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HARVEST INFLUENCES ON FLOODWATER PROPERTIES IN A FORESTED FLOODPLAIN[1]

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ABSTRACT: Floodplain forests directly influence water quality by serving as sinks, sources, or transformers of nutrients. Increases in the demand for timber raise the question of how silvicultural disturbance may affect this function. The objective of this research was to compare biogeochemical relationships between undisturbed vs. disturbed conditions in a floodplain forest. A randomized complete block design consisting of three blocks and two treatments (partial harvest and undisturbed) was installed on the Flint River floodplain, Georgia. The partial cut was conducted during September-October 1993. Automated water samplers were situated to sample during flood events as sheetflow entered and exited treatment plots during the 1994, 1996 and 1996 flood seasons. Pre- vs. post-contact comparisons indicated that the undisturbed floodplain has minimal influence on water chemistry at this scale of measurement. Although the partial harvest on an 8-ha scale had minimal effect upon sheetflow water chemistry for three years following harvest, the data suggest that harvests may stimulate a minor increase in Ca and K sink activity.
(KEY TERMS: floodplain biogeochemistry; forested floodplain; silviculture; water chemistry.)

INTRODUCTION

One of the many values of forested wetlands is their ability to improve water quality Research has shown that wetlands may serve as nutrient sinks (Kitchens et *at.*, 1975), sources (Richardson, 1989), transformers (Elder, 1985), conveyors (Brinson, 1993) or as a combination of the above depending upon hydrology, type of nutrient, seasonal nutrient uptake patterns, wetland type, and climate year (Mitsch and Gosselink, 1993).

As an example, Kitchens et *al.* (1975) documented a significant reduction in both total and reactive PO_4 concentrations in sheetflow as it flowed through the Santee Swamp of South Carolina. Elder (1985) described a decrease in soluble reactive P and NH_4 concentrations as well as a yield in organic N (dissolved and particulate), particulate, dissolved and total P within the forested floodplain of Florida's Appalachicola River. Kemp and Day (1984) conducting research in a Louisiana swamp, found that while inorganic N was removed, organic N, organic P and PO_4 were exported from the system. Organic matter was exported from a forested floodplain along the Ogeechee River in Georgia (Cuffney, 1988). The latter two studies suggest that floodwaters import inorganic nutrients onto the floodplain and export organic nutrient forms (Sharitz and Mitsch, 1993).

Throughout the southern United States, timber production is considered an important use of floodplains. Approximately 55 percent of the 23.5 million hectares of bottomland hardwood forests in the United States are located in 12 southern states (Turner et al., 1981). Bottomland hardwoods comprise ca. 17 percent of the timberland in the southern United States, half of which are situated along alluvial floodplains (USDA, 1988). As demand for timber increases in the 21st century, forest managers will search for additional sources of fiber. Forested floodplains are considered as alternative sources of timber because of their generally high productivity, rapid growth rates, and high stocking density (Brinson, 1990; Brown et *al.*, 1978).

With approximately 70 percent of the riparian ecosystems having been altered (Brinson et *al.*, 1981), it is essential to understand how these alterations may affect riparian zone functions. Changing a physical variable in a forested wetland may create a cascade of events affecting both the abiotic and biotic components of the wetland. Hydrologic modifications

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may potentially alter decomposition rates, nutrient availability, sediment, pH, productivity and vegetation in the wetland (Mitsch and Gosselink, 1993).

Since floodplains rank high in terms of societal values and since most elemental inputs to forested wetlands come from hydrologic pathways (Mitsch and Gosselink, 1993), it is important to understand how altering forest vegetation may affect the biogeochemistry of the floodplain. Langdon et *al.* (1981) suggested that the effects of silvicultural treatments on hydrologic functions must be studied so that environmentally-compatible silvicultural treatments may be used in floodplain management. Consequently, the objectives of this research were to determine (1) if the Flint River floodplain near Reynolds, Georgia, acts as a source, sink, or transformer of nutrients during flood events; and (2) if partial harvesting alters the physical and chemical surface floodwater composition. Specifically, we hypothesized that (1) the harvested floodplain will act as a source for total suspended solids, NO_3, Ca, Mg, and K as the floodwaters contact exposed soil and large quantities of detritus; (2) the undisturbed floodplain will reduce both inorganic N and P in sheetflow; and (3) floodwater chemistry of the undisturbed and partial plots will converge as vegetation re-establishment occurs.

METHODS

Study Area

The research site was located on the Flint River floodplain near Reynolds, Georgia. Originating in the Georgia Piedmont, the Flint River is an alluvial, redwater river (Wharton, 1978). The floodplain soils are primarily inceptisols and are very fertile (Table 1) compared to other floodplain soils of the southeastern United States (Sharitz and Mitsch, 1993). Total precipitation for 1993, 1994, 1995, and 1996 was 122, 155, 102, 118 cm, respectively. During July 1994, above-normal precipitation caused a 500-year flood event.

Overstory vegetation consists of red maple (*Acer rubrum* L.), water hickory [*Carya aquatica* (Michx. f.) Nutt.], American beech (*Fagus grandifolia* Ehrh.), white ash (*Fraxinus americana* L.), sweetgum (*Liquidambar styraciflua* L.), water tupelo (*Nyssa aquatica* L.), laurel oak (*Quercus laurifolia* Michx.), water oak (*Quercus nigra* L.), willow oak (*Quercus phellos* L.), and *American* elm (*Ulmus americana* L.). Midstory species include hawthorn (*Crataegus* L. spp.), common persimmon (*Diospyros virginiana* L.), possumhaw (*Ilex decidua* Walt.), American holly (*Ilex opaca* Ait.), Eastern hophornbeam [*Ostrya virginiana* (Mill.) K. Koch], blueberry (*Vaccinium elliottii* Chapman), and hackberry (*Celtis Zaeuigata* Willd.).

Study Installation and Sampling

The experimental design was a randomized complete block consisting of three blocks with two treatment plots (one control and one partial harvest) within each block. The partial harvest treatments were installed during September-October of 1993 using rubber tire skidders and drive-to-tree feller bunchers. The partial harvest prescription was a deferment harvest, which establishes an even-aged stand and maintains aesthetics by removing approximately 90 percent of the basal area (i.e., 1.0 - 2.0 m^2 of residual basal area). Treatment plots were 8-ha in size (282 x 282 m) and were situated to avoid sheetflow contact with other harvested plots (Figure 1).

Following the harvest, automated water samplers were located at a position 30 m upstream from the plot (i.e., prior to surface floodwater contact with

TABLE 1. Soil Organic Matter, pH, Phosphorus, Potassium, and Magnesium in the Top 15 cm of Surface Soil on Treatment Plots on the Flint River Floodplain, Georgia.

Block	Treatment Plot	pH	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	Soil Organic Matter (percent)
I	Undisturbed	5.1	20.0	46.7	338.3	7.3
	Harvest	5.2	18.3	46.6	401.6	12.6
II	Undisturbed	5.1	33.3	48.3	265.0	18.7
	Harvest	4.9	31.6	38.3	266.6	5.7
III	Undisturbed	5.5	15.0	48.3	433.3	6.7
	Harvest	5.1	11.7	40.0	295.0	6.0

treatment plot) and 30 m upstream from the downstream boundary of the treatment plot (i.e., to sample post-contact floodwaters). Post-contact samples were in contact with about 280 m of the treatment plot prior to collection. Automated water samplers were programmed to collect 50 ml of sheetflow every 3 hours during the flood event until the 2.5 L sample bottle was full or floodwaters dropped below the water trigger. Automated water samplers were checked weekly to collect water and change batteries. To prevent algal growth during a long duration flood event, approximately 0.5 g of Thymol was added to the empty sample bottle. Samples were transported in coolers to Auburn University and stored overnight in a laboratory refrigerator prior to analysis.

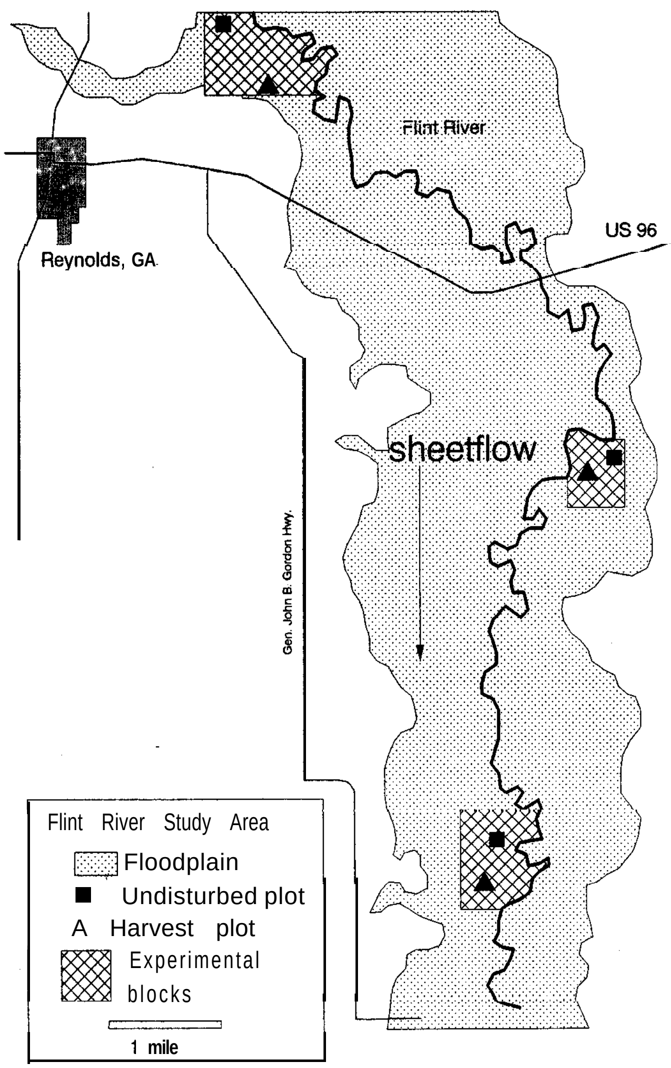

Figure 1. Orientation of Plots on the Flint River Floodplain.

Laboratory Analysis

Water samples were filtered and analyzed within 24 hours after collection using the following methods: NO_3, PO_4, SO.4 by ion chromatography (Dionex HPIC AS4A separator column); Ca, K, and Mg using interconductive argon plasma (ICAP); NH_4 by steam distillation. Total suspended solids (TSS) and total dissolved solids (TDS) were determined gravimetrically and by conductivity respectively on unfiltered samples (Lockaby *et al.,* 1997).

Statistical Analysis

The data were analyzed using a distribution free method described by Potvin and Roff (1993). This method of analysis was selected based on indications of non-normal distributions in similar data sets from studies on the Cache River, Arkansas. Researchers there concluded that statistical analyses of water chemistry data should take into account departures from normality (Godshalk *et al.,* in review). The randomization method described by Potvin and Roff allows researchers to analyze small samples (i.e., 3-5 flood events per season) as well as unbalanced data.

Potvin and Roff analyses took two forms: (1) pre- vs. post-contact comparisons of sheetflow characteristics were made within each treatment and (2) differences in pre- and post-contact values were compared among treatments. In (2) above, the reason for comparing differences was to relativize treatment comparisons from the perspective of pre-contact values for a particular treatment.

In all comparisons, concentration data were interpreted as being equivalent to loads since the water volumes probably did not change over these short distances. Comparisons were considered significant if associated with $P < 0.10$.

RESULTS

The Flint River floodplain hydroperiod (number, duration and height of flood events) varied by year (Table 2). Four flood events were observed during 1994, two in 1995, and three in 1996. However, during both 1994 and 1995, a single flood event occurred outside the normal season (i.e., December-March). A 500-yr flood event was recorded in July 1994. In October 1995, flooding was produced by Hurricane Opal. The number of event days ranged between four in 1994 to 19 in 1996. Mean length of events during the flood season for 1994, 1995, and 1996, respectively, were

6.8, 15, 13.6 days. River stage levels during flood season also varied from 2.83 m in 1994 to 6.42 m in 1996 (Table 2). During 1994, the partial harvest plots contained large piles of woody debris and areas of exposed soil. However, the partial plots were revegetated by the 1995 flood season.

TABLE 2. Duration of Flood Events on the Flint River Floodplain, Montezuma, Georgia, in 1994, 1995, and 1996.

Year	Flood Event	Event Duration (days)	Maximum River Stage (m)
1994	January 30-February 2	4	2.83
	February 12-February 18	7	3.66
	March I-March 9	7	3.76
	March 27-April4	9	3.98
	July 5-July 20*	16	8.05
1995	February 13-February 27	15	5.73
	March 2-March 16	15	3.51
	Cktober 4-October 14**	11	3.99
1996	January 28-February 11	15	5.66
	March 7-March 25	19	6.42
	March 28-April 3	7	3.05

*500-year flood event not during flood season.
**Flood event prior to winter flood season caused by Hurricane opal.

1994 Flood Season

Pre- and post-contact surface floodwater chemistry was compared on both the undisturbed floodplain plots and harvest plots. As sheetflow moved across undisturbed plots, there were no indications of statistically significant changes in chemical or physical properties. However, there were several indications of changes in floodwater properties after contact with harvested plots (Table 3). The latter changes consisted of concentration reductions for TDS, Ca, and K during that year.

There were no clear distinctions between undisturbed and harvested plots in terms of the magnitude of change during sheetflow contact (Table 4).

1995 Flood Season

As in 1994, decreases in TDS, Ca, and K were observed after contact with harvested plots (Table 3). Comparisons between undisturbed and harvested plots indicated that harvested plots had a greater influence on K concentrations than did undisturbed plots (Table 4).

1996 Flood Season

Data from the 1996 flood season showed no statistically significant changes between pre- and post-contact on either undisturbed or harvested plots (Table 3).

DISCUSSION

The data suggest that the undisturbed floodplain had inconsistent (i.e., 1994 vs. 95 and 96) and generally minimal influences on sheetflow biogeochemistry. Variation among years may be attributable to hydrologic differences which could drive annual changes in sheetflow contact time and velocity (Schnabel, 1986). Minimal effects in general relate closely to findings of Godshalk et al. (in review) after comparing upstream vs. downstream samples collected from the main channel of the Cache River. Few statistically significant differences were noted in the Cache study as well. In the present study, minimal influence may be linked to several factors. These include: (1) actual lack of an effect in general, (2) insufficient contact time (i.e., too short a distance for an effect to develop), or (3) insufficient sampling intensity.

Based on a considerable body of literature (Kitchens et al., 1975; Elder, 1985; Cuffney, 1988; Richardson, 1989; Meyer, 1990; and many others), factor (1) is unlikely. However, much of this literature is conceptual and relatively few studies have rigorously demonstrated the transformation function in a quantitative manner. We suggest that, while such a function exists, we know very little about its specific nature or how to measure it. As an example, it is possible that the primary influence of the riparian forest may occur after contact with a minimal width of forest (i.e., prior to contact with these plots). Consequently, little additional influence may be measurable thereafter. This conclusion might also relate to the similar results of Godshalk et al. (in review).

Similarly, the primary "influence" zone may be associated with lower-order reaches as would be suggested by the River Continuum Concept (RCC) (Vannote et al., 1980). In this context, the importance of floodplains associated with high-order reaches is unclear (Meyer, 1990). Given the uncertainties regarding the specific nature of transformations, it is possible that the most appropriate place to look for such influences is closer to headwaters.

TABLE 3. Comparisons of Flint River, Georgia, Floodwater Properties Between Undisturbed and Harvested Floodplain Plots.

Treatment	Analyte*	1994			1995			1996		
		Entry	Exit	Prob.	Entry	Exit	Prob.	Entry	Exit	Prob.
Undisturbed	TSS	14.00	29.92	0.5353	36.67	16.50	0.3306	16.67	32.50	0.6064
	TDS	26.6;	25.00	0.2336	30.06	26.67	0.4552	36.67	36.00	0.7120
	Cl	2.414	2.169	0.9108	2.422	2.264	1.000	1.648	2.281	0.5892
	NO_3	0.123	0.224	0.4582	0.526	0.321	0.1738	0.099	0.343	0.2950
	PO_4	2,115	2.041	0.4636	0.004	0	NA	0.006	0.101	0.4010
	SO_4	2.431	2.447	0.9928	3.063	2.903	0.6434	3.479	4.517	0.7012
	NH_4	0.490	0	NA	0.006	0.007	0.7344	0	0.032	NA
	C	0.120	0.110	0.3334	0.077	0.086	0.7070	0.070	0.080	0.4000
	pH	5.95	6.92	1.000	6.68	6.62	0.6542	6.66	6.29	NA
	Ca	2.605	2.500	0.3352	1,967	1.903	0.8462	1.760	2.035	0.8118
	K	1.810	1.830	1.000	1.082	1.062	0.8416	1.390	1.590	0.3982
	Mg	0.790	0.725	0.3352	0.683	0.642	0.7782	0.643	0.695	0.4000
Harvest	TSS	18.45	22.09	0.8076	48.06	48.56	0.9852	21.83	27.80	0.6966
	TDS	33.64	27.00	0.0562	31.25	26.25	0	31.67	35.00	0.8824
	Cl	2.241	2.516	0.9344	2.025	2.465	0.0360	1.734	1.996	0.6874
	NO_3	0.093	0.306	0.1848	0.193	0.191	0.9874	0.186	0.167	0.8240
	PO_4	3.893	3.102	0.7694	0.006	0	NA	0.029	0	NA
	SO_4	2.643	2.187	0.7630	2.367	2.444	0.8638	2.963	3.088	0.7136
	NH_4	0	0.476	NA	0.391	0.455	0.8790	0	0	NA
	C	0.086	0.098	0.6506	0.076	0.093	0.1692	0.070	0.067	0.8694
	pH	6.17	6.15	0.9792	6.69	6.66	0.771	6.62	6.38	NA
	Ca	2.766	1.788	0.0776	2.149	1.614	0.0316	2.702	1.842	0.2114
	K	2.370	1.462	0.0212	l.491	0.954	0.0062	1.483	1.233	0.1302
	Mg	0.826	0.586	0.2458	0.633	0.561	0.2522	1.060	0.736	0.2136

*Units = mg/l for all analytes except C and pH. C units = percent.

Factor (2) is a possibility. Given the uncertain nature of the transformation function and the high likelihood that a strong influence is exerted on the function by the "type" of floodplain forest (Lockaby and Walbridge, 1998), an inadequate contact time is certainly possible. If so, this uncertainty reinforces the points made in the preceeding paragraph.

Factor (3), sampling intensity, is probably a contributing factor. In this study, water chemistry data were highly variable temporally as well as spatially with coefficients of variation ranging from 30-150 percent. It appears that this is of particular concern when interest is focused on detection of subtle effects of sheetflow contact with undisturbed floodplain.

The floodwater chemistry on the harvest plots reflected that of the undisturbed floodplain with the addition of retention of TDS, Ca, and K during two of the three sample years. An influence of harvesting on K exchange was also supported by magnitude of change comparisons between the two treatments in 1995.

In combination, the statistically significant decreases in K and Ca concentrations and numerical decreases for Mg suggest retention of base cations by this system. Although Lowrance et *al.* (1984) emphasized removal of N and P by riparian deciduous forests, they also noted net retention of Ca, Mg, and, to a lessor degree, K. High vegetative demands and assimilative capacities for base cations have been acknowledged as attributes of many bottomland hardwood ecosystems (Nelson *et al.*, 1987; Francis, 1984) and it is not. surprising that there are indications of positive geochemical balances in this instance. The data of Table 1 in comparison with those presented in Sharita and Mitsch (1993), suggest that the Flint floodplain has natural tendencies toward retention of a number of elements to a greater degree than many other floodplains of the same region. However, the

TABLE 4. Comparisons of Differences in Entry vs. Exit Values Between Undisturbed and Harvested Plots During Sheetflow Contact on the Flint River Floodplain, Georgia.

Analyte	1994 Control	1994 Partial	1994 Prob.	1995 Control	1995 Partial	1995 Prob.	1996 Control	1996 Partial	1996 Prob.
TSS	-6.25	-3.64	0.9266	19.17	-0.50	0.4576	-16.50	-5.97	0.8286
TDS	1.67	8.00	0.6340	3.33	6.00	0.4918	5.60	-3.33	0.4344
Cl	0.255	-0.467	0.1336	0.181	-0.429	0.1064	-0.63	-0.26	0.7176
NO_3	-0.101	-0.213	0.6784	0.205	0.002	0.3536	-0.245	0.019	0.3976
PO_4	0.074	0.791	0.5990	0.0035	0.005	1.000	-0.095	0.029	0.000*
SO_4	-0.017	0.456	0.9428	0.149	-0.077	0.3238	-1.04	-0.125	0.5076
NH_4	0.490	-0.476	0.2398	-0.001	-0.064	0.7838	-0.032	0.0	0.6594
C	0.010	-0.012	0.6712	-0.008	-0.016	0.6600	-0.005	0.003	0.5042
pH	0.035	0.026	0.9508	0.062	0.030	0.4606	0.260	0.235	1.00
Ca	0.105	1.00	0.6796	0.063	0.535	0.1990	0.035	0.860	0.7482
K	-0.020	0.908	0.7748	0.020	0.538	0.0880*	-0.080	0.250	0.6390
Mg	0.065	0.240	0.8442	0.042	0.121	0.4520	-0.005	0.325	0.7482

*Units = mg/l for all analytes except C and pH. C units = percent.

lack of evidence regarding source or sink activity of N and P necessitates the rejection of that hypothesis.

Examination of the pre-contact vs post-contact data across sampling years does suggest a convergence of biogeochemical behavior between disturbed vs undisturbed plots. Thus, the associated hypothesis seems acceptable. Such a convergence over a relatively brief span of time has positive implications for environmentally-compatible forest management within riparian corridors.

Whether these indications of retention of dissolved solids and base cations are linked and reflect filtration enhancement is unclear. Gosselink (1984) reported that erosion was reduced by wetland vegetation binding sediments. In addition, Aust et al. (1997) documented enhanced detention of solids following recent harvests and attributed this to increased roughness resulting from higher densities of post-harvest debris and low vegetation. Similarly, Godshalk *et al.* (in review) recorded that the Cache River wetlands retained solids. However, in the present study, it is uncertain why filtration might occur with dissolved solids but not be detectable with total suspended solids.

The apparent retention observed on the harvest plots may be attributed to the effect of the 500-yr flood event that occurred in July 1994. This out-of-season flood event exceeded the duration and depth observed during the entire 1994 flood season. Large piles of logging debris were relocated within and outside plots. A sediment film was observed on slash, live vegetation, and plot markers and may have contributed to the lower post-contact TDS values observed. The sediment depths recorded in June 1994 after the 1994 flood season were 4.6 mm on the undisturbed plots and 2.3 mm on the partial cut plots. However, in Sept. 1994, sediment depths recorded following the 500-year flood event were 4.4 mm on the undisturbed plots and 4.6 mm on the partial cut plots (Lockaby *et* al., 1997).

Sedimentation rates on the treatment plots were statistically different after the 1994 season. Brinson (1988) suggested that sediment accretion in one location of a riverine wetland may represent short-term, intrasystem transfers. Thus, removal from one location within the floodplain may be deposited upon another location and, thus, not reflect import or export. During the 500-year flood event, 0.2 mm of sediment was removed from the undisturbed floodplain while an average of 2.3 mm was deposited on the harvest plots. Although the longevity of such an effect is uncertain, Szabo (1998) noted that enhanced sediment filtration could still be observed eight years after harvest in the Mobile River Delta of Alabama.

CONCLUSIONS

Biogeochemical functions of the undisturbed floodplain were quite subtle over the distances (i.e., 282 m) involved here. In general, the harvest plots were similar to the undisturbed floodplain in terms of minimal influence on sheetflow properties. However, the harvest plots also altered physical (retention of TDS) and some chemical properties (retention of Ca and K) of the floodwaters crossing the plots. Throughout the first two post-harvest seasons, harvest disturbance seemed to promote sink activity for these parameters. Cairns et al. (1981) noted that when alterations occur to the driving forces of a bottomland hardwood ecosystem, such as the hydrology, the alteration has a greater effect than changes influencing plant communities, such as biomass removal. In this study, the harvest on an 8-ha scale had minimal effects on sheetflow water chemistry, However, the subtle effects observed may become more significant at a watershed scale as management-induced changes in water properties become integrated.

Although predictions are difficult to make, these data suggest that the biogeochemical behavior of harvest plots (with the exception of K) are beginning to approach that of the undisturbed floodplain. This falls within the time frame noted for water quality parameters on harvested sites to return to undisturbed levels (Shepard, 1994). Also, these results indicate that clearcut-natural regeneration combinations on a small scale within river corridors are not in conflict with the maintenance of riparian forest function.

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