NATURAL HISTORY OF A LARGE SCALE DISTURBANCE
THE FEBRUARY 1996 FLOOD AT LA SELVA

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Summary. The February 1996 flood at La Selva Biological Station, Costa Rica was the second largest on record and the largest since 1970. Flood waters drove over 25,000 people from their homes and caused over 600 million U. S. dollars in damage. The flood provided a number of opportunities for current and long-term projects on the effects on the flora and fauna. Several rare animal species presented themselves, most notably *Gymnopis multiplicata*, a caecilian. Many other animals were displaced from their habitats and the effects on populations that are relatively sessile (*eg*, leaf-cutter ants) are yet to be determined. The flood altered some patterns of seed dispersal and seemed to be responsible for an abnormally high rate of tree falls. The gaps resulting from these tree falls combined with the flood aided seed dispersal event could have long-lasting effects on the forest composition at La Selva.

THE FLOOD OF FEBRUARY 1996

From 13-15 February 1996, La Selva Biological Station experienced the second largest flood on record. The Rio Puerto Viejo and Rio Sarapiqui surged beyond their banks, covering most of the secondary forest and experimental plots at their highest point. The rivers began rising on 12 February and peaked the following day at 1300. The Rio Puerto Viejo peaked at 9.3 m above the post-flood water level at 1547 on 16 February, or only 3.7 m below the bridge that extends over the river. The Rio Puerto Viejo rose to < 1 m short of the record high-water mark of 1970. The Rio Puerto Viejo and Rio Sarapiqui tributaries also overflowed. The water at the lower portion of the Quebrada Sura was actually flowing backward as the Rio Puerto rose faster than this tributary. At the high water mark the Quebrada Sura was 8.32 m above the post-flood water level (1540 on 16 February). On 13 February, the Puente Sura leading to the River Station was completely immersed. Data for much of the flood mapping project (Bird et al. 1996) was collected by swimming through the forest. As of 1500, 16 February, sections of the Camino Cantarrana were still submerged.

The flood was caused by sustained high-intensity precipitation. At the La Selva Bridge Station, 305.6 mm of precipitation fell from 11 February to 14 February. Peak rainfall occurred on 12 February when 171.3 mm of rain fell. During the period of 11-14 February, the highest rate of rainfall was 13 mm in 0.5 hour; the record rate was set just three months earlier on 9 November 1995 when 27 mm fell in 0.5 hour (Bill Graul, personal communication). This period of continuous precipitation was caused by a weather system known as a temporales, in which cold air masses from North America flow south over the Caribbean and trigger the development of a slow-moving low-pressure system that brings stratus clouds and steady rain that can cover much of the Caribbean side of Central America. Most of the streams and rivers that run through the La Selva reserve have their headwaters at 150-500 m in Braulio Carrillo National Park. In the storm of February 1996, heavy rains also fell in the mountains, causing the water level to reach greater heights than in most previous temporales.

As of 17 February, there had been 406.7 mm of precipitation recorded at the Bridge Station for the month of February. This far surpassed both the average February rainfall of 162.1 mm (Sanford 1994) and the 1995 February rainfall of 157.5 mm (1995 Daily Summary, unpublished data). In mid-February, the rainfall had nearly reached the 1970 record of 477.3 mm for February (Sanford, 1994). The typical climatic pattern at La Selva only includes infrequent temporales. Average precipitation patterns at La Selva include a season of relatively low precipitation that lasts from January to March, with bi-modal peaks of precipitation July and December.

EXPLANATIONS FOR THE FLOOD

Several theories attempt to explain the recent increase in rain and flooding at La Selva. Some believe the area is experiencing a cyclical rain pattern that was elevated in the early 1970s, dry through the 1980s, and is now increasing again. One observer recalled yearly floods in the 1970s, with few in the past 10 years (D. Clark, pers. comm.). Others speculate that global warming, with concomitant changes in regional patterns of air movement, is responsible for

the flooding increase (O. Vargas and B. Graul, pers. comm.). Regional deforesetation, by altering patterns of water flux in terrestrial ecosystems, represents yet another possible factor. Approximately 100 hectares per year are currently deforested in the county that contains La Selva, which is the highest deforestation rate in Costa Rica. Only 15-20% of all Costa Rica remains forested, a three fold decrease since 1970, and deforestation in the caribbean lowlands of adjoining countries is even more severe.

Although the mechanism causing the recent surge of floods and rain remains undetermined, their devastating effects are still being felt. The flooding not only altered natural landscapes, as seen at La Selva, it also damaged the livelihoods of many local Costa Ricans. While a cyclical model provides some hope that Costa Ricans must only acclimate for the coming decade, the global warming theory is far more bleak. Multiple floods of the same magnitude as this one, or worse, could destroy the lives of many of the local people, and the biological implications are only slowly becoming known, including weather plants and animals must only acclimate to a number of wet years, or if long term adaptations are their only hope for survival.

IMPACTS ON THE FLORA AND FAUNA

Among the plant community, *Heliconia* spp., *Musa* spp. and palms (Aracaceae) seemed to be especially affected, perhaps due to their relatively limited root systems. There were tree-falls throughout the flood; > 3 tree-falls were recorded by a single observer in some 10 minute periods, especially near streams and rivers. The numerous newly formed light gaps caused by tree-falls will likely have an impact on forest composition and dynamics for decades. In the short term, early successional plants should increase. There were many seeds and fruits dispersed by the flood, including as many as 40 coconuts in a 2 x 6 m area near the receding waters of the Puerto Viejo River. *Pentaclethra* spp. seeds were also in high abundance and hundreds were observed germinating hours after the flood waters disappeared (e.g., in the arboretum).

Once the waters receded there was surprising little visible damage to herbs, shrubs, and trees that had remained rooted. While there was mud on many of the leaves on the banks of the streams and rivers, much of the area that had been under as much as 2 m of water appeared to be relatively silt free. Effects on the soil microorganisms that drive decomposition could have been important, but were impossible to evaluate. The long-term effects of the flood on leaves, root structures, and decomposition rates in the litter can only be seen with time and careful study.

One of the most impressive images created by the flood was the complex aggregations of invertebrates. Branches and tree trunks alongside the trail were covered by coleopterans, orthopterans, arthropods, hymenopterans and hemipterans. On one leaf alone, four or five different orders of insects were all seen resting within centimeters of each other.

Millipedes were observed in great numbers. In four transects along the Sendero Tres Rios, we recorded an average of 0.42 millipedes / m; most were resting on tree trunks within 10 cm of the water. One millipede, still alive, was found with its body submerged entirely under 3 mm of water. Spiders were seen running across and swimming through the flood waters, as well as resting with other invertebrates on low hanging foliage. Tarantulas were frequently seen clinging to twigs and vines above the water's surface.

As the flood waters began to recede, transects were examined for dead arthropods. Three people carefully combing through the leaf litter for 2 hrs found only 14 dead arthropods, primarily drowned millipedes and earthworms. This implies that most arthropods survived the flood.

Ants also appeared to have a high survival rate. During the flood, some individual leaves were covered with > 100 adult ants clutching larvae. After the waters receded, ants were quick to recolonize. Leaf-cutter and army ants were seen foraging in areas that had been covered by water less than an hour previously. Most colonies of leaf-cutter ants were active following the flood (Table 1). However, it is possible that in some colonies the queen had drowned or the fungus gardens had been destroyed. Table 1 gives the location of 24 nests of *Atta cephalotes*, 7 of which were completely submerged in the flood. In the hours following the flood, most ant workers appeared to be engaged in removing mud from collapsed galleries. However, members of one leaf-cutter colony were observed swarming over a living millipede, which was dead 0.5 hrs later, suggesting some degree of opportunistic feeding.

Sightings of rare species sightings became almost common. A 15 cm crab was found traveling above the high-water mark in the arboretum. Dozens of Onychophorans were observed. A Rocky Mountain Frog was heard calling during the flood: a rarity for the dry season. Several *Gastrophryne pictiventris*, a triangular-headed frog with a white speckled ventral side that is usually buried deep in the mud during the dry season, were observed in the litter. At least three *Gymnopis multiplicata*, a caecilian, were seen in the flooded areas of secondary growth. Three turtles of

Table 1. Atta Cephalotes ant colony location at La Selva Biological Station, Costa Rica on 14 and 15 February 1996.

Location[a]	Submerged	Activity[b]	dr, f, sc[c]	Comments
SUR780	no	m-h	dr, s	10 x 7 m mound visible
SUR550	no	m	dr	10 x 5 m mound
CCA1550	yes	m	dr	
STR950	no	m	f, dr	med. size mound
STR170L	yes	h	dr	50 m off trail
CCC104	no	m	f	
CCC540L	no	h	dr, f	large mound
CCC1000R	no	l	f, dr	
CCC455R	no	l	f	
CCA/CCCR	yes	l	dr	30 m off trail
SOR20R	no	l	dr	
SOR-R	no	m	f, dr	by River Station
STR300	partially	h	dr	
SLV0	yes	l	dr	
STR655	yes	m	dr	
CES198L	no	h	dr, f	10 x 30 m mound
CES617L	no	m	f	
SURA1150	yes	h	f	
SURA1000	no	h	dr	
SURA790	no	h	f, dr	
SURA620	no	h	f	Huge mound
SOR450	no	m	f	20 m off at 210°, 10 x 15 m
CCC997R	no	m	dr	
FrogSong	no	m	dr, f	past end of boardwalk

[a]"L" or "R" denotes Left or Right off trail

[b]"h," "m," and "l" refer to high, moderate, and low activity levels, respectively

[c] "dr" refers to dirt removal from colony, "f" refers to foraging, and "s" refers to scouting

lengths from 10 to 15 cm, one of them a snapping turtle, were seen swimming on the trail.

Lizards seemed to be absent from the flood zone, perhaps climbing high into the vegetation to avoid the rising waters. Only one blue-tailed lizard, a species in high abundance before the flood (as many as 1 / meter), was found (dead) on the night of February 13. *Dendrobates pumilio* were prevalent during the flood, and were observed resting on tree trunks and other vegetation above the waterline, as well as on the fringes of the flood (Table 2). Some frogs were found clinging to trees in frog study plots set up before the flood, but most amphibians, including *D. pumilio* were found along the flood line, suggesting a primarily horizontal escape pattern (Table 3).

Bird activity seemed to decrease markedly during the flood. A little tinamou (*Crypturellus soui*) was seen foraging on the fruit of the peach palm, not often in its diet. Altitudinal migrants such as the bay-headed tanager (*Tangara gyrola*), the silver-throated tanager (*T. icterocephala*), and the white-ruffed manakin (*Corapipo leucorrhoa*) were seen, raising questions about the degree of flooding disturbance in the highlands above La Selva. These birds are usually found at high altitude during this season. Two accidental species to La Selva (< 5 sightings total) were seen: the rufous-winged tanager (*T. lavinia)* and the black-faced solitaire (*Myadestes melanops*).

Effects of the flood on mammals were difficult to judge, but it appeared that most were able to relocate to high ground. Central American agoutis (*Dasyprocta punctata*) were foraging in the muddy

Table 2. Abundance and vertical location of *Dendrobates pumilio* during the flood along Sendero Tres Rios at La Selva Biological Station, Costa Rica on 13 February 1996.

Meter Mark	Sex	Water Depth (cm)	Height Above H2O (cm)	Substrate
375	M	96	10	Trunk
370	F	96	15	Trunk
325	F	110	20	Leaf
320	F	100	40	Stick
320	F	100	10	Trunk
318	F	105	1	Log
315	F	125	51	Leaf
315	F	125	31	Leaf
310	Juv	120	10	Leaf
280	F	120	30	Leaf
280	M	120	30	Leaf
280	F	135	38	Leaf
280	F	122	28	Leaf
275	M	125	11	Leaf
273	Juv	115	24	Leaf
270	F	115	20	Leaf

Table 3. Frog abundances during the flood.

Date/time	Area	# frogs / obs. hr	# species /obs. hr
13 Feb. - Night	Flooded	4.33 - 8.67	1.33 - 2
14 Feb. - Day	Dry	0	0
14 Feb. - Day	Edge	30	--
14 Feb. - Day	Flooded	5	2
14 Feb. - Night	Dry	4	4
14 Feb. - Night	Edge	4	2
15 Feb. - Day	Dry	4	1
15 Feb. - Day	Edge	8	2

litter where 2 m of water had been just hours before. Collared peccaries (*Tayassu tajacu*) were seen in high abundance on high ground where there had been no water, but their behavior seemed relatively unaffected. Two troupes of spider monkeys (*Ateles geoffroyi*) were seen going over currently flooded areas and those previously flooded. A Jaguarundi (*Felis yagouaroundi*) was seen walking on the main suspension bridge. Animals frequently use the bridge to cross the river (O. Vargas, pers. comm.), so this sighting may have been unrelated to the flood. A southern river otter (*Lutra longicaudis*) was spotted walking on the STR trail away from a small stream in the direction of the Puerto Viejo River. Though this species is fairly common at La Selva, it is not usually seen so far from the river.

The flood also had enormous impact on the local human community. Sarapiqui county, containing 4% of Costa Rica's land and 50,000 people, was hardest hit with 25,000 people left homeless and 9 dead. Damage to banana crops (10,000 ha), palm crops (2,000 ha), and local cattle ranges contributed to losses of over 1.7 billion colones ($600 million U.S.) Highway landslides made many roads temporarily impassable.

Conclusions

The flood of February 1996 provided an opportunity to observe an ecological disturbance that only occurs a few times per century. Such rare large scale disturbances are frequently hypothesized to exert strong and lasting influences on biological communities, but are extremely difficult to study. Information provided here and in the flood mapping project of Bird et al. (1996) may provide the foundation for future studies that test for residual effects of the 1996 flood.

Literature Cited

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