DEGRADED FORESTS ARE MORE SUSCEPTIBLE TO FOREST FIRES: SOME POSSIBLE ECOLOGICAL EXPLANATIONS

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ABSTRACT

There is a strong belief that degraded forests are, more susceptible to forest fires than non-degraded ones but this is more intuitive than scientifically proven. The present study was conducted to investigate how fuel loading and moisture content of combustible materials; two variables that influence ignition and fire impact and therefore forests' susceptibility to fire, differ in forests with different levels of degradation. The study was done in Tain II Forest, situated in the northwest part of the forest zone and adjacent to the savanna woodland. Three forest sites compared in this experiment were categorized as slightly degraded, moderately degraded and heavily degraded. Fuel loading was determined using the planar transect method (Brown 1974). Sampling was done on forty 200m long line transects laid in each forest site. To determine fuel and soil moisture content, wood particles and soil were monitored for changes in moisture content from November to February in the main dry season using the oven dry method. The overall pattern showed significant increases in fuel loading in more degraded forest sites. The fuel moisture content decreased from less degraded sites to heavily degraded sites for all types of fuel. The moisture content of soil sampled from the first 5cm depth was significantly lower in more degraded sites. Below 5cm depth, however the differences were not significant. These observations may explain why degraded forests have a higher likelihood of ignition and severer levels of fire damage once there is fire.

Keywords: Degraded forests; Forest fires; Fuel loading; Moisture content

INTRODUCTION

A significant portion of Ghana's high forest reserves lies in a climatic belt with a pronounced dry season where wild fires on agricultural and fallow lands are almost an annual ritual, and these fires do often enter the forests causing various degrees of fire damage. There is therefore a high tendency to blame the incidence of forest fires only on agriculture and related activities that take place essentially outside the forest boundaries. However, prescriptions resulting from forest management objectives may significantly alter the likelihood of the forest catching fire as well as the impact that the fire will have on the forest. When a forest is well protected and a close canopy maintained, its susceptibility to accidental fires, may be relatively low because a lot of conditions that predispose it to fire are held in check.

Ecological studies have established the fact that isolated and infrequent fires were known in the dry forests of Ghana long before fires began to destroy the forests completely but the fires were unable to wipe out the forests (Swaine, 1992) most probably due to the then limited level of human interference in the ecosystem. Swaine *et al.* (1997) have suggested that a combination of reduced canopy cover leading to a drier, more flammable forest; the invasion of *Chromolaena* weed which is flammable but re-grows strongly after fire; further reduction in tree cover by logging; a somewhat drier and warmer climate; and a steady increase in farming activities may be the reasons for the frequent and devastating forest fires.

The analogy here is that whilst the location of a piece of forest may increase its likelihood of being burnt, the treatment and use to which the forest is put are equally important in influencing this probability.

In this study an attempt was made to determine how forest degradation brought about by a combination of logging and frequent fires predisposes the residual forest to fire.

The specific objective was to determine the differences between fuel loading and particle size distribution as well as moisture content of combustible materials and soil in the dry season in forests that have received different levels of logging and burning resulting in three distinct levels of degradation.

MATERIALS AND METHODS

Study site

The study was conducted in Tain II Forest Reserve (7^{o} 35"N; 2^{o} 30"W), which has an area of 509.2km^{2}. The reserve lies within the Fire zone subtype of the Dry Semi-deciduous Forest. It has a bi-modal rainfall pattern with a major and minor peak in June and October respectively. The main dry season is from November to March and there is a second dry spell in August. The mean annual rainfall is 1200mm and the maximum and minimum annual temperature for 26 years were 23.6^{o}C and 26^{o}C respectively (Orgle, 1994). Relative humidity in the dry season ranges from 100% at night to 30% near midday when the harmattan is strongest.

The reserve has been extensively burnt and logged but with variable severity. This makes it possible to compare the effect of different levels of degradation on forest's susceptibility to fire. Three forest sites compared in this study were categorized as slightly degraded, moderately degraded and heavily degraded. The slightly degraded forest had a continuous upper canopy and little undergrowth with tree basal area (gbh>10cm) ranging from 27.7 - 26 m^2/ha. The moderately degraded site had a patchy canopy and basal area of 19 - 17.3m^2/ha whilst the severely degraded site was a thicket of *Chromo-laena odorata* with virtually no trees (basal area of 0.23 - 0.3m^2/ha).

Determination of fuel loading and fuel characteristics

Forty line-transects of length 200m each were randomly laid in each site. Because the fuels in the three sites were unevenly distributed 40 sampling points were chosen along each transect as recommended by Brown (1974). The methods in Brown (1974) for establishing the planar transect method for fuel analysis were followed. For each diameter size class of the fuel sampled, a particle was selected randomly from each sampling plane and its length measured. Mean values were calculated for each size class.

Determination of soil and fuel moisture content

For each site four sampling points were demarcated and woody material of varying diameters (0-2cm, 2.1-4.1cm, 4.2-6.2cm and 6.3-8.3cm) were deposited at the sampling points. Samples were taken from the deposited materials at monthly intervals and the moisture content determined by the oven dry method. Litter and live herbaceous vegetation around the deposited woody materials were also sampled and treated likewise. Soil samples at three different depths (0-5cm, 5-10cm, and 10-15cm) were taken from each point monthly within the sites for moisture content determination using the above method.

RESULTS AND DISCUSSION

Site variation in fuel loading

The overall pattern indicated increasing fuel loading in more disturbed forests (Table 1). Using mean values for all size classes based on 160 sampling points an analysis of variance showed that these differences were highly significant ($F_2 = 9004.325$, $P<0.05$). An examination of the fuel loading of different fuel size classes in the three sites also suggested that forest degradation affects the distribution of fuel particle size. Whilst heavier particles contributed more fuel in almost all the sites, more degraded forest sites had a higher proportion of their fuel from small diameter class materials.

Site variation in fuel moisture content

Generally there was a gradual decrease in fuel moisture content from November when the monitoring started to February when the experiment had to be terminated due to an extensive bush fire that swept through the entire forest. For all size classes of woody materials, higher rates of moisture loss from the slightly degraded through the moderately degraded to the heavily degraded sites were recorded. The differences were in all cases statistically significant ($P<0.05$, Table 1). This could be attributed to the increased evaporation from the fuel samples as a result of exposure to direct sunlight in the heavily degraded site where almost all the big trees have been removed through logging. Beazley (1993) observed that the removal of the forest cover changes the illumination at ground level from a small fraction to a full daylight. This results in increases in temperature range and the average and minimum humidity of the air become much lower, thereby increasing the rate at which forest fuels lose moisture. One should therefore expect more open forest canopies to be associated with higher levels of moisture loss.

The site variation in fuel loading and particle size distribution can be attributed to logging and recurrent fires. Whelan (1995) reported that total fuel load in slash created by logging can reach 100 – 600 tons per acre in tropical forests. Recurrent fires may actually reduce the amount of large woody materials on the ground through regular burning and therefore removal. Nevertheless the rapid colonization and build up by small woody pioneers after each fire incidence could lead to heavy phytomass accumulation on the ground. This may result in an overall heavier fuel load in fire-damaged forest as observed in this study.

Table 1. Fuel loading (tons/ha) and moisture content of deposited fuel in the dry season (November – February) at forest sites with different levels of degradation in Tain II Forest Reserve

Fuel particle diameter (cm)	Slightly degraded forest		Moderately degraded forest		Heavily degraded forest	
	Fuel load	%Moisture content	Fuel load	%Moisture content	Fuel load	%Moisture content
0-2.0	3.11	14.81	11.73	13.81	40.95	11.51
2.1-4.1	12.86	15.91	37.85	14.25	65.47	12.56
4.2-6.2	23.31	15.49	32.59	14.25	14.95	12.67
6.3 – 8.3	-	17.48	-	15.79	-	13.53
Total fuel load	39.28	-	82.17	-	121.37	-

As expected smaller-size materials dried faster than bigger ones. Of the already dead and dry combustible materials, forest floor litter consisting basically of leaves had the highest rate of moisture loss. The moisture content at the end of February was about 48% lower than what obtained in November in the slightly degraded forest whilst for the heavily degraded site the drop was about 60%. For wood samples of diameter less than 6cm the average monthly moisture loss ranged from 5% in the relatively good forest to 7% in the heavily degraded forest. Corresponding figures for the largest samples (18 –24cm) were 2.5% and 7.7% respectively (Fig.1). The intermediate fuel materials had values between these. It has been observed that changes in weather affect fine fuels faster and these could gain or lose 63% of their moisture in just an hour (Ford-Robertson, 1971).

Live herbaceous materials and litter lost moisture in the same manner as in wood except that change was more drastic especially in the green material (Fig. 2 and 3). In the heavily degraded site for instance moisture content dropped from 76% in November to 22% by the end of February. For both materials moisture differences in the three sites became more pronounced as the dry season became severer.

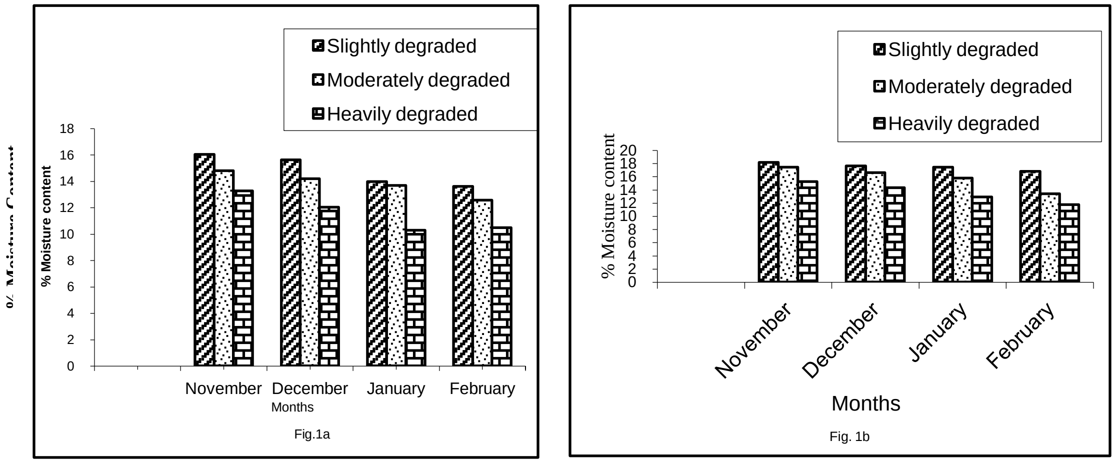

Fig.1a

Fig. 1b

Figure1. Changes in moisture content of woody materials <2cm diameter (Fig.1a) and >6.3<8.3 diameter (Fig. 1b) from November to February at three forest sites in Tain II Forest Reserve

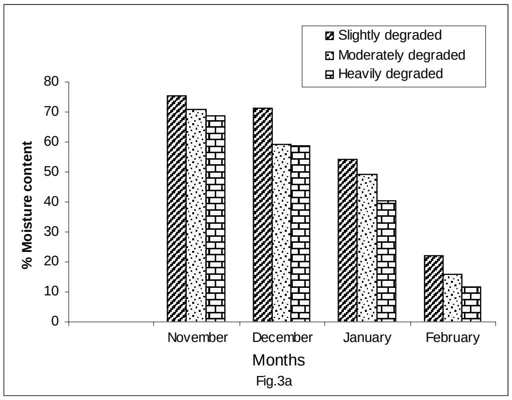

Fig.3a

Figure 2.Changes in moisture content of Chromolaena dominated green herbaceous materials in the dry season (November to February) at three forest sites with different levels of degradation in Tain II Forest Reserve.

One of the popular speculations about bush fires in Ghana is that *Chromolaena odorata* an exotic weed, plays a key role in the present forest fire regime. The present study has confirmed this role. This plant, which is a pioneer species and therefore confined to more open conditions allows a greater biomass to develop at ground level and provides more fuel load and consequently more intensive fires. Green vegetation is generally less combustible compared with litter or dead wood because of its high moisture content (Whelan, 1995). However, in the case of *Chromolaena* the large drop in moisture content from 68.6% of live biomass in November to less than 12% in February implies the plant is more of a fire hazard than a possible retardant even whilst still green. Orgle (1994) found that moisture contents of various components of fuel load did not differ significantly between two forest sites with different levels of degradation except for live *Chromolaena* which was somewhat lower in the degraded forest. Therefore using moisture content as an indicator, even live *Chromolaena* is more likely to ignite and burn than dead wood in the dry season.

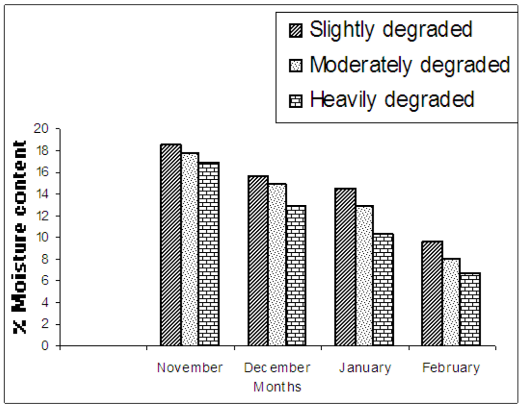

Figure3. Changes in moisture content of forest floor leaf litter in the dry season (November to February) at three forest sites with different levels of degradation in Tain II Forest Reserve.

Site variation in soil moisture content

The moisture content of soil sampled from the 0 – 5cm depth differed significantly between the three sites ($P<0.05$) and the trend was that of percentage moisture content of soil decreasing with the severity of degradation. For the other depths the differences were not significant. Actually in the 10 –15cm depth, the tendency was rather towards a higher, soil moisture content in the moderately degraded forest and least in the slightly degraded (Table 2). The soils from the surface layer appeared to contain more moisture than those lower down in the slightly and moderately degraded sites but this was not the case for the heavily degraded site. These results can be attributed to the forest canopy differences between the sites. The extent to which soil moisture evaporates has been linked to the degree of forest canopy loss (Johns, 1997). It has long been observed that the removal of the forest canopy exposes the soil surface to direct sunlight, surface temperatures fluctuate more widely and rise to a higher maxima, occasionally up to 45°C; and the accompanying moisture evaporation leads to considerable drying of surface layers (Corbet, 1935).

Despite being the topmost layer litter had higher moisture content for the various sites, than soil from the 0 – 5cm depth. This confirms the observation made by Kimmins (1997) that litter forms a superficial organic layer that plays an important role in regulating soil moisture status and evaporation from soil surface. Litter may therefore actually play a better role in reducing soil moisture loss than tree shade.

Susceptibility of the various sites to fire

The heavy fuel load and the high rates of moisture loss observed in the degraded portions of the forest suggest that the degraded site is more susceptible to ignition and therefore likely to suffer from wildfires. The amount of fuel load an area contains determines how vigorously a fire will burn it since fuel load has influence on reaction intensity, flame heights and residence time (Whelan, 1995). A traditional method of reducing fire risk is to employ early burning to reduce the amount of fuel load an area contains so that later and fiercer fires could be avoided.

Table 2. Percentage Moisture content of soils sampled from three depths in the dry season at forest sites with three levels of degradation. Sampling was done in a Dry Semi-deciduous forest with a mean annual rainfall of 1200mm.

Time	***Slightly degraded***			***Moderately degraded***			***Heavily degraded***		
	0-5cm	*5-10cm*	*10-15cm*	*0-5cm*	*5-10cm*	*10-15cm*	*0-5cm*	*5-10cm*	*10-15cm*
November	*9.98*	*8.55*	*7.73*	*10.88*	*9.20*	*8.70*	*9.35*	*8.78*	*9.73*
December	*8.10*	*5.60*	*5.58*	*8.15*	*6.78*	*7.45*	*6.32*	*7.1*	*7.50*
January	*7.65*	*5.33*	*4.78*	*7.28*	*6.05*	*6.95*	*5.03*	*3.88*	*4.95*
February	*5.15*	*3.33*	*2.78*	*4.23*	*3.80*	*4.63*	*4.05*	*3.45*	*3.78*
Mean	*7.72*	*5.7*	*5.19*	*7.64*	*6.46*	*6.93*	*6.19*	*5.8*	*6.49*

The incidence of fire in a forest plays a role in the future vulnerability of the same forest to fires. A strong view held by Swaine *et al.* (1997) on forest's susceptibility to fires is that the effects of fire are progressively augmented by a history of prior fires. This is presumably due to profuse growth of undergrowth following a fire event, which apparently dries up in the following dry season to offer a more conducive fuel bed for the next fire. Thus a burnt forest is more likely to burn again than a non-burnt one.

Logging on the other hand, creates fire risks by opening the canopy, allowing proliferation of easily combustible herbaceous vegetation and the drying of logging debris (Beazley, 1993). It is argued that only where forest canopies are opened artificially, such as by logging are fire incursions frequent and potentially threatening to the forest community. Large quantities of fuel increase the vulnerability of a site to ignition because they determine the maximum energy available to fire and they also help to carry the fire. The extensive forest fires in Borneo during the drought of 1982-83 were exacerbated by large quantities of dry logging debris on the forest floor (Richards, 1996). In the Ivory Coast tree mortality following an accidental fire increased with increases in forest disturbance caused by logging and thinning (Berthault, 1992). Casual observations show fires do not easily start under closed canopy forest unless the forest is unusually dry because in most cases there is insufficient dry combustible material on the ground to spread the flame (Longman and Jenik, 1987). On the contrary more open canopy conditions, created by logging allows greater biomass to develop at ground level, which combined with more dead wood, provides a greater fuel load and fiercer fires (Kellman and Tackaberry, 1997).

Even where large fuel loads exist in closed canopy forest communities, fires do not frequently enter because of the stable microclimate. In the dry season of 2001 fire entered a compartment of Worobong South Forest Reserve along a logging road and did a lot of damage in a felled block within the compartment but could not burn the rest of the non-logged closed canopy forest (Pers. observ.).

Therefore although logging cannot be advanced as primary cause of forest fires (Hall and Swaine, 1981), the rapid insurgence of bush fires since 1983 can be partly attributed to logging which reached its peak in these forests in the said period. Prior to the early 80s logging in the fire-prone forests was very limited and highly selective because the forests were regarded mainly as protected forests. Consequently fires were less active in these areas. The introduction of *Chromolaena odorata* also a major fire risk factor, can be linked to logging since apart from fire, logging is the major means of opening the canopy large enough to make *Chromolaena* habitation possible in the forest. In the Amazon forests, Holdsworth and Uhl (1997) linked logging to forest fires and suggested that low impact logging techniques are required to reduce the risk of fire.

The fuel characteristics described above have other implications. For example we may expect higher tree mortality after fire in degraded forests. Tree seedlings may have little if any chance of surviving fires in such sites and therefore forest recovery will be severely impaired. The fact that fire may occur more frequently also in degraded forest should caution forest managers to be more strategic in dealing with these forests. Firm and decisive policies are needed either to convert all degraded forests into plantations, which of course will need even more fire protection or efforts should be made to achieve zero fire incidence.

When to expect fire in the forest

An important inference that can be made from tracing the changes in fuel moisture content is the probable time to expect forest fires. The earlier termination of the experiment did not make it possible to build a complete profile of soil and fuel moisture dynamics in the dry season for the various sites. However, one could identify a clear trend in diminishing moisture content as the dry season progressed. The occurrence of the accidental fire at the end of February presumably signified a critical level of moisture in the forest fuels. Long-term records show that in Ghana forest fires have, a much higher probability in February (Orgle, 1994). Thus,together with weather data fuel moisture content can be used to predict the occurrence of fire in the forest. The changes in moisture content of combustible materials probably explain better why more fires occur at the end of the dry season rather than the months with the lowest average rainfall (sensu Swaine *et al.*, 1997). Variations in moisture loss in fuels also suggest that more degraded forest patches could burn earlier than relatively undisturbed ones.

CONCLUSIONS

The results of the study indicated that more degraded forests have significantly higher levels of fuel load as well as a lower moisture content of soil and combustible materials in the dry season than less degraded forest areas. This may explain why degraded forests have a higher likelihood of ignition and severer levels of fire damage once there is fire. Forest management in the dry forest zones need careful planning to minimize disturbance that could lead to degradation and increased fire hazard. Therefore fire-prone forests may, be better protected by excluding or minimizing logging and other canopy disturbances.

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