira by measuring distance burned on a paper stip by sunlight focussed through a glass sphere.

$$Y=156.68-0.180\ A \quad \text{(Equation 2)}$$

where : Y=Monthly insolation (hours); A=Monthly rainfall (mm); ($P=0.0002$, $r=0.52$, $SE=44.05$, $N=45$ months).

Variability is added to predictions from both regressions using the standard error of the estimate (SE).

The expected mean proportion of the monthly total for any weather character for any given day is calculated as the inverse of the number of days in the month. The proportion of the monthly total for rain, evaporation, or insolation is generated for each day using the expected mean proportion of the monthly total and the appropriate standard deviation from Table 3. The values for rainfall (in millimeters), evaporation (in millimeters), and insolation (in hours) for each day are calculated by multiplying the monthly total that has been generated for that character and day.

The carrying capacity program of which the meteorological parameter generation algorithm described above represents a subroutine, may be run for any period of simulated years. A series of simulations of 25 years for the entire system, and 50 years for the program's agriculture sector, has been used in investigating the impact of variability on carrying capacity (Fearnside 1978).

TABLE 3. *Variability in daily weather as proportion of monthly totals**

Month	Precipitation SD	Precipitation N (days)	Evaporation SD	Evaporation N (days)	Insolation SD	Insolation N (days)
Jan	0.0485	142	0.0219	123	0.0243	122
Feb	0.0490	113	0.0178	113	0.0307	85
Mar	0.0412	159	0.0123	153	0.0261	123
Apr	0.0479	150	0.0270	150	0.0289	120
May	0.0696	155	0.0258	155	0.0667	124
Jun	0.0648	150	0.0302	150	0.0312	120
Jul	0.0843	155	0.0302	154	0.0162	124
Aug	0.1096	147	0.0267	146	0.0108	124
Sep	0.0969	120	0.0289	120	0.0136	120
Oct	0.1013	119	0.0250	119	0.0231	69
Nov	0.1346	120	0.0150	120	0.0263	120
Dec	0.0677	124	0.0302	124	0.0336	124

*Means used are monthly totals divided by number of days in month.

DISCUSSION

An alternative to simulating weather parameters would be to use the Altamira data set directly as input to the larger carrying capacity program. Reasons for selecting simulation include: 1) the greater transferability to the many other areas in Amazonia where available data are less complete, including stations where only rainfall data are available such as the ones used in the carrying capacity study the to their location nearer the study site than Altamira, 2) the ability to use the monthly rainfall data from the 1931-1971 period for which daily measurements are no longer available for Altamira, and 3) the avoidance of limiting simulation outcomes to the few possibilities represented by the 1972-1976 period of relatively complete data.

Monthly means for rainfall could be used directly, rather than deriving monthly rainfall from seasonal totals as in the present program. However, the derived monthly rainfall values provide a more realistic simulation because one avoids the assumption of months being independent of each other. Months within a season are highly correlated, producing the pattern of "wet" and "dry" years that so greatly a affects agriculture in the Amazon region.

Several other algorithms exist for generating values for precipitation and other weather parameters, often including provisions to maintain their stochastic features. One approach is to generate sequences of "wet" and "dry" days using a Markov chain. Best results for many regions being obtained with higher order Markov models (Chin 1977). Days identified as "wet" can have precipitation amounts generated using an exponential model (*e. g.* Richardson 1981). Regularly fluctuating seasonal variations in parameters for such mixed Markov chain-exponential models can be generated from Fourier coefficients (Woolhiser and Pegram 1979). Another approach to introducing seasonality is through cyclically standardized time series obtained using Box-Jenkins models (Delleur and Kavaas 1978; see also Chander *et al.* 1979).

The approach used in the present study is believed to be a cautions one at this stage, as meteorological features observed to have marked impact on farmers' success are incorporated into the model as directly as possible. Seasonal changes are much more irregular than in many parts of the world. The mechanism of dividing the agricultural year into agricultural seasons, and generating seasonal totals based on observed distributions, assures the character of wet and dry years for agricultural operations. The variation in proportions of each season's rainfall attributed to each month assures the variation associated with distribution of rainfall within each season. Such variation underlies the frequently disastrous circumstance observed on the Transamazon Highway of no sufficiently dry month occurring during the burning period, or of appropriate months not falling at the necessary time for an adequate burn given any particular colonist's schedule of agricultural operations. At all levels, the variability in meteorological parameters is preserved in the simulated weather patterns.

CONCLUSION

Weather patterns relevant to the agroecosystem of Transamazon Highway colonists can be simulated in stochastic models. Variability in precipitation, evaporation, and insolation must be preserved in such models due to their known importance for soil change processes such as burning and erosion, thus affecting crop yields and human carrying capacity.

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