DROUGHT IN THE RAIN FOREST: EFFECTS OF THE 1991 EL NIÑO-SOUTHERN OSCILLATION EVENT ON A RURAL ECONOMY IN WEST KALIMANTAN, INDONESIA

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Abstract. In this paper, I first conduct a preliminary analysis of monthly rainfall data from West Kalimantan, Indonesia that indicates that (1) dry periods periodically occur in this otherwise humid environment; (2) these dry periods are often linked to El Niño-Southern Oscillation (ENSO) events; and (3) the intensity of these ENSO linked dry periods has been increasing over the past two or three decades. I then examine the economic costs of the 1991 dry period to residents of several small villages near Gunung Palung National Park. Costs I considered included reduced durian fruit harvest, loss of coffee gardens, delayed rice crops, increased water hauling labor, lost wages in the forest product industry, and increased health problems. The total cost was estimated to be between approximately one-quarter and one-half of annual township income. These results of this 'economic ground truthing' indicate that even in one of the wettest places of the world, droughts occur and can have serious welfare consequences. To the extent that the increasing intensity of these droughts may be linked to climate change, prudence dictates that policy and decision makers should use these results to plan accordingly.

1. Introduction

1.1. *Drought in the Rain Forest?*

Throughout the world, droughts have had a substantial impact upon human welfare (Sircoulon, 1991). Extrapolation from recent history indicates that in the coming decades, the impact of droughts will likely increase, driven by the interlinked forces of human population growth and climate change (Second World Climate Conference, 1991; Sircoulon, 1991).

As a rule, drought has primarily been considered a problem in desert and savannah areas where prolonged water shortages regularly occur (Lins *et al.*, 1991). Forested areas, by contrast, receive regular amounts of rainfall by definition (Walter, 1983). Accordingly, droughts in forested areas generally receive wide publicity only when they are accompanied by large-scale fires that threaten scenic attractions or human lives and property such as occurred in the United States in Yellowstone Park in 1988 or in Oakland, California, in 1991 (Fuller, 1991). Droughts and fires in remote forested areas of the world, however, rarely seem to command

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much attention (Johns, 1989). Perhaps the most dramatic illustration of this neglect was the 1982–1983 forest fire in eastern Borneo. This fire burned an estimated 3.5 million ha of forest in the Indonesian province of East Kalimantan and an additional 1 million ha in the Malaysian state of Sabah, a total area greater than that of Switzerland (Malingreau *et al.*, 1985; Malingreau, 1987). The extent of the damage, however, only came to the world's attention nine months later when the fires were noted on satellite photos (Malingreau, 1987).

In the late 1970s and especially following the 1982 drought, a number of researchers began to suspect that dry periods are a normal occurrence in the rain forests of Borneo and are perhaps linked to regional climatic patterns including El Niño-Southern Oscillation (ENSO) events which occur on a 3 to 7 year cycle (Quinn *et al.*, 1978; Leighton and Wirawan, 1986; Malingreau, 1987; Allen *et al.*, 1989).

Nonetheless, the general feeling among these researchers was that, as one team of authors concluded, "droughts as severe as that of 1982–83 occur on the order of once every fifty to several hundred years or so" (Leighton and Wirawan, 1986, p. 75). In 1991, less than a decade later, however, the forests of Boreo were again struck by what has been termed for Indonesia as a whole, "the most severe drought of this century" (Harger in UNESCO/ROSTSEA, 1992, p. 9). In the aftermath of the 1991 event, it now seems necessary to consider the hypothesis that ENSO linked dry periods are not only a normal occurrence in the region, but are increasing in intensity and turning into economically significant droughts.

1.2. *Research Objectives*

If this drought hypothesis proves to be even partially correct, land-use planners and decision makers will need to consider policies that can take into account and mitigate the effects of water shortages and fires. In order to design and implement workable policies, these planners will need substantial information about the extent and effects of droughts in the region. For the most part, this information will have to come from broad-scale studies by scientists and planners with access to remote sensing and land-use data from the region as a whole (Malingreau *et al.*, 1985). Within this overall analysis, however, it is also important to consider the impact of drought and fires upon the lives of residents of the region – an 'economic ground truthing' that examines in detail how drought and fires can affect individual human welfare.

In this paper, I have two primary objectives. First, I conduct an analysis of rainfall records from West Kalimantan to provide a preliminary test of the hypothesis of increasing intensity of ENSO linked dry periods in the region. Second, I attempt to quantify the economic effects of the 1991 dry period on residents of several small villages in the province to demonstrate that from a human perspective, this dry period can indeed be considered a severe drought with substantial economic impact. I then use these findings to speculate on the potential impacts of human

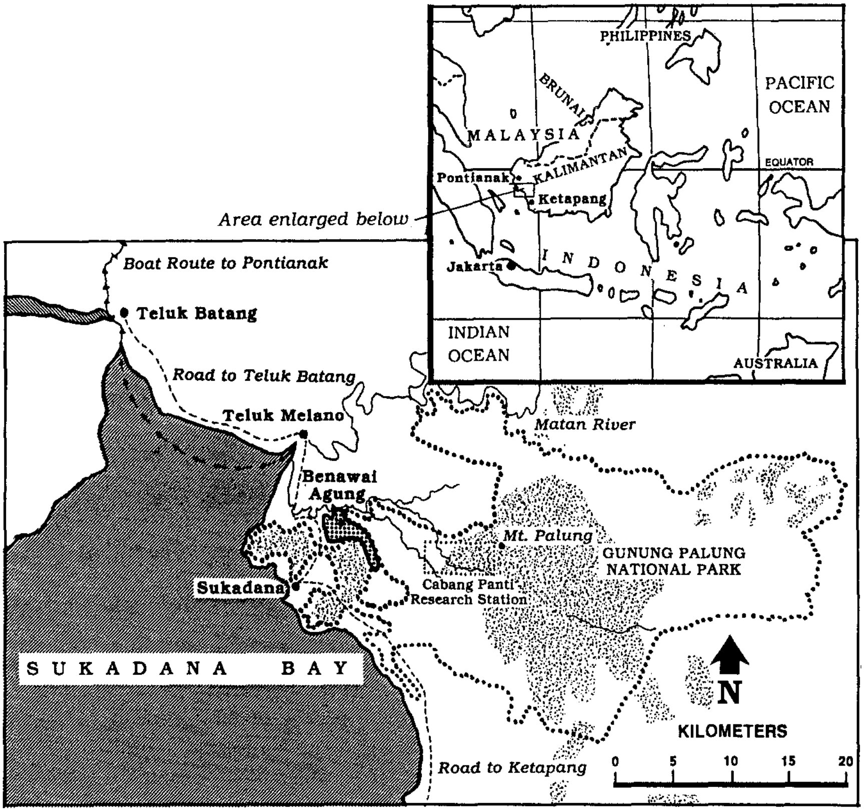

Fig. 1. Location of the study site in West Kalimantan, Indonesia.

induced climate change in the region and to suggest ways in which the results of this and similar studies could be used to facilitate planning efforts that take into account and mitigate the effects of future droughts.

2. Rainfall and Dry Period Patterns in West Kalimantan

2.1. *Data Sources and Analyses*

This study was conducted in the township of Benawai Agung which is located on the border of Gunung Palung National Park in West Kalimantan, Indonesia (Figure 1). Since no studies are currently available looking at the overall pattern of dry periods in West Kalimantan, in this paper I am forced to rely on locally available rainfall records. Although no long term rainfall records exist for the township itself, unpublished monthly records of varying length are available for the district capital of Sukadana located 3 km southwest of Benawai Agung (Dept. of Agriculture-Sukadana), the regency capital Ketapang located 65 km south (Dept. of Agriculture-Ketapang), and the airport near the provincial capital Pontiak located 130 km northwest (Dept. of Meteorology-Supaido).

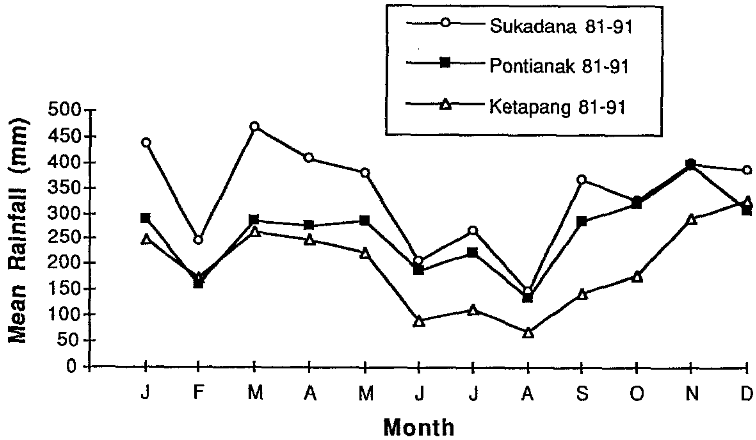

Fig. 2. Rainfall patterns in West Kalimantan, 1981–1991. Unpublished data from Dept. Agriculture in Sukadana and Ketapang and Dept. of Meteorology-Supaido in Pontianak.

The Sukadana data set used in this study is from January 1981 to August 1992 and is not missing any months. The Pontianak data set is from January 1948 to August 1992 and has two missing 5 month spans (Jun–Oct 1949 and Jan–May 1980) that were treated as missing values and four 1 month spans that were interpolated from neighboring values. Finally, the Ketapang data set is from January 1964 to November 1991 and has one missing 5 month span (Jan–May 1976) and six 1 or 2 month spans that for most analyses were treated in the same fashion as the Pontianak data. Since, however, there is some cause to suspect that the 1 and 2 month gaps in the Ketapang data represent true zero values, analyses that look at total June–September ranfall have also been conducted treating these blank values as months with no rainfall.

2.2. *'Normal' Rainfall Patterns*

The township of Benawai Agung is normally a high rainfall environment, averaging over 4000 mm of rain per year. Figure 2 shows available monthly rainfall averages for Sukadana compared with similar ten year periods for Ketapang and Pontianak. In all months, the average rainfall exceeds the 100 mm per month that traditionally defines a humid climate (Walter, 1983; Whitmore, 1984). Furthermore, although there is some variation in total amounts of rainfall received between the three sites, in general they seem to have similar patterns with a small decrease in rainfall in February and a greater decrease between June and September. This overall similarity between the three sites suggests that the longer-term Ketapang and Pontianak records can be used to make inferences about patterns in Benawai Agung.

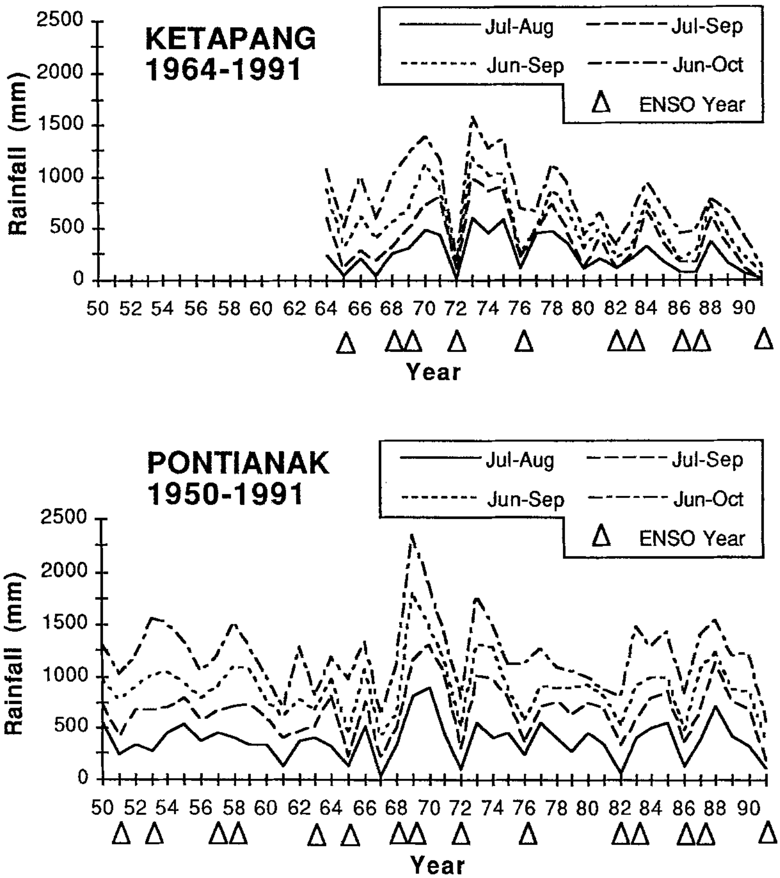

Fig. 3. Dry period rainfall in Ketapang and Pontianak. A few blank values in Ketapang record are treated as zeros (see Section 2.1). If they are interpolated, results are similar except for 1982 where no drought is apparent.

2.3. *Dry Periods and Links to ENSO Events*

A closer examination of the rainfall patterns reveals that the dry period between June and September that appears in the monthly averages shown in Figure 2 does not occur every year. Instead, as shown in Figure 3, some years have substantial rainfall during these months whereas others are marked by a prolonged dry period. Furthermore, these dry periods appear despite the fact that the aggregate nature of the monthly rainfall records can obscure dry spells that begin or end in the middle of a month.

Triangles beneath the X-axes in Figure 3 show the occurrence of El Niño-Southern Oscillation events during this time period based on the Southern Oscillation Index (SOI) which tracks differences in sea-level air pressure between Tahiti and Darwin (Philander, 1989; Harger, 1992). Although not all ENSO years have June to September dry periods associated with them and vice versa, overall there appears to be a fairly high correlation. In addition, as shown in Part A of Table I, for both Pontianak and Ketapang, mean rainfall during the months of June to September is significantly reduced during ENSO years when compared to non-ENSO years. Furthermore, this difference is even more pronounced when the ENSO years include only the first year of two-year events.

Similar results are obtained in Parts B and C using an index of consecutive months with less than the 100 mm rainfall needed for rice cultivation in the tropics (Wasser in UNESCO/ROSTSEA, 1992) and the Dry Period Index (Allen, 1989), two other measures of drought intensity that consider the entire year rather than just the somewhat arbitrary June–September period. In general, this evidence indicates that West Kalimantan fits into the overall pattern in the Indonesia-New Guinea region in which dry periods occur between June and October during the first year of a 'typical' 2 year ENSO cycle (Hackert and Hastenrath, 1986; Nicholls, 1987; Ropelewski and Halpert, 1987; Allen *et al.*, 1989; Kerr, 1992; UNESCO/ROSTSEA, 1992).

2.4. *Recent Increases in Dry Period Intensity*

The rainfall patterns from West Kalimantan not only show that ENSO linked dry periods occur, but that over the last two or three decades they have been increasing in intensity. Part A of Figure 4 and Table II show the results of regressions of June–September rainfall on time for ENSO (1st year of 2 year events only) and non-ENSO years in Pontianak. Although the slope coefficient for non-ENSO years is not significantly different from zero, the coefficient for ENSO years is both significantly negative and significantly different from non-ENSO years.

Part B and C of Figure 4 and Table II show the results of similar regressions for the two measures of dry period intensity. In the case of the dry period length index, while the slope coefficient for non-ENSO years is not significantly different from zero, the coefficient for ENSO years is both significantly positive and different from non-ENSO years (the slope here is positive since the index measures dry period intensity and thus moves in the opposite direction as rainfall). In the case of the Dry Period Index, neither slope is significantly different from zero or each other. Acceptance of the null hypotheses may in part be a function of the relative insensitivity of the index (which was developed to detect more severe dry seasons in the New Guinea Highlands) to the comparatively brief dry periods in West Kalimantan. Finally, the Ketapang data in Table II also show decreasing rainfall (with a corresponding increase in dry period intensity) over time, especially in ENSO years. Here, however, differences between ENSO and non-ENSO years are not significant, presumably due to the lack of a baseline reference period in the record which only dates back to 1964.

Overall, these findings support the hypothesis that the intensity (although not necessarily the frequency) of ENSO linked dry periods has been increasing over the past two or three decades in West Kalimantan. The short 30 and 45 year rainfall

TABLE I: The association between dry periods and ENSO Years with 3 measures of dry period intensity.
For Part A, lower values indicate reduced rainfall. For Parts B and C, higher values indicate increasing dry season intensity

INDEX	Pontianak (1948–1991 Data)							Ketapang (1964–1991 Data)						
Comparison	Non-ENSO Years		ENSO Years		*t* test (2-tail)			Non-ENSO Years		ENSO Years		*t* test (2-tail)		
	mean	sd	mean	sd	*df*	*t*	*p*	mean	sd	mean	sd	*df*	*t*	*p*
A. June–Sept. rainfall (mm)														
Pontianak (1948, 1950–1991)														
Non-ENSO vs.														
ENSO 1 and 2[1]	961	215	793	368	41	1.89	0.066	703	291	307	197	25	3.83	0.001[3]
Non-ENSO vs.														
ENSO 1 Only[2]	994	252	635	199	41	4.29	<0.000	667	293	247	165	25	3.58	0.001[3]
B. Duration of dry season (months)														
Pontianak (1948–1992)														
Non-ENSO vs.														
ENSO 1 and 2	0.77	0.68	1.20	0.78	43	1.93	0.061	1.17	0.86	3.00	1.83	26	3.64	0.001
Non-ENSO vs.														
ENSO 1 Only	0.76	0.65	1.36	0.81	43	2.49	0.017	1.24	0.94	3.57	1.72	26	4.57	<0.000
C. Dry period index (scale of 0–100)														
Pontianak (1948–1992)														
Non-ENSO vs.														
ENSO 1 and 2	6.0	10.0	10.3	12.3	43	1.28	0.214	7.2	12.2	17.0	19.8	26	0.16	0.115
Non-ENSO vs.														
ENSO 1 Only	5.3	9.6	14.0	12.4	43	2.45	0.019	6.2	11.5	24.3	19.6	26	3.01	0.006

Notes:
(A) June–September rainfall is the total amount of rainfall for these months.
(B) Duration of dry season is no. of consecutive months in year with < 100 mm rain (UNESCO/ROSTSEA, 1992).
(C) Dry period index is derived from consecutive months with rain > 0.5 and 1 sd below monthly mean (Allen, 1989).
[1] ENSO 1 and 2 includes both 1st and 2nd years of a 2 year event.
[2] ENSO 1 Only includes only 1st year of a 2 year event with 2nd year added to Non-ENSO data.
[3] Results shown are based on treating missing values as zeros, but no major differences are found if interpolated values are used.

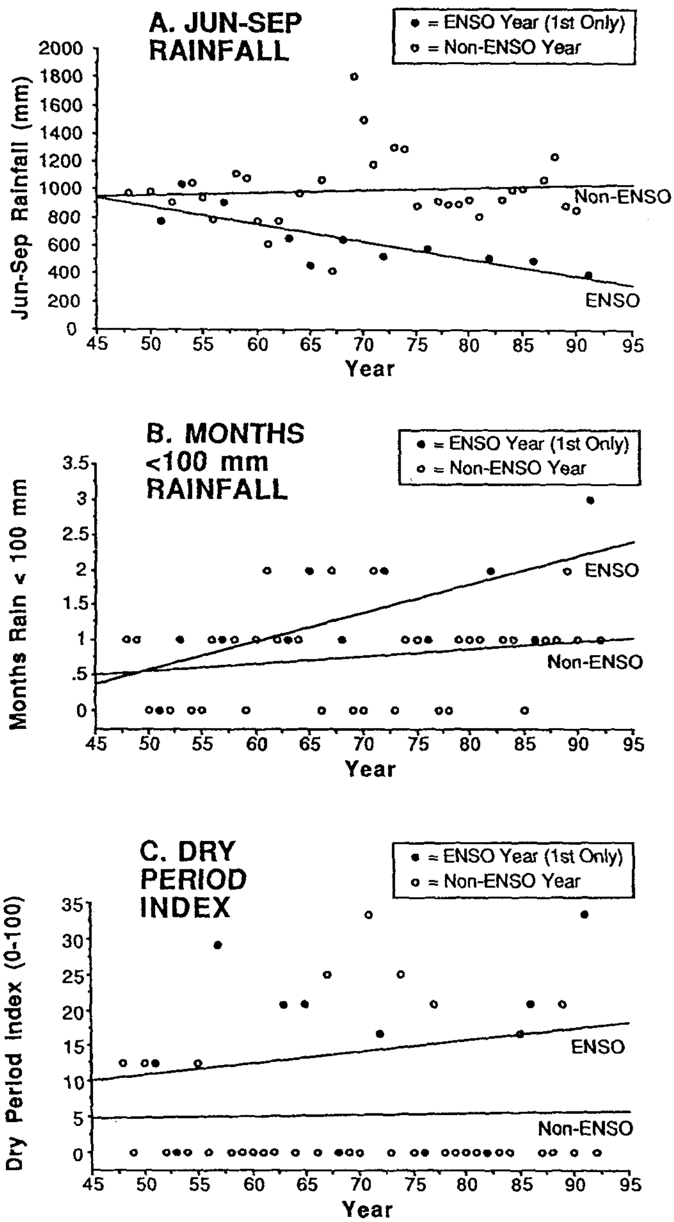

Fig. 4. Increasing intensity of ENSO linked dry periods in Pontianak. Values for regression coefficients are listed in Table II. Drought intensity indexes used include (A) Total rainfall (mm) between June and September; (B) Number of consecutive months in year with less than 100 mm rainfall; and (C) the Dry Period Index which is derived from consecutive months with rain >0.5 and 1 sd below monthly mean (Allen, 1989). For Part A, lower values indicate reduced rainfall. For Parts B and C, higher values indicate increasing dry period intensity.

TABLE II: Increasing intensity of ENSO linked dry periods. Regression model is: $Y = a + bX$. For Part A, negative slopes represent indicate decreasing rainfall. For Parts B and C, positive slopes indicate increasing dry season intensity.

Parameter	Pontianak (1948–1992 Data)				Ketapang (1964–1992 Data)			
	Slope	Std Err	*t*	*p* (2-tail)	Slope	Std Err	*t*	*p* (2-tail)
A. June–Sept. rainfall (mm)								
ENSO Years[1]								
Constant	1487.9	200.5	7.42	0.000	1165.0	431.5	2.70	0.043
Year	–12.3	2.8	–4.33	0.002	–11.9	5.6	–2.14	0.085
Non-ENSO Years[2]								
Constant	883.0	259.9	3.40	0.002	2153.0	559.9	3.85	0.001
Year	1.6	3.6	0.43	0.667	–19.2	7.2	–2.67	0.015
F-Test[3]	$F(1, 39) = 4.69$		$p < 0.05$		$F(1, 24) = 0.37$		$p =$ not significant[4]	
B. Duration of dry season (months)								
ENSO Years[1]								
Constant	–1.46	1.06	–1.38	0.202	–3.33	5.39	–0.62	0.564
Year	0.04	0.02	2.71	0.024	0.09	0.07	1.29	0.254
Non-ENSO Years[2]								
Constant	0.02	0.61	0.04	0.970	–0.41	1.73	–2.35	0.030
Year	0.01	0.01	1.24	0.223	0.07	0.02	3.08	0.006
F-Test[2]	$F(1, 41) = 2.94$		$p < 0.1$		$F(1, 24) = 0.16$		$p =$ not significant	
C. Dry period index (scale of 0–100)								
ENSO Years[1]								
Constant	2.9	21.6	0.13	0.896	–88.7	49.4	–1.80	0.133
Year	0.2	0.3	0.52	0.613	1.5	0.6	2.30	0.070
Non-ENSO Years[2]								
Constant	4.0	9.1	0.44	0.664	–43.6	23.2	–1.88	0.076
Year	0.0	0.1	0.14	0.887	0.6	0.3	2.16	0.044
F-Test[2]	$F(1, 41) = 0.25$		$p =$ not significant		$F(1, 24) = 1.93$		$p =$ not significant	

[1] ENSO Years include 1st year of 2 year events only.
[2] Non-ENSO years include 2nd year of 2 year ENSO events.
[3] *F*-Test is of the null hypothesis: Slope ENSO Yrs = Slope Non-ENSO Yrs (Sokal and Rohlf, 1981, p. 505).
[4] Results for Ketapang in Part A are based on treating missing months as zeros.

records used in the above analyses coupled with the lack of any supporting information from temperature trends and other climatological data make forecasting about future years extremely risky. At a minimum, however, it seems safe to say that a strong possibility exists that severe ENSO linked dry periods will play a reoccurring role in the region. This finding fits into a growing body of evidence that is beginning to suggest that the intensity of ENSO linked dry periods in the Indonesia-

New Guinea region has been increasing over the past two or three decades, perhaps as the result of climatic change (Harger, 1992; UNESCO/ROSTSEA, 1992).

2.5. *Are Dry Periods Turning into Droughts?*

The above analysis of rainfall patterns in West Kalimantan indicates that (1) dry periods periodically occur in this otherwise humid environment; (2) these dry periods are often linked to El Niño-Southern Oscillation (ENSO) events; and (3) the intensity of these ENSO linked dry periods has been increasing over the past two or three decades. It leaves unanswered, however, the question of whether or not these dry periods should be considered droughts.

In general, 'drought' seems to be a relative term that can have vastly different meanings to a cattle herder in the Sahel and a rice farmer in Southeast Asia or to a meteorologist using a climate based index and an agronomist using a plant oriented measure (Hounam *et al.*, 1975; Dunne and Leopold, 1978). In the remainder of this paper, I attempt to demonstrate that the 1991 dry period had substantial economic impact upon the residents of Benawai Agung and thus from a human welfare perspective at least, rainfall shortages of this magnitude should be regarded as a severe drought.

3. Study Site and Methods

3.1. *Study Site*

This research was conducted as part of a larger interdisciplinary study of the land-use systems developed by residents of the township of Benawai Agung in West Kalimantan, Indonesia. In 1991, at the start of this study, the township contained about 565 households subdivided into four smaller villages (see Salafsky 1993 for a more detailed description of the structure and history of the township).

The local economy is primarily agriculturally based. Most township residents own or work on small farms on which they grow rice, cassava, and vegetables for household consumption and soybeans and maize for sale. In addition, about half of the households own forest gardens, a multi-species agroforestry system in which they grow durian (a prized fruit), coffee, sugar palm, rubber, and peppers for sale and various fruits and other products for household consumption. Other economic activities include small-scale timber and non-timber forest product extraction, various cottage industries, and work in government sponsored construction projects (see Salafsky, 1993, for a more detailed description of the ecological and socioeconomic structure of the different land-use systems).

3.2. *Data Collection*

Calculations of the economic costs of the 1991 dry period to Benawai Agung are presented in Table III and described in the following sections. Data used in the calculations were collected as a part of the overall study during two visits to the township between Sep 1991–Jan 1992 (which included the last month of the dry period) and Sep 1992–Dec 1992 (a year after the dry period). During these visits, I conducted formal socioeconomic interviews with a randomly selected 15% of the households in the four villages, mapped and monitored production in the forest gardens, and consulted with numerous local, regional, and national governmental officials about policies and practices in the study area (see Salafsky, 1993, for complete details of methods used).

3.3. *Parameter Calculation*

For each cost parameter in Table III, I have attempted to calculate both a minimum and a maximum estimate to obtain a range for the potential effect. In order to calculate this range, for factors that are directly related to the dry period (i.e., length of dry period or % loss of durian crop), I have used minimum and maximum estimates of factor values. For those factors that are not directly affected by the dry period (i.e., number of durians harvested per household or value of the rice crop in normal years), however, I used the mean value obtained from socioeconomic interviews and/or mapping sessions and then multiplied this value by the total number of households ($n = 565$) in the village. In doing so, I am assuming that mean values estimated for surveyed households are an unbiased estimator of the true value for the township as a whole.

Although ideally the economic impact of the dry period would be calculated by comparing annual income for a large sample of households in one or more normal reference years to income during the dry year, data for such detailed comparisons are not available. Accordingly, the methods used in this paper represent the best available alternative to place crude 'error bars' on the true cost of the dry period. While there is a danger in attempting to quantify the impact of the dry period that the bottom line numbers will be taken out of the context of their assumptions, there is even a greater danger that if no numbers are provided, decision makers will implicitly assume these costs to be zero. My goal is thus not to calculate the exact value of costs imposed by the dry period on township residents, but rather to demonstrate that these costs are both existent and extensive.

3.4. *General Assumptions*

An important set of assumptions in modeling the costs of the dry period for each parameter involves prices. It is a basic tenet of microeconomics that for normal goods, as quantity produced decreases, the price tends to rise. This effect of prices should to some degree compensate producers in the villages for lost crops. This compensation effect only occurs, however, if it is assumed that demand remains constant (in technical terms, the good has a low price elasticity) and if there is no outside supply of the good in question (the township is a closed economy).

Furthermore, the net impact of the price effect can be ambiguous since farm households can be simultaneously producers and consumers of many goods (Singh *et al.*, 1986). The assumptions made for each parameter are discussed in greater detail in the following sections.

Another set of assumptions that appears in several of the following sections relates to parameters that involve a stream of benefits or costs over time. Economic theory holds that these future benefits and costs should be expressed in present value terms by dividing the future net benefit by a discount factor. Within the literature, however, there has been much debate over the choice of a discount rate, especially in rural sectors of developing countries (Pearce and Nash (1981; Markandya and Pearce, 1988). In this study, I have used a range of rates (the higher rate being used in calculating the minimum estimate and vice versa). For the low rate, I have assumed an annual real discount rate of 10% as this is commonly used in development research. For the high rate, however I have used a 50% annual discount rate based on preliminary empirical evidence indicating that many village residents routinely pay interest rates of this magnitude or more (see Salafsky, 1993). Although this rate may seem excessively high, ultimately the discount rate is a measure of the time value of money. In a frontier situation such as in Benawai Agung where natural resources are being explosively exploited and capital is scarce, money in hand today can generally be invested to produce substantial returns in the future. Accordingly, when coupled with township residents' present oriented consumption patterns, the high return rate seems at least as plausible as the lower one.

4. Economic Effects of the 1991 Dry Period

4.1. *Reduced Durian Fruit Harvest*

The greatest impact of the dry period upon the township was that it severely affected local durian trees which produce a highly valued fruit that is the major source of cash income to the residents (Salafsky, 1993). Periods of low rainfall in normal years are actually beneficial to the durian harvest in that the trees apparently will not flower without a prolonged period of warm dry days (or associated cool clear nights). Township residents reported that if there are approximately 10 or fewer continuous days of dry weather in a given year there is no flowering, that 10–15 days results in a normal crop, and that 15–25 days results in an extremely large crop. These large crops appear to occur in conjunction with masting events (periodic synchronized fruitings of Dipterocarps and many other tree species that are characteristic of Southeast Asian rain forests) in nearby natural forest that may be triggered by ENSO linked dry periods (Ashton *et al.*, 1988).

In about August of 1991, many of the durian trees in the township, most of which had just produced large crops the previous February, began to flower and set fruit in response to the climatic cues provided by the onset of the dry period.

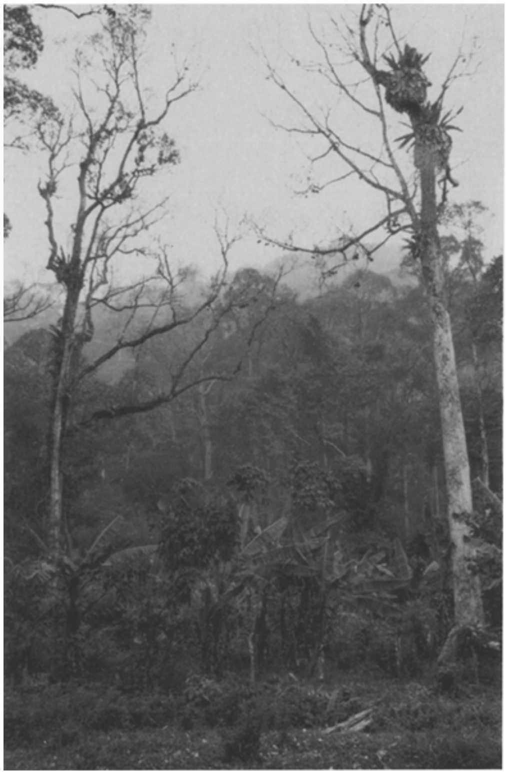

Fig. 5. Drought stressed durian trees with a few remaining fruits. Photograph by N. Salafsky.

As the lack of rain continued beyond normal dry season length, however, many of these trees appeared to undergo severe water stress, causing them to drop first their leaves and eventually their fruits (Figure 5). The overall effect seemed to vary from tree to tree, presumably due to microsite conditions and/or genetic variability; some trees lost all their leaves and fruits, while others kept most of their leaves and maintained sizeable fruit crops.

As shown in Line 1 of Table III, the loss due to the dry period is the value of the anticipated durian harvest multiplied by an estimate of the percentage of the crop that was lost due to the extended dry period. The fruits/garden-household values are derived from mapping based production figures for masting and normal-crop years, the percentage of garden owing households and price estimates are based on survey data, and the percentage of fruits lost values are calculated by dividing reported crop sizes during the dry period by reported crop sizes during masting and normal-crop years (see Salafsky, 1993). Assumptions in this calculation are that harvesting costs are negligible and that there are no long-term effects on the health of the trees from the dry period in 1991. In addition, this analysis ignores the costs incurred by many garden owners who were forced to replant durian and

TABLE III: Estimates of the cost of the 1991 drought and fires to Benawai Agung. See text for detailed explanations of assumptions used to calculate values; All monetary values in '000s Rupiah (kRp) where 1 \$U.S. ≈ Rp 2000 = 2 kRp'

Cost parameter		Method calculated	Minimum estimate	Maximum estimate
1.	Lost durian fruit harvest	fruits/garden hshld * % garden hshlds * n hshlds * kRp/fruit * % fruits lost	124,286	176,080
2.	Burned coffee garden	ha land burned * $\sum_{t=0}^{t} \frac{\text{kg coffee/ha-yr*kRp/kg coffee}}{(1+r)^t}$	6,401	37,928
3a.	Delayed rice crop (consumer)	kg/hshld-mth * n hshlds * m mths drght * kRp/kg price incr	3,526	21,154
3b.	Delayed rice crop (producer)	$\text{kRp/rice crop} - \frac{\text{kRp/rice crop}}{(1+r_m)^m}$	2,330	30,798
4.	Increased water labor	$\sum_{v=1}^{4}$ {extra min/day − hshld$_v$ * n hshlds/village$_v$}* 1 day/1440 min * days of drought * kRp/day	487	3,893
5.	Lost forest product wages	% hshlds harvesting * n hshlds * kRp/yr-hshld * % loss due to drought	6,712	22,374
6.	Increased health problems	unquantifiable costs	+	++
7.	Improved transport	$\sum_{v=1}^{4}$ {reduced min/day − hshld$_v$ * n hshlds/village$_v$}* 1 day/1440 min * days of drought * kRp/day	–345	–2,760
Total Township Costs			143,396	289,466
8.	Loss/hshld	kRp total loss/n hshlds	254	512
9.	Hshld income/yr	kRp/day-hshld * 270 days/yr	1,080	1,080
Loss as % of Income			23%	47%

Note: Values for Parameter Calculations in Table III:
Data from Salafsky (1993). Where one value is listed, it is used in both minimum and maximum calculations. Where two numbers are given, the first is used in the minimum calculation and the second in the maximum.

TABLE III: *(continued)*

1.	2736–6891	fruits/garden household
	40.2	% garden households in survey
	565	households in township
	0.4–0.15	kRp/fruit
	50–75	% fruits lost
2.	5–15	ha land burned
	2–4	t yrs until plants regrow
	346	kg coffee/ha-yr
	2.0	kRp/kg coffee
	0.5–0.01	r_{annual}
3a.	62.4	kg rice consumed/hshld-mth
	565	households
	1–2	mths delay
	0.1–0.3	kRp/kg price increase
3b.	341,699–512,549	kRp/crop*
	1–2	mths delay
	0.03436–0.00797	r_{monthly}**
4.	{10–20, 20–40, 20–40, 60–120}	extra min/hshld$_v$
	{230, 139, 129, 67}	hshlds/village$_v$
	30–60	days droughts
	2–4	kRp/day
5.	26.4	% hshlds harvesting in survey
	565	households in township
	150–300	kRp/households-yr
	30–50	% loss due to drought
7.	{10–20, 10–20, 20–40, 30–60}	reduced min/hshld$_v$
	{235, 139, 129, 67}	hshlds/village$_v$
	30–60	days drought
	2–4	kRp/day
8.	143,387–289,411	kRp total loss
	565	households
9.	4	kRp/day-hshld average wage
	270	days/yr

* From 1093 kg hulled rice/farm hshld $*$ 95.4% farm hshlds in survey $*$ 565 hshlds $*$ 0.5 $-$ 0.8 kRp/kg rice.

** From the formula $r_{\text{monthly}} = [(1 + r_{\text{annual}})^{1/12}] - 1$.

other fruit tree seedlings and saplings and productive coffee and pepper plants that were killed by the dry period.

In general, the durian market is a good example of the compensating effect that prices can have; a number of households make more money during normal-crop years when there is an average sized crop and prices are stable than during masting-crop years when there is more product available, but the price crashes. As a result of this compensating effect, there is only a limited range between the minimum and maximum estimates of the dry period imposed loss. In theory, this strong effect of prices should compensate for losses imposed by the dry period by raising prices for remaining fruits even more than in normal times (as has occurred in past years when too much rain has caused the crop to fail). In 1991, however, this compensatory effect was limited because store owners in the region still had large stocks of dried durian candy, the primary use of harvested durians, left over from the bumper harvest the previous February. In effect, the stocks of durian candy acted as an outside supply, forcing the market to be more open and dampening the magnitude of the price compensations.

4.2. *Loss of Coffee Gardens*

Another obvious cost of the dry period were the resources that literally went up in smoke due to dry conditions created by the lack of rain. Within the township, the biggest losses were in one village where 5 to 15 ha of coffee gardens were destroyed by agricultural fires that escaped control. Most, if not all farmers affected by these fires began to replant their lost coffee within a few months after the dry period ended.

As shown in Line 2 of Table III, the loss due to the dry period is the area of coffee garden burned multiplied by the per hectare gross present value of foregone harvests until the coffee grows back. Assumptions in this calculation are that the first crop loss is in year zero, that households only grow coffee as a cash crop and thus there is no consumption cost incurred as a result of high coffee prices, and that the labor involved in replanting the coffee gardens is comparable to the labor that would normally be expended in tending and harvesting existing plants so that it becomes a negligible factor. In this case, there is no compensating effect of prices since the dry period caused not just reduced yields, but instead loss of the entire crop relative to normal production.

4.3. *Delayed Rice Crop*

The 1991 dry period also affected rice crops that provide the staple food for the township. Farmers in the township can be subdivided into three groups: those with access to irrigation who generally grow two crops per year using improved rice varieties, those without access to irrigation who grow one crop using a mix of improved and local rice varieties followed by a crop of soybeans and/or corn, and those without access to irrigation who plant only one crop of local rice on marginal land which then lies fallow the remainder of the year. In normal years, farmers in all three classes plant the first rice crop in August or September to coincide with the onset of the rainy season. Harvest occurs a few months later with, as is the case for staple goods in many agricultural economies, the price reaching its maximum just before the onset of the harvest season during what is locally termed 'a half-hungry season'.

In 1991, farmers in all three classes had to delay their planting until the onset of the rains in mid-October, leading to a corresponding delay in the harvest season similar to one that occurred throughout the region after the 1982–83 ENSO event (Malingreau, 1987; Allan, 1991). Since most households in the township are both consumers and producers of rice, this delay had two important economic impacts. First, the delay imposed by the dry period meant that consumers had to pay high rice prices for an extended length of time. Second, producers had to forego income earned from rice production for the length of the dry period.

As shown in Line 3a of Table III, the consumption loss due to the dry period is the amount of rice eaten by the average household in one month multiplied by the length of the dry period and the value of rice (at the high pre-harvest price). In Line 3b, the production loss is the value of the crop (at the lower post-harvest price) discounted by the number of months of dry period. Assumptions in the calculations are that no township residents gain in income from selling rice during the high price period (an unlikely assumption, but the effect is offset since these storekeepers also lose income generated by selling goods after the rice harvest), and that the demand for rice is inelastic so that households do not substitute other foods during the high price period (a generally valid assumption given that rice is the most important dietary staple). These calculations also ignore that the rice harvest was for some farmers greatly reduced by the dry period.

In this case, there is potentially a compensating effect of prices with regards to the consumption loss. I have thus assumed that the economy is somewhat open in the minimum estimate (so that the price increases only a small amount) and less open in the maximum estimate (so that there is a greater price increase). With regard to the production loss, on the other hand, the same price is used for both minimum and maximum estimates since the dry period is merely delaying the producers from receiving the normal market price.

4.4. *Increased Water Hauling Labor*

Another impact of the dry period was that it increased the amount of effort that people expended to obtain water for household consumption. Most of the township obtains its water from streams flowing out of the mountains of the neighboring national park. Stream water is generally drawn by hand and then carried to the houses except in one village which has a pipe system leading to public fountains built by the government. During the rainy season, people collect water from streams that flow near their houses or use rainwater collected from their roofs. During the dry period, however, it became necessary to travel to the few larger streams that did not dry up. Furthermore, owing to the low water flow, most people collected their water from farther upstream because the water near the villages was contaminated. Hauling 20 to 30 l of water is not an easy task and involves significant labor expenditure, even when a bicycle is available.

The amount of effort expended to transport water varied widely within and between villages in the township depending on the distance to streams that did not dry up. Residents of the village with the pipe system had little or no extra work because the piped water did not fail. Residents of the poorest village, on the other hand, had to walk an hour or more to get water since the small freshwater streams in their village dried up and the main river became saline. Residents of the remaining two villages had an intermediate increase in the amount of labor depending on their distance from the main streams. Some of these households were able to use bicycles or motorcycles to transport water, but it still required additional time, labor, and expense.

As shown in Line 4 of Table III, the loss due to the dry period is the estimated daily increase in household time spent in obtaining water summed across the four villages and then multiplied by the days of dry period and an approximation of the daily wage rate. One assumption in the calculations is that the shadow wage rate for labor spent hauling water is equal to the daily wage rate. Use of a low wage rate in the minimum estimate implies that there is not much opportunity cost for labor whereas use of a higher rate in the maximum estimate implies a greater cost.

4.5. *Lost Wages in the Forest Product Industry*

Yet another impact of the dry period was that of fires in nearby forests. Many households in the study villages supplement their annual income by spending a month or more harvesting timber and, to a lesser degree, non-timber forest products from designated production forest upstream along the Rantau Panjang River. Timber is generally harvested by teams of six young men who spend a month or so felling trees by hand, skidding logs out on wooden rails, and then floating the logs downstream in small rafts. Other forest products are collected by men working alone or in small groups.

For both timber and non-timber products, harvesters are generally sponsored by middlemen traders who provide the harvesters with supplies in advance (at high interest rates) which are then paid off only when the harvester returns to the township with the product (Salafsky *et al.*, 1993). Since these middlemen capture most of the value of harvested products and only a few of them are from Benawai Agung, the benefit of this work to the township's economy is largely the value of wages earned by harvesters.

Harvesters reported that large tracts of forest had burned during the dry period, including especially areas located along the river where previous exploitation had occurred. These harvesters also told me that these fires would be bad for them because it would be much more difficult in the future to find timber and other products within a distance from the river that made them economically worthwhile to harvest. Accordingly, they expected that over at least the short term, harvesting by township residents would be reduced.

As shown in Line 5 of Table III, the loss due to the dry period is the value of the wages made by township residents harvesting products multiplied by a factor accounting for the reduction in timber harvesting owing to the fires. Although through observations from mountain overlooks and a trip up the river I was able to confirm qualitatively that large areas of forest had burned, I have no way of estimating the area of land affected or its actual impact on harvesting behavior. Accordingly, the percentage of reduced harvesting factor is a rough estimate based on conversations with a few harvesters. Other assumptions in these calculations include that the percentage of surveyed households that said they harvested products is the same as in the township as a whole (somewhat unlikely since some respondents illegally harvested products from the national park and would have been reluctant to say so), and that in the short-run, at least, harvesting wages will not rise to compensate for the increased cost of obtaining products. As was the case for the labor involved in hauling water, use of a low wage rate in the minimum estimate implies that there is not much opportunity cost for labor whereas use of a higher rate in the maximum estimate implies a greater cost.

4.6. *Increased Health Problems*

One of the most striking effects of the dry period and associated fires was that for much of September and October, it was not possible to see the sun owing to the dense clouds of smoke in the air (Figure 6). This smoke blanketed most of the province and extended as far as Singapore and peninsular Malaysia (Harger, 1992). In general, the smoke did not appear to greatly affect day to day life in the township and most people did not seem particularly perturbed about it. Nonetheless, it is conceivable that the smoke had costs in terms of its impact on long-term health. Certainly, in the developed world it has been established that people have positive willingness-to-pay values to avoid air pollution. For example, one hedonic housing cost study in Los Angeles found that all other factors being equal, people paid between US$ 15.44 and 128.46 per month to gain access to improved air quality (Brookshire *et al.*, 1982).

Furthermore, while it is debatable whether or not residents of Benawai Agung would pay to avoid smoke, there may have been other health effects due to the dry period including an increased incidence of disease due to poor sanitation related to low water flow or malnutrition due to the delay in the rice harvest as occurred in much of Indonesia during the 1982–83 dry period (Nicholls, 1991). Although I was not aware of any cases in Benawai Agung, I did hear reports that cholera struck other towns in the province during the dry period.

Fig. 6. Darkness at noon: the sun obscured by smoke during the drought. Photograph by N. Salafsky.

At this point, it is not possible to place a monetary value on the impact of the dry period on long-term health. Accordingly, in Line 6 of Table III, I have placed a plus in the low estimate and two plusses in the high estimate to indicate the existence of unquantifiable negative health effects which, in this analysis, are expressed as positive costs.

4.7. *Improved Land-Based Transport*

Although the dry period caused a number of problems, not all of its effects were necessarily negative. One example of a positive effect is that the dry weather improved land-based transportation. Although the main road through the township was paved, other side roads were unpaved and tended to get extremely muddy during the rainy season, making transport difficult.

As shown in Line 7 of Table III, the gain due to the dry period is the daily decrease in household time spent in travelling summed across the four villages and then multiplied by the days of dry period and the daily wage rate. Assumptions for this calculation are similar to those for increased water hauling labor.

5. Discussion and Conclusions

5.1. *Total Costs of the 1991 Dry Period to the Township and Region*

The last lines in Table III show the total loss from the 1991 dry period, the loss expressed on a per capita basis, and the loss as a percentage of household income with income being roughly estimated by multiplying the daily household wage rate by 270 days. These calculations indicate that the 1991 dry period caused between 143 and 289 million rupiah of damage to the township or between approximately one-quarter and one-half of annual household income.

Having arrived at specific estimates of per household cost of the dry period, two caveats are now in order. First, since the values used to calculate parameters in Table III are means for township as a whole, the results overlook variation among households. In reality, some households were undoubtedly much more affected by the dry period then others. Second, since all of these calculations involve a large number of assumptions and approximations, the bottom line values reported above should not be taken as statistically significant estimators of the true cost of the dry period. Instead, these values should be regarded as an attempt to place crude 'error bars' around this true cost (see Methods section). Nonetheless, although the exact cost will never be known, the important finding is that the 1991 dry period clearly caused substantial impact upon the local economy.

Furthermore, Benawai Agung appeared to suffer much less damage than other areas in the region. In the nearby town of Rantu Panjang, for example, dozens of hectares of mature coconut plantation were destroyed by fires. Many other towns were also not as fortunate as Benawai Agung in that their drinking water sources failed during the dry period. In the regional trading center of Teluk Melano, for instance, residents were forced either to transport water themselves from a marginally clean source located over an hour away or buy fresh water that was brought in by boat (at a price of 0.60 kRp for 20 l). In the provincial capital of Pontianak, water had to be purchased as well.

On a larger scale, at least 88,000 ha of government owned forest in Kalimantan burned creating a pall of smoke that covered most of West Kalimantan and reached to Malaysia and Singapore (Jakarta Post in Harger, 1992). The dense smoke grounded all airplanes in the province for a month or more, compounding the problems created by the reduced water flow in rivers which kept many boats (the primary means of transport and trade) from traveling into the interior of the island. Furthermore, as noted above, the dry period potentially could have caused numerous health problems throughout the province. And finally, in Indonesia as a whole, an estimated 843,000 ha of rice paddies were affected by the lack of rain, forcing the previously self-sufficient country to import 600,000 t of rice (Harger, 1992).

5.2. *Drought in the Rain Forest: Implications for Policy Design*

The total cost of the 1991 dry period to residents of Benawai Agung and the region as a whole indicates that from an economic perspective, rainfall shortages of this magnitude should be regarded as a severe drought. Even in the humid tropics, droughts occur and can have serious welfare consequences.

Currently existing global climate models do not yet accurately reproduce ENSO behavior (Pittock and Salinger, 1991). Accordingly, it is still unclear whether the pattern of increasingly intense ENSO linked droughts in Kalimantan is part of a normal climatic cycle, or is the result of climatic change caused by human-induced environmental alterations ranging from regional deforestation that disrupts local precipitation cycles (Shukla *et al.*, 1990; Salati and Nobre, 1991; Clark, 1992) to global warming that alters weather patterns world-wide (Sircoulon, 1991). What is clear, however, is that if this climate change is indeed occurring, it has the potential to cause severe economic consequences. Prudence thus dictates that policy and decision makers should plan accordingly.

Studies such as this one will be helpful in this planning process in three ways. On a local level, information about the specific impacts of droughts could be used to mitigate negative effects. For example, in Benawai Agung, existing irrigation and household water supply projects could be expanded to cover the remainder of the township (as in fact was done for two of the villages in late 1992). On a regional level, information about the costs imposed by droughts could provide a rough estimate of some of the externalities imposed by human-induced environmental alterations. For instance, if a link can be established between droughts and localized deforestation, then the impact of the drought could be included in a benefit-cost analysis of a logging concession. Finally, on a global level, information about droughts occurring in one of the wettest areas of the world could hopefully serve as potent reminder of the potential impact of climate change on human well-being.

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References

Allan, R. J.: 'Australasia', in Glantz, M. H., Katz, R. W., and Nicholls, N. (eds.), *Teleconnections Linking Worldwide Climate Anomalies: Scientific Basis and Societal Impact*, Cambridge University Press, Cambridge, U.K., pp. 73–120.

Allen, B.: 1989, 'Frost and Drought through Time and Space, Part I: The Climatological Record', *Mtn. Rsrch. Develop.* **9**, 252–278.

Allen, B., Brookfield, H., and Byron, Y.: 1989, 'Frost and Drought through Time and Space, Part II: The Written, Oral, and Proxy Records and Their Meaning', *Mtn. Rsrch. Develop.* **9**, 279–305.

Ashton, P. S., Givinish, T. J., and Appanah, S.: 1988, 'Staggered Flowering in the Dipterocarpaceae: New Insights into Floral Introduction and the Evolution of Mast Fruiting in the Aseasonal Tropics', *Amer. Nat.* **132**, 44–66.

Brookshire, D. S., Thayer, M. A., Schulze, W. D., and D'Arge, R. C.: 1982, 'Valuing Public Goods: A Comparison of Survey and Hedonic Approaches', *Amer. Econ. Rev.* **72**, 165–177.

Clark, C.: 1992, 'Empirical Evidence for the Effect of Tropical Deforestation on Climatic Change', *Env. Conserv.* **19**, 39–47.

Dunne, T. and Leopold, L.: 1978, *Water in Environmental Planning*, W. H. Freeman, New York, New York.

Fuller, M.: 1991, *Forest Fires: An Introduction to Wildland Fire Behavior, Management, Firefighting, and Prevention*, John Wiley and Sons, New York, New York.

Hackert, E. C. and Hastenrath, S.: 1986, 'Mechanisms of Java Rainfall Anomalies', *Mon. Wea. Rev.* **114**, 745–757.

Harger, J. R. E.: 1992, 'Global Change, Temperature Patterns, ENSO Variations, and Climate Effects as Shown by Long-Term Data from Indonesia and the Philippines', Paper presented at the *Workshop on Transboundary Pollution of Haze in the Asean Regions, Balikpapan, Indonesia.*

Hounam, C. E., Burgos, J. J., Kalik, M. S., Palmer, W. C., and Rodda, J.: 1975, *Drought and Agriculture: Technical Note No. 138*, World Meteorological Organization, Geneva, Switzerland.

Johns, R. J.: 1989, 'The Influence of Drought on Tropical Rainforest Vegetation in Papua New Guinea', *Mtn. Rsrch. Develop.* **9**, 248–251.

Kerr, R. A.: 1992, 'A Successful Forecast of an El Niño Winter: The Pacific Warming and Its Entourage of Floods and Heat Are Here on Schedule, Raising Hopes for Longer-Ranger Forecasts', *Science* **255**, 402.

Leighton, M. and Wirawan, N.: 1986, 'Catastrophic Drought and Fire in Borneo Tropical Forest Associated with the 1982–83 El Niño Southern-Oscillation Event', in Prance, G. T. (ed.), *Tropical Forests and the World Atmosphere*, American Association for the Advancement of Science, Washington, D. C., pp. 75–102.

Lins, H. F., Shiklomanov, I. A., and Stakhiv, E. Z.: 1991, 'Impacts on Hydrology and Water Resources', in Jäger, J. and Ferguson, H. L. (eds.), *Climate Change: Science, Impacts and Policy: Proceedings of the Second World Climate Conference*, Cambridge University Press, Cambridge, U.K., pp. 87–97.

Malingreau, J. P.: 1987, 'The 1982–83 Drought in Indonesia: Assessment and Monitoring', in Glantz, M. H., Katz, R., and Krenz, M. (eds.), *The Societal Impacts Associated with the 1982–83 Worldwide Climate Anomalies*, National Center for Atmospheric Research, Boulder, Colorado, pp. 11–18.

Malingreau, J. P., Stephens, G., and Fellows, L.: 1985, 'Remote Sensing of Forest Fires: Kalimantan and North Borneo in 1982–83', *Ambio* **14**, 314–321.

Markandya, A. and Pearce, D.: 1988, *Environmental Considerations and the Choice of the Discount Rate in Developing Countries*, World Bank Environment Department, Washington, D.C.

Nicholls, N.: 1987, 'The El Niño-Southern Oscillation Phenomenon', in Glantz, M., Katz, R., and Krentz, M. (eds.), *Climate Crisis: The Societal Impacts Associated with 1982–83 Worldwide Climate Anomalies*, National Center for Atmospheric Research, Boulder, Colorado, pp. 2–10.

Nicholls, N.: 1991, 'Teleconnections and Health', in Glantz, M. H., Katz, R. W., and Nicholls, N. (eds.), *Teleconnections Linking Worldwide Climate Anomalies: Scientific Basis and Societal Impact*, Cambridge University Press, Cambridge, U.K., pp. 493–510.

Pearce, D. W. and Nash, C. A.: 1981, *The Societal Appraisal of Projects*, John Wiley and Sons, New York, New York.

Philander, G.: 1989, 'El Niño and La Niña', *Amer. Sci.* **77**, 451–459.
Pittock, A. B. and Salinger, M. J.: 1991, 'Southern Hemisphere Climate Scenarios', *Clim. Change* **18**, 205–222.
Quinn, W. H., Zopf, D. O., Short, K. S., and Kuo Yang, R. T. W.: 1978, 'Historical Trends and Statistics of the Southern Oscillation, El Niño, and Indonesian Droughts', *Fish. Bull.* **76**, 663–678.
Ropelewski, C. F. and Halpert, M. S.: 1987, 'Global and Regional Scale Precipitation Patterns Associated with the El Niño/Southern Oscillation', *Mon. Wea. Rev.* **115**, 1606–1626.
Salafsky, N.: 1993, 'The Forest Gardens and Land-Use Spectrum of West Kalimantan, Indonesia: Ecological and Economic Diversity in a Locally Developed Agroforestry Based Land-Use System', Chapter 1 in *The Forest Garden Project: An Ecological and Economic Study of a Locally Developed Land-Use System in West Kalimantan, Indonesia*, Ph.D. Dissertation, Duke University, Durham, North Carolina.
Salafsky, N., Dugelby, B. L., and Terborgh, J. W.: 1993, 'Can Extractive Reserves Save the Rain Forest? An Ecological and Socioeconomic Comparison of Non-Timber Forest Product Extraction Systems in Petén, Guatemala and West Kalimantan, Indonesia', *Conserv. Biol.* **7**, 39–52.
Salati, E. and Nobre, C. A.: 1991, 'Possible Climatic Impacts of Tropical Deforestation', *Climatic Change* **19**, 177–196.
Second World Climate Conference: 1991, 'Final Statement of the Second World Climate Conference', *Environ. Conserv.* **18**, 62–66.
Shukla, J., Nobre, C., and Sellers, P.: 1990, 'Amazon Deforestation and Climate Change', *Science* **247**, 1322–1325.
Singh, I., Squire, L., and Strauss, J.: 1986, 'An Overview of Agricultural Household Models', in Singh, I., Squire, L., and Strauss, J. (eds.), *Agricultural Household Models*, World Bank, Washington, D.C., pp. 1–23.
Sircoulon, J.: 1991, 'Climate, Water, and Development', in Jäger, J. and Ferguson, H. L. (eds.), *Climate Change: Science, Impacts and Policy: Proceedings of the Second World Climate Conference*, Cambridge University Press, Cambridge, U.K., pp. 243–252.
Sokal, F. and Rohlf, A.: 1981, *Biometry*, Academic Press, New York, New York.
UNESCO/ROSTSEA: 1992, *Contending with Global Change, Study No. 5: Human Action to Control Global Climate through Designed Ecosystems*, UNESCO Regional Office for Science and Technology in Southeast Asia, Jakarta, Indonesia.
Walter, H.: 1983, *Vegetation of the Earth and Ecological Systems of the Geo-Biosphere*, 3rd edition, Springer-Verlag, Berlin, Germany.
Whitmore, T. C.: 1984, *Tropical Rain Forests of the Far East*, Clarendon Press, Oxford, U.K.

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