A Survey of Three Successive Recent Fire Seasons

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Background

There has been a long term trend of conversion of forest to agricultural land through the use of fire in Nicaragua. Fire is thus a major risk to forest resources since it is itself a cause of deforestation. It is also a prime indicator of human-induced land use changes, particularly land conversion from forest to agriculture. Monitoring of forest conditions and fire activity in particular is essential for the sound management of Nicaragua's important areas of forest resource and for the rational allocation of limited resources to meet fire threats and outbreaks.

Nevertheless, until recently, the available information on the occurrence, extent and impact of fires (and changes to the national forest estate generally) was limited in quality, quantity and timeliness. This presented a major handicap to forest management. While comprehensive analysis of fire data can improve understanding of fire activity and enable better management decisions to be made, such an approach may be a real challenge for a budget constrained government.

Fire monitoring through NOAA satellite data reception in Nicaragua

The UK Department For International Development (DFID) supported a joint environmental monitoring project between the Nicaraguan *Ministerio del Ambiente y los Recursos Naturales* (MARENA) and the Natural Resources Institute (NRI). MARENA is the government agency charged with responsibility for a sustainable management of renewable natural resources in forestry, and in other areas of environmental damage.

The overall purpose of the Nicaragua Land Resources (Fire) Monitoring Project was to encourage more integrated and sustainable environment monitoring methods in Nicaragua towards improved management of natural resources, particularly forests. The particular objective was to assist with appropriate and cost effective forest fire and environmental monitoring through utilisation of real-time local reception of data from environmental satellites and to evaluate their relevance and sustainability in the context of Nicaraguan institutions. The project ran from June 1995 to June 1998.

The project installed a PC-based NOAA satellite receiving ground station at MARENA headquarters in Managua to enable daily observation of active fires occurring in Nicaragua. This is used to assist forest protection, fire control and natural resource management activities in Nicaragua. Information products are generated on a routine basis and supplied to a number of Nicaraguan institutions at local, provincial and national level. Regional level information can also be generated and this is attracting a wider base of end users. The information on fire activity is delivered to departmental authorities in charge of fire control in the form of lists of co-ordinates with references to the 1:50,000 topographic map index and to observation towers where appropriate. At a local scale, this provides an early-warning tool for fire fighting.

At a national scale, the data are analyzed in their context (land cover, forest type, administrative divisions) by using GIS, to provide thematic information which can be used for example to locate possible deforestation fronts, helping to raise political awareness, or to direct extension programmes to promote adequate strategies, such as alternative land use.

Results

In Nicaragua, most fire activity occurs during the dry season, which stretches from the end of December up to the end of May. Three successive seasons were monitored by the project (1996 to 1998). Table1 presents a synthesis of the number of fires (i.e. hot pixels) that were detected in Nicaragua over these three seasons.

Tab.1. Number of detected hot pixels on Nicaraguan territory over three dry seasons

Year	January	February	March	April	May	Total Fire Season
1996	279	496	1,729	5,996	251	8,751
1997	88	174	575	4,359	4,334	9,530
1998	151	395	1,601	14,024	1,987	18,158

Figure 1 illustrates the typical West-to-East movement of fire activity in Nicaragua. The earliest fires (in January and even December some years) are generally observed only in the pacific region (the driest, most densely populated and most farmed region of the country). Two months later, the central mountain region begins to suffer outbreaks of fire activity. Toward April, fire activity invades the rest of the country and especially increases in the Atlantic region, although this has the lowest population density and the wettest climate.

January 1997

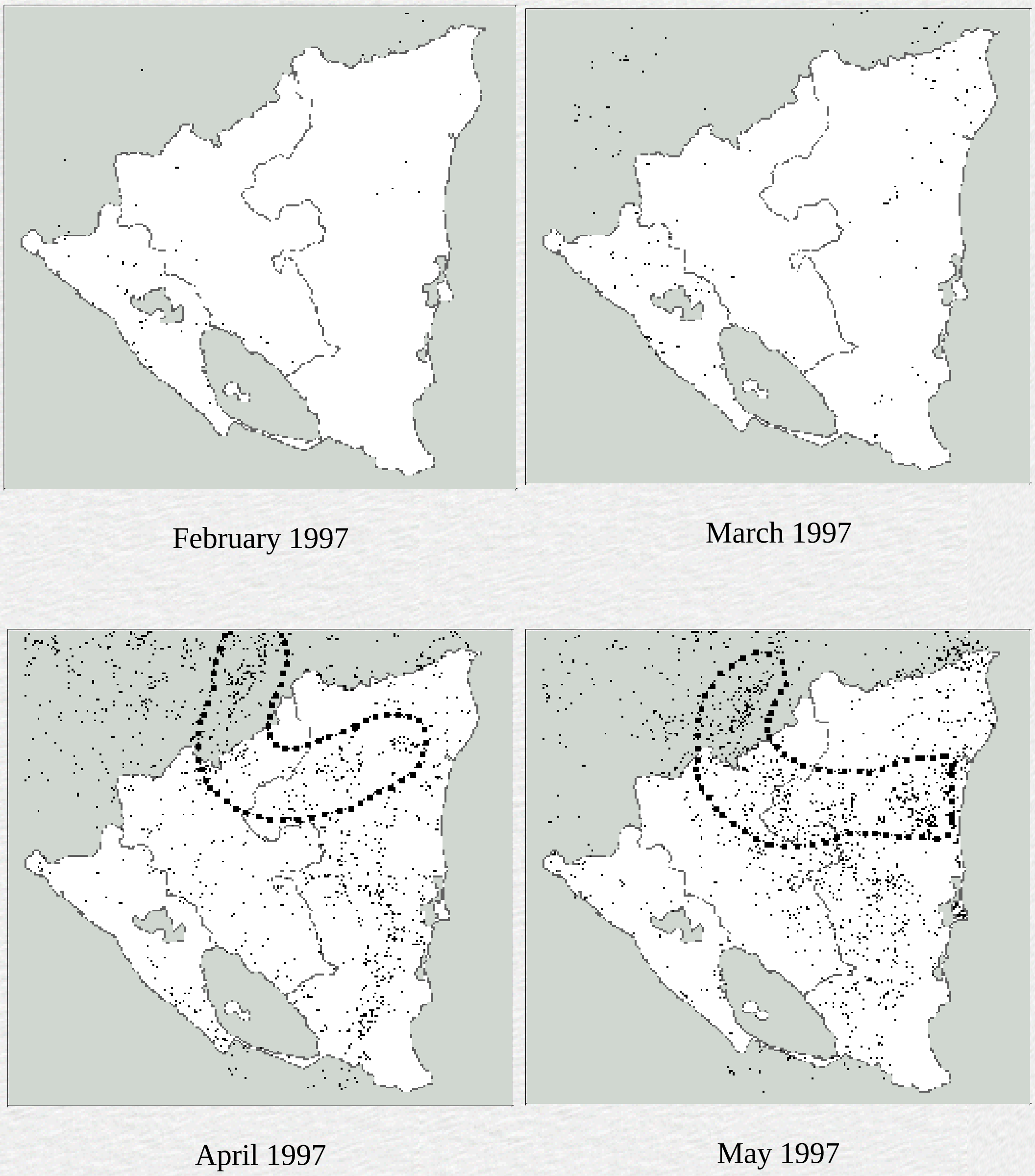

Fig. 1 : Monthly hot pixel maps for the 1997 fire season in Nicaragua. The inside boundaries represent the main geographical regions: Pacific Coast, Central Mountains, Atlantic Coast. The dotted line represents a likely 'human settlement belt' around one of the last large extensions of primary rainforest in central America.

Analysis

Data weighting

For various reasons, it was not possible to ensure an uninterrupted coverage of the respective periods. The rate of valid data captured varied slightly over the respective months and between years. In order to compare data from different seasons, the monthly and seasonal hot pixel number figures were weighted. The numbers of hot spots were divided by the respective numbers of days of actual data capture and multiplied by the total number of days in every month or in the whole fire season, as shown in Table 2.

Tab.2. Number of days of actual captures every month (maximum number of days in brackets)

Year	January	February	March	April	May	Total Season
1996	17 (31)	18 (29)	24 (31)	22 (30)	18 (31)	99 (152)
1997	13 (31)	13 (28)	23 (31)	19 (30)	19 (31)	87 (151)
1998	16 (31)	17 (28)	17 (31)	25 (30)	18 (31)	93 (151)

In this correction, we assumed that fire occurrence increases linearly and that acquired data are evenly distributed within every month, which may be close to the reality. On this basis, all the tables and diagrams shown below are produced from the figures weighted by number of captures. As shown in Table 3.

Tab.3. Weighted numbers of detected hot pixels

Year	January	February	March	April	May	Total Season*
1996	509	799	2,233	8,176	432	13,436
1997	210	375	775	6,883	7,071	16,541
1998	293	651	2,919	16,829	3,422	29,482

* The figures under 'Total Season' are not the sums of all the months, but are the 'raw' figures of Table 1 divided by the total number of captures and multiplied by the total number of days as shown in Table 2.

After three years of monitoring, a number of observations can be made, based on these data. It appears that fire activity can show a different pattern in each season. For example, it began rather early in 1996 and rather late in 1997. Unusually, in 1997, most of fire activity occurred in May. 1998 has been the most dramatic year in terms of fire occurrence by far; most of which was caused by an increased burning activity throughout the country. There is a likely cause-effect relationship with the exceptional level reached by *El Niño* phenomenon in late 1997 to early 1998, which is reported to have induced a very severe and long drought (WFP 1998).

Fire occurrence in its context

As indicated above, it is critical to analyze fires in their context. As a first approach, we compared the detected fires (i.e. hot pixels) with available geographical information on:

- administrative boundaries (140 municipalities, 17 departments, 3 main regions) (MARENA, 1995)
- land use; dividing the country into 11 categories, including gross forest types, according to inventories dating from 1988 to 1992 (see Fig.2) (MARENA, 1995)
- population and rural poverty rate in each municipality (Lacayo 1998).

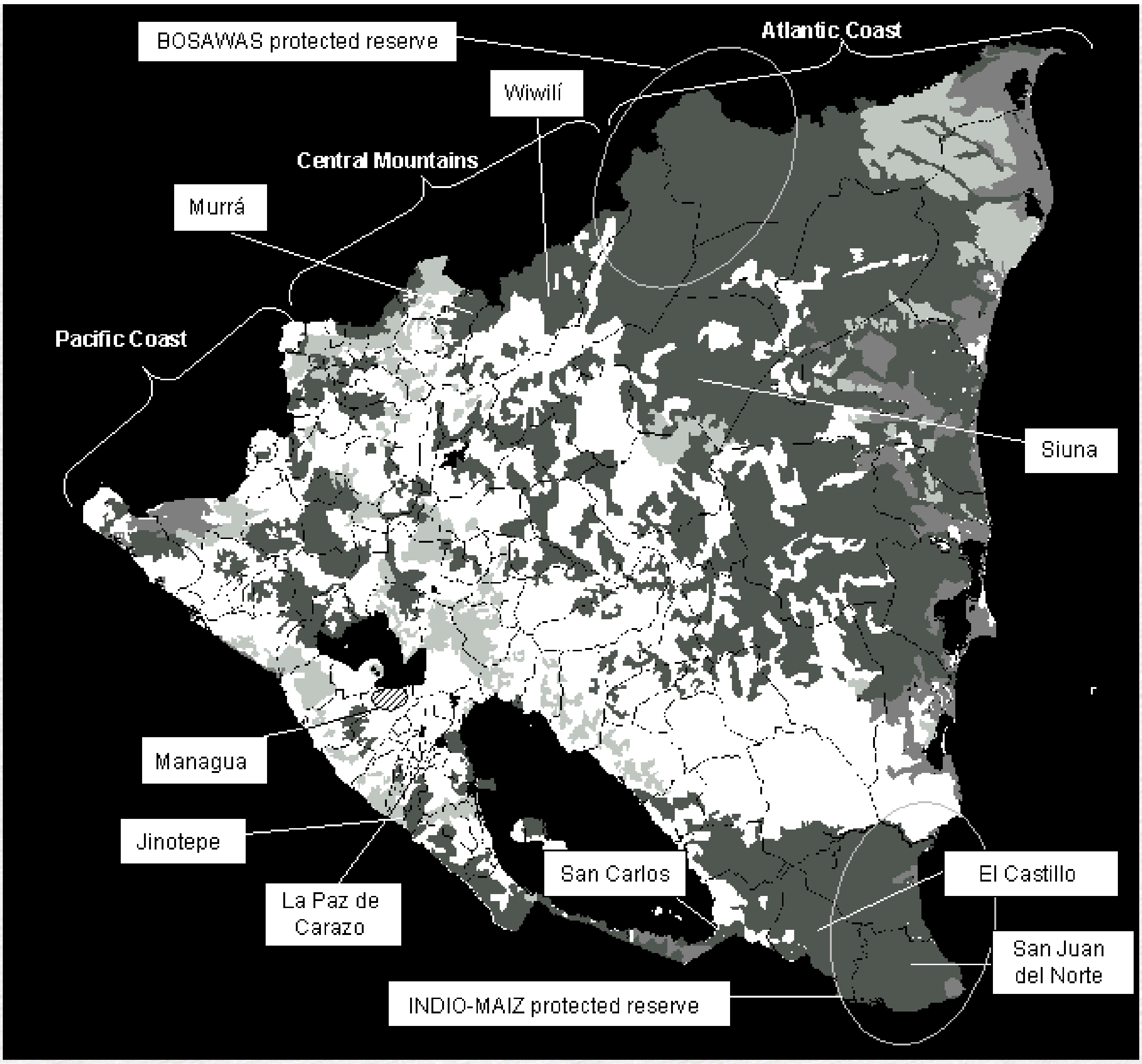

Fig. 2 : Land use and municipality map of Nicaragua (Marena 1995) For clarity the 11 original land use categories have been gathered into 4 new classes, which are:

- Dark grey : broadleaf evergreen forests (>20m, 12 to 20m) and forest fallows
- Middle grey : mangroves, swamps and wet lands
- Light grey : pine forests and tropical deciduous dry forests
- White : crops and pastures, incl. perennial crops, other marginal categories and areas outside the study area

Tables 4 and 5 show the fire occurrence distribution according to the geographical regions, and to the gross land use categories, respectively.

Tab.4. Numbers of hot pixels in each geographical region, over three seasons (weighted figures)

Year	Pacific Coast	Central Mountains	Atlantic Coast	Total
1996	1,550	3,548	8,318	**13,436**
1997	1,920	3,891	10,730	**16,541**

1998	1,287	6,103	22,092	**29,482**
Ancillary information				
Area (km^2)	18,702.61	36,136.42	66,594.04	**121,433.0**
% forested	41,58%	43,06%	74,16%	**59,90%**
Population	2,467,742	1,354,246	535,111	**4,357,099**

Absolute figures draw attention to the lowland broadleaf evergreen forest areas, where the highest number of fires occurs. If those numbers are considered in relative terms however, it can be seen that the percentage of fires in those forests with regard to the total number of fires in the whole country is not significantly different from the proportion of territory they occupy, at least as far as the two first years are concerned. But the increase observed in 1998 is significant (from around 35 to 37 % to more than 44 %). Both tables 4 and 5 make clear that the drought caused by *El Niño* phenomenon and the consequent increase of fire activity mostly affected the evergreen rainforest that lies across the wide Atlantic plain.

The density of 'fires' (hot pixels) was also investigated. In this way, the size of the respective areas is taken into account, since it is obvious that, whilst the greatest fire occurrence has been registered in the Atlantic Coast region (Tab.4), this one also covers the largest territory, representing more than half of the country. Observing fire occurrence density, expressed in number of hot pixels per 10km^2, reveals that forest fallows as well as swamps and inundable lands have been the two most affected zones by fire activity over the three monitored seasons. Hot pixel density in swamps and wetlands nearly doubled between 1997 and 1998 (Tab.5). This is likely to be a direct effect of an *El Niño*-related drought, making those areas more prone to be burned than usual. This observation might mean that burning activity is exerting an increasing pressure particularly on wetlands. These are essentially located along the Atlantic coast and play an evident ecological role in the balance of the large catchments which drain the eastern half of the country. Most of these aquatic or semi-aquatic ecosystems are included among the highest priority areas in terms of biodiversity value (World Bank 1997).

Forest fallows are assumed to correspond to land parcels temporarily left to forest recolonization inside complex forest-crop-pasture mosaics, at the margins of larger forest areas. The high fire activity observed there implies an acceleration of the traditional migrant agriculture cycle and then an increased reconversion to crop or pasture, which dramatically increases the fragility of soils that were already considered as marginally or not suitable for agriculture (Herrera 1995).

Intuitively, but also according to the results in Tables 4 and 5, features such as a high proportion of forest, and a fairly low population density but with a high proportion of rural poor, would seem to be a typical combination to observe a high fire occurrence density. But fire activity is so complex a phenomenon that studying it on a case-by-case basis is likely to result in more relevant information than trying to find correlations between variables over the whole set of data. For example, the five municipalities which had the highest observed hot pixel density for every season were selected. These were examined with respect to the other recorded features (% forested area, population density, % poverty rate) corresponding to each municipality. This is shown in Table 6.

Tab.5. Number of hot pixels by type of land cover in Nicaragua (weighted figures)

Forest types	Area (ha)	%	Hot Pixel Occurrence 1996			Hot Pixel Occurren	
			Absolute Number	Proportionin the country	Density No./10 km^2	Absolute Number	Proportion the countr
Broadleaf evergreen forest > 20m	4,358,121.44	*36.56*	4,699	34.97%	1.06	6,226	37.64%
Broadleaf evergreen forest 12-20 m	1,195,853.58	*10.03*	1,452	10.80%	1.20	1,627	9.84%
Broadleaf deciduous forest 4-12 m	487,653.25	*4.09*	459	3.42%	0.93	556	3.36%
Pine forest	595,901.94	*5.00*	501	3.73%	0.83	809	4.89%
Mangrove	145,987.90	*1.22*	121	0.90%	0.82	244	1.47%
Crop or pasture land	4,335,413.31	*36.37*	5,169	38.47%	1.18	5,522	33.39%
Perennial crop (e.g. coffee)	221,342.10	*1.86*	180	1.34%	0.80	177	1.07%
Swamp and wetland	496,050.79	*4.16*	745	5.55%	1.48	1,254	7.58%
Small islands	11,850.96	*0.10*	0	0.00%	0.00	2	0.01%
Forest fallow	59,130.57	*0.50*	105	0.79%	1.77	115	0.69%
Rocky outcrop	11,677.04	*0.10*	5	0.03%	0.39	9	0.05%
Total	**11,918,982.88**	***100***	**13,436**	**100.00%**	**1.11**	**16,541**	**100.00%**

Tab.6. Features of the municipalities with the five highest fire occurrence densities per season.

	San José de Cusmapa	Central Mountains	3.48	57.91%	37.04%	74
	Nueva Guinea	Atlantic Coast	2.30	7.73%	7.73%	28
	El Rama	Atlantic Coast	2.20	45.36%	43.99%	13
	San Miguelito	Atlantic Coast	2.13	76.05%	76.05%	12
1997	La Paz de Carazo	Pacific Coast	3.87	0.00%	0.00%	223
	Jinotepe	Pacific Coast	3.86	56.14%	56.14%	194
	Murrá	Central Mountains	3.41	73.31%	67.45%	23
	Prinzapolka	Atlantic Coast	2.81	92.55%	69.86%	1
	Wiwilí	Central Mountains	2.68	55.35%	55.35%	18
1998	Siuna	Atlantic Coast	5.91	80.15%	80.15%	12
	Nueva Guinea	Atlantic Coast	5.38	7.73%	7.73%	28
	El Castillo	Atlantic Coast	5.24	96.85%	96.85%	6
	Cruz del Rio Grande	Atlantic Coast	5.03	75.21%	74.04%	2
	San Carlos	Atlantic Coast	4.73	47.04%	34.98%	19
Average over the 3 seasons	Murrá	Central Mountains	3.65	73.31%	67.45%	23
	Siuna	Atlantic Coast	3.32	80.15%	80.15%	12
	Nueva Guinea	Atlantic Coast	3.19	7.73%	7.73%	28
	Cruz del Rio Grande	Atlantic Coast	3.14	75.21%	74.04%	2
	Wiwilí	Central Mountains	2.90	55.35%	55.35%	18

Table 6 shows that in 1997, the most affected municipalities are two densely populated ones in the Pacific Coast region, with a fairly low proportion of rural poor population. One of them has even no forest coverage at all. This is clearly in opposition to the expected combination as mentioned above.

The case of the municipality of Nueva Guinea (south-east of Nicaragua) is one of particular interest. In average over the three monitored fire seasons, it is third in terms of hot pixel density (3.19/10 km^2), although its forest coverage rate is fairly low (7.73 %). This broad municipality has undergone a strong expansion of settlement and land clearing for a long while, since it has been particularly devoted to developing livestock production. Focused field studies might confirm that fire activity there is essentially aimed at refreshing pasture for cattle. Moreover, its forest coverage was particularly struck by Hurricane Joan which devastated the south-eastern coast of Nicaragua in 1988 and created an open 'track' within the original broadleaf evergreen forest (Ciesla 1997).

Siuna, which also lies on the Atlantic coast region of Nicaragua but in the north-east, is very different. It also had a high average fire density over the three seasons but still has a high forest cover proportion. As this municipality is at the junction of the two highways linking the west to the east of the country, it is subject to increasing pressure from both sides of those roads. In addition, the main traditional economic activity there used to be mining, which is not as space consuming as livestock rearing or migrant agriculture. With the recent decline of this 'industry', lots of small miners lost their jobs and remained without resources (Stührenberg 1996). A more intensive settlement process then began, invading the primary forest gradually. Hot pixels maps clearly show a 'settlement belt' around those large forest extensions, which include the Bosawas Biosphere Reserve.

Both Murrá, the most fire affected municipality on average over the three seasons, and Wiwilí, which has the fifth highest hot pixel density over the same period (Tab.6) are in the Central Mountains region. Although the same consideration about land clearance pressure can be made (it is actually the ‘western’ settlement front of the same large forest area), another factor might influence fire activity. That part of Nicaragua is arguably the region most affected by the '*desarmados*' problem that appeared at the end of the civil war in 1990. Indeed, when peace was signed, several thousands of ex-soldiers from both sides were given a little land in order to facilitate their return to a civil life after several years fighting. But most of them knew nothing of agriculture and in most cases they were left alone, with fire as their only clearance tool.

Another interesting fact is observed when comparing two neighbouring municipalities, in the extreme south-east of Nicaragua, along the San Juan River which makes the boundary with Costa Rica: El Castillo and San Juan del Norte. According to the land cover map, those territories have 97 % and 96 % covered by broadleaf evergreen primary forest respectively. But the difference between them in terms of hot pixel density is significant (see Tab.7).

Tab.7. Comparison between two neighbouring municipalities

Municipality	Region	% Forests (all types)	% Broadleaf Forests	Population Density	% Rural Poor
San Juan del Norte	Atlantic Coast	99.66%	95.85%	0.16	9.59
El Castillo	Atlantic Coast	96.85%	96.85%	5.85	77.76
Hot Pixel Density (No./ 10 km^2)					
Municipality	**Region**	**1996**	**1997**	**1998**	**Average**
San Juan del Norte	Atlantic Coast	0.00	0.00	0.12	0.04
El Castillo	Atlantic Coast	1.62	1.65	5.24	2.84

An explanation can be found in the fact that San Juan del Norte is almost completely situated within the protected Indio-Maiz natural reserve, while El Castillo is mostly crossed by its buffer zone, which is subject to a high migrant agriculture pressure (Valerio 1998). Population figures clearly show that in the latter, the population is generally rural and poor, thus dispersed throughout a large part of its territory. In the former, although the population is perhaps as poor, it is concentrated in the municipal capital, just on the Caribbean littoral. Along with Bosawas Reserve, Indio-Maiz Reserve, which is the core zone of the 'Si-a-Paz' protection area, is the last primary tropical rainforest area of relevant extension that still remains intact in Nicaragua. But despite all, fire activity also increased notably there in 1998.

Conclusions

Results from three complete seasons clearly indicate fire incidence, severity and variation over time and between different regions. The availability of this time series information enables inter-year comparisons, initial studies of fire distribution within the country and analysis of seasonal trends.

Our interpretation demonstrates the potential of such data to increase understanding on extent and type of fire. It is critical to be able to discriminate detected fires between 'good' and 'bad' fires according to their impact on the environment, by including them in the ecological, social and economical contexts. This study also emphasises the importance of accurate and updated ancillary data to enhance appropriate interpretation of the information provided by the satellite imagery.

What was achieved throughout this Project is very encouraging. There is now a greater appreciation and knowledge, within MARENA and on the part of forest managers and a number of local authorities, of the relevance, importance and use of NOAA/AVHRR data to assist monitoring and evaluating forest fires. A small scale remote sensing unit is now established and managed on a routine basis. In parallel, GIS capacity there has also experienced a recent and spectacular development, either in different divisions of MARENA or in other government agencies.

Up to now, Nicaragua has had no means to monitor the situation effectively and thus make informed decisions on natural resource pressures, effectiveness of policies, and areas to prioritise. Within the context of existing forest fire and natural resources management, Nicaragua now has a cost-effective mechanism to demonstrate the scale and nature of the problem and to adapt its policies accordingly. Nicaragua will also be able to use the same tool as a verifiable indicator to monitor the effectiveness of protection measures.

It is in this way that this low-cost and decentralised technology transfer may manage to bear fruit: by contributing to a better allocation of human and logistical resources, and improving forest fire prevention and control strategies.

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