Aggregate Extraction Impacts on Unionid Mussel Species Richness and Density

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Abstract: Kentucky Reservoir on the Tennessee River supports a diverse freshwater mussel community including federally-listed endangered species. Resource extraction operations have been conducted on the Tennessee River since at least the 1920s. The condition of abandoned dredge sites as aquatic habitat for benthic organisms, including freshwater mussels, is relatively unknown. Objectives of this study were to determine the condition of abandoned dredge sites as aquatic habitat for freshwater mussels, compare species richness and density between sites in relation to years post dredging, collect information relevant to future permitting consultations, and provide a greater understanding of the effects of resource extraction in a large regulated river. Six hundred 0.25 m^{-2} quadrat samples were collected and processed from 12 study sites. Both mean density (54.51 mussels · m^{-2}; SD = 58.335) and species richness (15 taxa; SD = 1) were significantly higher at reference sites than at the dredged sites ($P < 0.0001$). Correlation analysis indicated no significant relationship ($r = 0.2059$, $P > 0.10$) between mean mussel density and time (in years) since the last dredge event. The Wilcoxon's rank sum tests indicated significantly lower mussel abundance ($P < 0.05$) and richness ($P < 0.05$) at the dredge sites relative to the reference sites. Based on data obtained during this study, we will advocate additional protection of specific sites within the lower Tennessee River reach currently permitted for commercial dredging.

Key words: Unionids, freshwater mussel density, regulated river, dredging

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Freshwater mussels (Unionidae) are large bivalve mollusks that live in the sediments of rivers, streams, and lakes. Mussels are a food source for many species of fish and terrestrial animals such as raccoons, otters, and muskrats. Adult mussels are suspension feeders that improve water quality by filtering contaminants, sediments, and nutrients. The long life span of unionids (decades to centuries), coupled with their sensitivity to toxic chemicals makes these organisms important indicators of water quality (Strayer et al. 2004). Freshwater mussels are a renewable resource, providing important ecological and economic benefits. Aboriginal peoples utilized mussels for food, tools, and ornamentation. Modern commercial exploitation has progressed from pearl hunting and shell button blank material to the production of mother of pearl inlay and cultured pearl nuclei (Parmalee and Bogan 1998). Olson (2005) noted that Tennessee leads the United States in pearl and mother of pearl shell production. According to Hubbs (2003), greater than 90% of Tennessee's multi-million dollar commercial mussel shell harvest is taken from the Kentucky Reservoir portion of the Tennessee River, and this area produces more commercial shell products than anywhere else in the world (Neves 1999).

Riverine ecosystems account for the highest species richness of freshwater mollusks among various habitat types because these ecosystems are more permanent in regards to evolutionary time scale (Neves et al. 1997). The mussel fauna of the southeastern United States evolved in rivers suited to their life history needs where clean water flowed over shoals composed of sand and gravel. Southeastern rivers once supported a freshwater mollusk species richness of unparalleled proportion (Ahlstedt et al. 2004). In large river systems freshwater mussels typically occur in dense aggregations (10–100 mussels · m^{-2}) known as "mussel beds." Freshwater mussels are intolerant of adverse changes in water and habitat quality and cannot survive excessive exposure to fine sediment which clogs the gills and interferes with respiration, feeding, and reproduction (Dennis 1984). Except for a brief parasitic larval stage on fish, freshwater mussels spend their entire lives partially or completely buried in the river bottom. Sedentary by nature, freshwater mussels require a stable bottom environment with good current to bring food and to disperse reproductive elements and metabolic waste products. Thus, an abundant and diverse mussel bed is an indicator of good habitat quality.

Habitat alteration resulting from in-stream activities has been identified as a contributing factor in the precipitous decline of

North American freshwater mussel resources. Watters (2000) concluded that hydraulic impacts to freshwater mussel habitats are often catastrophic, both immediately and over time. He further noted that impacts resulting in mussel declines rarely have a single causative agent. Yokley (1976) observed decreased mussel shell growth rates at sites located downstream of commercial dredging operations. Dennis (1984) demonstrated that high concentrations of suspended silt interfere with food uptake of freshwater mussels. Loss of productive substrates resulting from altered stream morphology may result in long term declines in aquatic invertebrate abundance and corresponding declines in the organisms that depend on them as food.

Aggregate resource extraction operations have been conducted on the Tennessee River since at least the 1920s. In Tennessee, commercial dredging operations are regulated by the U.S. Army Corps of Engineers (USACE), Tennessee Valley Authority (TVA), and the Tennessee Department of Environment and Conservation (TDEC) in consultation with the U.S. Fish and Wildlife Service (USFWS) and Tennessee Wildlife Resources Agency (TWRA). Instream aggregate mining is accomplished using draglines, shovels, or dredges. The hydraulic suction dredge is the most common implement currently employed in the removal of sand and gravel deposits on the Tennessee River. Commercial operations abandon dredging sites when the production of marketable aggregates fails to produce acceptable profits. Dredge operators must continually seek areas that have not been depleted of sand and gravel resources to maintain profitability.

The condition of mined areas as habitat for freshwater mussels is not well documented. However, Nelson (1993) noted that instream mining increases bedload movement and turbidity, changes substrate composition and stability, and alters stream morphology. Further, substrate type is directly tied to benthic production where more diverse invertebrate assemblages are associated with complex gravel substrates. He also indicated that increased sedimentation and turbidity can limit primary productivity and secondary production and can destroy fish spawning habitat and stocks. These impacts vary with habitat type, biota, and extent of mining activity.

Dredge operators must apply for new permits at five-year intervals; current permits are valid until January 2007. In 1989, the permitting process resulted in ~89 km of the lower Tennessee River, between Tennessee River km (TRK) 131–314, being excluded from commercial dredging activity. This process also resulted in the protection of nine islands in the lower Tennessee River, prohibition on dredging adjacent to the mouths of tributary streams, and within 46 m of the shoreline. Objectives of this study were to determine the condition of abandoned dredge sites as aquatic habitat for freshwater mussels, compare species richness and density between sites in relation to years post dredging, collect information pertinent to future permitting consultations, and provide a greater understanding of the effects of resource extraction in a large regulated river.

Methods

Study Area

Kentucky Reservoir is operated by the TVA for flood control, water supply, and hydroelectric power generation. It flows 296 km northward from Pickwick Dam (completed in 1938) at TRK 333 in Hardin County, Tennessee, to Kentucky Dam (completed in 1944) at TRK 36 near Gilbertsville, Kentucky. The Tennessee portion of the reservoir contains 3,171 shoreline km and approximately 44,918 surface ha, ending at TRK 80 in Stewart County, Tennessee. Main channel and over-bank width ranged from 0.40–3.2 km and offer diverse and abundant habitats for freshwater mussels. The study reach is located south of the confluence with the Duck River at TRK 179. Commercial sand and gravel dredging is currently permitted on approximately 77 km of the 152 km reach. Lotic habitats are maintained by minimum flow and hydroelectric power generation releases which dominate the reach.

Records for several endangered mussel species exist for this reservoir reach (Hubbs 2002). Population densities could exceed 100 mussels · m^{-2}. In this reach, mussels were typically found in water depths ranging 1–10 m, buried in sand and gravel deposits around the inside river bends and at the head and tail areas of mainstream islands. Mussel recruitment in these habitats was generally high, and they have served as important areas for commercial mussel harvest for many years.

Site Selection

TWRA and USACE personnel selected study sites during September 2000. Potential study sites were located by referencing USACE commercial dredging activity file data followed by field verification. During two days of field reconnaissance, a boat equipped with a differentially corrected Global Positioning System (GPS) and liquid crystal display depth sounder traversed each potential site. Nine dredged sites were selected based on evidence of dredging activity (e.g., clearly defined trenches, holes and sudden changes of river bed contour) indicated by depth soundings (Fig. 1). Once a dredged area was located, the GPS coordinates for the site were recorded along with references to physical structures (navigation lights, buoys, or other permanent structures) and approximate river km location from USACE navigation charts. Dredged site depths ranged from 6–20 m and had not been dredged for periods ranging from 1–15 yr.

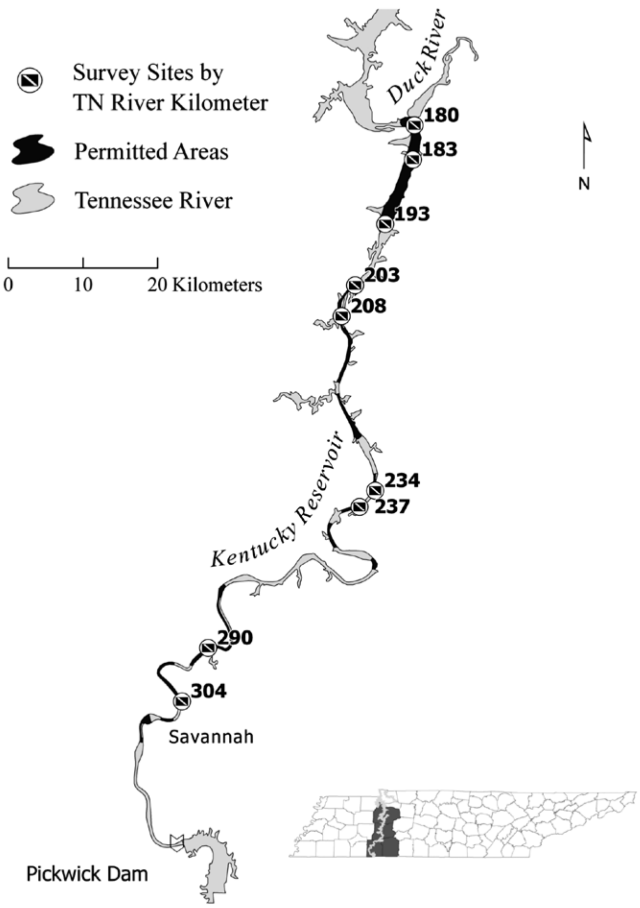

Figure 1. Kentucky Reservoir permitted commercial sand and gravel dredging areas and abandoned dredge sites sampled during 2001–2002.

Three reference sites were chosen based on relative proximity to the previously-selected dredge sites, habitat characteristics, and presence of an extant mussel population. Reference sites were dispersed throughout the study reach in areas where dredging was permitted for only one side of the river. Reference sites appeared to have physical characteristics similar to dredge sites prior to resource extraction and their representation of the mussel fauna inhabiting the immediate vicinity. Reference site depths ranged from 7–13 m.

Freshwater Mussel Sampling

Freshwater mussel sampling began in May 2001 and was completed in September 2002. Sites were located by navigating to the dredged area using previously-recorded GPS and sonar data. Once the site location was established, a 150-m sample reach was marked with survey flagging, and individual stations were selected and sampled by anchoring the boat and deploying the divers. Each site was sampled at five stations approximately 30 m apart.

Work began at the downstream end of each site and progressed upstream. Divers employed scuba and surface air supply equipment during sample collection. At each station, 10 replicate quadrat (0.25-m^{-2}) samples were collected by hand. Samples were spaced at a distance of ~2 m. Visibility was generally >1 m and underwater flashlights were used to assist mussel gathering. All live mussels and substrate within each 0.25-m^{-2} metal frame were removed to a depth of ~10 cm. All mussels were identified to species, counted, and measured (length in mm). Mussels not retained as voucher specimens were returned to the river prior to repositioning the boat at the next station.

Data Analysis

Freshwater mussel data were analyzed using Statistical Analysis System (SAS) software. Quadrat counts were pooled across sites and anchor points within the dredge and reference site types. A Wilcoxon's rank-sum test was used to test for differences in mussel density between dredge and reference sites. To test for differences in species richness between dredge and reference sites, the total number of different species reported at each sample site was compared using a Wilcoxon's rank sum test.

Results

We found a total of 15 mussel species at dredge sites and species richness ranged from 0–9 species per site. Mean richness at dredge sites was 3.67 species ($P < 0.0001$, SD = 2.916). Ebony shell (*Fusconaia ebena*) was the most abundant species (54.6%), followed by pink heelsplitter (*Potamilus alatus*, 10%), mapleleaf (*Quadrula quadrula*, 8.2%) and threeridge (*Amblema plicata*, 6.4%); (Table 1). We found 110 mussels at dredged sites and abundance ranged from 0–42 mussels per site. Mean mussel density ranged from 0–3.36 mussels · m^{-2}. The mean density from all 450 0.25-m^{-2} quadrat samples was estimated at 1.02 mussels · m^{-2} ($P < 0.0001$, SD = 3.042).

Density and species richness values were significantly higher ($P < 0.0001$) at reference sites than at dredged sites. A total of 19 species were encountered at reference sites and richness ranged from 14–16 species ($\bar{x} = 15.0$). Total abundance was 2,044 mussels (Table 1). Both mean density (54.51 mussels · m^{-2}; SD = 58.335) and species richness (15 taxa; SD = 1) were significantly higher at reference sites than at the dredged sites. Ebony shell was the most abundant species and comprised 83.9% of all mussels (Table 1).

Six hundred 0.25-m^{-2} quadrat samples were collected and processed from the 12 study sites (Table 1). Correlation analysis indicated no significant relationship ($r = 0.2059$, $P > 0.10$) between mean mussel density and time (in years) since the last dredge event. The Wilcoxon's rank sum tests indicated significantly lower mussel abundance ($P < 0.05$) and richness ($P < 0.05$) at the dredge sites relative to the reference sites.

Table 1. Mussel species occurrence and density estimates collected during quantitative sampling from 2001–2002.

	Dredge sites										Reference sites			
River km	**180**	**183**	**193**	**203**	**208**	**234**	**237**	**290**	**304**	**Total**	**203**	**234**	**304**	**Total**
Species														
Amblema plicata	2						5			7		2	3	5
Arcidens confragosa										0	1			1
Cyclonaias tuberculata										0	1		5	6
Elliptio crassidens							1			1	8	29	6	43
Ellipsaria lineolata			1					1		2	5	11	10	26
Fusconaia ebena	4						3	36	17	60	96	983	636	1715
Fusconaia flava	1									1				0
Leptodea fragilis			1							1	3	11	4	18
Ligumia recta								1		1		1	3	4
Megalonaias nervosa			1				1		1	3	7	5	2	14
Obliquaria reflexa										0	2	10	13	25
Pleurobema cordatum	1									1	1	5	3	9
Potamilus alatus	1	2	3		1		2	2		11	5	5	2	12
Quadrula apiculata	2	1	2							5	3	1		4
Quadrula metanevra									2	2			20	20
Quadrula nodulata										0	3			3
Quadrula pustulosa	1							2	1	4	9	18	68	95
Quadrula quadrula	5			1			3			9	13	4	4	21
Truncillia donaciformis										0		10	5	15
Truncillia truncata	2									2		6	2	8
Species richness	9	2	5	1	1	0	6	5	4	15	14	15	16	19
Mussel abundance	19	3	8	1	1	0	15	42	21	110	157	1101	786	2044
										Mean				Mean
Density · m^{-2}	1.5	0.2	0.6	0.1	0.1	0	1.2	3.4	2	1.02	13	88.1	63	54.5

Discussion

Our results indicate that freshwater mussel density, total abundance, and species richness were significantly lower at dredged sites than at adjacent reference sites, and suggest that mussel populations are slow to recover following dredging (up to 15 yr past). Substrates altered by dredging provide poor conditions for establishment of mussel populations. All three reference sites were located adjacent to dredge sites and habitat characteristics appeared similar to pre-dredging conditions. Ebony shell was the most abundant freshwater mussel species collected during this study. Ebony shell is the dominant freshwater mussel species in Kentucky Reservoir and appears well-suited to reservoir habitats. However, even this adaptable species was not able to colonize recently dredge sites.

Pennington (2001) reported that macroinvertebrate (excluding unionids) species richness in Kentucky Reservoir was greater at six of seven dredged locations than at adjacent reference sites. Macroinvertebrate abundance was higher at dredged sites than at reference sites. Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) species richness was reported as similar for both dredged and reference sites with approximately four species per site. Reporting that only the most recently-dredged location showed a statistically significant reduction in macroinvertebrate species richness, Pennington concludes that re-colonization of dredged locations by benthic macroinvertebrates is to be expected. However, the relatively short life cycle of most benthic macroinvertebrates inhabiting the study reach permitted them ample opportunity to colonize favorable habitats. To the contrary, freshwater mussel life histories are protracted and complex; mussels require stable habitats that facilitate close association with their respective fish hosts during spawning to allow mussels an opportunity to complete their life cycle.

Upstream of Kentucky Reservoir, the mainstream Tennessee River is impounded by eight hydroelectric dams. The movement of sand and gravel in the Tennessee River is drastically altered by these huge impoundments. Reduced movement of sand and gravel through the lower Tennessee River makes these materials a limiting resource for freshwater mussels. The most valuable commercial material obtained by dredging in the lower Tennessee River is sand. The large conical depressions which remain after deep water suction dredging collect fine colloidal silts and clay. Although dredged areas tend to become level over time, the amount of embedded silt and clay retained in post-dredged areas is much greater than in historical shoals. Pennington (2001) reported that relative to control sites, substrate at dredged locations exhibited a reduction in gravel from 75%–39% and an increase in sand from 22%–49%. Similarly, silt increased in dredged sites from 2%–8% and clay from < 1%–4%.

Our study examined a reach within the lower Tennessee River from Pickwick Dam (TRK 333) to confluence of the Duck River (TRK 179). This reach offers the longest river segment that still contains suitable habitat for conservation and restoration of surviving mainstem Tennessee River freshwater mussels, including commercially important, threatened, and endangered species. Shannon et al. (1993) noted that without habitat protection, conservation and restoration of freshwater mussel resources is not possible. Results of our study suggest that dredged sites afford poor mussel habitat relative to reference sites. Mussel populations at dredged locations will likely require decades to recover.

The next five-year permit process should, at a minimum, result in dredging being restricted to currently permitted lower Tennessee River segments in effect since 1989. The USACE should conduct an evaluation of the impact of current resource extraction on river channel and habitat stability both adjacent to dredge operations and upstream and downstream of extraction sites. Of particular concern is the stability of the important island complexes found between TRK 179–314. Resource extraction can result in new deep water habitat. Understanding the influence of these habitat alterations on the complex interactions between freshwater mussels and their host fish is essential for the conservation of these resources in this river reach. Based on data obtained during this study, TWRA will advocate additional protection of specific sites within the lower Tennessee River currently permitted for commercial dredging.

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Literature Cited

Ahlstedt S. A., S. Bakaletz, M. T. Fagg, D. Hubbs, M. W. Treece, and R. S. Butler. 2004. Current status of freshwater mussels (*Bivalvia: Unionidae*) in the Big South Fork National River Recreation Area of the Cumberland River and Recreation Area of the Cumberland River, Tennessee and Kentucky (1999–2002). Evidence of faunal recovery. 2003–2004, Walkerana 14(31): 33–77.

Dennis, S. D. 1984. Distributional analysis of the freshwater mussel fauna of the Tennessee River system, with special reference to possible limiting effects of siltation. Tennessee Wildlife Resources Agency, Fish Management Division, Nashville. Report Number 85-2.

Hubbs, D. 2002. 2001 statewide commercial mussel report. Tennessee Wildlife Resources Agency, Fish Management Division, Nashville. Report Number 02-26.

———. 2003. 2002 statewide commercial mussel report. Tennessee Wildlife Resources Agency, Fish Management Division, Nashville. Report Number 03–24.

Nelson, K.L. 1993. Instream sand and gravel mining. Pages 189–196 *in* C.F. Bryan and D.A. Rutherford, editors. Impacts on warm water streams: Guidelines for evaluation. Southern Division, American Fisheries Society, Little Rock, Arkansas.

Neves, R.J. 1999. Conservation and commerce: management of freshwater mussel resources in the U. S. Malacologia 41(2): 461–474.

———, A.E. Bogan, J.D. Williams, S.A. Ahlstedt, and P.W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of species richness. Pages 43–85 *in* G.W. Benz and D.E.Collins, editors. Aquatic Fauna in Peril: The Southeastern Perspective. Special Publication 1, Southeastern Aquatic Research Institute. Lenz Design and Communications, Decatur, Georgia.

Olson, D.W. 2005. 2004 Annual review mineral industry surveys, gemstones. U.S. Geological Survey, 983 National Center, Reston, Virginia.

Parmalee, P.W. and A.E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville.

Pennington, W. 2001. Benthic macroinvertebrate survey, commercial sand and gravel dredging areas Tennessee River miles 111.0–189.0. Pennington and Associates, Inc. 570 East 10th Street, Cookeville, Tennessee.

Shannon, L., R. G. Biggins, and R. E. Hylton. 1993. Freshwater mussels in peril: perspective of the U.S. Fish and Wildlife Service. Proceedings of the UMRCC Symposium.

Strayer, D.L., J.A. Downing, W. R. Hagg, T.L. King, J.B. Layzer, T. J. Newton, and S. J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. BioScience. (5): 429–439.

Watters, G.T. 2000. Freshwater mussels and water quality: A review of the effects of hydrologic and instream habitat alterations. Pages 269–274 *in* R. A. Tankersley, D.I. Warmolts, G.T. Watters, B.J. Armitage, P.D. Johnson, and R. S. Butler, editors. 2000 Freshwater Mollusk Symposia Proceedings. Ohio Biological Survey, Columbus.

Yokley, P. 1976. The effect of gravel dredging on mussel production. Bulletin of the American Malacological Union, Inc.