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Geomorphic disturbance and its impact on darter (Teleostomi: Percidae) distribution and abundance in the Pearl River drainage, Mississippi

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Abstract

We examined channel and point bar changes over time in the Pearl River, a meandering, Coastal Plain stream in Mississippi and Louisiana. We interpreted extreme changes in bar area as evidence of channel instability and related this to the diversity and abundance of darters in the river. Darters were less diverse and abundant in more disturbed reaches in comparison with relatively undisturbed reaches. Darter abundance was positively correlated with proximity to extreme bar-area changes. The relationship between channel instability and darter abundance observed here points to the importance of landscape level approaches to in-stream habitat management. The results suggest that river management practices that prevent or mitigate extreme changes in channel or sediment dynamics should be adopted for the benefit of benthic communities.

Introduction

Rivers are complex ecosystems, driven by interactions among hydrologic, geomorphic, chemical and biological processes. Although all of these elements contribute to the continuous shaping and re-shaping of lotic systems, the morphology of a stream channel is in large part dependent on water discharge, bed characteristics and sediment load (Knighton, 1984).

The river continuum concept (Vannote et al., 1980) describes the gradient of physical conditions and resulting biotic responses from headwaters to mouths of rivers. In discussing how the river continuum concept can be applied to biotic communities in natural or perturbed stream ecosystems, Vannote et al. (1980) conclude that a concept of dynamic equilibrium for biological communities is useful because it suggests that community structure and function adjusts to changes in certain geomorphic, physical, and biotic variables. Physical habitat changes more quickly in streams than in most other ecosystems (Power et al., 1988), but organisms are adapted to cope with most of these changes. However, relatively rapid and extreme changes in the physical habitat of streams – changes that are of a greater magnitude than the system usually experiences – would be expected to affect the composition of the biotic community.

Resh et al. (1988, p. 434) defined disturbance as any relatively discrete event in time that disrupts ecosystem, community, or population structure, and that changes resources, availability of substratum, or the physical environment. To this, the notion of predictability was added because organisms are adapted to predictable seasonal fluctuations of habitat parameters like discharge, temperature, etc. (Resh et al., 1988). Geomorphic disturbances alter the form of the channel, composition and stability of the stream bed, and the rate of stream flow.

The geomorphology of stream systems has been studied for some time; however, impacts of geomorphic disturbance on biotic systems have only recently been given attention (Reger, 1980; Shankman, 1993; Osterkamp & Hupp, 1996; Brown et al., 1998; Box and Mossa, 1999). Osterkamp & Hupp (1996) noted that the complexities of geomorphic systems, hydrology, and biotic communities have inhibited many researchers from studying system interactions. Box & Mossa (1999) examined the way in which channel change, and concomitant changes in sediment dynamics, can affect unionid mussels.

Rabeni & Jacobson (1993) investigated the influence of certain geomorphic and fluvial processes on centrarchid densities and found that when the geomorphic system is altered by landscape changes, habitat diversity is usually reduced. Sedimentation resulting from bank and channel erosion has been shown to negatively impact densities of benthic, riffle inhabiting insectivorous and herbivorous fishes (Berkman & Rabeini, 1987). Few studies have examined the impacts of major variation in channel morphology on southeastern fish communities (but see Ross et al., 2001).

This study examines the impact of fluvial geomorphic instability on darters, small benthic fishes of family Percidae. Most darters favor habitats composed of clean gravel and sand substrate in shallow, flowing-water. Darters are sensitive to habitat degradation and are a useful indicator of aquatic community health in general (Page, 1983; Karr et al., 1986). Analysis of darter abundance and diversity is one of the metrics employed in the Index of Biological Integrity (IBI, Karr et al., 1986). Habitats favored by darters are degraded by channelization, siltation, and activities modifying riparian areas; it is our assumption that darters will also be sensitive to general channel instability as reflected by bar area changes because of their dependence on the shallow stream bottom near bars.

Twenty-one darter species occur in the Pearl River and its tributaries. Common mainstream species include the dusky darter (*Percina sciera*), saddle darter (*Percina vigil*), bright-eye darter (*Etheostoma lynceum*), the crystal darter (*Crystallaria asprella*), the naked sand darter (*Ammocrypta beani*) and the scaly sand darter (*Ammocrypta vivax*). All of these species favor riffles and runs with substrates of gravel and sand (Page, 1983). Sand darters (genus *Ammocrypta*) favor sand and often bury themselves with only their eyes exposed (Etnier & Starnes, 1993). This burying behavior may be related to stabilization of the darter's immediate environs under changing current conditions (Daniels, 1989).

We hypothesize that the accelerated erosion and redeposition of point bars associated with geomorphic instability will negatively impact darter abundance and diversity in the river.

Study area

The Pearl River basin lies within the Gulf Coastal Plain of Louisiana and Mississippi. It drains an area of 22 688 km^2 and flows generally from north to south for approximately 640 km to its outlet in the Gulf of Mexico. The Pearl River is a meandering, alluvial river. In a meandering channel, centrifugal force drives the water flowing around a bend toward the outside bank. Thus the outside bank of a meander bend is eroded and a commensurate amount of deposition occurs on the inside bank to form a point bar. By this means the channel migrates laterally leaving behind a series of meander scrolls with many bendways and point bars (Langbein & Leopold, 1966).

The Pearl River has been subjected to several anthropogenic activities that have the potential to affect channel stability, including localized channelization, dredging, snagging and aggregate mining within the floodplain. Within the bounds of our study area, the US Army Corps of Engineers (USACE) completed a bank stabilization project in the town of Monticello in the summer of 1980, but nothing of note since that time (pers. comm. USACE personnel). The two biggest changes to the Pearl River as a whole have been the construction of the Pearl River navigational canal and Ross Barnett Dam. The West Pearl River navigational canal features a 25 m wide, 38 km long canal parallel to the natural channel downriver of Bogalusa, LA. Canal construction was completed in 1953. The second major change to channel hydrology came with the construction of the Ross Barnett Dam in 1964. The dam was constructed in order to provide recreation, flood control, and a water source for the city of Jackson, MS.

The study area is entirely in Mississippi and runs approximately 81 km in length from the confluence of the Strong River to approximately 11 km southeast of Monticello (Fig. 1).

Materials and methods

Geomorphic analysis

The assessment of channel conditions and stability was determined by field observations and by analysis of aerial imagery. Stereo pairs were examined under a magnifying stereoscope. Black and white aerial photographs from 1986 (1:24,000) and 1999 (1:20,000) were examined. Each set of photos was taken during periods of similar flow: 1986 (37 m^3/s) and 1999 (39 m^3/s) as recorded at the Monticello gauging station. Areas of unconsolidated point bar, newly vegetated bar, and open water were traced by hand onto mylar sheets overlaying the photos. These maps were digitized into a geographic information system (Map-X™, Delta Data Systems) for data management. A total of 80 individual point bars were mapped for 1986 and 1999. Distances between bars were calculated from the 1999 mapping, from the farthest upstream point moving downstream.

Mapping was ground truthed to ensure accuracy of signature interpretation. Ground truthing

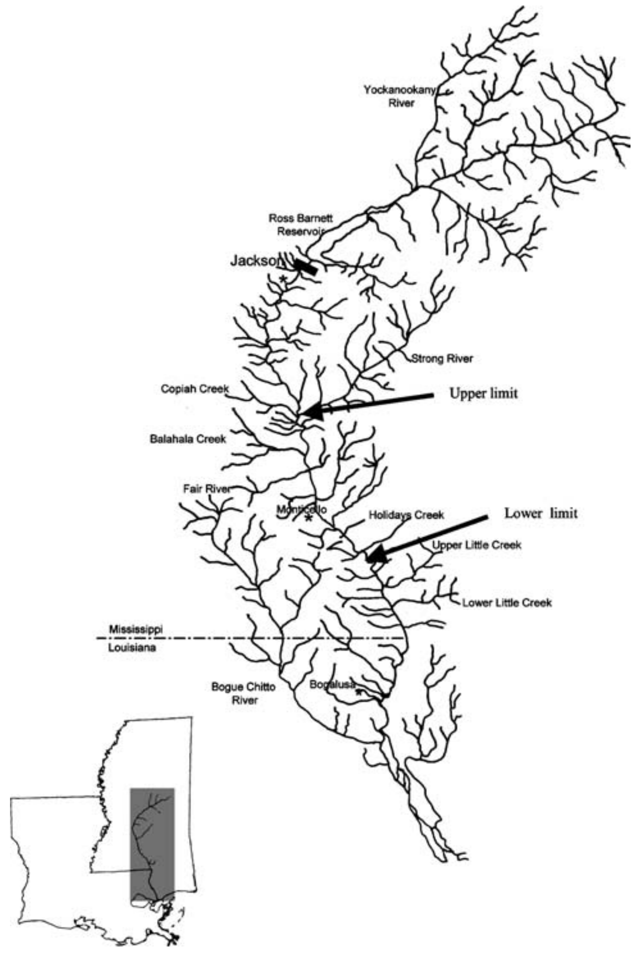

Figure 1. Map of Pearl River Drainage showing the approximate upper and lower limits of the study area.

also provided some corroborative evidence of channel changes, such as severely eroded banks, downed vegetation, etc. New areas created by bar growth are rapidly colonized by flood-tolerant, opportunistic species (Shankman, 1993), especially black willow (*Salix nigra*). In ground truthing, trees on newly vegetated bars were aged in order to confirm that the bar movements evident on aerial photographs had taken place and to determine a time frame for such movements.

Areas for each of the 80 bars were calculated for 1986 and 1999 and differences in point bar area between the time periods were determined. The absolute value of this difference was taken and the minimum, maximum, mean, and standard deviation were calculated. Point bars that saw a change greater than 1 standard deviation were identified as 'extreme changes.' The bar area data for the extreme changes was calculated with the GIS software and sorted by bar moving from upstream to downstream (in Table 1). The absolute value of the change in point bar area was used because it was assumed that large gains or losses in bar area would both constitute a disturbance to the benthic fish community.

Fish sampling

Fish were collected along bars throughout the study area. Bars were at first chosen without regard to the geomorphic analysis, but rather haphazardly or based on accessibility; for example, we could not collect on bars in the upper 10 km of our study area due to private property issues and obstacles that prevented boat travel. As the collecting progressed, effort was made to return to bars where extreme changes occurred in order to sample or resample the surrounding locales. Each bar was divided into thirds (upper, middle and lower sections) so as to ensure sampling as much of the bar as possible. A standard seine (3.3 × 2 m) was used to sample the fish community of each bar. Three seine hauls, approximately 10 m in length parallel to the shore, within 3 m of the water line, were made in each of the three sections (nine seine hauls per bar). Each seine haul was initiated by tossing a flagged, metal stake over the shoulder to determine the starting point of the sample. No special effort was made to collect particular fish; we pulled the seine approximately 10 m parallel to the shore then pulled it onto shore. Fish were preserved in a 10% formalin solution. Dividing the number of darters collected by the number of seine hauls (9) per collection gave the darter abundance for each bar within each section. A total of 33 different samples were made on 28 bars (5 bars were sampled on more than one occasion, during different seasons). Samples were made in May 1999, September 1999, October 1999, January 2000 and February 2000.

Table 1. Extreme changes in point bars between 1986 and 1999

No.		Area 1986 (m^2)	Area 1999 (m^2)	Change in area (m^2)	Absolute value of change	Distance in km upstream to downstream
PB	9	34316	0	−34316	34316	12.5*
PB	30	37055	0	−37055	37055	30.8*
PB	41	89676	0	−89676	89676	44.5*
PB	42	18504	47009	28505	28505	44.6
PB	46	38905	0	−38905	38905	46.0*
PB	58	17640	49305	31664	31664	66.2
PB	61	29177	0	−29177	29177	67.5*
PB	64	29053	0	−29053	29053	69.1*
PB	65	63664	0	−63664	63664	69.1*
PB	66	0	45359	45359	45359	69.4
PB	77	69651	100587	30936	30936	79.4

Distances identified with '*' are approximated distances; these are point bars that were identifiable from the photos in 1986, but not in 1999.

Fish were sorted and archived at the R.D. Suttkus Fish Collection in the Tulane Museum of Natural History.

Effort was made to sample bars across large swaths of the study area during each sampling trip. All collecting trips were made during low water conditions, when flow was <39 m^3/s as measured at the Monticello, MS gauging station. This minimized flow-related effects on sampling and fish community composition and also corresponded to the low flow conditions represented in the aerial photographs.

Fish and geomorphic data analysis

To examine the relationship between darter abundance and extreme bar-area changes, distances from fish sampling location to the nearest extreme bar-area change were calculated using the GIS software. Non-parametric rank correlation (Kendall's-tau-b) was used to test the null hypothesis of no correlation between darter abundance and proximity to extreme bar changes. In addition, non-parametric rank correlation was used to evaluate the hypothesis of no correlation between darter abundance and the distance to bars changing by 0.5 standard deviation of the mean (=non-extreme changes).

The observed differences between the upper and lower sections of the study area with regard to these extreme bar movements and darter abundance was also characterized. The study area was divided into two 40 km segments, each containing approximately 40 bars (PB1-PB39 in the upper 40 km segment, and PB40–80 in the lower 40 km segment). The Wilcoxon Signed-Rank test was used to test for differences in darter abundance and bar-area change between upper and lower segments.

Results

Geomorphology

Analysis of bar area changes suggests that the channel of the Pearl River has changed significantly since 1986. A total of 80 bars were mapped for each of the periods, 1986 and 1999 (Table 1, Figs 2–7). The majority of the bars evident in 1986 were visible in 1999. However, a few of the bars

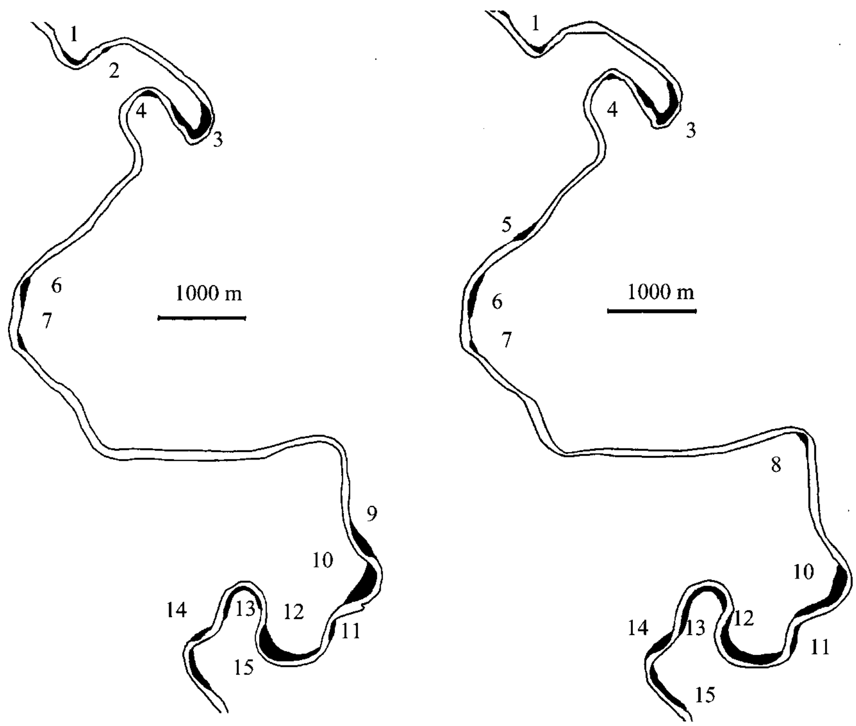

Figure 2. GIS plots of point bar mapping for 1986 (left) and 1999 (right) for PBs 1–15.

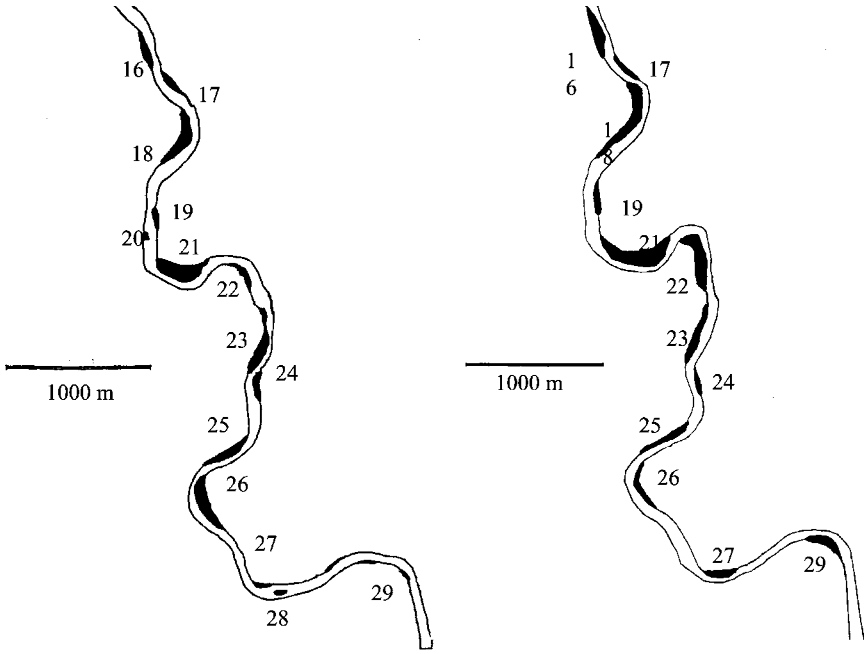

Figure 3. GIS plots of point bar mapping for 1986 (left) and 1999 (right) for PBs 16–29.

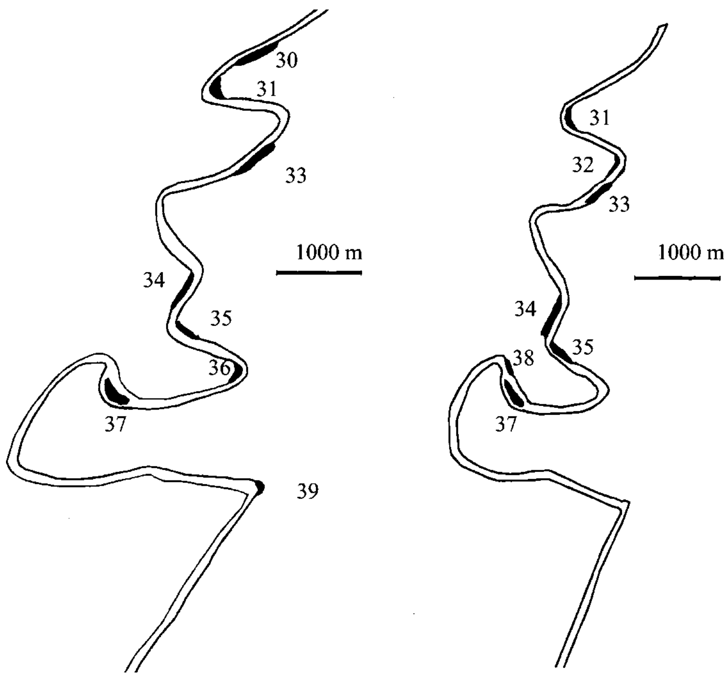

Figure 4. GIS plots of point bar mapping for 1986 (left) and 1999 (right) for PBs 30–39.

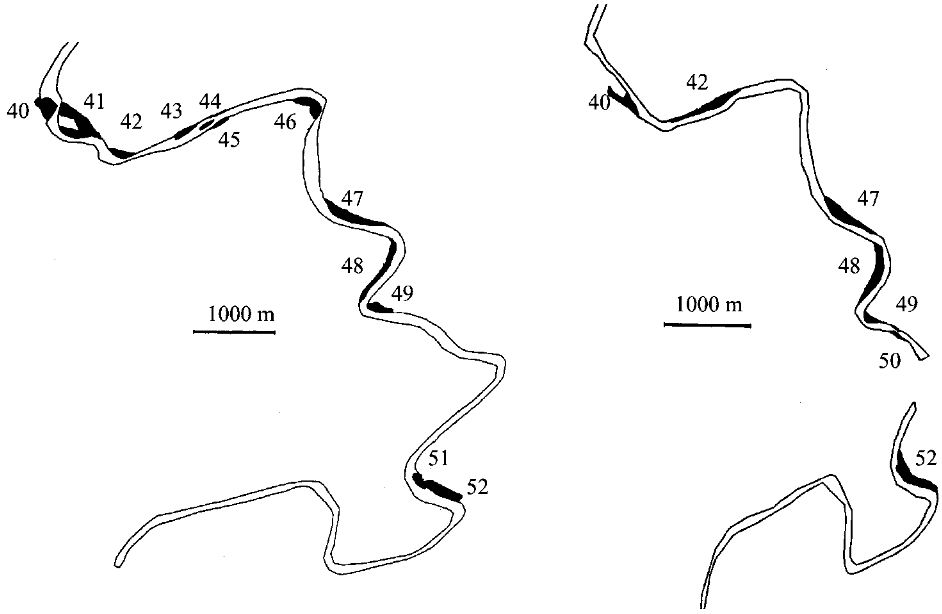

Figure 5. GIS plots of point bar mapping for 1986 (left) and 1999 (right) for PBs 40–52.

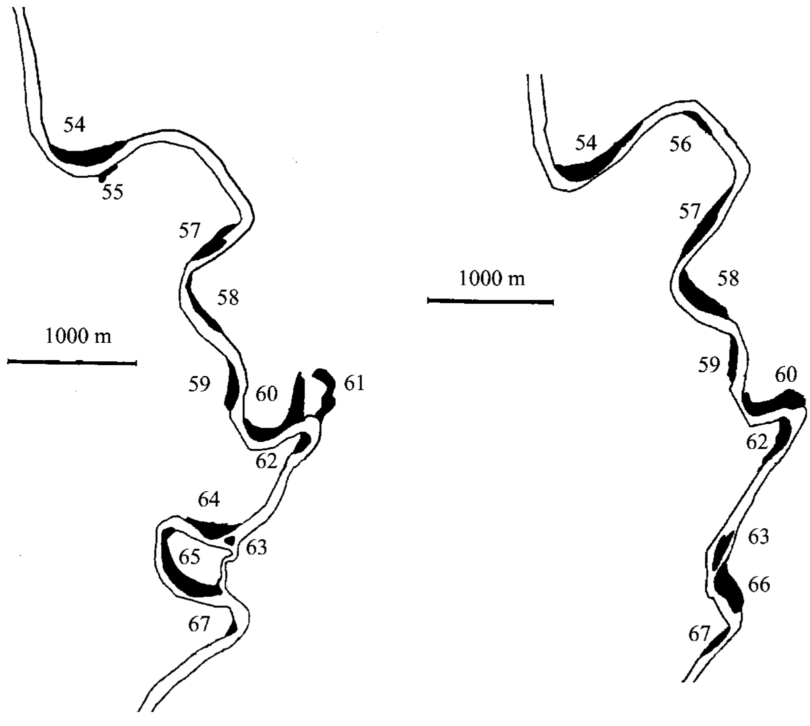

Figure 6. GIS plots of point bar mapping for 1986 (left) and 1999 (right) for PBs 54–67.

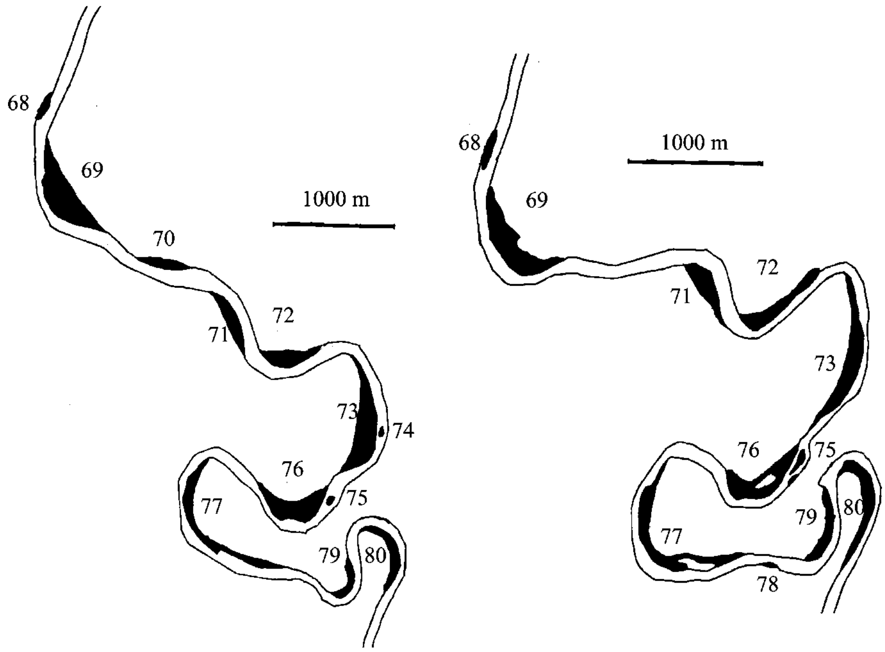

Figure 7. GIS plots of point bar mapping for 1986 (left) and 1999 (right) for PBs 54–67.

that were present in 1986 were not present in 1999 (e.g. PB9, Fig. 2). The gap in mapping between PB 50–52 for the 1999 data was a result of inadequate aerial photo coverage.

The mean of the absolute value of bar area change between the two time periods is 13 390 m^2 (SD = 14 217 m^2). Bars that had changes greater than 1 standard deviation changed by more than 27 608 m^2 on average over the 13-year period; those that exceeded 2 standard deviations changed by more than 41 825 m^2. Eleven bar area changes exceeded 27 000 m^2 (Table 1). The largest change (89 676 m^2) occurred at PB41 and was immediately upstream from another extreme change (PB42). In five of the cases where bar-area changed by more than 1 standard deviation of the mean (PB9, PB30, PB46, PB61 and PB64), the bar disappeared completely. Three other bars (PB42, PB58 and PB77) experienced significant growth in area in the 13 years. Likewise, two (PB41 and PB65) of the three most extreme bar area changes – those which exceeded 2 standard deviations – involved cases where large bars disappeared completely.

Taking all of the extreme changes together, the lower section of the study area has experienced more of these events than the upper section. For example, the section of river between PB40 and PB46 (Fig. 5) had three extreme bar area changes. The aerial photos from 1986 show what appears to be a large sand wave moving into this section of the Pearl from a tributary in the vicinity. The extreme bar area changes witnessed between PB60 and PB66 can be explained by a cutoff in the river there (Fig. 6).

Fish

A total of 33 fish samples were taken over 28 bars; five bars were sampled twice (Table 2). *Ammocrypta beani* was the most frequently collected darter. Included in all the collections were 294 *Ammocrypta beani*, 30 *A. vivax*, and 9 *P. sciera* in addition to some less common percid fishes such as *E. lynceum*, *E. artesiae* and *P. nigrofasciata*. The mean number of darters per seine haul over the entire study area was 1.3 (SD = 1.92). The mean catch per unit effort in the upper 40 km of the study area was 2.4 (SD = 2.38), whereas that in the lower 40 km was 0.30 (SD = 0.38). There was also variation in the number and diversity of darters that were collected during the study. Some reaches were depauperate, whereas others were relatively rich in darters. Five bars (PB16, PB54, PB62, PB69 and PB72) yielded no darters. PB56 was sampled

Table 2. Summary of darters collected and a measure of collecting effort in the Pearl River study area (1998–1999)

		Ammocrypta beani	*Ammocrypta vivax*	*Percina sciera*	Other Percids	Total Percids	# samples [9seine hauls]	Catch per unit effort	Month of sample(s)	Distance in km upstream to downstream
PB	10	4	0	0	0	4	1	0.4	Feb	13.5
PB	11	34	0	0	0	34	2	1.9	May, Feb	14.6
PB	13	31	1	0	0	32	1	3.6	Feb	16.3
PB	16	0	0	0	0	0	1	0.0	May	18.0
PB	21	55	0	2	0	57	1	6.3	Oct	21.1
PB	24	14	0	0	0	14	1	1.6	May	23.2
PB	25	28	1	0	0	29	1	3.2	Oct	23.7
PB	27	0	6	1	0	7	1	0.8	Oct	25.3
PB	32	13	7	0	0	20	1	2.2	Oct	31.8
PB	34	64	0	3	0	67	1	7.4	Oct	34.2
PB	35	0	1	1	0	2	1	0.2	Sept	34.8
PB	38	20	0	0	0	20	2	1.1	Sept, Jan	37.2
PB	47	0	1	0	0	1	1	0.1	Oct	47.5
PB	48	11	2	0	0	13	1	1.4	Oct	48.4
PB	49	4	1	0	0	5	1	0.6	Feb	49.4
PB	50	4	0	0	0	4	2	0.2	Oct, Feb	49.9
PB	52	1	7	0	3	11	2	0.6	Oct, Feb	51.5
PB	54	0	0	0	0	0	1	0.0	Sept	63.0
PB	56	1	0	0	0	1	2	0.1	Sept, Feb	64.3
PB	57	0	1	0	0	1	1	0.1	Sept	65.4
PB	58	2	0	2	0	4	1	0.4	Oct	66.2
PB	59	5	2	0	0	7	2	0.4	May, Oct	67.0
PB	62	0	0	0	0	0	1	0.0	Feb	67.9
PB	66	3	0	0	2	5	2	0.3	May, Jan	69.4
PB	69	0	0	0	0	0	1	0.0	Sept	72.7
PB	72	0	0	0	0	0	1	0.0	Sept	75.4

twice and yielded only one darter (Table 2). The bar with the greatest number of darters taken in the nine seine hauls was PB34 with 67 darters for an average of 7.4 darters/seine haul.

Fish and geomorphic data

The five point bars that failed to yield darters during this study were within 0.5–5.5 km of an extreme bar change. Likewise, a number of bars that yielded relatively few darters experienced extreme changes or were in close proximity of bars that experienced extreme changes. PB56 was sampled twice, in September 1999 and February 2000, and yielded a total of one darter; PB56 is less than 2 km upstream from the site of an extreme bar area change (PB58). In contrast, a total of 57 darters were collected at PB21, which was 8.7 km upstream from a bar that experienced extreme changes (PB30) and 8.6 km downstream from one (PB9). A non-parametric correlation analysis revealed a significant positive relationship between darter abundance and distance from bars that changed by more than 2 standard deviations ($r = 0.389$, $p = 0.008$, Table 3). Thus, the null hypothesis of no correlation between darter abundance and proximity to extreme channel changes can be rejected.

The correlation between darter abundance and distance to extreme changes exceeding one standard deviation of mean bar area change was not significant ($r = 0.234$, $p = 0.105$), but was

Table 3. Results of non-parametric correlations for darter abundances and distances to extreme changes (1 and 2 standard deviations) and changes that were 0.5 standard deviations

			AVGPERC
Kendall's tau-b	AVGPERC	Correlation coefficient	1.000
		Sig. (2-tailed)	.
		N	26
	Distance to extreme changes (>1 standard deviation).	Correlation coefficient	0.234
		Sig. (2-tailed)	0.105
		N	26
	Distance to extreme changes (>2 standard deviation).	Correlation coefficient	0.389
		Sig. (2-tailed)	0.008**
		N	26
	Distance to those bar changes that were 0.5 standard deviations	Correlation coefficient	0.218
		Sig. (2-tailed)	0.131
		N	26

** Correlation is significant at the 0.01 level (2-tailed).

consistent with the overall trend of lower darter abundance in proximity to areas of channel instability. The correlation between darter abundance and distance of the fish sample from bar area changes greater than 0.5 standard deviation of the mean was also non-significant (changes of 20 500 m^2 or more, $p = 0.131$, Table 3).

Upper and lower segments of the study area differed significantly in both bar-area changes and darter abundance. The more extreme bar-area changes in the lower reach of the study area (16,663 m^2 versus 9.548 m^2 in the upper reach, $Z = 1.963$, $p < 0.05$) was associated with lower darter abundances (0.3 per seine haul versus 2.4 per seine haul in the upper reach, $Z = 2.943$, $p = 0.003$, Table 4).

Table 4. Wilcoxon signed-rank test for differences in darter abundance and bar area changes for the upper and lower portions of the study area

	Lower 40 km fish – upper 40 km fish	Lower 40 km bar – upper 40 km bar
Z	−2.943	−1.963
Asymp. Sig. (2 tailed)	0.003	0.050

Discussion

Change in channel form is a natural characteristic of alluvial streams, and the organisms inhabiting them are adapted to such changes. However, as has been demonstrated here, extreme changes can constitute a disturbance to benthic fauna. In this study, analysis of bar area changes suggests that relatively strong geomorphic processes are active

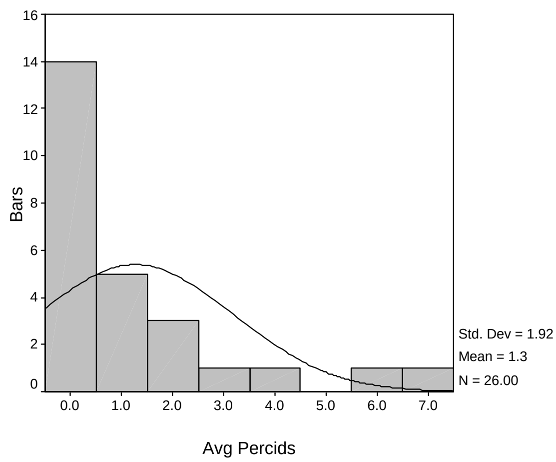

Figure 8. Histogram showing average number of percid fishes on point bars sampled within the study area.

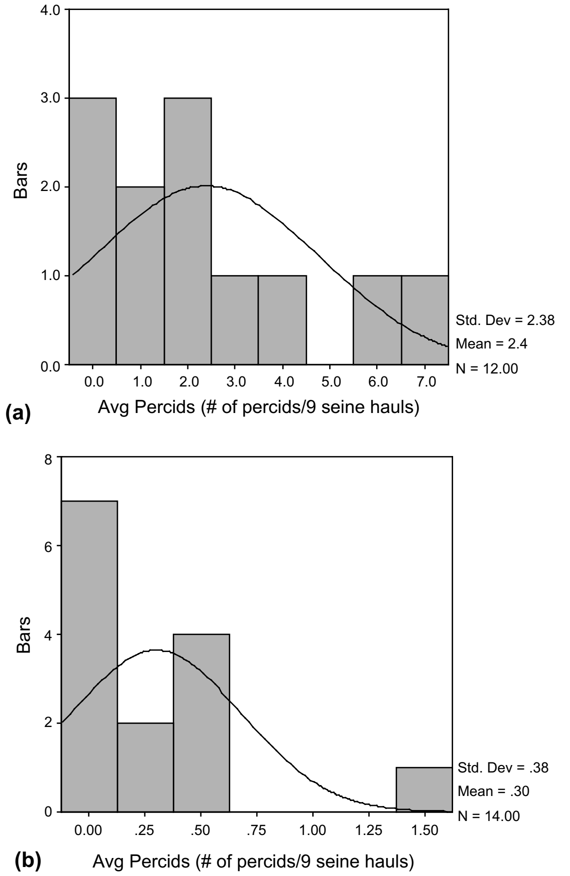

Figure 9. Catch per unit effort in the upper 40 km (a) and lower 40 km (b) of the Pearl River study area.

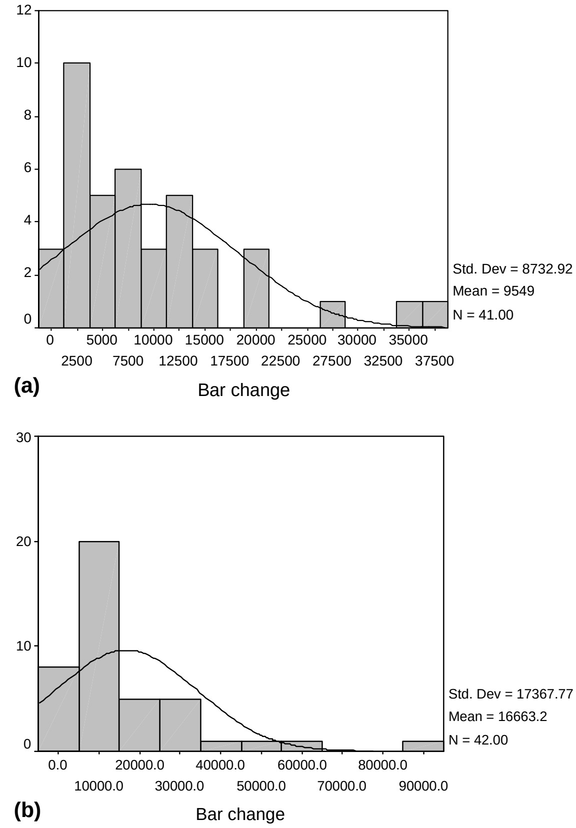

Figure 10. Bar area change (1986–1999) in the upper 40 km (a) and lower 40 km (b) of the Pearl River study area.

in areas of the Pearl River (Figs 8–10). The point bar data indicate that there were 11 cases in which point bars experienced extreme changes in area between 1986 and 1999 (increases or decreases > 27 000 m^2); and three of these were very extreme changes (>41 000 m^2). The most extreme changes tended to be clustered in the lower half of the study area (between PB 58-67 and PB41 and PB42), suggesting that this is an area of relatively extreme channel instability.

It has been shown that substrate instability and increases in fine substrate reduce the abundance of lithophilous fishes, presumably because of the importance of clean gravel substrate for spawning (Berkman & Rabeni, 1987). As a group, darters are highly susceptible to substrate instability. In our study, darter populations were significantly smaller in the reach of the Pearl River experiencing the most extreme geomorphic changes. Conversely, in reaches where the changes in channel morphology were not as extreme, darters were more abundant. These extreme channel changes apparently affect nearby darter populations, and, it is assumed the benthic fauna in general. The relationship was significant only for the most extreme bar area changes (41 825 m^2 or more), but there was a tendency for darter abundance to be lower in the vicinity of bars that changed by 1 standard deviation or more. Changes of 20 500 m^2 (0.5 standard deviation of the mean) or more in bar area were not associated with significantly lower darter densities in nearby localities. This suggests that only the most extreme channel changes constitute a disturbance to darter abundance. Our results are consistent with both the river continuum concept (Vannote et al., 1980) and the general understanding of disturbance in streams (Resh et al., 1988).

It is important to emphasize that the fish changes documented in this study involved common darter species that are probably the least sensitive to channel instability (e.g., species of *Ammocrypta*). A number of other darter species that were common in the river in the past (e.g. *Crystallaria asprella*, *Percina aurora*, *P. suttkusi*, *P. vigil*) were not collected or were only collected very rarely in this study. These species favor firm gravel substrates and perhaps are not as well adapted as sand darters for coping with changes in the streambed. More work needs to be done to determine the particular levels of geomorphic change that will constitute a disturbance to different species of darter and other benthic fishes.

The data presented in this study suggests that darter abundance and diversity is only negatively impacted by geomorphic instability above a certain magnitude. Darters and most other benthic fishes depend on relatively stable substrates for reproduction and foraging (Page, 1983). The relatively major shifts in channel geometry and the associated movements of sediment observed in this study negatively impacted Etheostomatine darters. Determining the various causes and sources of the changes that are seen in geomorphology and whether anthropomorphic activities contribute to these is beyond the scope of this study.

The relationship between benthic fishes (darters) and channel instability shown here might have a consequence for conservation concerns and points to the importance of landscape level approaches to habitat management. When viewed by family, percids (Percidae) have 31% of their species jeopardized, compared to the overall 19% of southeastern fish species that are considered jeopardized (Etnier, 1997). Changes in the geomorphology and sediment dynamics of southeastern streams may be one potential causal factor in the decline of benthic fishes. The relationship between channel instability and anthropogenic activity needs to be studied further. It is clear, however, that management practices that prevent or mitigate extreme changes in channel or sediment dynamics should be adopted for the benefit of the benthic fauna in the Pearl River and, we suspect, across the Southeastern United States.

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References

Berkman, H. E. & C. F. Rabeni, 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes 18: 285–294.

Box, J. B. & J. Mossa, 1999. Sediment, land use, and freshwater mussels: prospects and problems. Journal of the North American Benthological Society 18(1): 99–117.

Brown, A. V., M. M. Lyttle & K.B. Brown, 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127(6): 979–994.

Daniels, R. A., 1989. Significance of burying in Ammocrypta pellucida. Copeia 1989: 29–34.

Etnier, D. A. & W. C. Starnes, 1993. The fishes of Tennessee. University of Tennessee Press, Knoxville, TN.

Etnier, D. A., 1997. Jeopardized southeastern fishes: a search for causes. In Benz G. M. & D. E. Collins (eds), Aquatic Fauna in Peril: The Southeastern Perspective: 87–104.

Hupp, C. R. & W. R. Osterkamp, 1996. Riparian vegetation and fluvial geomorphic processes. Geomorphology 14: 277–295.

Karr, J. R., K. D. Fausch, P. S. Angermeier, P. R. Yant & I. J. Schlosser, 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5.

Knighton, D., 1984. Fluvial Forms and Processes. Edward Arnold, London.

Kondolf, G. M. & M. Larson, 1995. Historical channel analyses and its application to riparian and aquatic habitat restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 5: 109–126.

Langbein, W. B. & L. B. Leopold, 1966. River meanders theory of minimum variance. US Geological Survey, Professional Paper 422-II.

Mossa, J. & W. J. Autin, 1998. Geologic and geographic aspects of sand and gravel production in Louisiana. In Bobrowsky, P. T. (ed.), Aggregate Resources: A Global Perspective. A.A. Balkema/Rotterdam/Brookfield.

Osterkamp, W. R. & C. R. Hupp, 1996. Preface. Geomorphology 14: 275.

Page, L., 1983. Handbook of Darters. TFH Publications, Neptune City, New Jersey.

Power, M. E., R. J. Stout, C. E. Cushing, P. P. Harper, F. R. Hauer, W. J. Matthews, P.B. Moyle, B. Statzner & I. R. Wais de Badgen, 1988. Biotic and abiotic controls in river and stream communities. Journal of the North American Benthological Society 7: 433–455.

Rabeni, C. F. & R. B. Jacobson, 1993. Geomorphic and hydraulic influences on the abundance and distribution of stream centarchids in Ozark USA streams. Polskie Achiwum Hydrobiologii 40(1): 87–99.

Reger, S. J., 1980. Effects of stream channel alterations on aquatic insect communities. Dissertation, Utah State University.

Resh, V. H., A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G. W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace & R. C. Wissmar, 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society 7(4): 433–455.

Ross, S. T., 2001. Inland Fishes of Mississippi. University Press of Mississippi, Jackson, MS.

Ross, S. T., M. T. O'Connell, D. M Patrick, C. A. Latorre, W. T. Slack, J. G. Knight & S. D. Wilkins, 2001. Stream erosion and densities of *Etheostoma rubrum* (Percidae) and associated riffle-inhabiting fishes: Biotic stability in a variable habitat. Copeia 2001(4): 916–927.

Schlosser, I. J., 1991. Stream fish ecology: a landscape perspective. BioScience 41: 704–712.

Shankman, D., 1993. Channel migration and vegetation patterns in the Southeastern coastal plain. Conservation Biology 7(1): 176–183.

Sheldon, A. L., 1967. Species diversity and longitudinal succession in stream fishes. Ecology 49: 193–198.

Taylor, C. M., 1997. Fish species richness and incidence patterns in isolated and connected stream pools: effects of pool volume and spatial position. Oecologia 110: 560–566.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushing, 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130–137.