Effects of Highway Bridges on the Aquatic Biota of Three Florida Rivers

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ABSTRACT

Aquatic communities were studied at three bridge sites in Florida rivers to determine whether bridge design features have any adverse impacts on biota. Construction methods were considered where information was available. Benthic macroinvertebrates were collected along transects that extended across each river. Submerged macrophytes and associated epifaunal invertebrates that occurred in one of the rivers were also collected. Numbers of individuals for each of the taxa of benthic and epifaunal invertebrates and biomass for each of the plant species were determined. Dominance, diversity, and evenness values were calculated for sample collections. Significant alteration of the aquatic community occurred at one bridge site. Adverse impacts on the aquatic biota were attributed to bridge design and construction methods. Construction practices rather than bridge design were found to have potentially adverse impacts on the biota at a second site. At the remaining site, only minor disturbance of the aquatic community was detected. Impacts on aquatic communities can be minimized by (a) placing bridges at locations where alteration of the river channel or floodplain can be avoided; (b) designing bridges and selecting construction methods that maintain, as much as possible, the natural hydrological, sedimentary, and illumination characteristics of the river system and that minimize site disturbance, and (c) providing adequate quality control of construction practices.

Florida has extensive marine, river, and lake systems that make the construction of bridges a necessary and costly part of highway construction. Because these aquatic systems are important for recreation and sport and commercial fishing, bridging ideally should not adversely affect aquatic life. Previous studies have shown that aquatic communities are very sensitive to disturbance; therefore, state and federal environmental regulations require that bridge construction projects be reviewed for possible adverse impacts on aquatic systems and that a permit or other authorization be obtained before construction activities are begun. Regulatory agencies have often required bridge design modifications, realignment, and the use of various precautionary measures to minimize the environmental impact of bridging. If not considered early in the planning stages, many of these stipulations can be expensive and may lead to time-consuming delays in permit processing and roadway construction.

The evaluation of the anticipated impacts of bridge construction on aquatic communities has been based on subjective observations and inferences from the general literature. The most comprehensive report on the effects of construction activities on aquatic systems is that of Darnell (1). Darnell stresses the multivariate nature of the impacts of most construction activities on aquatic systems. Because of the complexity of natural systems, individual effects cannot be separated distinctly nor attributed easily to specific causes. A U.S. Department of Transportation training and design manual (2,pp.1-14) identified several potential impacts of bridging. Scour, erosion, shading, changes in sediments, and an increase in suspended solids may have a significant impact on aquatic biota. The report also stated that although construction activities may be of short duration, long-term damaging effects may result from the presence of bridges. Very few data, which quantify the effects of bridge construction or presence on aquatic systems and on which sound regulatory decisions can be based, have been compiled.

This study was designed to assess quantitatively the effects of highway bridge construction and presence on the aquatic biota of river systems in Florida. Data on benthic (bottom-dwelling) invertebrates, submerged macrophytes (aquatic vegetation), and epifaunal invertebrates (organisms living on the surface of the vegetation) were used in this assessment. Aquatic invertebrates were selected for study because of their important role in the food chain for sport and commercial fishes. Submerged macrophytes provide a food source for many invertebrates and some species of fish and assist in maintaining good water quality.

Three rivers were selected for study: (a) the Ochlockonee River, an alluvial river with an extensive floodplain; (b) the Wakulla River, a clear spring run with low sediment transport; and (c) the Braden River, a small blackwater river with low sediment transport. Data on the age, design, orientation, height, and construction techniques for each bridge were obtained from the Florida Department of Transportation (FDOT).

AREA DESCRIPTIONS

Ochlockonee River and I-10 Bridge Site

The part of the Ochlockonee River chosen for study was the site of the Interstate 10 (I-10) crossing. The Ochlockonee River is a mature alluvial stream in the northwest portion of the state. This river flows for approximately 160 miles before entering the Gulf of Mexico (3,p.27). The average width of the river measured at the study site was 107 ft. At the I-10 bridge, the Ochlockonee River drains an area of 1,180 square miles. A 49-year average river discharge of 1,014 cfs has been recorded at the U.S. Geological Survey (USGS) gauging station located approximately 4 miles upstream of the study area (3, p.31). Normal flow elevation of the Ochlockonee River at the study site is 68 ft mean sea level (MSL) with a recorded maximum water stage of 85.2 ft MSL (4).

The Ochlockonee River carries a heavy load of silts and clays that accounts for the relatively high turbidity levels of the water. Preconstruction core borings indicate that the river bottom consists of fine white sand, gray sand, and hard limerock (4). The study area is characterized as coastal lowlands with a floodplain varying from a quarter to half a mile in width (personal communication from Daniel Darden, Florida DOT). No submerged aquatic macrophytes were observed at the study site.

The I-10 bridge is a split roadway design with each bridge 40 ft in width separated by a distance of 64 ft. The 1,210-ft bridge traverses a major part of the floodplain, a small slough to the east, and the main river channel. Each 105-ft-wide span over the river is supported by two round-nosed piers 12 ft long by 3.6 ft wide placed in the river. The elevation of the low member of the bridge is 17.22 ft above the normal flow elevation (68.0 ft) of the Ochlockonee River. The bridge is oriented east-west. Construction of the bridge was completed in 1976 (Daniel Darden).

Wakulla River and US-98 Bridge Site

The second study site was located where US-98 crosses the Wakulla River. The Wakulla River, a clear calcarous spring run located in northwestern Florida, flows southward for a distance of 10.1 miles through flat coastal lowlands before joining the St. Marks River and entering the Gulf of Mexico (5-7).

Although the water at the study site is fresh, the water level is tidally influenced. Water temperature at the site remains fairly constant throughout the year. The average measured width of the river at the study site was 217 ft. A 37-year average river discharge of 432 cfs has been recorded at the USGS gauging station located 4 miles upstream of the study site at FL-365. Normal flow elevation of the Wakulla River is 5.0 ft MSL throughout the river (3, p. 65).

The river floodplain is approximately 280 ft wide on either side of the river at the study site. There is little sediment load in the Wakulla River. The river bottom at the study site consists of sand and silt overlying scattered limerock (6). The river bottom is covered with a dense growth of submerged aquatic macrophytes including *Sagittaria kurziana, Vallisneria americana, Potamogeton illinoensis,* and *Najas guadalupensis*.

The US-98 bridge over the Wakulla River is a single span built in 1956. It is 36 ft wide, 290 ft long, and traverses the Wakulla River and 45 ft of the floodplain on each side of the river. Filled causeways were constructed across the remainder of the floodplain on either side, and filled approach pads to the bridge constrict the river channel at the study site. The bridge is supported by seven sets of pilings. Each set of pilings consists of five square pilings placed 5.7 ft apart and measuring 1.6 ft on a side. The elevation of the low member of the bridge is 10.7 ft above the normal flow elevation (5.0 ft) of the Wakulla River. The bridge is oriented approximately 27 degrees east of true north (Daniel Darden and 8).

Braden River and I-75 Bridge Site

The third study site is located where I-75 crosses the Braden River in southwestern Florida. The Braden River is a small, slow-moving, blackwater river that meanders 20.2 miles northwest through low, level plains before discharging into the Manatee River (3). The average measured width of the Braden River at the study site was 114 ft. The river drains an area of 51 square miles at the I-75 bridge site (9).

The water is clear and pale brown in color due to a high tannin content. Preconstruction core borings indicated that the river bottom is composed of clayey, silty, fine sand (10), with a thin layer of detritus present at the sediment surface. No floodplain is present along the Braden River. The banks are steep, 4-5 ft high, and interrupted by several small sloughs that drain into the river near the study site. No submerged aquatic macrophytes were observed in the study area.

The I-75 bridge, a split roadway design, was completed early in 1979. The spans are 56 ft wide and separated by a distance of 68 ft. The northbound span is approximately 550 ft long and the southbound span is 600 ft long. The north and south spans are supported, respectively, by eight and nine sets of seven pilings that are placed within the river channel. Each piling measures 1.6 ft on a side. Approach pads for the bridge are placed on the high river banks. The elevation of the low member (20.2 ft) of the bridge is 13.22 ft above the normal high water elevation of the river (7.5 ft MSL). The I-75 bridge is oriented 13° 40' 40" west of true north (10).

METHODS AND MATERIALS

General

Five transects were examined at the Ochlockonee River and I-10 and the Braden River and I-75 sites because of the split roadway design of the Interstate bridges. Three transects were sampled at the Wakulla River and US-98 site. Transects were established perpendicular to the main channel upstream and downstream of the bridges and directly under the bridges at each site. Transects were also located between the bridges at split roadway design sites. Locations of upstream and downstream transects were based on habitate similarity and a subjective determination that these areas were outside the area of impact of the bridge. Transect locations are shown in Figures 1-3. Replicate benthic infaunal samples were obtained at stations along each transect using a petite PONAR grab (0.0256 m^2), except at the Wakulla River site where dense aquatic vegetation necessitated the use of a diver-operated core sampler (0.0079 m^2).

Benthic samples were preserved and stained in situ with Lavdowski's preservative (11) and rose bengal dye (12). Aquatic invertebrates retained on a No. 30 sieve (0.60 mm) were visually sorted and the majority of organisms was identified to the family level.

Site-Specific Sampling Methods

Ochlockonee River and I-10

Five transects were established across the river at locations approximately 75 m upstream and downstream of the bridges, beneath each bridge, and between the bridges as shown in Figure 1. A petite PONAR was used to take three replicate samples of the benthic infauna at stations along each of the five transects. Samples were collected at the I-10 bridge site in October 1978.

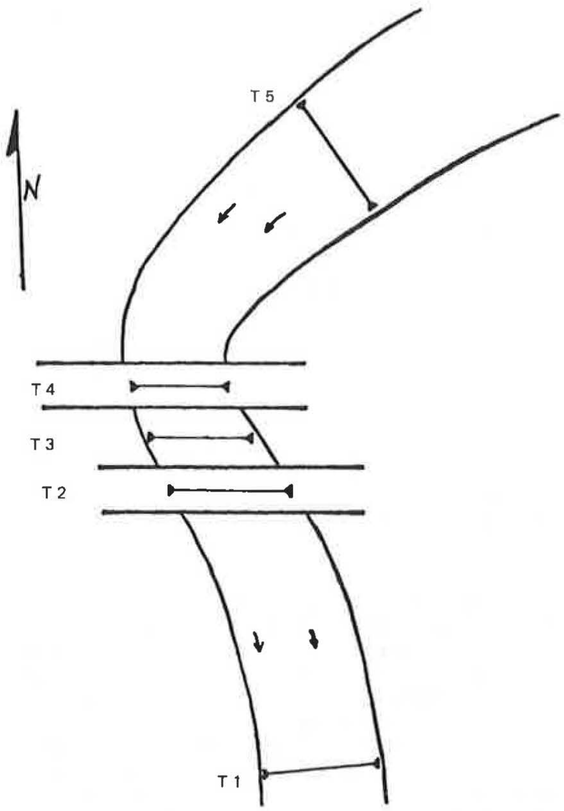

FIGURE 1 Locations of transects at the Ochlockonee River. Transects 2 and 4 are located beneath the bridge. Arrows indicate direction of flow.

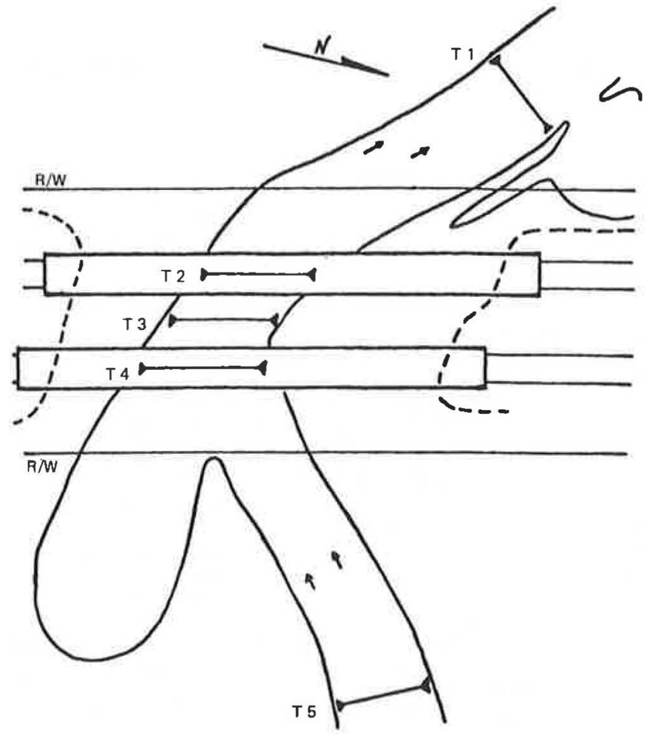

FIGURE 3 Locations of transects at the Braden River. Transects 2 and 4 are under the bridge spans. Lines labeled R/W indicate right-of-way. Dotted lines show toe of slope. Arrows indicate direction of flow.

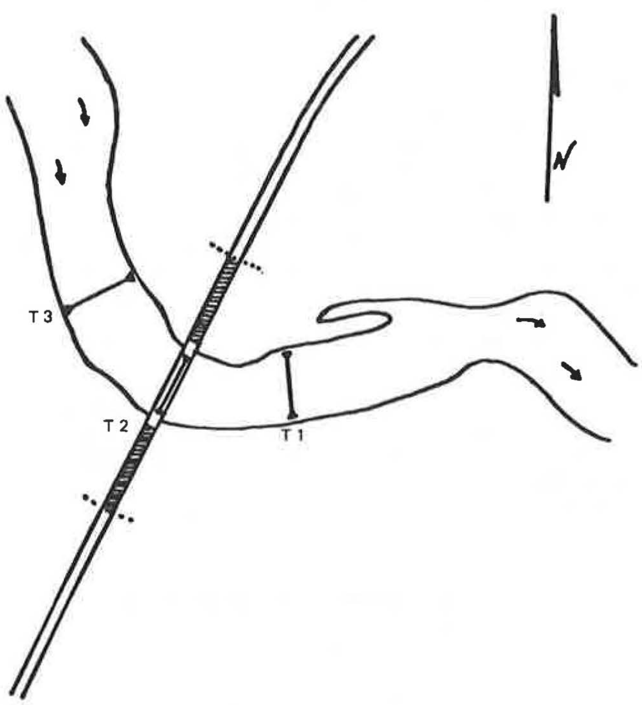

FIGURE 2 Locations of transects at the Wakulla River. Transect 2 is under the US-98 bridge. Arrows indicate direction of flow. Dotted lines show limits of flood plain. Cross-hatching indicates causeway fill.

Wakulla River and US-98

Three transects were established across the Wakulla River at locations approximately 100 m upstream and downstream of the bridge and at the centerline of the bridge as shown in Figure 2. Sampling stations were established at the center of the channel and at points equidistant between the center and each shoreline (three stations per transect). Four replicate benthic invertebrate and submerged macrophyte samples were taken at each station using SCUBA. Benthic infauna was sampled using a coring tube of polyvinyl chloride pipe (10 cm inside diameter). One benthic core sample was taken in each of the vegetation sampling plots. Epibenthic gastropods (*Neritina reclivata*) encountered within the sample area were collected by hand.

Aquatic macrophytes were sampled following a modified point-quarter method (13). Four sample areas of 2.69 ft^2 (0.25 m^2) were located at 90-degree angles, each 1 m from the center point of the station. Vegetation was removed by cutting individual plants at the water-sediment interface. Biomass of aquatic macrophytes was determined as grams of dry weight per replicate. Dry weight to wet weight conversion factors were determined for plants of the two most abundant species, *Vallisneria americana* and *Sagittaria kurziana* (14). Epifauna was removed from the macrophyte samples by rinsing the vegetation in the laboratory and passing the rinse through a No. 30 sieve. Epifaunal invertebrates on the sieve were preserved, stained, and sorted in the same manner as the benthic infauna. All samples were collected in March 1979.

Braden River and I-75

Figure 3 shows the five transects established across the Braden River at locations approximately 137 m upstream and 107 m downstream of the bridges and beneath and between the bridges. Three sampling stations were established per transect in the same relationship as the Wakulla River stations. Three replicate benthic invertebrate samples were obtained at each station using a petite PONAR grab. Samples were collected in August 1979.

Data Analysis

Four parameters were determined for each replicate and used to make statistical comparisons. The total number of organisms obtained (N) and the taxa to which they belong were recorded. Dominance (D), diversity (H'), and evenness (J') indices were calculated (15). The Shannon-Weaver measure of diversity was used in accordance with Pielou (16, pp. 269-311). For the plant biomass data, H' was calculated based on the dry weight biomass for each species and the total biomass for the sample (17). (The reader is reminded to exercise caution in the interpretation of environmental impacts indicated solely by comparisons of dominance, diversity, and evenness indices. These indices are derived mathematically and may not accurately characterize the biotic community. Numbers of individuals and the taxa to which they belong should also be taken into consideration in evaluating the presence or absence of impacts.)

Analyses of the data were performed using a computerized t-test procedure (18). The t-test was used to compare all stations within a transect with each other to determine the amount of intratransect variation. The transect mean for each parameter was compared with the mean value for each of the other transects to detect differences between the transects. Transects were assumed to differ significantly in a given parameter when the difference in transect means was greater than the differences in station means within a transect.

RESULTS AND DISCUSSION

Ochlockonee River

There were no statistically significant differences in the measured parameters of the benthic invertebrates at the Ochlockonee River study site (Table 1). However, when the data for individual taxa were examined, chironomids were found to be much more abundant beneath the bridge spans (transects 2 and 4) than elsewhere. Fifty-eight percent of the chironomids occurred under these spans, rather than the 40 percent that would be expected assuming even distribution.

The chironomid densities in transects 2 and 4 were greatest at stations nearest the piers, rather than evenly distributed along each transect. The disproportionate distribution of chironomids may be explained by a localized alteration of habitat caused by the piers. Accumulations of silt were seen adjacent to the piers. These accumulations are probably the result of deposition caused by a reduction in the speed of currents passing near the piers. Perhaps this silt provided a more suitable substrate for chironomids. No other taxa showed a pattern of abundance that suggested an influence of the bridges. The disturbance of benthic habitats was limited to the immediate vicinity of the piers.

TABLE 1 Dominant Benthic Invertebrates of the Ochlockonee River

	Dominant Group		
Transect	1	2	3
1	Oligochaeta (Annelida) 42.26%	Chironomidae (Insecta-Diptera) 31.17%	Ephemeridae (Insecta-Ephemeroptera) 13.60%
2[a]	Chironomidae (Insecta-Diptera) 48.87%	Oligochaeta (Annelida) 24.03%	Ephemeridae (Insecta-Ephemeroptera) 11.43%
3	Chironomidae (Insecta-Diptera) 49.38%	Oligochaeta (Annelida) 28.80%	Corbiculidae (Pelecypoda) 13.84%
4[a]	Chironomidae (Insecta-Diptera) 60.95%	Oligochaeta (Annelida) 21.33%	Corbiculidae (Pelecypoda) 7.01%
5	Chironomidae (Insecta-Diptera) 33.47%	Corbiculidae (Pelecypoda) 28.81%	Oligochaeta (Annelida) 25.42%

Note: Higher taxa for each group are given in parentheses. Percent dominance is presented for each.
[a]Transect located under bridge span.

The design and construction of I-10 favored minimal impacts on benthic communities. Only two piers for each bridge were placed in the river adjacent to the main channel, thereby causing little disruption to benthic habitats. These piers were round nosed, causing less eddying and therefore less bottom scouring than would be expected from pilings or piers with flat surfaces. The bridge spans were placed high enough above the water to allow at least partial illumination beneath the bridges. In addition, the approaches to the river channel were bridged, allowing the normal passage of water across the floodplain at flood stage and avoiding increased scouring of bottom sediments. No dredging was done in the river channel during bridge construction.

Wakulla River

Several noteworthy observations were made at the Wakulla River study site. First, no submerged aquatic macrophytes occurred directly under the bridge span, but these plants occurred in abundance in transects 1 and 3 (away from the bridge) and up to the edges of the bridge (Table 2). Based on biomass measurements, the lack of rooted submerged macrophytes under the bridges was determined to be statistically significant. Second, because of the absence of macrophytes, an epifauna was also absent. Epifaunal organisms were ascribed by Odum (19) as having importance in the food chain at Silver Springs, which is very similar to the Wakulla River in habitat and biota. Third, the number of benthic invertebrates was 4 to 5 times higher in transects 1 and 3 (away from the bridge) than in transect 2 under the bridge (Table 3). This difference was at-

TABLE 2 Dry Weight Biomass of Dominant Wakulla River Macrophytes

	Macrophyte		
Transect	*Sagittaria kurziana*	*Vallisneria americana*	*Potomogeton illinoensis*
1	627.51	452.66	9.42
2[a]	0.0	0.0	0.0
3	815.81	189.69	65.04

Note: Biomass is given as grams per 2.69 ft^2 (0.25 m^2) and is the sum of the station.
[a]Transect located under bridge span.

tributable mainly to the densities of oligochaetes and to a much lesser extent to nematodes and gammarid amphipods. These differences were statistically significant (Table 4). There were no significant differences in diversity, evenness, or dominance of benthic invertebrates in transect 2 compared with the other transects, even though several rather large differences in mean values were observed.

TABLE 3 Dominant Benthic Invertebrates of the Wakulla River

	Dominant Group		
Transect	1	2	3
1	Oligochaeta (Annelida) 71.59%	Gammaridae (Amphipoda) 4.36%	Chironomidae (Insecta-Diptera) 2.95%
2[a]	Oligochaeta (Annelida) 41.08%	Chironomidae (Insecta-Diptera) 16.22%	Gammaridae (Amphipoda) 10.27%
3	Oligochaeta (Annelida) 70.63%	Gammaridae (Amphipoda) 6.90%	Chironomidae (Insecta-Diptera) 3.83%

Note: Higher taxa for each group are given in parentheses. Percent dominance is presented for each.

[a]Transect located under bridge span.

TABLE 4 Summary of Statistically Significant Results

Study Site	Parameter	Transects Compared	t	p
Wakulla River	N	1 and 2	3.13	.008
		3 and 2	3.38	.005
	W	1 and 2	5.43	.001
		3 and 2	8.19	.001
Braden River	H'	1 and 5	4.36	.001
		2 and 5	4.63	.001
	J'	2 and 4	3.41	.004
		2 and 5	3.64	.002

Note: N = number of benthic invertebrates, W = plant biomass, H' = benthic invertebrate diversity, J' = benthic invertebrate evenness, t-value of t-statistic, p = probability associated with t.

Questions arise about why there are no rooted macrophytes under the bridge and why there are fewer benthic organisms under the bridge. Several differences in the physical environment that are caused by bridging apparently have affected the biota. The bridge, at only 10.7 ft above the normal water surface, effectively blocks sunlight in approximately the same dimensions as the area of the bridge. Aquatic macrophytes do not grow under the bridge probably because of insufficient light and unsuitable substrate. Dredging may have been performed at this site because it was common practice at that time (1956) to dredge a river channel during bridge construction. The fact that the river bottom is lower under the bridge than either upstream or downstream of the bridge could be the result of such dredging. Another factor contributing to depauperate biota under the bridge is the alteration of bottom sediments as a result of bridge design. At midchannel along transect 2 (beneath the bridge) the bottom consisted of limestone and only a little sediment indicating scouring. Toward shore, a deep accumulation of silt covered the limestone. In contrast, the bottom along transects 1 and 3 (away from the bridge) consisted primarily of sand with little silt and only occasional outcrops of limestone. The Wakulla River bridge is supported by numerous pilings with flat surfaces placed within the main channel of the river. These interrupt the flow and cause eddying. Filled causeways and bridge approach pads on either side of the river constrict the river channel and act to increase the velocity of the water flowing beneath the bridge and thereby to increase the possibility of scouring. The absence of macrophytes beneath the bridge exacerbates scouring by allowing the full force of the flowing water to reach the bottom without deflection by aquatic vegetation. The low number of benthic invertebrates beneath the bridge is most probably related to the alteration in bottom sediments, although possible effects of shading cannot be discounted.

The results at this study site do not allow the evaluation of the relative importance of each of the design criteria and construction methods that caused environmental impacts. Further, the results do not allow the effects of shading on benthic organisms to be distinguished from the effects of the substrate and other factors. Hynes (20, pp. 112-300) related the distribution of benthic invertebrates to current velocity, sediment composition, presence or absence of vegetation, and shading. Nonetheless, the collective impact of bridging on the biota beneath the bridge has been severe and has persisted since the bridge was built 23 years ago. The impact, however, is localized directly beneath the bridge. In spite of the apparent impact of bridging, statistical analysis indicated that the taxa diversity and dominance patterns of the benthic community were not altered significantly.

Braden River

Significant differences in diversity of benthic organisms between transect 5 and transects 1 and 2 were found at the Braden River site. There were also significant differences in evenness between transect 2 and transects 4 and 5. These differences may not be real biologically because of atypical samples obtained at station 1-I where the junction of a slough entered the river and at station 3-V where an accumulation of detrital material occurred possibly affecting the distribution of organisms. The data must therefore be considered inconclusive with regard to the question of whether bridging has had an impact on the benthic biota. If nothing else, the interference of sloughs illustrates the complexity of environmental impact assessment in aquatic systems.

A nonstatistical assessment of the data allows limited interpretation. Although benthic community structure seems to be unaffected by the presence of the bridge, the decided decrease in the numbers of benthic organisms at the various stations downstream between transect 4 and transect 2 is of particular interest. The only exception in this otherwise pronounced reduction in values was at station 1 of transect 2, where a slight increase was recorded. This station is located just upstream from station 1 of transect 1, which had an atypically high density of benthic invertebrates.

The decrease in densities from transect 4 to transect 2 might be related to bridging. Certain design criteria and construction methods, though, seem not to be causative: Shade does not appear to be a factor because of the high elevation of the bridges and their nearly north-south orientation. Channel dredging was excluded as a construction practice. The bridge approach pads do not interfere with water flow because the water remains within the deeply incised channel at flood stage. In addition, even though large pilings with flat sides were installed within the channel, the low velocity of this river appears to be insufficient to cause scouring of the bottom. Limited scouring may be occurring but is not yet detectable because of the short time since the bridge was constructed. Also, scouring may increase during flood stage.

Two causative agents remain suspect for the decrease in numbers of benthic organisms downstream. One is an accumulation of silt or other surface sediments that may have eroded from the banks during construction. Straw from bales of hay used for checking erosion was obtained with the benthic samples in some areas indicating previous erosion. The silt or other surface sediments would have been transported a short distance downstream before settling to the bottom. Observations are insufficient to test this hypothesis.

The second causative agent may be oil and grease that are present in the sediments at most sampling stations under the bridged area. Petroleum products were allowed to escape into the river during bridge construction. Monitoring at this site during construction of the bridge indicated oily sheens to the river's surface (21). These petroleum products may have been transported a short distance downstream before they were incorporated into the sediments. As a result, benthic organisms may have been exposed to less petroleum at transect 4 than at 3 or especially 2. The effect of petroleum products on benthic organisms in the Braden River can only be surmised. Boesch and Hershner (22) reported that grease and oil adversely impact benthic communities. The sampling may have been done too soon after bridge construction to determine the full effects of petroleum products on benthic organisms.

CONCLUSIONS AND RECOMMENDATIONS

Three main conclusions were obtained from this study.

1. There were no significant impacts on biological productivity or diversity (as measured by benthic invertebrate diversity, dominance, and evenness) because of bridging at the I-10 bridge site on the Ochlockonee River. The absence of impact appears to be due to the favorable consideration of environmental factors in bridge design and construction practices.
2. The US-98 bridge over the Wakulla River appears to have caused severe adverse impacts on the submerged aquatic macrophytes and on the benthic community structure. The impacts are localized beneath the bridge and do not extend beyond it. The adverse impacts probably resulted from dredging during bridge construction, scouring that was caused by hydrologic changes related to construction of the causeway and approach pads in the floodplains, and shading caused by the low elevation of the bridge.
3. The study results at the I-75 bridge across the Braden River were inconclusive because of the complexity of the system. Sloughs entering the river near the study site were the main cause of this complexity. The bridge appears to be of an environmentally sound design. Construction activities may have resulted in undetermined adverse effects on aquatic biota. Large amounts of grease and oil and eroded surface sediments were allowed to be deposited in the river because of inadequate quality control during construction. These petroleum products and perhaps recent sediment deposition caused by surface erosion may be causing a moderately adverse impact on benthic organisms.

At any bridge site, several factors contribute to a given adverse impact. It is nearly impossible to determine which factors of bridge design or construction are the most detrimental. Even if it were possible, a given factor that has a severe impact at one bridge site might have no impact at another because of wide differences in site conditions. However, because of the importance of aquatic invertebrates and vegetation to the fish communities and water quality in a river system, impacts on aquatic biota should be considered in the location, design, and construction of bridges. Several recommendations can be made that would be expected to reduce the impacts of the construction and placement of bridges.

1. Locations should be selected where alteration of the river channel or floodplain can be avoided or minimized.
2. Dredging or other disturbances of natural bottom sediments should be minimized.
3. Bridges should be designed to minimize the alteration of the natural hydrologic characteristics of the river. Preferably, bridges should span floodplains. Culverting, adequate to maintain natural flow patterns, should be placed in any fill causeways. Incorporation of these considerations would help prevent the scouring of bottom sediments caused by increased current flow.
4. Bridge spans should be positioned so that they do not cause continuous shading of the river, especially if aquatic macrophytes occur at the bridge site. Spans should be placed at a sufficient height to allow at least partial illumination under the bridge. A direct east-west orientation should be avoided if possible.
5. Construction methods should be monitored carefully to ensure adequate erosion control, containment of oils and greases, and minimal disturbance of the river system and watershed area by heavy equipment and clear-cutting practices. Timber matting has proven useful in some areas for minimizing site disturbance.

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