Technical Centre for Agricultural and Rural Cooperation CTA

The Effects of Cyclone Val On The Vegetation Of Western Samoa

Institute for Research, Extension and Training in Agriculture (IRETA)
USP Alafua Campus
Western Samoa

Published by : The Institute for Research, Extension and
Training in Agriculture (IRETA)
USP Alafua Campus
Apia
Western Samoa

Printed by : IRETA Print Media

Production : Emil Adams

Inputing : Ms Susie Pedebone

ISBN: 982-175-115-6

The Effects of Cyclone Val On The Vegetation Of Western Samoa

by James Epila-Otara
USP Alafua Campus

The Institute for Research, Extension and Training in Agriculture (IRETA)
USP Alafua Campus
Western Samoa

FOREWORD

It is now nearly five years since cyclone Val struck W. Samoa which lies on the North Eastern part of the South Pacific region. The wounds Val inflicted on both living and non-living aspects of human lives in this country are no longer that visible -- time and rehabilitation effort by the government and the people of W. Samoa have healed most of them up. But the scars of these wounds in some cases will not disappear so easily. For example, a great many woody plant species carry dead branches and tops. The coconut industry was virtually wiped out. The people suffered great economic losses.

It is indeed needless to say that before Val, there have been countless number of cyclones of varying destructive forces. Fortunately, we have forgotten the pain and suffering they brought to the people. And yet, what we see around us on these islands, especially the flora and fauna are subtle synthetics of past cyclones.

Thus, if cyclones do indeed mean so much to the islands of the Pacific economics, biology, ecology, conservation efforts and/or environment at large, then its important to us to do everything possible to minimise their impacts by regularly monitoring and documenting their impact. Such documents will provide permanent records of the effect of cyclones on the fauna and flora and the countries at large.

Dr Epila-Otara's technical report is perhaps the first such report which describes the impact of cyclone Val on the vegetation of Western Samoa with emphasis on the island of Upolu. This report records some startling insights into the post-cyclone plant recovery and reproductive strategies of selected woody plant species. The pictures included in this report tell graphic stories of the cyclone which I believe will remind both the people who lived through the Val's ordeal as well as those who were fortunate to have escaped it. This report now pushes the frontier of the two brief previous ones: the Ofa Saga recorded by Mr Trevor Clark in 1992 which emphasised the impacts on agricultural crops and that on a series of cyclones whose impacts on the natural and plantation forests were reported by Wood (1970).

The data presented in the report will serve two very critical purposes -- information for those involved with disaster management and rehabilitation work; and those working in conservation and environmental protection areas.

This report can also serve as useful reference material for students of agriculture and forestry at High Schools and Universities.

Let me conclude by saying that this report is a challenge to us all who deal with environment related activities to see that it is used to the fullest because it is about what we in the South Pacific fear most -- the cyclones.

The printing and distributing of this report was made possible through a grant kindly provided by CTA. The USP/IRETA acknowledges its sincere thanks and gratitude to CTA.

I must also acknowledge IRETA's appreciation to Dr James Epila-Otara for taking time to undertake research and produce this excellent reference manual on the impact of cyclones on our biota.

Mohammed Umar
Director, Institute for Research, Extension and Training in Agriculture (IRETA)

The Effects Of Cyclone "Val" On The Vegetation Of Western Samoa

Abstract: The effects of cyclone Val on the vegetation of Western Samoa were monitored from the end of the cyclone (10.12. 1991) through June 1993. Physical damage during the storm varied with vegetation strata. Vegetation in the lower stratum was hardly affected while those occurring in the higher strata were seriously affected. The canopy and subcanopy tree species were defoliated, deblossomed; had their twigs and branches broken off and many snapped at varying heights above the ground. Few coconuts were decapitated. Some of the trees which retained their leaves during the cyclone were severely sunburned and their leaves withered and dried up momentarily. ***Pinus, Araucaria*** spp., ***Casuarina equisetifolia*** and some aboriginal woody species were never defoliated by the storm. Treefall occurred selectively among older trees of coconut, ***Albizia chinensis, Artocarpus altilis*** and ***Ficus obliqua***.

Post-cyclone leaf flushing, flowering and fruiting of woody species in peri-urban villages of Apia, the capital of Western Samoa were variable. Three models of leafing were observed: leaf growth initiated by the old shoots, growth of epicormic shoots on old twigs and branches which had suffered dieback and epicormic branch development. These refoliation models varied amongst species; some plants refoliated exclusively from the old shoots, others combined old shoot/epicormic shoot strategies while some only recovered through epicormic branches. Whichever model the species adopted, refoliation predominantly started from the bottom of the canopies and progressed upwards. However, plant species with umbrella-shaped canopies such as ***Delonix regia*** tended to refoliate spontaneously. And some woody species began leafing from the southern aspect of their canopies. Branch dieback was particularly common on Eucalyptus and mango trees. Deblossomed trees initiated off-season breeding bouts weeks or months later. Similarly, the storm induced premature off-season breeding in some woody plants. However, regardless of the nature of response to the storm, flowering and fruiting in many plants were scarce and erratic.

Introduction

Cyclones in the Pacific Ocean are inherently weaker than their Atlantic counterparts (Stoddart 1969) and in southern Pacific, their winds move in a clockwise direction; with greatest wind speed in the left forward quadrant just outside the eye (Anfinson and Harris 1973). Here, frequency of occurrence of cyclones vary with longitudinal location. Cyclones are more frequent in parts of the ocean closer to Australia and tend to move southwesterly before dying down somewhere between latitude 26 and 30° south (Crane 1991).

Because of strong winds, heavy rainfall, salt spray and associated flooding, cyclones affect plants and animals very profoundly. Typically, the aftermaths of most cyclones are analogous to wild fire (**Fig. 2**). Even then, each cyclone affects plants and animals differently. These effects are evident either immediately or delayed (Stoddart 1969). For example, in severe storms most animals are killed outrightly. And every plant that survives such storms may be debilitated for a long time. Debilitation begins when plants are defoliated, deblossomed, uprooted, or stems snapped off, crowns decapitated, branches and twigs broken off and defoliated plants sunburned. The degree of susceptibility to any of these impairments depends on a number of factors. For example, defoliation may depend on the species, age, crown shape and position in the canopy, leaf texture, size and shape, relation with other vegetation and whether the plant is situated on the leeward or windward side of the island being lashed by the cyclone (Fosberg 1961a). Similarly, trees may be toppled as a result of topography (altitude and slope), imbalance in the root-canopy development, mal-adapted rooting strategy, crown shape etc. Bole snapping is related to tree species, age, pre-disposing altitudes and terrains and wood quality. And sunburn is a function of age of plants and tissues exposed and the degree of defoliation suffered. Similarly, most plants that survive the onslaught of cyclones have their biological rythyms altered. Shifts in biological rythyms of course affect the life systems of the plants themselves and the life styles of animals which depend on such plants. For instance, the food ecology of most herbivorous animals are grossly interfered with especially during the several weeks that follow the cyclone. Plant recovery from cyclone impacts is also species-specific although the process is undoubtedly mediated by the pre-cyclone phenological and physiological states of the plants (Ewusie 1980) and other related factors.

Surprisingly, very little has been reported on the environmental impacts of cyclones in the South Pacific island countries. Wood (1970) reported the cumulative effects of three consecutive cyclones on Western Samoan forest. Jordan (1980) claimed that approximately 90% of the Mexican lime trees in Niue were levelled by cyclone "Ofa" which struck the island in December 1979. Clarke (1992) made an extensive narrative of the consequences of cyclone "Ofa" on the agriculture of Western Samoa, Anfinson and Harris (1973) described the environmental impact of cyclone "Bebe" which struck the Fiji group in October of 1973 and Crane (1991) has published some graphic pictures of cyclone damage in Tonga. The environmental consequences of cyclones in northern Pacific are well documented (e.g. Marie-Helene Sachet 1957, 1962; Fosberg 1961a,b; Wiens 1961, 1962; Trujillo 1971; Ragone 1988) and so are the Atlantic hurricanes (Stoddart 1963, 1969). This paper reports the impact of cyclone "Val" on the vegetation of Western Samoa. First, the paper reviews the climate and major vegetation formations of Western Samoa. And describes briefly cyclone Val before reporting its effects on the vegetation. Woody plants **(Tables 2 and 3)** on which post-cyclone leaf flushing, flowering and fruiting were observed comprised of both exotic and indigenous species. From the outset, it is important to realize that it was difficult to separate the delayed effects of cyclone Ofa of February 1990 from those of Val.

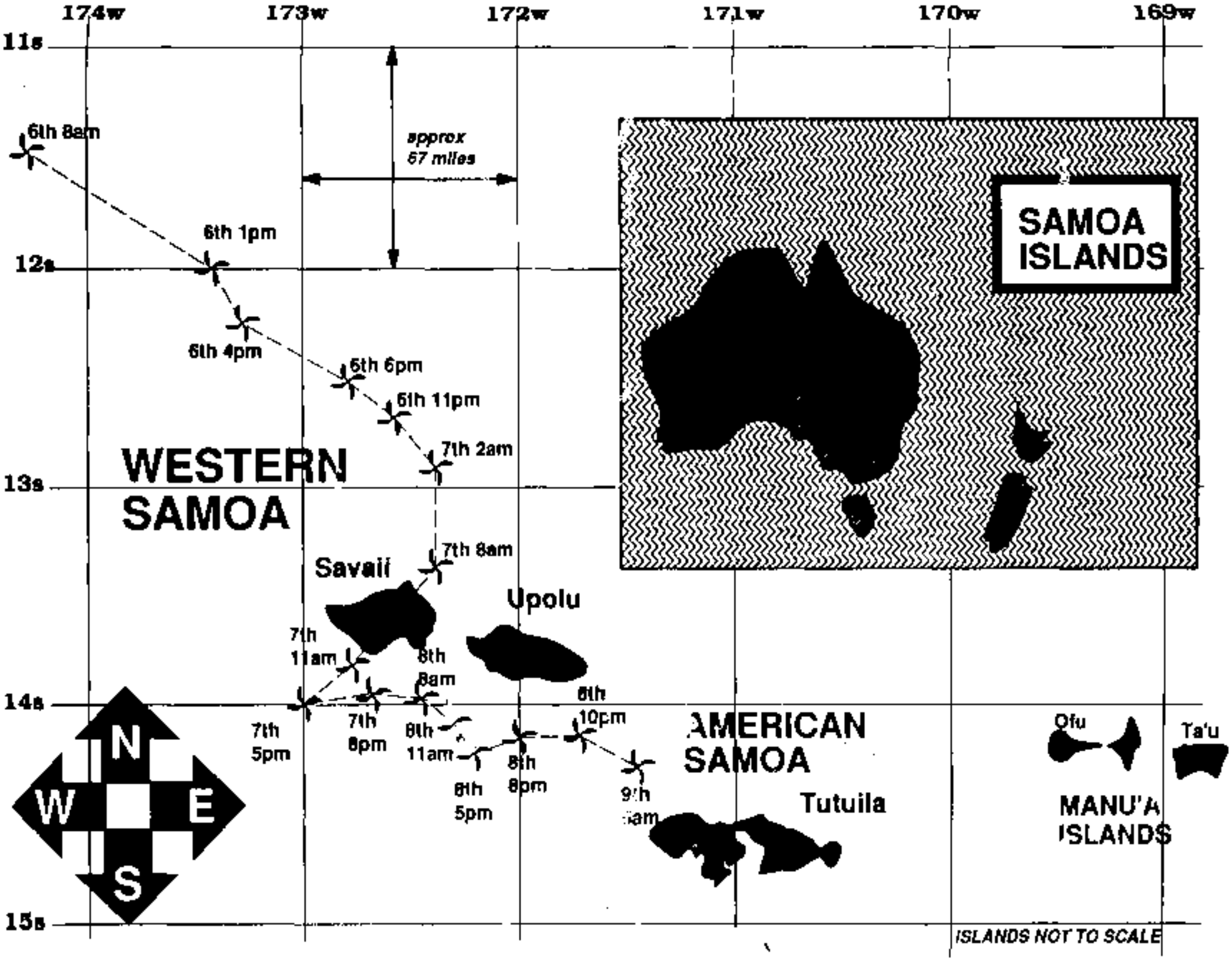
Climate of Samoa

Samoa is situated in the middle of the Pacific ocean at about 13 to 14° S and 168 to 171° W. Therefore its climate is both latitudinally tropical, and maritime due to the prevailing influence of the surrounding sea (Whistler 1980). The average annual temperature and humidity are 27° C and 80 % respectively. The hottest months are January through March and the coldest months are only 2 degrees cooler. The prevailing winds in Samoa throughout the year are the southeast trade winds. And the average windspeed during the year is 18-20 mph (Wright 1963). Rainfall is monomodal: the wettest period is from

December to March. And much of the rain during this period is due to tropical storms, technically known as cyclones. Two main factors account for the pattern of rainfall: one is the position of an area in relation to the prevailing winds and the other is elevations. Windward sides of the islands get more rain than the leeward sides. Similarly, higher altitudes get more rain than otherwise. Although Samoa is peripheral to the cyclone belt, these tropical storms periodically hit the islands, sometimes with devastating results (Wood 1970) although Buxton (1935) stated that the two or three cyclones which were then recorded yearly from Samoa were not very violent or destructive. Here, the cyclones have sharply defined season: one-third occurs in January and three-quarters in the first three months of the year. From May to November they are extremely rare. Cyclones come to Samoa from the north or the east. Since 1968, no cyclone has ever struck Samoa before Ofa, 1990; Val, 1991; and Lin, 1993. According to an unwritten record, the worst cyclone which hit Samoa was in 1889 (Imo, personal communication). The story goes that during this storm all but one of the ships which had docked at Apia harbour were destroyed.

Cyclone Val

Of the three recent cyclones, Val was the most violent. Val developed from a tropical depression to the southeast of Tuvalu Island on 4 December 1991. The system reached cyclonic wind force on 5 December and was named "Cyclone Val". Strong northerlies caused Val to change direction to a more southeast course and it headed for Samoa group of islands (Anon.1992). The spatial and temporal behaviour of Val in the vicinity of Samoan archipelago is shown in **Fig.1**. Val sustained gusty winds of about 90-130 knots and lingered on for about 4 days around Samoa moving at less than 8-10 knots per hour in a south-easterly direction. Over Western Samoa, two wind systems developed during the cyclone: the northeast on the first 3 days and westerly on the night preceding the end of Val. Comparatively, the northeast winds were less fierce than the westerly winds. Indeed, it was the westerly winds which caused extensive damage of both man-made and natural structures in Savaii and Upolu. No rainfall information is available from Western Samoa during the storm. In any case it is questionable whether standard rain gauges could



Track of Cyclone Val over Samoa. Reprinted from Samoa Observer, 6 Nov. 1992 have given an approximation of a mainly horizontal rainfall. Stoddart (1963) however, notes that rainfall is generally concentrated near or a little ahead of the cyclone centre.

Vegetation of Samoa

Notwithstanding cyclones, the prevailing climatic conditions of Samoa fosters a lush growth of tropical evergreen forest which floristically resembles the Tongan and Fijian flora (Balgoony 1971 and Whistler 1980). This original vegetation has been savaged out of existence in many islands of the group. And this disturbance hampers classification of the vegetation. Buxton (1935) reported that there are over 800 flowering plants in Samoan archipelago of which 30% are endemic to Samoa or to one island in Samoa. Characteristically, seasonal changes in the vegetation are difficult to detect despite the fact that particular species of plants and trees have definite breeding seasons. Setchell (1924) attributed differential floral phenology to temperature; a view which Buxton (1935) did not accept on the ground that Samoan temperatures are remarkably equable to cause differences in flowering episodes. He however suggested that the cause could be great differences in solar radiant heat received at different seasons.

Samoan vegetation are distributed in repeatedly occurring plant communities. Whistler (1980) divided these communities into two categories: climax and disturbed communities. Climax communities are those in which the component species perpetuate themselves through reproduction. Disturbed communities are those which have undergone some severe disturbance, either man-made or natural. Sixteen communities characterise the climax category. And these are arranged in four categories: littoral, wetland, rain forest and scrubby summit vegetation. Whistler (1980) notes that all the 16 plant communities are found in both Eastern and Western Samoa, with the possible exception of the cloud forest which may be absent from the latter islands. He further noted that there are however several communities found in Western Samoa which do not occur in Eastern Samoa (e.g. montane marsh and the vegetation on lava flows).

Littoral vegetation occurs along the sea shore and is dominated by plant species whose presence and distribution are affected directly or indirectly by the sea. In this community, ***Barringtonia asiatica, Pisonia grandis, Hernandia nymhpaeifolia, Calophyllum inophyllum, Erythrina variegata, Terminalia catappa, Pandanus tectarius*** and ***Ficus scabra*** are most common while occasionally one may come across ***Diospyrus elliptica, Diospyrus samoensis, Hibiscus tiliaceus, Cocos nucifera, Thespesia populnea, Guttarda speciosa, Morinda citrifolia, Messerschmidia argentea, Premna obtusifolia*** and ***Grewia crenata*** as well. In the wetland, the following species of vascular plants are dominant: ***Acrostichum aureum, Cyclosorus interruptus, Eleocharis dulcis, Ludwigia octovalis*** and ***Rhynchospora corymbosa***. And ***Bruguiera gymnorhiza*** is the dominant tree in the mangrove forests of Samoa.

Six rainforest communities are recognisable: the community dominated by (i) ***Diospyros*** spp- ***Syzygium*** spp, (ii) ***Syzygium inophylloides***, (iii) ***Dysoxylum samoense***, (iv) ***Pometia pinnata*** , (v) ***Dysoxylum huntii*** and (vi) ***Syzygium samoense***. The physiognomy of these forests is fairly uniform. Average basal areas ranged from 0.59 to 0.81 m^2 per 100 m^2, densities from 8.8 to 52.4 trees per 100 m^2 and heights from 15 to 30 m (Whistler 1980). The average basal areas in particular are markedly different from the mean global basal area of 32m^{2}per 100 m^2 (Hawkins 1959) and suggest that Samoan rainforest is either very young or is frequently disturbed by rather catastrophic natural forces (Hall and Swaine 1981). Similarly, it is not certain whether leaf size and shape of Samoan rainforest species is predominantly mesophyll class-size as recorded by Richards (1964) for a number of tropical rain forests. Nor is it possible to tell whether as one passes from the small trees and undergrowth to canopy species, the average type of leaf becomes progressively smaller, thicker and more leathery in texture (see Richards 1964). The species composition of the forest is, however, quite comparable to other tropical rainforests. The important species in the ***Diospyrus-Syzygium*** complex are ***D. samoensis, E. variegata, D. elliptica, Ficus obligua, Syzygium chustifolium, Syzygium deallatum, Planchonella liggensis, Rhus taitensis*** and ***Terminalia catappa***. In the ***Syzygium inophylloides*** community, ***C. samoense, P. liggensis, Fagrrea berteriana, Canarium samoense, Intsia bijuga, R. taitensis*** and *S.* ***samoense*** are important. The ***Dysoxylum samoense*** only has three important tree species: ***Myristica fatua, Neonauclea forsteri*** and ***Dysoxylum maota***. The order of relative abundance in the ***Pometia pinnata*** community is as follows: ***D. samoense, Planchonella torricellensis, N. forsteri, S. inophylloides*** and ***M. fatua.*** Seven species dominate the ***Dyspyrus huntii*** community, the ***Myristica hypargyraea, Buchanani merrillii, C. samoense, M. fatua, Crossostylis biflora*** and ***S. samoense***. The typical tree species in the ***Syzygium samoense*** are ***Cyathella*** spp, ***Weimannia affinis, Astronidium pickeringii, D. huntii, F. berteriana, Syzygium samarangense*** and ***Ascarina difusca.*** And the common woody plants in the montane community are ***Pandanus reineckei, Rapanea myricifolia, Syzygium brevifolium, Astronidium*** sp, ***Metrosideres collina, Alstonia godeffroyi*** and ***Spiraeanthemum samoense***.

Whistler's (1980) classification of the rainforest differs from Wright's (1963) and Parham's (1972). Nevertheless, all of them recognised that the distribution of many tree species of these forest formations overlap; prompting Whistler to observe that the rainforest of Samoa extends from the edges of the mangrove and littoral forests up to the cloud forest at the highest elevations. Another common characteristic of these forest communities is that the following tree species are the canopy species: ***D. samoense, P. torricellensis, N. forsteri, P. pinnata, Inocarpus fagifer, S. inophylloides, Macaranga stipulosa, B. merrillii, R. taitensis, C. samoense, D. huntii*** and ***Alphitonia zizyphoides*** with the rest of the woody species forming the subcanopy species (Whistler 1980). Typically, these forest communities have more or less open floors with epiphytes and climbers complementing their complexity. Similarly, the majority of woody plants of the littoral community are the same species that occur on most Pacific atolls (Fosberg 1961 a,b).

Vegetation of disturbed communities is in a state of flux. And is invariably dominated by exotic plants grown mainly for food, timber and ornamentals. The common crop plants of W. Samoa are **coconut, taro, ta'amu, cassava, yam, banana, breadfruit, mango, vi, pawpaw, cashew, avocado, cocoa, nonu, guava, orange, grapefruit, lemon, lime, pineapple, passion fruit, kava, coffee, maize, sugarcane, bean, groundnut, tomato, pumpkin, water melon, cucumber, chinese cabbage, head cabbage, lettuce, celery, and egg plant** (Anon. 1990). Most of the timber species are now naturalised and are growing in the wild (Parham 1972). Typical examples are the ***Albizia*** species which have invaded abandoned plantations of coconut in many areas of Upolu and Savaii. The recently introduced timber species such as ***Eucalyptus saligna*** and ***Eucalyptus grandis*** are yet grown in plantations and in parklands as ornamentals (**Figs. 31 and 32**). The following are ubiquitous ornamentals in W. Samoa: ***Delonix regia, Jacaranda mimosaefolia, Bauhinia*** spp., ***Spathodea campanulata, Mussaenda x philippica, Jatropha integerima, Bourgainvellia, Plumeria acuminata, Casuarina equisetifolia***, pines, ***Araucaria*** spp., ***Cassia simea*** and ***Cassia spectablis.***

Thus in summary, it can be stated that Samoan vegetation is evergreen, colourful; vigorously growing and invariably fruiting throughout the year. However, because of unknown reason(s) (probably cyclones) rainforest trees of Samoa do not attain optimal volume increments as reflected in the comparatively low average basal areas (Whistler 1980 and Hawkins 1959). And this was more or less the state of the vegetation when cyclone Val struck in December 1991; upsetting the physiology and reproductive strategy of every plant as well as disfiguring these plants in various ways.

Study techniques

Several techniques were used to investigate the effects of Val on the vegetation. Superficial physical damages were visually inspected, described and whenever the subject was exemplary, it was photographed. Woody trees toppled during the cyclone were censused along 30 km coastal road of northern Upolu from Faleolo international airport eastwards. Diameter at breast height (dbh) and the approximate direction of the tree falls were also recorded. Leaf flush was studied on tree species commonly found in peri-urban villages of Apia. The canopy of 2 to 7 refoliating trees of each of the species listed in **Table 2** was divided into cardinal quarters: north, east, south and west as well as vertically into bottom, mid and top crowns. Temporal progress of zonal foliage and epicormic shoot recruitments were monitored weekly with or without the aid of a binocular until the activity ceased. Flowering and fruiting episodes with special emphasis on ***D. regia, Albizia chinensis, Mangifera indica, Spondias dulcis*** (Vi), and ***Bauhinia monandra*** were observed around Apia (**Table 3**). Emphasis was placed on the above species because they are socio-economically important, and were abundant and characteristically conspicuous and easily identifiable in the field especially when in bloom. Five test trees of each of these species were earmarked as soon as they completed refoliation. Flowering intensity of these trees was visually scored thus: very intense, intense, less intense and not flowering. Fruit settings were similarly scored.

Results

Damage During the Cyclone

The effects of Val on the vegetation were profound and varied with canopy strata. Plants of the lower vegetation stratum (e.g. grass, herbs, seedlings and saplings) were the least affected (**Figs. 2, 3 and 4**). These plants were never defoliated, many resisted sunburn, few were broken or toppled. The staple crop plant, taro survived the storm quite well (**Fig. 5**). Short and hardy crops like peanut (**Fig. 6**) and pineapple (**Fig. 7**) also resisted the storm. However, a number of herbaceous crops such as tomato, bean, cucumber etc were very sensitive to the cyclone (e.g. **Fig. 8**). Evidently, even saplings of trees which were susceptible to defoliation during the storm, looked physically unaffected (**Fig. 9**).

Vegetation in the higher strata suffered tremendously. Firstly, a very significant proportion of the canopy and subcanopy plant species (Whistler 1980) were totally stripped off their leaves (**Figs. 3 and 4**). Some plants retained their leaves but these soon dried up when the cyclone stopped (e.g. **Figs. 9 and 10**) while pines, ***Auraucaria*** spp. and ***C. equsetifolia*** retained their leaves throughout the cyclone and thereafter (e.g. **Fig. 11**). Mango trees of Kensington variety and lime trees also retained their leaves during and after the cyclone. Even the coconut which because of its architecture is purported to be very resistant to cyclones was severely brutalised by the westerly winds (**Fig. 12**). Except pawpaw (**Fig. 13**) all the fruiting trees and to a marked degree, coconut (**Fig. 12**) lost their fruits during the Val onslaught. Few fruits that remained on the trees withered and died within days after the cyclone (e.g. **Fig. 14**). And apart from banana and coconuts, all the edible and/or commercial fruits were unsalvageable. Val broke the twigs and branches of nearly every tree. Stem breakage was definitely extreme and very nearly wholesale for the banana crop all over the country (**Fig. 15**). Census revealed that along the northern coast of Upolu, the following tree species suffered the worst treefalls: coconut, breadfruit, ***Albizia chinensis*** and ***F. obliqua*** (**Table** 1). These trees succumbed during the initial stages of the cyclone as most fell in the westerly direction (**Table 1**). Several factors were suspected to have contributed to the treefalls. The coconut which got toppled were obviously old trees (**Fig. 16**). Similarly, only old, incredibly huge ***Albizia*** trees (**Table 1**) with root systems (**Fig. 17**) spreading on the surface layers of the soil fell during the storm. All the overthrown Ficus trees were on the beaches. Again comparatively, the fallen trees were gigantic; suggesting that most probably collapsed under their own weights as a result of repeated undermining by the tidal waves. Breadfruit trees develop from root shoots of older trees (Ragone 1988). Characteristically, these trees produce masses of feeder roots (**Fig. 18**) near the surface of the soil to augment the "mother" roots. And this trait together with densely foliated crowns made breadfruit trees susceptible to windthrow.

Table 1. Census result of treefalls along 30 km coastal road on northern Upolu during cyclone Val [Figures in brackets are sample sizes].

			% Fall Direction	
Species	No.	mean DBH (cm)	West	East
Cocos nucifera	123	33.6 (11)	80	20
Artocarpus altilis	85	36.9 (11)	77	23
Albizia chinensis	71	127.8 (8)	56	44
Ficus obliqua	8	102.6 (8)	20	80
Others	27	-	70	30

At high altitudes, woody plants suffered severe stem breakages as evidenced by the tree stand (**Fig. 19**) at Afiamalu, Upolu (ca. 500m asl) and ***Eucalyptus*** trees (**Fig. 20**) at Puapua, Savaii (ca.200m asl). The interesting point about the ***Eucalyptus*** in Savaii was that its saplings in a plantation in the southern coastal lowland did not suffer as much stem breakage.

Plant Recovery

Recovery was either natural or induced. Thus, several physiotherapeutic treatments were given to a number of domesticated or semi-domesticated tree crops. For example, breadfruit, S. ***dulcis***, ornamentals such as ***Ficus*** were lopped, pollarded, pruned or limbed and uprighted soon after cyclone. Similarly, broken stems of nonfruiting banana trees were also cut to stimulate regrowth. Such banana trees responded within the week following the storm (**Fig. 21**). Similarly, woody plants which were not given any form of post-cyclone treatment also initiated new growth just about the same time (**Table 2**). In the second week following the cyclone, practically every plant species in the study areas had flushed new leaves. And except the lopped or pollarded breadfruit trees situated within 100m or less from the ocean (**e.g. Fig. 22**) and ***Eucalyptus*** spp. (**e.g. Fig. 31**) which took approximately three to four months to produce leaves, all the woody plants completed refoliation within the first two months after cyclone Val.

Leaf flush in woody plants was achieved in three principal ways. Leaves were either produced by the old shoots or epicormic shoots (**Figs. 23 and 24**) and epicormic branches (**Fig. 25**). And this varied from species to species. Shoots, twigs and branches of a number of tree species never recovered from the sunburn and therefore such species depended solely on the production of epicormic shoots on the older branches (**Fig. 24**) and epicormic branches (**Fig. 25**) to recover while in contrast, tree species with thick fleshy shoots (e.g. ***P. acuminata***, avocado, ***T. catappa***, pawpaw, etc) only used the old shoots as a bridgeway to full recovery. Breadfruit trees whose branches had not been lopped or pollarded adopted both strategies (**Fig. 23**) although clearly, the majority of such trees to the west of Apia town refoliated through epicormic shoots. Another interesting observation about breadfruit was that the trees which were lopped or pollarded presumably after cyclone Ofa (**Fig. 22**) took longer to refoliate and did so through development of epicormic shoots only. Other species like guava, mango, lime, and ***E. subumbrans*** also adopted old shoot/epicormic shoot refoliation strategy.

Leaf production in 64% of the woody plants studied (**Table 2**) began at the bottom third of the crowns (**Fig. 26**). Refoliation of the crown then progressed upwards either at a faster or protracted rate (**Table 2**). Exception to this rule however were the species in which leaf flush was spontaneous all over the crown. Typical examples of these dramatic species were the ***D. regia*** and ***T. catappa***. It was difficult to tell whether the mechanisms governing leaf flush in both species were the same. The two species are of course taxonomically unrelated. But architecturally, they branch similarly: plagiotropically although yet again, both grow in height differently (Halle et al. 1978). Ewusie (1980) reported that in West Africa, ***T. catappa*** may flower about four times in a year with hardly any break between the shedding of the old leaves and the growth of fresh ones. Observation of post-cyclone abscission revealed that once again, ***T. catappa*** abscissed and refoliated most of its leaves synchronously (**Figs. 27 and 28**). Thus providing circumstantial evidence for speculating that total defoliation of ***T. catappa*** by Val probably simulated a natural phenological event which stimulated a natural response.

Fig.2 Views of western slope of Mt. Vaea (a) and Alafua river valley (b) approximately 30 minutes after Val.

Fig.8. Damage of staked tomatoes; Alafua, Upolu (approx. 40 min. after Val)

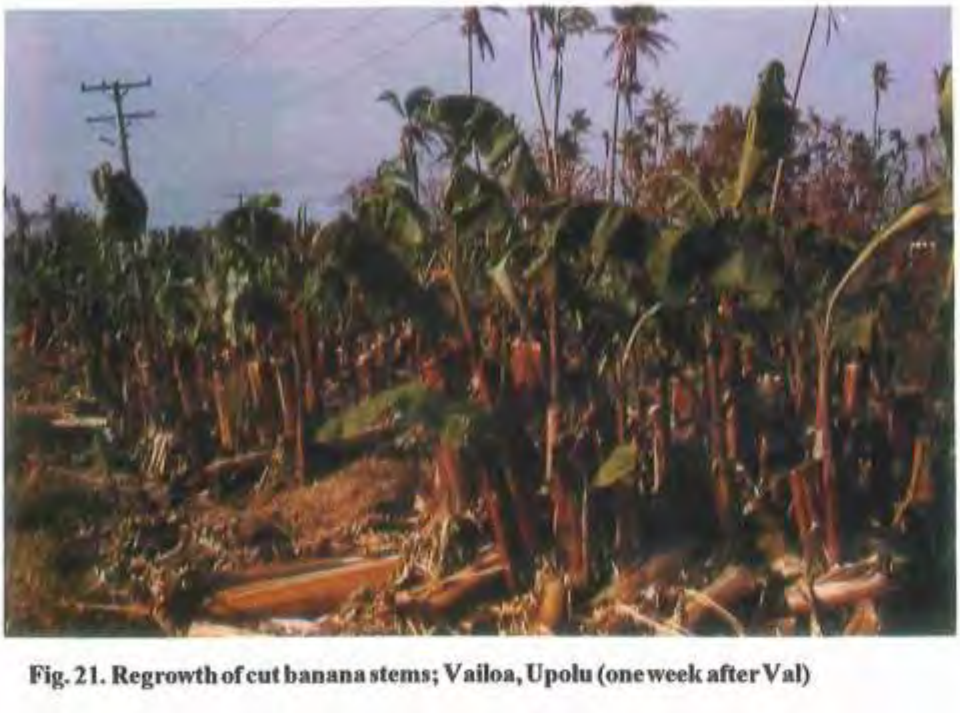


Fig. 21. Regrowth of cut banana stems; Vailoa, Upolu (one week after Val)

Fig. 3. Grass in a fallow at Alafua Campus, approximately 30 minutes after Val.

Fig.4. Vertical damage gradient of vegetation at Alafua Campus (approximately 20 minutes after Val)

Fig.23. Leaf flushing and growth of epicormic shoots on breadfruit.

Fig. 19. Mass stem breakage of native trees; Afiamalu, Upolu. [500m asl]

Fig. 24. Epicormic shoots on partially dead branches of *Albizia falcataria*

Fig. 20. Mass stem breakage of Eucalyptus; Puapua, Savaii. [200m asl]

Fig.9. Terminalia catappa sapling and breadfruit, Vaimoso, Upolu (Two days after Val).

Fig. 10. Mango tree retaining dry leaves; Moto'otua, Upolu (Two days after Val).

Fig. 16. Windthrow in old coconut plantation at Puipa'a, Upolu.

Fig. 15. Wholesale stem breakage of banana; Siusega, Upolu

Fig. 17. Root system of overthrown Albizia chinensis;

Fig. 18. [illegible]

Fig. 22. Pollarded breadfruit trees approx. 3 months after Val; Piupa'a, Upolu.

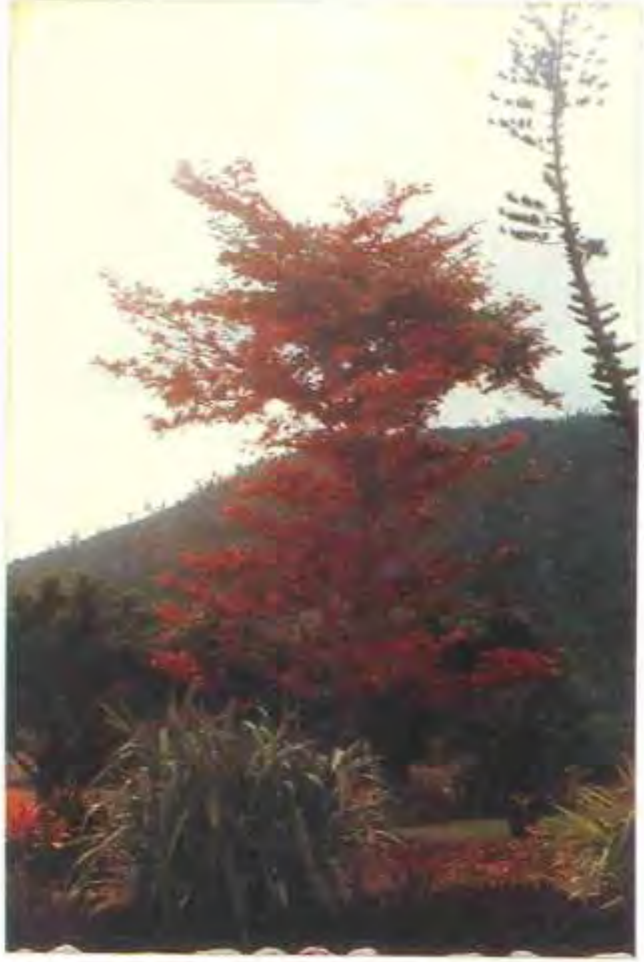


Fig. 27. Synchronized leaf senescence in *Terminalia catappa*; Alafua, Upolu.

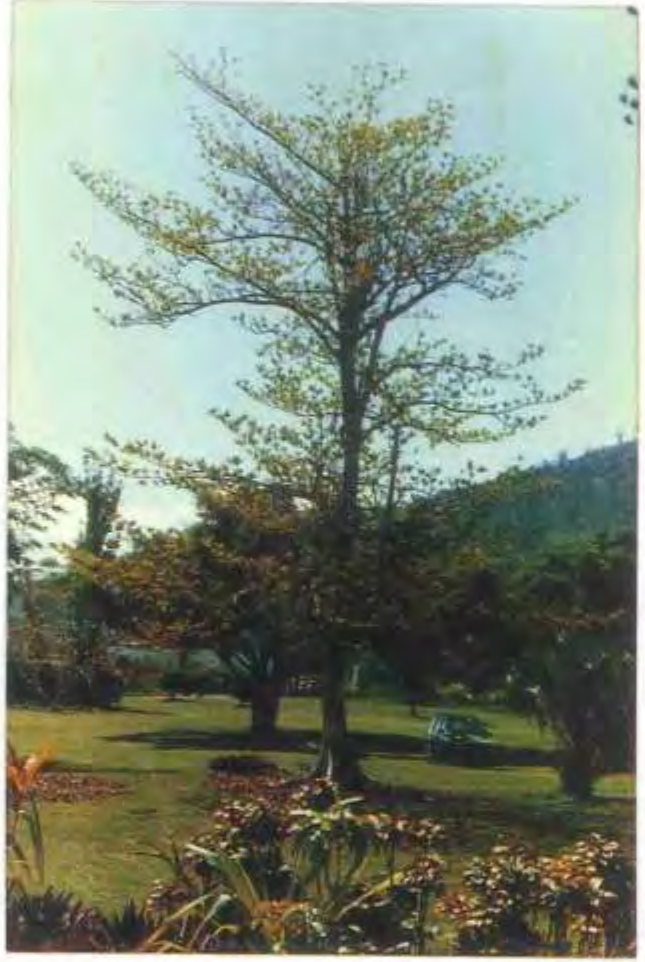


Fig. 28. Synchronized leaf flushing *Terminalia catappa*; Alafua

Fig. 26: **Bottom-up refoliation on Citrus sinensis; Apia, Upolu**

Fig. 30. Southern aspect/Bottom-up refoliation on avocado; Lotopa, Upolu

Fig. 32. Dieback of Eucalyptus saligna and E. cameldulenvis, Fagali'i, Upolu.

Fig.5. Taro in a breeding block at Alafua, Upolu (1 week after Val)

Fig.7. Pineapple at Vaigaga, Upolu (1 week after Val)

Fig.14. Withered cocoa pods; Lotopa, Upolu

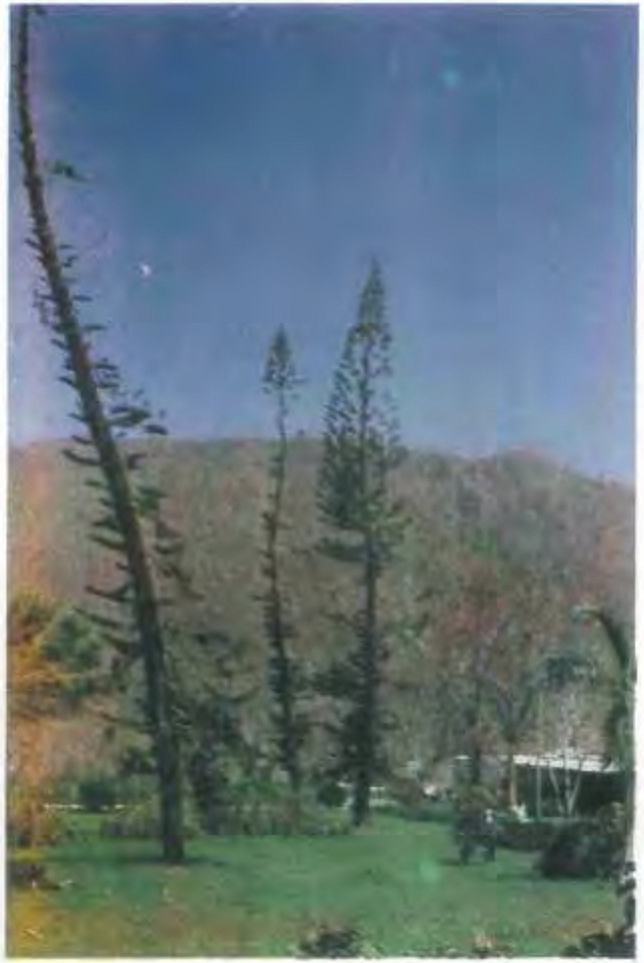


Fig. 11. Aurocaria sp. after Val (30 mins later)

Fig. 6. Peanut, two weeks after Val.

Fig. 13. Fruits on a decapitated pawpaw, Lotopa, Upolu.

Fig. 35. *Delonix regia*, post-cyclone bloom

Fig. 37. *Bauhinia monandra*, post-cyclone bloom

Fig. 39. *Bauhinia monandra*, post-cyclone fruiting.

Fig. 25. Epicormic branches on *Swietenia macrophylla*; Fagali'i, Upolu.

Fig. 29. Dead *Swietenia macrophylla;* Fagali'i, Upolu.

Fig. 31. Defoliated Eucalyptus; Fagali'i, Upolu.

Fig. 33. Dieback of old mango trees at Puipa'a, Upolu.

Fig. 34. *Spondias dulcis* with a single flowering branch; Lotopa

Fig. 41. Pollarded breadfruit trees approx. 4 months after

Fig. 42. Massive post-cyclone fruiting of *Albizia falcataria*

Fig. 36. *Albizia chinensis*, post-cyclone bloom.

Fig. 38. *Albizia chinensis*, post-cyclone fruiting.

Table 2. Leaf flushing strategies of selected woody plant species in Apia, Western Samoa (Bup=bottom-up, Sas=southern aspect, Uni=uniform).

						Refoliation	
	No.	Bup	Sas	Bup-Sas	Uni	Start	Finish
Albizia chinensis	3	-	-	-	-	> 2 wk	< 3 wk
Albizia falcataria	4	3	-	1	-	> 2 wk	< 3 wk
Atrocarpus altilis	5	5	-	-	-	≤ 2 wk	> 4 <16 wk
Bauhinia monandra	4	4	-	-	-	≤ 2 wk	> 2 wk
Citrus sinensis	2	2	-	-	-	≤ 2 wk	< 1 wk
Delonix regia	3	-	-	-	3	≥ 1 wk	< 1 wk
Erythrina subumbrans	7	6	1	-	-	≥ 2 w	> 1 wk
Eucalyptus saligna	3	3	-	-	-	> 4 wk	> 8 wk
Ficus graeffi	3	-	3	-	-	> 1 wk	< 2 wk
Mangifera indica	4	1	-	3	-	≤ 2 wk	> 8 wk
Spathodea campanulata	4	-	1	-	-	> 2 wk	< 1 wk
Spondias dulcis	4	1	-	3	-	> 3 wk	> 6 wk
Tamarindus indica	2	2	-	-	-	> 3 wk	> 4 wk
Terminalia catappa	3	-	-	-	3	≤ 2 wk	≤ 1 wk
Total	50	32	3	9	6	-	-
% Total	-	64	6	18	12	-	-

Table 2. Leaf flushing strategies of selected woody plant species in Apia, Western Samoa (Bup=bottom-up, Sas=southern aspect, Uni=uniform).

						Refoliation	
	No.	Bup	Sas	Bup-Sas	Uni	Start	Finish
Albizia chinensis	3	-	-	-	-	> 2 wk	< 3 wk
Albizia falcataria	4	3	-	1	-	> 2 wk	< 3 wk
Atrocarpus altilis	5	5	-	-	-	≤ 2 wk	> 4 <16 wk
Bauhinia monandra	4	4	-	-	-	≤ 2 wk	> 2 wk
Citrus sinensis	2	2	-	-	-	≤ 2 wk	< 1 wk
Delonix regia	3	-	-	-	3	≥ 1 wk	< 1 wk
Erythrina subumbrans	7	6	1	-	-	≥ 2 w	> 1 wk
Eucalyptus saligna	3	3	-	-	-	> 4 wk	> 8 wk
Ficus graeffi	3	-	3	-	-	> 1 wk	< 2 wk
Mangifera indica	4	1	-	3	-	≤ 2 wk	> 8 wk
Spathodea campanulata	4	-	1	-	-	> 2 wk	< 1 wk
Spondias dulcis	4	1	-	3	-	> 3 wk	> 6 wk
Tamarindus indica	2	2	-	-	-	> 3 wk	> 4 wk
Terminalia catappa	3	-	-	-	3	≤ 2 wk	≤ 1 wk
Total	50	32	3	9	6	-	-
% Total	-	64	6	18	12	-	-

The southern aspect of 6% of the test tree crowns (**Table 2**) refoliated earlier than other cardinal quarters (**Fig. 30**). Undoubtedly, this response was related to the direction of the cyclone. Val came from the north (**Fig. 1**) and the winds it generated travelled from northeast at first and from northwest when it eventually passed Samoa. Thus comparatively, the southern aspects of the crown were never directly blasted by these saltry winds and hence remained sufficiently healthier and vigorous to refoliate earlier than the rest of the crown. Both the bottom-up and the southern-aspect strategies were employed concurrently by 18% of the trees under observation (**Table 2**). Thus implying that for many plant species, tissues were progressively severely damaged in the vertical direction. That is, the bole and the older branches somewhat sustained less damage than the rest of the canopy: a situation which was probably brought about by a combination of vertical decrease in the age of plant tissues and vertical increase in wind speeds.

Some species were stressed so profoundly that even though they attempted to recover by invoking epicormic growth (**e.g. Fig.25**), many died (**e.g. Figs. 29**) while some were able to refoliate only the bottom two-thirds of the crowns. This was particularly very pronounced amongst the ***Eucalyptus*** trees (**Fig. 32**) and old mango trees (**Fig. 33**).

Post-cyclone reproduction

Post-cyclone breeding activities of 26 plant species observed from December 1991 through to May 1993 in Apia (**Table 3**) showed that flowering varied inter- and intra-specifically. B. purpurea was remarkable in that despite suffering total defoliation, it flowered in the third post-cyclone week. Coconut and lime trees then followed there after (**Table 3**). In general, flowering was extremely poor in a number of species. Cases in which only a few branches of a crown produced flowers and fruits were observed in ***S. dulcis*** and ***M. indica*** (**e.g. Fig. 34**). Medway (1972) also reported that ***M. indica*** together with several species flowered , fruited and abscised out of phase on different parts of the trees. Flowering in ***D. regia***, ***A. chinensis*** and ***B. monandra*** were spectacularly intense (**Figs. 35, 36, and 37**). However, only ***A. chinensis*** and ***B. monandra*** likewise fruited heavily (**Figs. 38 and 39**). Although some ***D. regia*** trees fruited heavily, none of the test trees fruited (**e.g. Fig. 40**). It was difficult to tell whether this behaviour was related to the cyclone effects. Ewusie (1980) recorded that in some woody plants, fruiting frequency is lower than flowering frequency.

Table 3. Post-cyclone flowering activities of plants in Apia, Western Samoa

	Year		
Species	**1991**	**1992**	**1993**
Albizia chinensis	-	Jan-Feb., Aug-Sept	April
Albizia falcataria	-	Jan-Feb.	-
Atrocarpus altilis	-	May-Dec.	January
Bauhinia monandra	-	April-Oct.	April
Bauhinia purpurea	-	Dec.	Oct.
Carica papaya	-	Jan-Dec.	January
Cassia siamea	-	April-June	April
Cassia spectablis	-	April-June	April
Citrus aurantifoli	Dec.	Oct.	-
Citrus sinensis	-	May	-
Cocos nucifera	Dec.	Jan-Dec.	Jan.
Delonix regia	-	Jan., Nov-Dec.	-
Erythrina subumbrans	-	Sept.	-
Eucalyptus saligna	-	Oct.	April
Ficus obliqua	-	July	-
Plumeria acuminata	-	Jan-Dec.	January
Gmelina arborea	-	Oct.	April
Jatropha integerima	-	Jan-Dec.	January
Mangifera indica	-	May-July	April
Musa spp.	-	May-Dec.	January
Psidium guajava	-	Jan-May	
Securinega samoana	-	June	June
Spathodea campanulata	-	April, Oct.	April
Spondias dulcis	-	Sept.	-
Tamarindus indica	-	Sept-Nov.	April
Terminalia catappa	-	Sept.	-

Discussions

Notwithstanding hexogenous factors, the age, root system, crown break and shape, and morphology and anatomy of both wood and leaves more or less determined the nature of physical injury a particular tree sustained, and subsequently its survivorship, recovery and immediate post-cyclone reproduction. These traits combined and created specific biophysical characteristics which pre-disposed plants either to defoliation, windthrow or stem breakage during the storm. For example, susceptibility to windthrow was mainly a function of age, crown shape and the rooting system of a species. Amorphous crowns coupled with shallow root systems and age appeared to have induced severe windthrows in tree species like ***A. chinensis*** and ***F. obliqua***. Banana trees which are technically "giant" herbs (Halle et al. 1978) with pseudostems composed of tightly clasping leaf sheaths (Samson 1986) snapped because of inherent physical weakness. Winds rolled over the umbrella-shaped crowns of trees like ***D. regia*** and apparently did very little damage on the twigs and branches of such trees despite causing total defoliation. Spindle-and oval-shaped crowns as those of ***E. subumbrans*** were smaller and therefore resisted the winds minimally so that although many were defoliated few were overthrown. Branchless crowns prevented many young coconut trees from getting toppled even on topography which would otherwise have pre-disposed many branching tree species. Similarly, needle-shaped leaves displayed on spindle-shaped and/or fox-tail canopies averted total defoliation in pines, ***Araucaria*** spp. and ***C. equisetifolia.***

A combination of various plant traits and physical factors appeared to have accorded protection to the plants at the lower stratum. Above bare ground or plant cover windspeed increases rapidly and logarithmically with height (Richards 1964; Jean-Pierre and Fauquet 1987) and thus severity of wind effects tend to increase vertically such that vegetation that falls within lower stratum suffers less damage (Fosberg 1961a). Similarly, grasses which were the dominant plants of this stratum, are morphologically very resilient (Grace 1976) and no doubt sheltered seedlings and saplings of many woody plants from the winds. However, winds of the Val magnitude must have caused both macroscopic and microscopic abrasions on the leaves of these grasses

(Thompson 1974). Such physical damage probably resulted in severe water loss soon after cyclone ceased (Grace 1976) although no mass necrosis was noted on the grasses.

Treefall occurred selectively among old trees. And this contrasted very sharply with Wood's (1970) observation that young trees of ***C. odorata, Swietenia macrophylla, P. pinnata, T. catappa, T. richii*** and ***G. arborea*** were more susceptible to windthrow than old ones. Clarke (1992) reported that cyclone Ofa blew over 100% of mature banana trees and that depending on the location, 50-90% of big mature breadfruit trees, 30-80% of pawpaw, 10-50% of citrus, 30-80% of mango, 30-80% of avocado, 10-50% of mature cocoa trees and 5% of coconut trees were toppled. Cumulatively, even the three cyclones of 1961, 1966 and 1968 never caused such massive windthrows (Wood 1970). The treefall statistics of all but banana and coconut were higher than what was observed for cyclone Val. Clarke's statistics were probably a reflection of a high proportion of weak trees which had accumulated over the intervening years since 1968 cyclone. On the other hand, it is possible that Clarke (1992) might have grossly over-estimated the windthrow. Admittedly, even my data was probably flawed on two counts. Firstly, treefall census was carried out on the third day following the cyclone and therefore did not take into account the number of fallen trees which might have been cleared off during the intervening period. Secondly, the present data were obtained from the coastal areas of Upolu island and therefore can not be claimed to be representative of what took place inside the inland forests of the country. Nonetheless, the discovery that only overmature trees fell during the storm can now be used to explain the incredibly (Hawkins 1959) low average basal areas of Samoan rainforests reported by Whistler (1980). This view concurs with Richards' (1964) that the mechanical effects of strong, frequent winds prevent the development of climax vegetation, a situation which Beard (1945) also reported from St. Vincent (West Indies). Direction of treefall (**Table 1**) agrees with Clarke's (1992) data.

Epicormic growth (**Figs. 23, 24 and 25**), intra-crown variation and prolonged period of leaf flush (**Table 2**), and branch and stem diebacks (**Figs. 32 and 33**) were clear symptoms of severe stresses woody plants experienced during and after cyclone Val. Sudden and wholesale leaf loss suffered by many woody plants (**Figs. 2, 3 and 4**) ushered in two immediate dangers: sunburn and severe mal-nutrition during the pre-refoliation periods which in most cases lasted for more than two weeks (**Table 2**). Both factors impaired growth and caused death and diebacks in many plant species (**Figs. 29, 32 and 33**). The ecology of mal-nutrition in evergreen tropical woody plants as a result of total defoliation is not very well understood. This problem is further complicated in some species (e.g. citrus, mango, avocado etc) which retain their leaves for up to 3 years or more and have 2-5 flushes a year (Samson 1986). Aldous (1943) theorised about what could happen under a wild fire scenario by reasoning that generally as new foliage of perennials reaches full size, the major part of the food reserves will have been withdrawn from the underground organs so that fire destroying leaves at this stage injures the plant most severely. In this regard, mention must be made of lopped or pollarded breadfruit and ***Eucalyptus*** trees which subsisted on the limited pre-cyclone food reserves in a leafless state (**Figs. 22 and 31**) for approximately four months without serious mortality (**Figs. 32 and 41**). The delay in leaf flush of breadfruit trees near the sea was probably caused by salt spray to which many varieties of breadfruit are known to be intolerant (Trujillo 1971). On atolls breadfruit suffers from dieback during droughts: the young branches die but the older ones survive. However, if the drought is too severe, the plant may die completely (Catala 1957; Trujillo 1971; Small 1972; Ragone 1988). Undefoliated leaves of some trees died momentarily apparently because they suffered severe "skin friction" which was compounded by mechanical buffeting of leaves in the winds thus leading to excessive water loss (Grace 1976). The aerodynamic resistance of the needles of conifers remain low and practically constant even in gale force winds (Grace 1976) and thus Val did little damage on the leaves of pines, ***Auraucaria*** spp. and ***C. equisetifolia***. Post-cyclone abscission and refoliation were highly synchronised events in ***T. catappa*** (**Figs. 27 and 28**). Both phenomena were suspected to have resulted from the branching and growth behaviour of this species. However, its leafing behaviour in W. Africa (Ewusie 1980) suggests that there could be other ways of explaining post-cyclone abscission and flushing of ***T. catappa*** in W. Samoa. And one of them was that the deciduousness of ***T. catappa*** resulted from synchronised senescencing of even-aged first post-cyclone leaves (**Fig. 27**); leading to the second mass refoliation (**Fig. 28**). In which case, it can be deduced that Val temporarily altered the phenology of ***T. catappa***. Presently, it is unknown whether ***T. catappa*** will ever become evergreen again.

Reproductive biology of many indigenous plants of Samoa is virtually unknown. And this missing knowledge makes it difficult to discuss the post-cyclone breeding activities of the woody plants observed during this study. However, pantropically, the points worth noting about the flowering frequency in woody plant species are that between 20-50% of these species flower once a year and about 44%, 5% and 1% of the remaining species flower 2, 3, 4 times respectively while 1% flowers throughout the year (Medway 1972 and Ewusie 1980). Ewusie further notes that there are some species which flower infrequently such as once every 2-3 years or once in 5-7 years and that such trees have no definite flowering frequency. Similarly, before attempting to interpret the post-cyclone flowering activities observed in this study (**Table 3**), it is important to note several well established facts that may directly or indirectly explain the breeding behaviour of the plant species. These are (i) alternating years of copious and poor fruiting by individual trees of a species, a phenomenon known as periodicity in cropping, is a widespread characteristic of many tropical woody plants (Merrill 1945; Ewusie 1980; Hall and Swaine 1981; Clarke and Clarke 1987; Cull 1987), (ii) off-season breeding is widespread among domesticated tree crop species (Carlos et al. 1980; Cull 1987, Ragone 1988), (iii) in some woody species (e.g. mango) vegetative and reproductive phases are distinct events (Halle et al. 1978) and (iv) in other species (e.g. citrus) roots and shoots show definite alternate cycles of growth; a cycle which lasts from 4-6 weeks and there are up to five of them in a year (Samson 1986). Against these backgrounds, several generalisations can be made. Circumstantially, it can be stated that tree species whose breeding seasons coincided with Val were severely affected. And that the converse was true for those species which breed early in the year. While species with distinct vegetative and reproductive phases were also affected since they had to build enough food reserves before producing determinate flowering systems.

Evidently, the majority of the species observed in this study appeared to breed once a year (**Table 3**). And several of these species definitely bred out of season; with varying degree of fruiting. For example, if Culll's (1987) report that in southern hemisphere flower bud developement and flowering of mangoes occur in May-June and July-September periods respectively, it becomes obviously clear that Val forced mangoes to breed prematurely (**Tables 2 and 3**). Similarly, data at hand (**Table 3**) also suggest that ***D. regia*** which breeds in the November-December period suffered the same fate. Indeed, in attempting to mitigate this blow, ***D. regia*** trees bloomed in the second week of January through to third week of February but fruited poorly. The reproductive capacities of species which breed between April and August (e.g. ***A. chinensis*** , **Table 3**) although induced to breed prematurely in January-February period, were apparently very little affected by cyclone Val as evidenced by the copious fruiting observed in these species (**Figs. 38 and 42**). Breeding of breadfruit was also affected because no sooner had the trees completed refoliation than fruiting commenced earnestly in May through to December 1992 and was still continuing in 1993 (**Table 3**) and yet Ragone (1988) reports that in southern Pacific, the main breeding season for most breadfruit varieties falls between October and February. Strictly speaking, those species which breed all year round such as coconut , ***P. acuminata***, ***J. integerima*** etc were only temporarily disrupted by Val: once fully refoliated, these species flowered and bred normally. In fact even without restoration of the leaves, some ***P. acuminata*** and ***J. integerima*** produced flowers. A very interesting breeding behaviour was observed in ***T. catappa***. These trees refoliated soon after Val, abscised the post-cyclone leaves in June 1992, refoliated and bred in September 1992 and upto now, most trees have not fruited again and yet Ewusie (1980) reported that this species flowers four times in West Africa. It was also interesting to note that nearly all the species under observation during this study have already bred about the same time as they did last year except ***A. chinensis*** (**Table 3**). It is difficult to tell whether the ***A. chinensis*** is experiencing periodicity in cropping as every tree of breeding age fruited so heavily in 1992 (**Fig. 42**). Samson (1986) argues that during the "on-year" very many small fruits are set whose development exhausts the tree so that in one or more subsequent "off-year" there are little or no fruits produced.

The physiological process which led to premature fruiting in these woody plants were not quite apparent. A strong correlation has been documented between defoliation and flowering in some tropical woody species (Medway 1972; Ewusie 1980), and is probable that the response observed in these species was similar. Biologically, fruiting in the wrong season is costly to many plant species especially if seasons are discrete as in temperate systems. However under insular climate where weather conditions may be very equable, off-season breeding may have little or no adverse consequences.

Acknowledgment: I would like to thank Steve Hazleman for assisting me in various ways during this study.

References

Anonymous 1992. Twelve months ago this week: The legend called Cyclone Val. Samoa Sunday Observer, 6 December,14-15pp.

Anonymous 1990. Report on the 1989 Census of Agriculture Western Samoa. Departments of Agriculture and Statistics. Apia, Western Samoa 179pp.

Anfinson A.P. and L. Harris 1973. The effect of Hurricane "Bebe" on Agriculture in Fiji. Part 1, Description of Hurricane. Fiji Agricultural Journal, 35: 35-41.

Balgoony M.M.J van 1971. Plant geography of the Pacific. Blumea Supplement 6: 1-222.

Beard J.S. 1945. The progress of plant succession on the Soufriere of St. Vincent. Journal of Ecology 33: 1-9.

Buxton P.A. 1935. Insects of Samoa. Part 4. Fascimile 1. Description of the environment, 31pp.

Carlos Jr. J.T. and P. Misipati 1990. Local mangoes in the market of Apia, W. Samoa. In South Pacific Fruit Production. Technologies and Recent Advances. Edited by J.T. Carlos Jr., IRETA, USP, Apia, Western Samoa, pp 113-120.

Carlos Jr. J.T., N.T. Tekiu and P. Misipati 1988. Induction of mango flowering in Western Samoa: a preliminary study. Alafua Agricultural Bulletin, 13: 39-41.

Catala R.L.A. 1957. Report on the Gilbert Islands: some aspects of human ecology. Atoll Research Bulletin, 59: 1-186.

Clarke T. 1992. The effect of a cyclone on crops. Journal of South Pacfic Agriculture, 1: 66-76.

Clarke A.P. and B.A. Clarke. 1987. A description of pre-harvest factors affecting yield in mango (*Mangifera indica*). In Mangoes - A review (R.T. Prinsley and G. Tucker eds.) Commonwealth Science Council pp 9-18.

Crane E.A. 1991. Geography of the Tropical Pacific. Nukualofa.

Cull B.W. 1987. A whole plant approach to productivity research for mango. In Mangoes -A review (R.T. Prinsley and G. Tucker eds.) Commonwealth Science Council pp 19-28.

Dawkins H.C. 1959. Volume increment in natural tropical high forest and limitation on its improvement. Empire Forest Review, 38: 175-180.

Ewusie J.Y. 1980. Element of Tropical Ecology. Heinemann Educational Books Ltd.

Fosberg F.R. 1961a. viii. Flora and vegetation. Atoll Research Bulletin, 75: 51-56.

Fosberg F.R. 1961b. Typhoon effects on individual species of plants. Atoll Research Bulletin, 75: 57-73.

Grace J. 1976. Wind damage to vegetation. In Commentaries in Plant Science (H.Smith ed.). Pergamon Press pp 209-220.

Hall J.B. and M.D. Swaine 1981. Distribution and ecology of vascular plants in a tropical rain forest. Forest Vegetation of Ghana. Series Geobotany, Volume 1. Dr W.Junk Publishers. The Hague- Boston-London.

Halle F., R.A.A. Oldeman and P.B. Tomlinson 1978. Tropical trees and forests. An Architectural

Analysis. Springer Verlag, Berlin, Heidelberg, New York.

Jean-Pierre A. and C. Fauquet 1987. African cassava mosaic disease. Summary report of the International Seminar. CTA-FAO-ORSTOM-IITA. Universa, Belgium pp. 50.

Jordan B. 1980. Lime production in Niue. Alafua Agricultural Bulletin 5:17-20.

Marie-Helene S. 1957. Climate and meteorology of the Gilbert Islands. Atoll Research Bulletin, 60: 1-4.

Medway L. 1972. Phenology of a tropical rain forest in Malaya. Journal of Linnean Society, (Biol.) 4: 117-146.

Merrill E.D. 1945. Plant life of the Pacific World. Macmillan Company, New York.

Parham B.E.V. 1972. Plants of Samoa. Whitcombe and Tombs Ltd. pp.162.

Ragone D. 1988. Breadfruit varieties in the Pacific atolls. Report of the UNDP Integrated Atoll Development Project.

Richards P.W. 1964. The tropical rainforest: An Ecological Study. Cambridge University Press.

Samson J.A. 1986. Tropical Fruits. Longman, London and New York.

Setchell W.A. 1924. American Samoa: Carnegie Inst. Wash., Department of Marine Biology.

Small C.A. 1972. Atoll agriculture in the Gilbert and Ellice Islands. Photographics International Publishers.

Stoddart D.R. 1963. Effects of Hurricane "Hatties" on the British Honduras reefs and cays, October 30-31. Atoll Research Bulletin, 95: 1-142.

Stoddart D.R. 1969. Post-hurricane changes on the British Honduras reefs and cays: Re-survey of 1965. Atoll Research Bulletin, 131: 1-25.

Thompson J. R. 1974. The effect of wind on grasses. ii. Mechanical damage on ***Festuca arundinacea*** Schreb. Journal of Experimental Botany, 25: 965-972.

Trujillo E.E. 1971. The breadfruit diseases of the Pacific Basin. SPC Information Document No. 27: 1-28.

Whistler W.A. 1980. The vegetation of Eastern Samoa. Allertonia 2: 1-190.

Wiens H.J. 1961. iii. General description of storm effects. Atoll Research Bulletin, 75: 21-36.

Wood T.W.W. 1970. Wind damage in the forest of Western Samoa. The Malayan Forester 33: 92-99.

Wright A.C.S. 1963. Soils and land use of Western Samoa. N. Z. Soil Bureau Bulletin.