Chapter 6.
Synthesis

Introduction

While often compartmentalized and studied separately, erosion and sedimentation are part of the same watershed process and must be understood in its entirety to be effectively managed. The only way to successfully mediate nearshore sedimentation is to arrive at a long-term solution to upland erosion. This requires a detailed understanding of the processes involved and the magnitude of the impact associated with each process. If the ultimate cause of the problem is not successfully addressed, any management problem will only serve as a stopgap measure.

This study has attempted to examine the erosion-sedimentation dynamics, including the role of anthropogenic fire, in the Asan sub-watershed to gain a better understanding of the process and to guide resource management and conservation. Chapter 2 examined sedimentation rates on Asan's nearshore coral reefs and raised concerns about sediment levels. Fire effects on vegetation were examined in Chapter 3, and Chapters 4 and 5 demonstrated upland erosion rates among the highest reported in the literature. While the results from each chapter illuminate aspects of this watershed process and suggest viable management solutions, a broader based understanding is needed. This chapter will synthesize information across the watershed in an effort to meet this objective.

On Guam, erosion occurs primarily from the action of water (as opposed to wind) on the island's weathered and highly erodible, tropical soils (NRCS 2001). Steep terrain and monsoonal weather conditions, including frequent large storm events (i.e., tropical storms and cyclones), contribute to the potential for high natural erosion rates. Coupled with human impacts, such as wildland arson and poorly managed development activities, Guam experiences some of the highest measured erosion and sedimentation rates in the world (Chapters 2-5).

In the Asan sub-watershed (Figure 6-1), storm events deposit rain in a seasonal pattern (Chapter 4), with distinct dry (January-June) and wet (July-December) seasons. Rainfall varies from year to year as a function of ENSO events, which have been linked to drought conditions (Lander and Guard 2003). As a result of poor soil infiltration (Young 1988), water deposited in the Asan sub-watershed moves primarily as laminar sheet flow. Some water flows directly into the marine environment as non-point source runoff. The remaining water ends up in flowing into gullies and eventually streams where it is transported through the watershed to the ocean. In the Asan sub-watershed, one primary stream outlet exists (Asan River), forming the sole natural runoff point source.

Along with soil properties and environmental conditions, vegetation cover also plays an important role in upland erosion (Chapters 4 and 5). Any activity that alters the characteristics of the vegetation community can alter the rate of erosion, and on Guam, anthropogenic fire is a significant problem (Niell and Rea 2004). Fire has played a key role in reducing forest cover (Athens and Ward 2004), and appears to be altering the species composition of Guam's native, and currently expansive, savanna ecosystem (Chapter 3).

Figure 6-1. Schematic diagram of water flow through the Asan sub-watershed. See text for an explanation.

Given the complex interaction of fire, vegetation, and erosion (Figure 6-2), effective management is problematic unless the numerous interactions can be investigated and understood. In the current climate of decreasing management dollars, it is critical that managers target their limited funding toward activities that will have the greatest environmental return. Each potential interaction needs to be assessed to determine the magnitude and nature of the interaction in order to better understand the process. Ultimately, only a broad understanding of the watershed-level process will make meaningful and appropriate management decisions possible. This chapter will examine sedimentation and soil loss at the watershed scale and will develop statistical models to examine features of the dynamics.

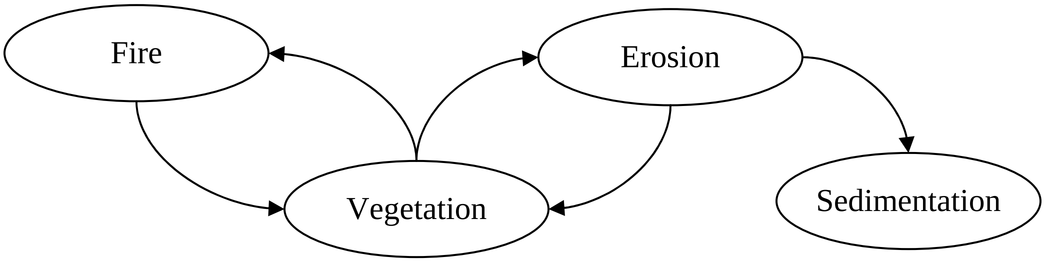

Figure 6-2. Schematic diagram of potential connections among fire, vegetation, erosion, and sedimentation. The strengths of these interactions must be understood to best target limited management funds to achieve the desired management results.

Materials and Methods

Marine Sedimentation

The total sediment load on the Asan reef was estimated by dividing the fore reef slope into fifty compartments using ArcGIS (Figure 6-3). Compartments were created by drawing lines (approximately) perpendicular to the reef crest that transected the midpoint between sediment collector sites. The shallow edge of the 10 meter compartments followed the reef crest and the deep edge of the 20 meter compartment followed the 40 meter depth cline. Compartments at the edge of the study were extended to 150 m either east or west of the last trap. The deep and shallow water compartments were separated by a line drawn along the 15 meter depth cline. The area of reef within each compartment was computed using ArcGIS.

The total weight of terrestrial material measured at each site was computed by multiplying the total weight of sediment by the percent terrestrial (see Chapter 2). The total weight of the terrestrials sediment measured during each temporal replicate at each station (Chapter 2) was extrapolated to estimate the sediment collected over the entire compartment during each replicate Appendix 1). Data for one year (replicates 1-14) were summed to estimate the yearly sediment collection rate. If a value was missing for a site during a replicate, a zero value was used in the estimate. To determine sediment collected in the Asan sub-watershed, the six eastern and three western most sites

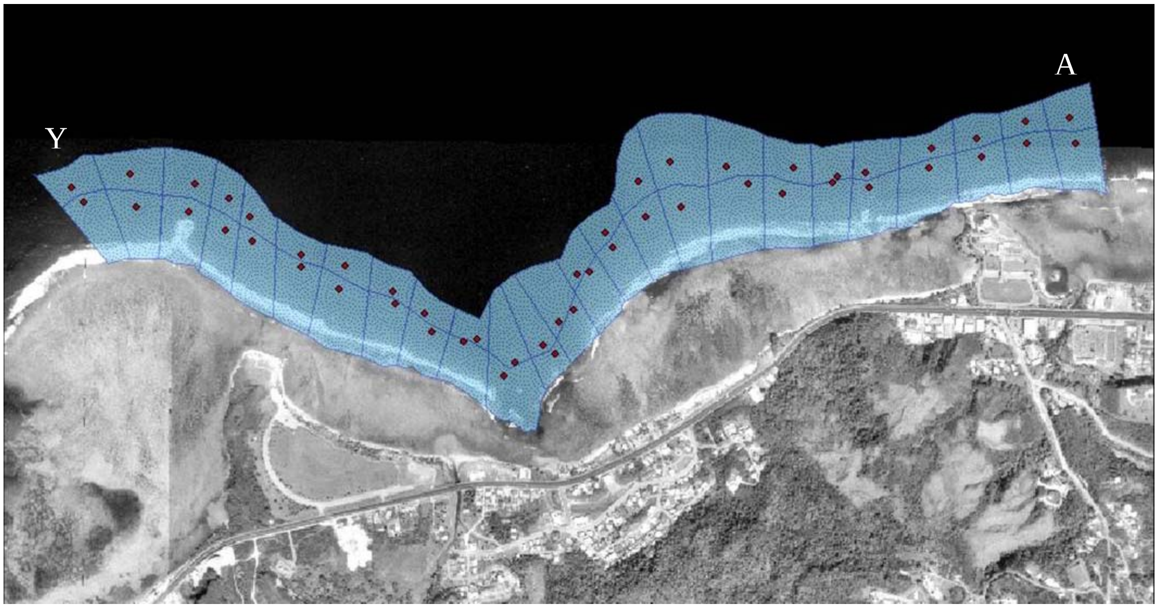

Figure 6-3. Reef compartments generated using ArcGIS to estimate total sediment load on the Asan fore reef. Dots are sediment collectors; letters are the site identifiers of the western most (Y) and eastern most (A) sediment collection sites. The sites are lettered alphabetically from right to left, but intervening site letters have been left off the figure for clarity (see Chapter 2).

(Location A, B, C, D, E, F & W, X, Y) were removed from the calculation. These sites were determined, based on the NRCS watershed delineations (CWAP 1998), to be outside of the Asan sub-watershed.

Sediment dynamics were modeled using the total weight of terrestrial sediment for all replicates. Stepwise linear regression techniques with five variables for rainfall quantity, three variables for rainfall intensity, and three spatial variables (Table 6-1) were used to generate a best fit sediment model. The best fit model was determined by highest r^2. Standardized residuals, Cook's distances, and leverages were examined to determine the model's overall fit.

Terrestrial Soil Loss

Total soil loss across the Asan sub-watershed was estimated by multiplying the average soil loss, in tonnes/ha, for each vegetation types buy the hectares of the vegetation type present in the sub-watershed. The number of hectares occupied by each vegetation type was calculating using ArcGIS and a vegetation habitat map obtained from the Guam Division of Forestry (Chapter 3; Table 3-4). Because the vegetation map did not differentiate savanna vegetation subtypes, an average soil loss of the mixed and fern subtypes was used in the calculations. For comparison, watershed level estimates of soil loss were also obtained using the available erosion data from the Fena (NRCS 2001). The Fena watershed estimate for soil loss in forested areas was used in all models. Limestone scrub and scrub forest categories were assumed to have the same soil loss rate of 1.8 tonnes/ha/year. Seasonal soil loss rates were incorporated into the calculations when possible.

A range of management scenarios were investigated, including: 1) no burning, no badlands; 2) 10% burning, no badlands; 3) no burning; 10% badlands; and 3) 10%

Table 6-1. Independent variables used in the sediment dynamics model.

Category	Term	Description
Rain Quantity	Rain	Total rainfall during replicate.
	Rain -1 day	Total rainfall starting 1 day before the replicate was deployed and ending 1 day before the replicate was collected.
	Rain -2 days	Total rainfall starting 2 days before the replicate was deployed and ending 2 days before the replicate was collected.
	Rain -3 days	Total rainfall starting 3 days before the replicate was deployed and ending 3 days before the replicate was collected.
	Rain -4 days	Total rainfall starting 4 days before the replicate was deployed and ending 4 days before the replicate was collected.
Rain Intensity	Days >2.5 cm	Number of days with more than 2.5 cm of rain.
	Days >5.0 cm	Number of days with more than 5.0 cm of rain.
	Days > 12.5 cm	Number of days with more than 12.5 cm of rain.
Spatial	Distance from Source	Linear distance from nearest point source to the sediment collector.
	Direction	Direction from nearest source. +1=up current; -1=down current
	Distance & Direction	Distance multiplied by Direction

burning and 10% badlands. The percentage values for burning and badlands were calculated as the hectares of savanna converted to either burned savanna or badland. A 10% conversion of savanna (10.6 hectares) equals approximately 2.9% of the total sub-watershed area. These estimates are intended to be realistic estimates of burned savanna and badland areas on southern Guam.

Results

Marine Sediment Collection

An estimated 36,000 tonnes/year of terrestrial sediment impact the fore reef slope within the study area. On the fore reef slope at the base of the Asan sub-watershed (excluding sites to the east and west of the watershed boundary), is impacted by approximately 25,200 tonnes/year of terrestrial sediment.

An initial best fit model was developed that included five significant terms (Table 6-2). All three spatial terms, Event>12.5 cm and Rain –3 days were all significant in the model. The model explained 52.7% of the variability in the data. Diagnostics showed that the model consistently underestimated sediment collection at site O-20. Further examination of this site found that its location was such that it collected more re-suspended material than other traps. The sediment collector at O-20 was at the base of the reef slope in a sandy patch, unlike all other collectors that were on hard substrate. For this reason, O-20 was excluded from the analysis.

When O-20 was excluded, only three terms remained in the best fit model (Table 6-2): Distance and Direction, Rain -3 days, and Events >12.5 cm. The model explains 56.2% of the variability in the data. Diagnostics showed that the fit of the model was improved, but the revised model consistently underestimated sediment collection during

Table 6-2. Significant terms and regression tables for the sediment collection model. Models are the result of a stepwise regression on sediment collection rates and using the terms in Table 6-1. Model 1 contains all sediment collection sites. Model 2 has had site O-20 removed. See text for full explanation.

Model 1

Term	Coefficient	St. Dev.	T	P
Constant	0.4433	0.1018	4.36	<0.001
Rain -3 days	0.45366	0.08555	5.30	<0.001
Events >12.5cm	0.22606	0.04999	4.52	<0.001
Dir.	0.42786	0.09706	4.41	<0.001
Dist.	-0.0006173	0.0001894	-3.26	<0.001
Dist. & Dir.	-0.0004670	0.0001893	-2.47	0.014

Source	DF	SS	MS	F	P
Regression	5	79.089	15.818	48.71	<0.001
Residual Error	634	205.868	0.325		
Total	639	284.956			

Model 2 (Site O-20 removed)

Term	Coefficient	St. Dev.	T	P
Constant	0.15043	0.02959	5.08	<0.001
Dist. & Dir.	0.00025479	0.00002602	9.79	<0.001
Events >12.5cm	0.23677	0.03753	6.31	<0.001
Rain -3 days	0.34442	0.06428	5.08	<0.001

Source	DF	SS	MS	F	P
Regression	3	51.742	17.247	96.14	<0.001
Residual Error	623	111.766	0.179		
Total	626	163.508			

replicate 12 (9 June – 8 July 2005). These date corresponded with the onset of the 2005 wet season, and during which a significant rain event occurred. Typhoon Tingting (June 27-28) deposited over 50 cm of rainfall in 24 hours (PEAC 2005), and was the largest single rainfall event of 2005.

Terrestrial Soil Loss

Using data obtained for this study, soil loss in the Asan sub-watershed was estimated at 2,531.5 tonnes/year (Table 6-3a). Using soil loss calculated in the Fena watershed, estimated soil loss in the Asan sub-watershed was approximately five times greater at 12,022.1 tonnes/year. Under this initial scenario, over 88.6% of the soil was lost off the savanna complex (including badlands).

Under the no burning-no badland scenario (Table 6-3b), erosion drops slightly (0.68%) relative to the initial IKONOS 2002 data estimates. The low incidence of badland in the original IKONOS 2002 data accounts for the small drop in soil loss. Under the 10% burning-no badlands scenario (Table 6-3c), erosion rises to 2,779.4 tonnes/year, a 9.8% increase. A smaller increase (2.1%) is observed if the Fena is used. Under the no burning-10% badland scenario (Table 6-3d), soil loss increases by 23.2% relative to the original IKONOS 2002 estimate. This rate of increase is lower than that

Table 6.3. Soil Loss (tonnes/year) under five separate scenarios for the Asan sub-watershed. Scenarios include: a) habitat area derived from 2002 IKONOS data (see Chapter 3); b) no burning-no badlands; c) 10% burning-no badlands; d) no burning-10% badlands; and e) 10% burning-10% badlands. Yearly soil loss rates for Fena Watershed were obtained from NRCS (2001). For the NPS estimate (this study), seasonal data for savanna, burned savanna and badlands were used where available. For other habitat types (e.g., scrub forest), Fena watershed estimates (NRCS 2001) were used.

a) IKONOS 2002		**Soil Loss Rate (tonnes/ha)**			**Asan Soil Loss (tonnes/year)**	
Habitat Type	**Hectares**	**Rain**	**Dry**	**Fena**	**NPS**	**Fena**
Scrub Forest	149.7	-	-	1.8	269.5	269.5
Limestone Scrub Forest	10.5	-	-	1.8	18.9	18.9
Savanna Complex	105.2	14.2	6.9	110.0	2,219.7	1,1572.0
Burned Savanna	0.0	35.3	10.8	146.0	0.0	0.0
Barren	0.3	43.9	34.2	539.0	23.4	161.7
Urban	96.4	?	?	?	0.0	0.0
	362.1				2,531.5	12,022.1

b) No burning-no badlands		**Soil Loss Rate (tonnes/ha)**			**Asan Soil Loss (tonnes/year)**	
Habitat Type	**Hectares**	**Rain**	**Dry**	**Fena**	**NPS**	**Fena**
Scrub Forest	149.7			1.8	269.5	269.5
Limestone Scrub Forest	10.5			1.8	18.9	18.9
Savanna Complex	105.5	14.2	6.9	110.0	2,226.1	11,605.0
Burned Savanna	0.0	35.3	10.8	146.0	0.0	0.0
Barren	0.0	43.9	34.2	539.0	0.0	0.0
Urban	96.4	?	?	?	0.0	0.0
	362.1				2,514.4	11,893.4

c) 10% burning-no badlands		**Soil Loss Rate (tonnes/ha)**			**Asan Soil Loss (tonnes/year)**	
Habitat Type	**Hectares**	**Rain**	**Dry**	**Fena**	**NPS**	**Fena**
Scrub Forest	149.7			1.8	269.5	269.5
Limestone Scrub Forest	10.5			1.8	18.9	18.9
Savanna Complex	94.9	14.2	6.9	110.0	2,002.4	10,439.0
Burned Savanna	10.6	35.3	10.8	146.0	488.7	1,547.6
Barren	0	43.9	34.2	539.0	0.0	0.0
Urban	96.4	?	?	?	0.0	0.0
	362.1				2,779.4	12,275.0

Table 6-3. (continued)

d) No burning-10% badlands Habitat Type	Hectares	Soil Loss Rate (tonnes/ha) Rain	 Dry	 Fena	Asan Soil Loss (tonnes/year) NPS	 Fena
Scrub Forest	149.7			1.8	269.5	269.5
Limestone Scrub Forest	10.5			1.8	18.9	18.9
Savanna Complex	94.9	14.2	6.9	110.0	2,002.4	10,439.0
Burned Savanna	0.0	35.3	10.8	146.0	0.0	0.0
Barren	10.6	43.9	34.2	539.0	827.9	5713.4
Urban	96.4	?	?	?	0.0	0.0
	362.1				3118.6	16440.8

e) 10% burning-10% badlands Habitat Type	Hectares	Soil Loss Rate (tonnes/ha) Rain	 Dry	 Fena	Asan Soil Loss (tonnes/year) NPS	 Fena
Scrub Forest	149.7			1.8	269.5	269.5
Limestone Scrub Forest	10.5			1.8	18.9	18.9
Savanna Complex	84.2	14.2	6.9	110.0	1,776.6	9,262.0
Burned Savanna	10.6	35.3	10.8	146.0	488.7	1,547.6
Barren	10.6	43.9	34.2	539.0	827.9	5,713.4
Urban	96.4	?	?	?	0.0	0.0
	362.1				3,381.5	16,811.4

observed using the calculations from the Fena watershed (36.8% increase). Under the final scenario, 10% burning-10% badland (Table 6-3e), a 33.6% increase in soil loss was observed. Once again, this is a lower percent increase than that observed when using the soil loss estimates from the Fena watershed (39.8%).

Discussion

Overall, there was poor agreement between the estimated sediment loads and upland soil loss for the Asan sub-watershed. The sediment load calculated for the Asan fore reef (25,200 tonnes/year) was nearly 10x the estimate calculated for upland erosion (2,531.5 tonnes/year). This discrepancy may be explained by the fact that the upland erosion rates measured in this work are minimum estimates. These rates were measured on low slop (9-12%) plots. Additionally, the upland erosion estimate does not account for burned savanna or urbanized areas, and does not contain the appropriate area of badland. If realistic estimates for the area of burned savanna and badlands are added to the soil loss estimate, it increases to 3,381.5 tonnes/year. This value is still only 13% of the marine terrestrial sediment load on Asan's nearshore reef slope.

The estimate including realistic burned savanna and badland areas (Table 6-2e) derived from the Fena watershed data (16,811.4 tonnes/year) is closer to the calculated sediment load. The Fena soil loss rates (NRCS 2001) were estimated using the RUSLE, and concerns about the appropriateness of this method on Guam have been raised. Schemen et al. (2002) found that RUSLE estimates were consistently higher than empirical estimates, raising serious questions about the applicability of the RUSLE method for Guam. In reality, erosion rates in the Asan sub-watershed are probably closer to those calculated using the soil loss measurements obtained in this study.

Reconciling the large difference between the soil loss and sediment collection on the reef is difficult. Our methods primarily measured sheet and rill erosion, which is believed to account for approximately 93% of the soil loss on Guam (NRCS 2001). However, significant streambank erosion has been observed on both major tributaries of the Asan River (Minton, pers. obs.) The contribution of this type of erosion to the coastal sediments is currently unknown.

No soil loss is available for the urban areas of Asan. Many of the homes and roads are cut into the hillside and may be producing significant erosion. Housing development on the west side of the Asan sub-watershed was also underway during this study, and the contractors were less than meticulous in maintaining appropriate sediment barriers around construction sites. It seems unlikely, however, that these activities could account for the 10-fold increase in soil loss need to reconcile with the calculated near shore sediment collection rates.

In all likelihood, a combination of these factors is probably accounts for the discrepancy. Soil loss over the range of slopes present in the watershed is higher than those reported here, and Streambank erosion and erosion off urban and construction sites also contribute to the watershed's soil loss. These impacts need further investigation to quantify.

The best-fit sediment model provides interesting insight into the sedimentation dynamics on Asan reef. The model includes three predictors, one from each of the three variable categories: rainfall quantity, rainfall intensity, and spatial (Table 6-2b). The model shows that the distance and direction from the nearest point source is the best single predictor of sediment collection rates on the Asan fore reef slope. The inclusion of this specific spatial term suggests that non-point source runoff does not contribute significantly to sedimentation on Asan reef. This is supported by visual observations of sediment plumes originating from the Asan River and not along the length of the coast (Figure 6-4).

The model illustrates the importance of the rainfall intensity and quantity, with rainfall intensity having a higher significance. Daily rainfall events over 12.5cm (Events >12.5cm) were important predictors, suggesting that large events are a significant driver on this system. These large events are rare, with only two occurring in 2002 (July and December), one in 2003 (October), and three in 2004 (June (x2) and August). All of these events occurred during the wet season or at the start of the wet season (i.e., the end of June). Storm events of this magnitude are usually associated with tropical storms or cyclones and yearly variability in these storms is related to ENSO events (Guard et al. 1999).

The rainfall window offset by three days (Rain -3 days) proved to be the best rainfall quantity predictor, suggesting a three-day residence time of water in the watershed. This residence time is also certain to be a function of rain intensity. Following large storm events, flow at point sources rises significantly within a few hours of rainfall (USGS pers. comm.), as does the subsequent sediment discharge. Average

Figure 6-4. A sediment plume originates from the Asan River (lower left) following a large event in late June 2005 (replicate 12).

events (~0.75 cm/day), however, appear to move more slowly through the watershed (Minton pers. obs.).

The fit of the model was improved after removing site O-20 from the analysis. Diagnostics on the revised model revealed that it consistently underestimated the observed values in replicate 12 (9 June – 8 July 2004). This replicate occurred at the start of the 2004 wet season and had two large rain events (June 28-29) occur during it. The higher than predicted sediment collection values are interpreted as a sediment flushing event. During the dry season, rain events are small, usually <2.5cm, and total rainfall is low. This lack of rainfall quantity and intensity may not flush sediments entirely through the watershed. Instead sediments are probably transported into gullies and slow flowing streams were they collect over the course of the dry season. With the onset of the wet season, the quantity of rain fall and the intensity of events may be sufficient to flush these accumulated sediments onto the fore reef slope.

The timing of this flushing event is potentially problematic to coral reefs on Guam. The principal coral spawning season corresponds with the full moon during the months of June, July, and August (Richmond and Hunter 1990). Coral spawn and settling juveniles are susceptible to poor water quality (Richmond 1997; Gilmour 1999), including elevated sediment levels. Anthropogenically increased sediments loads could impact successful coral reproduction and/or recruitment to the reef, presenting a significant threat to the long term health and survival of Asan's coral reefs. Coral recruitment rates are under active investigation by the National Park Service (Lundgren and Minton 2005) on the Asan fore reef slope, and preliminary data show low coral recruitment rates on the reef, but also no apparent correlation with sediment collection rates. Reasons for the lack of relationship between the coral settlement and sediment collection are currently unclear, but the research is ongoing (Lundgren and Minton 2005).

Upland erosion rates in Guam's savanna ecosystem are a result of the complex interaction of fire, vegetation and climate (Figure 6-5). Fire is a primary driver in tropical savanna ecosystems (D'Antonio and Vitousek 1992; Higgins et al. 2000; van Langevelde et al. 2003), and on Guam, is capable of altering plant species composition (Chapter 3). Changes in savanna vegetation affect erosion rates (Chapter 4). While sediment loss is occurring in vegetated savanna, erosion rates in burned and badland areas are six times higher than those observed in vegetated areas (Chapter 4). Following burning, invasive species, particularly grasses, tend to dominate the regenerating savanna, and these species appear to promote higher rates of soil loss than the mixed savanna community (Chapter 4). These invasive species alter the fire regime (Figure 6-5), increasing the fire frequency and intensity. The increased prevalence of burned savanna likewise increases the overall soil loss, altering the soil's physical and chemical properties (Chapter 5) and eventually exposing the underlying saprolite clays, which are highly acidic and have high concentrations of aluminum. These clay areas are incapable of supporting vegetation, and become badlands, which erode at a high rate (Chapter 4).

The mechanism that converts grasslands to badlands is still unclear, but may be related to declining soil quality associated with repeated burning and erosion. Repeated burning of tropical soils can increase the bulk density while lower pH, organic matter content (Wang et al.2003), and the cation exchange capacity (CEC) (Giovannini and Lucchesi 1997), which directly affects soil nutrient levels. Lower pH causes increased concentrations of saturated aluminum in the Akina soils that prevalent in the Asan sub-watershed (Young 1988). Burn also influences soil erodibility by producing microaggregates and particle that are more easily transported by rain splash (Ternan and Neller 1999). Increased erosion following burns degrades soil quality by removing topsoil, altering soil pH, lowering nutrients and organic material, altering texture and permeability, and lowering the cation exchange capacity (Lal 1995a, 1995b; Giovannini and Lucchesi 1997; Kaihura et al. 1999; Ternan and Neller 1999; Wang et al. 2003). Eventually, topsoil is removed exposed the underlying saprolite clays, which are incapable of supporting vegetation (Young 1988). Slumping of soils may also contribute to the formation of extensive badlands (Schemen et al. 2002), as water infiltrating the soils reaches the impermeable clays and "floats" the overlying soil layers causing them to slump.

Swordgrass (*Miscanthus floridulus*), which can form dense monotypic stands, is fire tolerant and capable of growing to three meters in height. Its presence on volcanic slopes (Stone 1970) suggests that it is more tolerant of acidic soils and elevated aluminum than mixed savanna species. Studies have shown *Miscanthus* is capable of growing under these harsh soil conditions (Wang et al. 2003). These features suggest a plausible mechanism allowing swordgrass to persist in Guam's savanna (Figure 6-5). As fire burns mixed savanna, soil erosion reduces soil quality and allows for exotic specie to invade. These species promote increase fire and, because of their bunch grass growth form, have a reduced capacity to hold soil, leading to further soil degradation. Eventually, swordgrass is able to invade, and because of its fire tolerance (Stone 1970), survive additional burning. Swordgrass sprouts quickly from its root crown following fire (Stone 1970) and can grow several meters tall in single season (GFD, pers. comm..). The dense monotypic stands are capable of shading other species, particular the shade intolerant exotic grass, such as Pennisetum polystachion (Ismail et al. 1994). Eventually

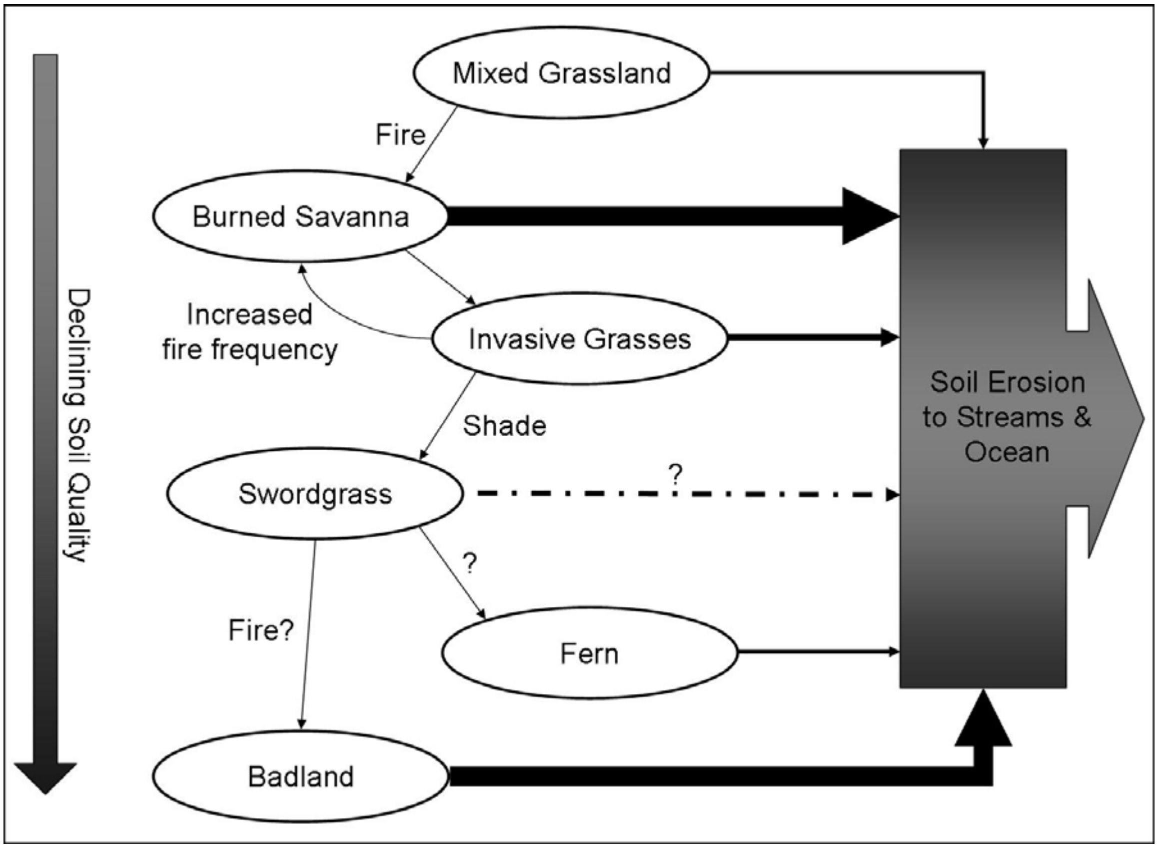

Figure 6-5. Schematic for fire-erosion-sedimentation cycle in the Asan sub-watershed. See text for an explanation. The thickness of the horizontal arrows represent the relative contribution to overall soil loss.

these grasses are excluded and replaced by a monotypic stand of swordgrass. Given that much of the erosion in southern Guam is the result of rill and sheet flow (NRCS 2001), swordgrass, a bunch grass characterized by large, widely spaced bunches, is probably less effective than mixed savanna at holding soils. Further erosion may eventually lead to badland formation (Figure 6-5).

Savannas in Asan exist as a vegetation mosaic (Chapter 3) that appears to be shifting toward vegetation states dominated by invasive species, swordgrass, and badland. As more mixed savanna is converted to other vegetation communities, upland erosion and coastal sedimentation will continue to increase.

Over 90% of the soil lost from the Asan sub-watershed comes off habitat associated with the savanna complex. Much of the eroded soil originates from vegetated savanna. Because of their relatively small area, badland complexes and burned savanna contribute less to watershed soil loss than vegetated savannas. The extensive cover of savanna on Guam is believed to be associated with anthropogenic fire (Athens and Ward 2004), and, prior to arrival of humans (sometime between 3,500-4,400 years ago), the island was probably heavily forested. As such, upland erosion rates and subsequent sedimentation rates on nearshore reefs could have been as low as 20% of the current estimated rates. Having evolved under these environmental conditions, it would not be surprising if Guam’s marine species were poorly adapted high erosion and sedimentation rates.

To reduce soil erosion and associated coastal sedimentation, three potential management actions could be taken in Asan's savannas: 1) remove fire; 2) restore badland areas; and 3) both remove fire and restore badland areas. While each of the three management actions would have positive effects on erosion, removing fire and restoring badlands would lower soil loss by approximately 25%. An active badland restoration program without a substantial effort to lower burning will lower soil loss by approximately 18%. Simply removing fire from the savanna without addressing the existing badland will lower soil loss by only 7-8%.

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