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Attraction to and Avoidance of Instream Hydrokinetic Turbines by Freshwater Aquatic Organisms

May 2011

Prepared by

Glenn F. Cada
Mark S. Bevelhimer

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ORNL-27 (4-00)

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ORNL/TM-2011/131

Environmental Sciences Division

Final Report

ATTRACTION TO AND AVOIDANCE OF INSTREAM HYDROKINETIC TURBINES BY FRESHWATER AQUATIC ORGANISMS

Glenn F. Cada
Mark S. Bevelhimer

Date Published: May 2011

Prepared for the
Wind and Water Power Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
Washington, D.C

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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Abstract

The development of hydrokinetic (HK) energy projects is under consideration at over 150 sites in large rivers in the United States, including the Mississippi, Ohio, Tennessee, and Atchafalaya Rivers. These waterbodies support numerous fish species that might interact with the HK projects in a variety of ways, e.g., by attraction to or avoidance of project structures. Although many fish species inhabit these rivers (about 172 species in the Mississippi River alone), not all of them will encounter the HK projects. Some species prefer low-velocity, backwater habitats rather than the high-velocity, main channel areas that would be the best sites for HK. Other, riverbank-oriented species are weak swimmers or too small to inhabit the main channel for significant periods of time. Some larger, main channel fish species are not known to be attracted to structures. Based on a consideration of habitat preferences, size/swim speed, and behavior, fish species that are most likely to be attracted to HK structures in the main channel include carps, suckers, catfish, white bass, striped bass, smallmouth bass, spotted bass, and sauger. Proper siting of the project in order to avoid sensitive fish populations, backwater and fish nursery habitat areas, and fish migration corridors will likely minimize concerns about fish attraction to or avoidance of HK structures.

Acknowledgments

We thank Jocelyn Brown-Saracino for her reviews of earlier versions of this report. This research was supported by the United States Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy, Wind and Water Power Program. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the DOE under contract DE-AC05- 00OR22725.

1. Introduction

New, renewable energy developments are being proposed for large rivers and coastal areas in the United States. It is not known whether these technologies will harm aquatic organisms, but a number of possible negative effects have been identified, some as a consequence of the new structures that would be placed in the aquatic environment. For example, hydrokinetic (HK) structures (generating devices and their associated support structures, anchors, and cables) could attract or repel animals or interfere with their movements. There is a complex relationship between structural characteristics of a river and the occurrence of fish species or age/size classes (see overview by Schlosser 1999). HK development may create new fish attraction structures, pose a threat of collision or entanglement to some organisms, and potentially alter both local movements and long distance migrations of aquatic animals. Because the transport of planktonic (drifting) life stages is affected by water velocity, localized reduction of water velocities by large, multi-unit HK projects could influence recruitment of some species. A variety of aquatic organisms use magnetic, chemical, and hydrodynamic cues for navigation; these have been best studied for marine organisms, but freshwater fish such as sturgeon and paddlefish also respond to these cues. Thus, in addition to mechanical obstructions, the electrical and magnetic fields and current and wave alterations produced by energy technologies could interfere with local movements or long-distance migrations. Anadromous fish (e.g., green sturgeon, salmon, steelhead, American shad) and catadromous fish (e.g., eels) migrate through both rivers and oceans and therefore may encounter both hydrokinetic devices in the rivers and wave and current energy projects in the oceans.

We compiled lists of freshwater fish species associated with large rivers for which hydrokinetic (HK) developments have been proposed (e.g., Mississippi, Ohio, Tennessee, and Atchafalaya Rivers). We divided those species into two categories: those that display only localized movements (i.e. resident fish) and those that migrate longer distances through rivers (i.e., migratory fish). We used information in the published literature to predict the behavioral responses (e.g., attraction or avoidance) of the members of these two groups to the new HK structures in rivers and estuaries. The objectives of this report are to (1) identify the potential interactions (attraction, avoidance, no effect) of migratory and resident aquatic organisms with HK projects; and (2) use the information to prioritize and focus studies of other environmental issues, e.g., strike, EMF, noise, and food web alterations. To accomplish this, we:

- collected information from the Federal Energy Regulatory Commission's (FERC) MHK database about the geographical distribution of proposed hydrokinetic projects, the HK turbine design (horizontal axis, vertical axis, cross-flow), the nature of the installation (attached to bridge piers or other existing structures, gravity-anchored or pile-driven into the sediments), and number of units per project.
- compared the geographical distribution of proposed projects to distribution of resident fish species and long-distance migrants in rivers and estuaries to ascertain potential interactions. This information is used to evaluate whether interference with fish movements is a significant issue for freshwater and estuarine HK projects.

2. Proposed Hydrokinetic Energy Projects in U.S. Rivers and Estuaries

As of August, 2010, one license for a HK project had been issued by the FERC. The City of Hastings, Minnesota modified its license for the Mississippi Lock and Dam No. 2 Hydroelectric Project (FERC No. 4306) to incorporate two HK turbines in the tailrace of its existing dam and powerhouse on the Mississippi River. The HK array would consist of two ducted, 35-kW horizontal axis turbines provided by Hydro Green Energy LLC (Figure 1). The HK turbines would be suspended below a floating barge that is tethered to the dam and anchored for stability using anchors and pilings.

In addition to the single HK license, FERC has issued (or has pending) numerous preliminary permits for marine and HK projects. (Whereas a license authorizes construction, operation, and maintenance of a hydropower project under the FERC's jurisdiction, a preliminary permit maintains priority of application for a license at a site for up to three years while the permit holder studies project feasibility and prepares an application for license. Thus, a preliminary permit indicates the locations for potential future HK development.) Of 143 issued preliminary permits (Figure 2), 78 are for projects in the Mississippi River (mainly in Louisiana, Mississippi, and Tennessee), 19 in the Atchafalaya River in Louisiana, and 11 in the mid-Ohio River. Of 13 pending preliminary permits for riverine and estuarine areas, 4 are for projects in the mid-Ohio River, 3 in the Tennessee River, and 2 in the East River estuary in New York.

Unlike FERC licenses, preliminary permits specify the potential locations of HK projects, but do not specify in detail the turbine technology or mooring/attachment methods that might be employed. Free Flow Power Corporation (FFP) holds 86 of the 141 FERC preliminary permits, all in the lower Mississippi and Atchafalaya River basins. The FFP website (http://www.free-flow-power.com/) suggests that ducted, 3-m-diameter, horizontal-axis HK turbine-generators are being considered for these large river applications. These HK devices could be suspended from the surface, attached to bridge abutments, maintained from barges, or suspended between or attached to pylons.

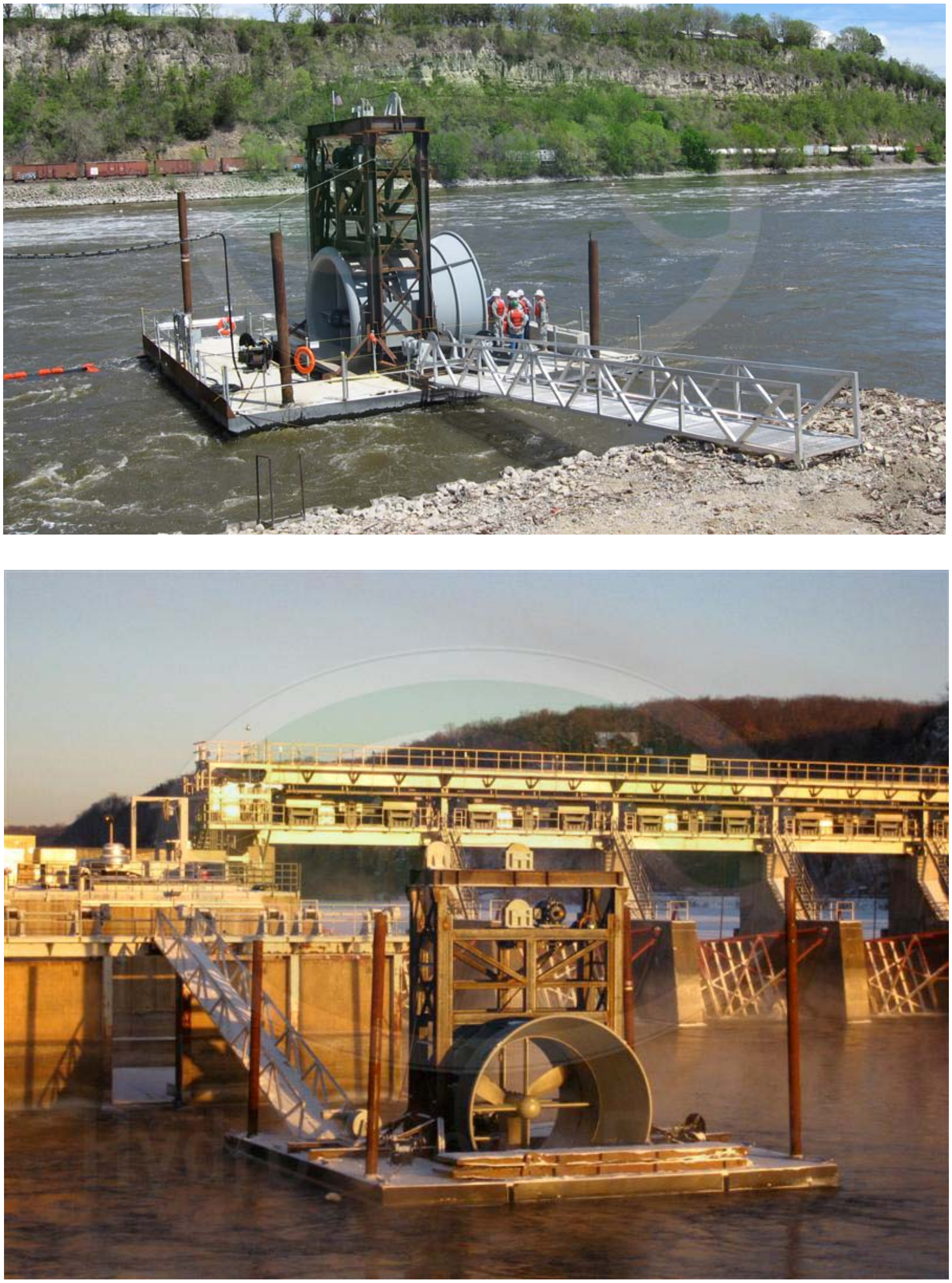

Figure 1. Photographs of the Hydro Green Energy LLC horizontal axis turbine installed at the Mississippi Lock and Dam No. 2 hydroelectric project, Hastings, Minnesota. Source: Hydro Green Energy LLC http://www.hgenergy.com/index.html

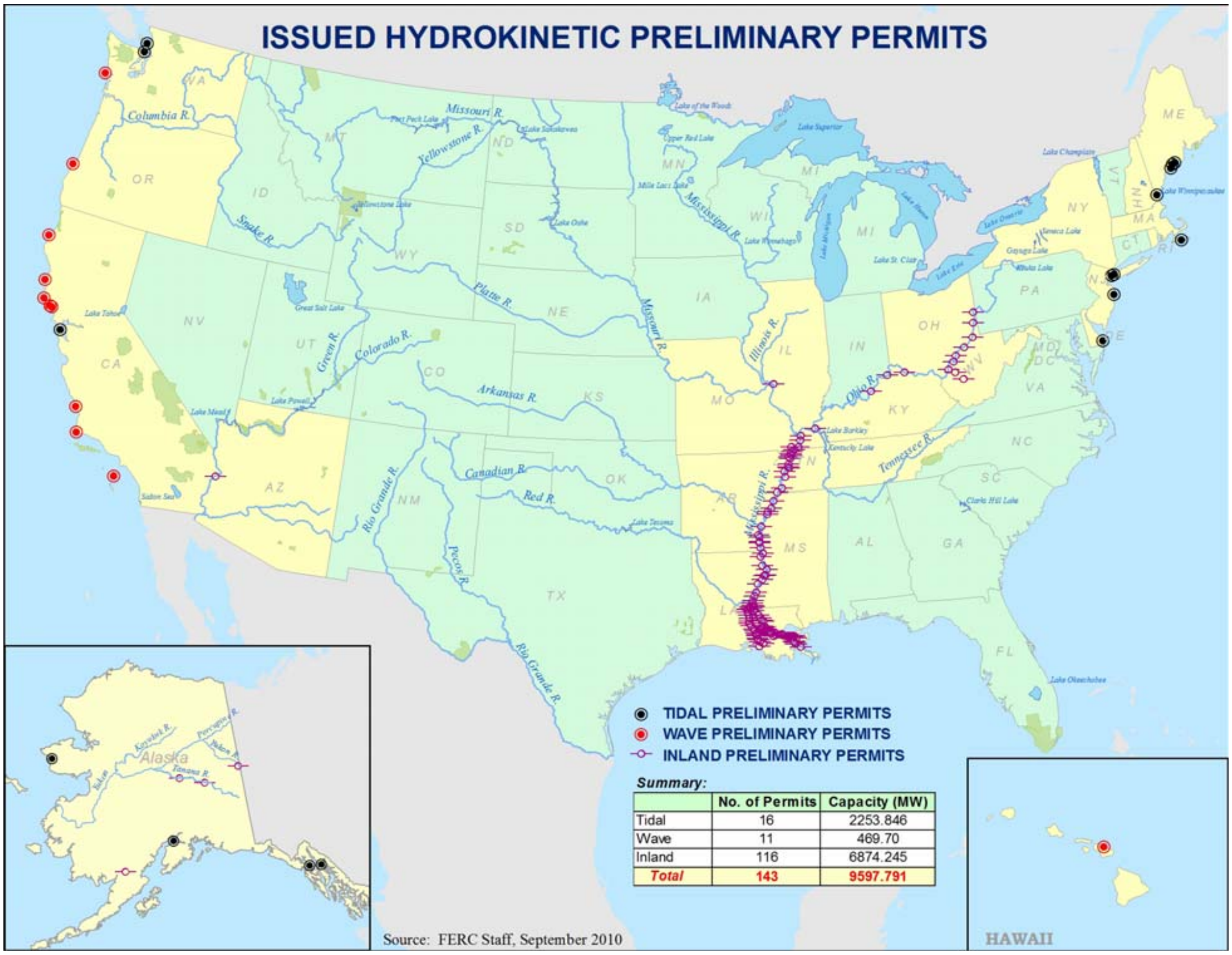

Figure 2. Preliminary permits for hydrokinetic projects issued by the Federal Energy Regulatory Commission as of September 2010. Source: http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp

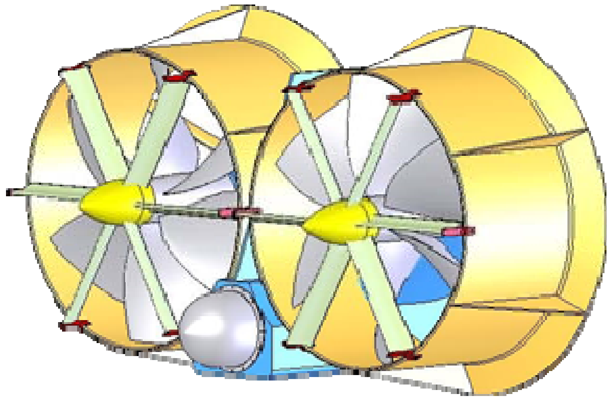

Figure 3. Artist's conception of a UEK Corporations's dual hydroturbine unit, a ducted, horizontal axis hydrokinetic turbine. Source: UEK Corporation http://www.uekus.com/index.html

Similarly, two preliminary permits issued to UEK Corporation for sites on the Atchafalaya River are for projects that are expected to install ducted horizontal axis turbines. The fully developed 10-MW project would consist of 23 dual hydroturbine units. Each unit would be 5.2 m tall x 9.9 m wide x 6.1 m long (Figure 3). The units would be anchored in columns using common cables laid on the bottom of the river channel. The units would be located in the river channel 4.6 m below the surface of the water during normal or flood flows, and would be kept that that depth by an elevation control system. That is, the UEK system is a free-standing device that is maintained in the axis of the prevailing river flow by two cables secured to the main anchored bottom cables; no pilings, large concrete bases, or surface support platforms are anticipated.

3. Resident and Migratory Fish Species in U.S. Rivers and Estuaries

As the largest river in North America, the Mississippi River is 3,731 km long and drains a 3.25 million square km^2 watershed. Discharge in the lower river, where many HK projects are being considered, ranges from 3,568 to 55,558 m^3/s (Schramm 2004). Fremling et al. (1989) listed 193 freshwater fish species in 27 families for the Mississippi River. Schramm (2004) updated that information and concluded that 172 species presently reside in the Mississippi River (see Table 1). Of these, 17 species are considered to be riverine dependent, that is, they require flowing water and sand, gravel, or rock substrate during at least some portion of their life cycle. This type of habitat is found in the main channel or channel borders, where HK projects are likely to be located. Schramm considered 31 species to prefer main channel habitat and another 77 species to prefer the channel border between the main channel and the riverbank. These main channel and channel border species would be most susceptible to interactions with HK projects. Many of the other species listed in Table 1 have more general requirements or prefer backwater habitats with no current and a soft sediment or vegetated bottom.

Although the list of fish species in the Mississippi River basin is large, a few species numerically dominate the fish community. For example, Barko et al. (2004a) reported that in the upper Mississippi River, 50% of the adult fish assemblage by number is made up of 3 species: gizzard shad (*Dorosoma cepedianum*), common carp (*Cyprinus carpio*), and channel catfish (*Ictalurus punctatus*). Among young-of-the-year fish, freshwater drum (*Aplodinotus grunniens*) and gizzard shad accounted for 76% of the total catch.

The mainstem of the Ohio River is 1579 km long, drains a 371,793-square km^2 watershed, and is the second largest river in the U.S. as measured by annual discharge. The Ohio River drainage contains at least 350 species of fish (Table 2) ranging from endemic darters and dace in the headwaters to a suite of large river fish (e.g., paddlefish, blue sucker, lake sturgeon, and shovelnose sturgeon) and more than 120 mussel species, including a number that are federally listed threatened or endangered species. These figures approach half of the freshwater fish species and over a third of all mussel species found in the United States.

Table 1. Distribution and abundance of fishes in the headwaters (HW), upper (UMR) and open river (OR) segments of the Mississippi River. Fish are resident in the Mississippi River unless noted otherwise (Residence). Source: Schramm (2004).

Family species	Residence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Ascipenseridae							
Lake sturgeon, *Acipenser fulvescens* (Rafinesque)			O[4]	R[4]		Yes	MC, CB
Atlantic sturgeon, *Acipenser oxyrhynchus* (*Mitchill*)	D			R[5]			MC, CB
Pallid sturgeon, *Scaphirhynchus albus* (Forbes and Richardson)			R	O		Yes	MC, CB
Shovelnose sturgeon, *Scaphirhynchus platorynchus* (Rafinesque)			O	O		Yes	MC, CB
Polyodontidae							
Paddlefish, *Polyodon spathula* (Walbaum)			O	O		Yes	MC, CB, BW
Lepisosteidae							
Alligator gar, *Atractosteus spatula* (Lacepede)				R	Yes		BW
Spotted gar, *Lepisosteus oculatus* (Winchell)			U	O	Yes		BW
Longnose gar, *Lepisosteus osseus* (Linnaeus)			O	C	Yes		MC, CB, BW
Shortnose gar, *Lepisosteus platostomus* (Rafinesque)		H1	C	C	Yes		MC, CB, BW
Amiidae							
Bowfin, *Amia calva* (Linnaeus)		R	C	O	Yes		BW
Anguillidae							
American eel, *Anguilla rostrata* (Lesueur)	D	R	O	U			CB
Hiodontidae							
Goldeye, *Hiodon alosoides* (Rafinesque)			U	O			CB
Mooneye, *Hiodon tergisus* (Lesueur)			O	U/R			CB
Clupeidae							
Alabama shad, *Alosa alabamae* (Jordan and Everman)	D			R			MC, CB
Skipjack herring, *Alosa chrysochloris* (Rafinesque)			O/R	C			MC, CB, BW
Gizzard shad, *Dorosoma cepedianum* (Lesueur)		A	A	A	Yes		MC, CB, BW
Threadfin shad, *Dorosoma petenense* (Gü nther)			U	A	Yes		CB, BW
Salmonidae							
Cisco, *Coregonus artedi* (Lesueur)		R	R				BW
Umbridae							
Central mudminnow, *Umbra limi* (Kirtland)		U	O		Yes		BW
Esocidae							
Grass pickerel, *Esox americanus vermiculatus* (Lesueur)			R	R	Yes		BW
Northern pike, *Esox lucius* (Linnaeus)		O	O		Yes		BW
Muskellunge, *Esox masquinongy* (Mitchill)		O/U			Yes		BW
Chain pickerel, *Esox niger* (Lesueur)				R[5]	Yes		BW
Cyprinidae							
Central stoneroller, *Campostoma anomalum* (Rafinesque)		R	R	H2[6]			MC, CB
Goldfish, *Carassius auratus* (Linnaeus)	I		U	R	Yes		BW

Table 1 (continued).

Family species	Residence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Grass carp, *Ctenopharyngodon idella* (Valenciennes)	I		U	U		Yes	MC, CB, BW
Bluntface shiner, *Cyprinella camura* (Jordan and Meek)	P			H2			CB
Red shiner, *Cyprinella lutrensis* (Baird and Girard)			O	C/O	Yes		CB, BW
Spotfin shiner, *Cyprinella spiloptera* (Cope)		C	C	R			CB, BW
Blacktail shiner, *Cyprinella venusta* (Girard)				O			CB, BW
Steelcolor shiner, *Cyprinella whipplei* (Girard)	P			R			CB, BW
Common carp, *Cyprinus carpio* (Linnaeus)	I	C	A	C	Yes		CB, BW
Gravel chub, *Erimystax x-punctatus* (Hubbs and Crowe)				R			CB, BW
Western silvery minnow, *Hybognathus argyritis* (Girard)				R			BW
Brassy minnow, *Hybognathus hankinsoni* (Hubbs)		U	R				CB
Cypress minnow, *Hybognathus hayi* (Jordan)				R	Yes		BW
Mississippi silvery minnow, *Hybognathus nuchalis* (Agassiz)			U/R	O	Yes		CB, BW
Plains minnow, *Hybognathus placitus* (Girard)				U/R		Yes	MC, CB
Clear chub, *Hybopsis winchelli* (Girard)				R[5]			CB
Silver carp, *Hypophthalmichthys molitrix* (Valenciennes)	I		C/O	C			CB
Bighead carp, *Hypophthalmichthys nobilis* (Richardson)	I		O	O			CB
Striped shiner, *Luxilus chrysocephalus* (Rafinesque)	P			R			CB
Common shiner, *Luxilus cornutus* (Mitchill)		C	O/R				MC, CB, BW
Ribbon shiner, *Lythrurus fumeus* (Evermann)	P			R			BW
Redfin shiner, *Lythrurus umbratilis* (Girard)	P		R	H2			CB, BW
Speckled chub, *Macrhybopsis aestivalis* (Girard)			O	C			CB
Sturgeon chub, *Macrhybopsis gelida* (Girard)				U/R			CB
Sicklefin chub, *Macrhybopsis meeki* (Jordan and Everman)				U/R			CB
Silver chub, *Macrhybopsis storeriana* (Kirtland)			C/O	C/O			CB, BW
Pearl dace, *Margariscus margarita* (Cope)		R					MC, CB, BW
Black carp, *Mylopharyngodom piceus* (Richardson)	I			R			CB, BW
Hornyhead chub, *Nocomis biguttatus* (Kirtland)		O	R				CB
Golden shiner, *Notemigonus crysoleucas* (Mitchill)		O	C/O	U	Yes		BW
Pallid shiner, *Notropis amnis* (Hubbs and Greene)			R				CB
Emerald shiner, *Notropis atherinoides* (Rafinesque)		A	A	A			CB, BW

Table 1 (continued).

Family species	Residence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
River shiner, *Notropis blennius* (Girard)			C	C			CB, BW
Bigeye shiner, *Notropis boops* (Gilbert)	P			R			CB
Ghost shiner, *Notropis buchanani* (Meek)			R	U/R	Yes		CB, BW
Bigmouth shiner, *Notropis dorsalis* (Agassiz)		P	O	O/R	R		CB
Blackchin shiner, *Notropis heterodon* (Cope)		U	O/R		Yes		BW
Blacknose shiner, *Notropis heterolepis* (Eigenmann and Eigenmann)		U	R				BW
Spottail shiner, *Notropis hudsonius* (Clinton)		U	U	R			CB
Longnose shiner, *Notropis longirostris* (Hay)				U[5]		Yes	MC, CB
Ozark minnow, *Notropis nubilus* (Forbes)	P		R	R			CB
Chub shiner, *Notropis potteri* (Hubbs and Bonham)				R			CB
Rosyface shiner, *Notropis rubellus* (Agassiz)	P		R				CB
Silverband shiner, *Notropis shumardi* (Girard)			R	O			CB, BW
Sand shiner, *Notropis stramineus* (Cope)	P	R	O	U[5]			CB
Weed shiner, *Notropis texanus* (Girard)			O	U	Yes		BW
Mimic shiner, *Notropis volucellus* (Cope)		R	C	O			CB, BW
Channel shiner, *Notropis wickliffi* (Trautman)			C/O	O			MC, CB
Pugnose minnow, *Opsopoeodus emiliae* (Hay)			O	O	Yes		BW
Suckermouth minnow, *Phenacobius mirabilis* (Girard)			R	R			CB, BW
Northern redbelly dace, *Phoxinus eos* (Cope)		C					CB
Southern redbelly dace, *Phoxinus erythrogaster* (Rafinesque)		P		H1	H2		CB
Finescale dace, *Phoxinus neogaeus* (Cope)		R					CB, BW
Bluntnose minnow, *Pimephales notatus* (Rafinesque)		P	O	O	U		BW
Fathead minnow, *Pimephales promelas* Rafinesque		C/U	U	R	Yes		BW
Bullhead minnow, *Pimephales vigilax* (Baird and Girard)		R	O	O	Yes		BW
Flathead chub, *Platygobio gracilis gracilis* (Richardson)				R		Yes	CB
Eastern blacknose dace, *Rhinichthys atratulus* (Hermann)	P	U	R			Yes	CB
Longnose dace, *Rhinichthys cataractae* (Valenciennes)		C/O	R			Yes	CB
Creek chub, *Semotilus atromaculatus* (Mitchill)		O	R			Yes	MC, CB
Catostomidae							
River carpsucker, *Carpiodes carpio* (Rafinesque)			C	A		Yes	CB, BW
Quillback, *Carpiodes cyprinus* (Lesueur)		R	C	U			CB, BW
Highfin carpsucker, *Carpiodes velifer* (Rafinesque)			O/U	R			CB, BW
White sucker, *Catostomus commersoni* (Lacepū de)		C	C				MC, CB, BW

Table 1 (continued).

Family species	Resi-dence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Blue sucker, *Cycleptus elongatus* (Lesueur)			O	O		Yes	MC, CB
Creek chubsucker, *Erimyzon oblongus* (Mitchill)				U			BW
Lake chubsucker, *Erimyzon succetta* (Lacepū de)				U			BW
Northern hog sucker, *Hypentelium nigricans* (Lesueur)		O	R				CB
Smallmouth buffalo, *Ictiobus bubalus* (Rafinesque)			C/O	A/C	Yes		MC, CB, BW
Bigmouth buffalo, *Ictiobus cyprinellus* (Valenciennes)		O	C	C/O	Yes		CB, BW
Black buffalo, *Ictiobus niger* (Rafinesque)			U/R	U	Yes		CB, BW
Spotted sucker, *Minytrema melanops* (Rafinesque)			C/O	U/R[5]	Yes		CB, BW
Silver redhorse, *Moxostoma anisurum* (Rafinesque)		O	C/O	H2			CB, BW
River redhorse, *Moxostoma carinatum* (Cope)			O/R	R			CB
Golden redhorse, *Moxostoma erythrurum* (Rafinesque)			O				MC, CB
Shorthead redhorse, *Moxostoma macrole pidotum* (Lesueur)		C	C/O	U[7]			MC, CB
Greater redhorse, *Moxostoma valenciennesi* (Jordan)		O	R			Yes	MC, CB, BW
Ictaluridae							
White catfish, *Ameiurus catus* (Linnaeus)	P			H3			
Black bullhead, *Ameiurus melas* (Rafinesque)		R	O	U	Yes		BW
Yellow bullhead, *Ameiurus natalis* (Lesueur)		R	O	U	Yes		BW
Brown bullhead, *Ameiurus nebulosus* (Lesueur)		R	O		Yes		BW
Blue catfish, *Ictalurus furcatus* (Lesueur)			O	A			MC, CB
Channel catfish, *Ictalurus punctatus* (Rafinesque)		O	C	C			CB, BW
Mountain madtom, *Noturus eleutherus* (Jordan)				H1		Yes	CB
Stonecat, *Noturus flavus* (Rafinesque)		R	R	O		Yes	CB
Tadpole madtom, *Noturus gyrinus* (Mitchill)		R	O	U/R	Yes		BW
Freckled madtom, *Noturus nocturnus* (Jordan and Gilbert)			R	O/U			BW
Northern madtom, *Noturus stigmosus* (Taylor)				H2			CB, BW
Flathead catfish, *Pylodictis olivaris* (Rafinesque)		R	C/O	A			MC, CB
Aphredoderidae							
Western pirate perch, *Aphredoderus sayanus* (Gilliams)			R	R	Yes		BW
Percopsidae							
Trout-perch, *Percopsis omiscomaycus* (Walbaum)		O	O		Yes		BW
Gadidae							
Burbot, *Lota lota* (Linnaeus)		O	R				CB, BW

Table 1 (continued).

Family species	Resi-dence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Fundulidae							
Golden topminnow, *Fundulus chrysotus* (Gü nther)	P			R	Yes		BW
Banded killifish, *Fundulus diaphanus* (Le Sueur)		R	H1				
Starhead topminnow, *Fundulus dispar* (Agassiz)	P		R	R			BW
Blackstripe topminnow, *Fundulus notatus* (Rafinesque)			O	O	Yes		BW
Blackspotted topminnow, *Fundulus olivaceus* (Storer)				O	Yes		BW
Poeciliidae							
Western mosquitofish, *Gambusia affinis* (Baird and Girard)			O	O	Yes		BW
Atherinidae							
Brook silverside, *Labidesthes sicculus* (Cope)		O	C/O	C/O			BW
Inland silverside, *Menidia beryllina* (Cope)				O			CB, BW
Gasterosteidae							
Brook stickleback, *Culaea inconstans* (Kirtland)		R	R				MC, CB
Cottidae							
Mottled sculpin, *Cottus bairdi* (Girard)		R					
Percichthyidae							
White bass, *Morone chrysops* (Rafinesque)		R	C	C			CB, BW
Yellow bass, *Morone mississippiensis* (Jordan and Everman)			R/O	O			BW
Striped bass, *Morone saxatilis* (Walbaum)[7]	D			O			MC, CB
Centrarchidae							
Rock bass, *Ambloplites rupestris* (Rafinesque)		C	C/O		Yes		BW
Shadow bass, *Ambloplites ariommus* (Viosca)	P			U[5]			BW
Flier, *Centrarchus macropterus* (Lacepü de)				O	Yes		BW
Banded pygmy sunfish, *Elassoma zonatum* (Jordan)				R[5]	Yes		BW
Green sunfish, *Lepomis cyanellus* (Rafinesque)		R	C/O	U	Yes		BW
Pumpkinseed, *Lepomis gibbosus* (Linnaeus)		R	C/O		Yes		BW
Warmouth, *Lepomis gulosus* (Cuvier)			O/U	C/O	Yes		BW
Orangespotted sunfish *Lepomis humilis* (Girard)			O	O	Yes		BW
Bluegill, *Lepomis macrochirus* (Rafinesque)		O	A	C	Yes		BW
Longear sunfish, *Lepomis megalotis* (Rafinesque)				U	Yes		BW
Redear sunfish, *Lepomis microlophus* (Gü nther)				U	Yes		BW
Bantam sunfish, *Lepomis symmetricus* (Forbes)				O[5]	Yes		BW
Smallmouth bass, *Micropterus dolomieu* (Lacepü de)		C	O				CB, BW
Spotted bass, *Micropterus punctulatus* (Rafinesque)	P			R			CB, BW
Largemouth bass, *Micropterus salmoides* (Lacepü de)		O	C	C	Yes		BW
White crappie, *Pomoxis annularis* (Rafinesque)		R	C	C	Yes		BW
Black crappie, *Pomoxis nigromaculatus* (Lesueur)		O	C	O/U	Yes		BW

Table 1 (continued).

Family species	Resi-dence[1]	HW[2]	UMR[2]	OR[2]	Back water dependent	Riverine dependent	Probable zone[3]
Percidae							
Western sand darter, *Ammocrypta clara* (Jordan and Meek)	P		O	R		Yes	CB, BW
Crystal darter, *Crystallaria asprella* (Jordan)	P		R	R		Yes	CB
Mud darter, *Etheostoma asprigene* (Forbes)			O/R	O			BW
Rainbow darter, *Etheostoma caeruleum* (Storer)	P		R	R			CB
Bluntnose darter, *Etheostoma chlorosoma* (Hay)			R	U			BW
Iowa darter, *Etheostoma exile*			R				
Fantail darter, *Etheostoma flabellare* (Rafinesque)	P		R			Yes	CB
Swamp darter, *Etheostoma fusiforme* (Girard)				U[5]	Yes		BW
Slough darter, *Etheostoma gracile* (Girard)				U			BW
Johnny darter, *Etheostoma nigrum* Rafinesque		O	O	R[5]			CB, BW
Cypress darter, *Etheostoma proeliare* (Hay)	P			O[5]			BW
Missouri saddled darter, *Etheostoma te trazonum* (Hubbs and Black)	P			R[5]			
Banded darter, *Etheostoma zonale* (Cope)	P		R				
Yellow perch, *Perca flavescens* (Mitchill)		O	C/O		Yes		CB, BW
Log perch, *Percina caprodes* (Rafinesque)		O	C/O	R[5]	Yes		CB, BW
Gilt darter, *Percina evides* (Jordan and Copeland)	P		H1				CB
Blackside darter, *Percina maculata* (Girard)		C	R				
Saddleback darter, *Percina vigil* (Hay)				U			CB
Slenderhead darter, *Percina phoxocephala* (Nelson)			R	R[5]			CB
River darter, *Percina shumardi* (Girard)			O	O/U			CB
Sauger, *Stizostedion canadense* (Smith)		R	C	O			CB
Walleye, *Stizostedion vitreum* (Mitchill)		O	C	U/R			CB, BW
Sciaenidae							
Freshwater drum, *Aplodinotus grunniens* (Rafinesque)		R	A	A		Yes	CB, BW
Mugilidae							
Striped mullet, *Mugil cephalus* (Linnaeus)	M			O			CB
Petromyzontidae							
Chestnut lamprey, *Ichthyomyzon castaneus* (Girard)			O/U	O/R			MC, CB
Silver lamprey, *Ichthyomyzon unicuspis* (Hubbs and Trautman)			O	R			MC, CB
American brook lamprey, *Lampetra appendix* (DeKay)			R				MC, CB, BW

Table 1 (continued).

[1]All fish in this table are considered residents unless designated with one of the following letters: D – Diadromous; I – Introduced; M - Marine; P - Peripheral (typically occupies tributary streams and rivers but may temporarily enter the Mississippi River).

[2]A - Abundant in all river surveys. C - Common in most surveys. O - Occasionally collected; not generally distributed but local concentrations may occur. U - Uncommon, does not usually appear in survey samples. R - Rare. H1 - Taxon has been collected in the Mississippi River but no records of collection since 1978 (Fremling et al. 1989). H2 - Taxon reported as present by Warren et al. (2000) but abundance not known. H3 - Taxon presumed by Warren et al. (2000) to be present but not verified by collection records.

[3]MC - Main Channel is the portion of the river that contains the thalweg and the navigation channel; water is relatively deep and the current, although varying temporally and spatially, is persistent and relatively strong. CB - Channel Border is the zone from the main channel to the riverbank. Compared to MC, the CB is a zone of slower current, shallower water, and greater habitat heterogeneity. The channel border includes secondary channels and sloughs, islands and their associated sandbars, dikes and dike pools, and natural and revetted banks. BW – Backwater zone includes lentic habitats lateral to the channel border that are connected to the river for at least some time in most years. The backwater zone includes abandoned channels (including floodplain lakes) severed from the river at the upstream or both ends, lakes lateral to the channel border, ephemeral floodplain ponds, borrow pits created when levees were built, and the floodplain itself during overbank stages.

[4]Occasional occurrence in UMR; rare occurrence in OR attributed to stocking.

[5]Not listed as present in the open-river reach of the Mississippi River by Warren et al. (2000).

[6]Warren et al. (2000) list Mississippi stoneroller (*C. a. pullum*) as present in the open-river reach of the Mississippi River.

[7]Warren et al. (2000) list Pealip redhorse (M*. m. pisolabrum*) as present in the open-river reach of the Mississippi River.

Table 2. List of fishes of the Central Ohio River (River Mile 328 – 654). Source: http://www.fallsoftheohio.org/OhioRiverFishList.html

Bass – Crappie Family

Largemouth Bass	*Micropterus salmoides*
Rock Bass	*Ambloplites rupestris*
Smallmouth Bass	*Micropterus dolomieui*
Spotted Bass	*Micropterus punctulatus*
Striped Bass	*Morone saxatilis**
White Bass	*Morone chrysops*
Yellow Bass	*Morone mississippiensis*
Black Crappie	*Pomoxis nigromaculatus*
White Crappie	*Pomoxis annularis*

Bowfin

Bowfin	*Amia calva*

Carp Family

Bigmouth Buffalo	*Ictiobus cyprinellus*
Black Buffalo	*Ictiobus niger*
Smallmouth Buffalo	*Ictiobus bubalus*
Bighead Carp	*Hypophthalmichthys nobilis*
Carp	*Cyprinus carpo*
Grass Carp	*Ctenopharyngodon idella*
Silver Carp	*Hypophthalmichthys molitrix*
River Carpsucker	*Carpiodes carpio* t
Lake Chubsucker	*Erimyzon sucetta*
Goldfish	*Carassisus auratus**
Northern Hogsucker	*Hypentelium nigricans*
Quillback	*Carpiodes cyprinus*
Black Redhorse	*Moxostoma duquesnei* t
Golden Redhorse	*Moxostoma erythrurum* t
Greater Redhorse	*Moxostoma valenciennesi*
River Redhorse	*Moxostoma carinatum*
Shortnose Redhorse	*Moxostoma macrolepidotum*
Silver Redhorse	*Moxostoma anisurum* t
Blue Sucker	*Cycleptus elongatus* t
Highfin Sucker	*Carpiodes velifer* t
Spotted Sucker	*Minytrema melanops* t
White Sucker	*Catostomus commersoni*

Catfish Family

Black Bullhead	*Icatulurus melas*
Brown Bullhead	*Icatulurus nebulosus*
Yellow Bullhead	*Icatulurus natalis*
Blue Catfish	*Icatulurus furcatus*
Channel Catfish	*Icatulurus punctatus* t
Flathead Catfish	*Pylodictis olivaris* t
White Catfish	*Icatulurus catus*
Brindled Madtom	*Noturus miurus*
Mountain Madtom	*Noturus eleuthurus*
Tadpole Madtom	*Noturus gyrinus*
Stonecat	*Noturus flavus* t

Codfish

American Burbot	*Lota lota*

Darters

Banded Darter	*Etheostoma zonale*
Crystal Darter	*Ammocrypta asperella*
Dusky Darter	*Percina sciera*
Eastern Sand Darter	*Ammocrypta pellucida*
Fantail Darter	*Etheostoma flabellare* t
Greenside Darter	*Etheostoma blennioides* t
Johnny Darter	*Etheostoma nigrum*
Orangethroat Darter	*Etheostoma spectabile*
Rainbow Darter	*Etheostoma caeruleum*
River Darter	*Percina shumardi*
Slenderhead Darter	*Percina phoxocephala*
Stripetail Darter	*Etheostoma kennicotti*
Variegate Darter	*Etheostoma variatum*

Drum

Freshwater Drum	*Aplodinotus grunniens* t

Eel

American Eel	*Anguilla rostrata*

Gar

Alligator Gar	*Lepisosteus spatula*
Longnose Gar	*Lepisosteus osseus*
Shortnose Gar	*Lepisosteus platostomus* t
Spotted Gar	*Lepisosteus oculatus*

Minnow-like: Chubs, Minnows and Shiners

Bigeye Chub	*Hybopsis amblops* t
Cheek Chub	*Semotilus atromaculatus*
Hornyhead Chub	*Nocomis biguttatus*
River Chub	*Nocomis micropogon*
Silver Chub	*Hybopsis storeriana*
Speckled Chub	*Hybopsis aestivalis*
Streamline Chub	*Hybopsis dissimilis*
Blacknose Dace	*Rhinichthys atraculatus*
Redside Dace	*Clinostomus elongatus*
Bluntnose Minnow	*Pimephales notatus* t
Bullhead Minnow	*Pimephales vigilax*
Fathead Minnow	*Pimephales promelas*
Silverjaw Minnow	*Ericymba buccata*
Silvery Minnow	*Hybognathus nuchalis*
Suckermouth Minnow	*Phenacobius mirabilis*
Bigeye Shiner	*Notropis boops*
Common Shiner	*Notropis cornutus*
Emerald Shiner	*Notropis atherinoides*
Ghost Shiner	*Notropis buchanani*
Golden Shiner	*Notemigonus crysoleucas*
Mimic Shiner	*Notropis volucellus*

Ribbon Shiner	*Notropis fumeus*
River Shiner	*Notropis blennius*
Rosefin Shiner	*Notropis ardens*
Rosyface Shiner	*Notropis rubellus*
Sand Shiner	*Notropis stamineus*
Silver Shiner	*Notropis photogenis*
Spotfin Shiner	*Notropis spiloterus*
Spottail Shiner	*Notropis hudsonius*
Steelcolor Shiner	*Notropis whipplei*
Striped Shiner	*Notropis chrysocephalus*

Miscellaneous Minnow-type Fish

Common Stoneroller	*Campostoma anomolum*
Blackstripe Topminnow	*Fundulus notatus*
Brook Silverside	*Labidethes sicculus*
Mosquito Fish	*Gambusia affinis*
Pirateperch	*Aphredoderus sayanus*
Troutperch	*Percopsis omiscomaycus*

Lamprey

American Brook Lamprey	*Lampetra appendix*
Ohio Lamprey	*Ichthyomyzon bdellium*
Silver Lamprey	*Ichthyomyzon unicuspis*

Mooneyes

Goldeye	*Hiodon alosoides* t
Mooneye	*Hiodon tergisus* t

Paddlefish

Paddlefish	*Polyodon spathula*

Perch

Logperch	*Percina caprodes* t
Yellow Perch	*Perca flavescens*

Pike Group

Muskellunge	*Esox masquinongy*
Grass Pickerel	*Esox americanus vermiculatus*
Northern Pike	*Esox lucius**

Sauger – Walleye

Sauger	*Stizostedion canadense*
Walleye	*Stizostedion vitreum vitreum*

Sculpin

Mottled Sculpin	*Cottus carolinae*

Shad Family

Alabama Shad	*Alosa alabamae*
Alewife	*Alosa pseudoharengus**
Skipjack Shad	*Alosa chrysochloris* t
American Shad	*Alosa sapidissima**
American Gizzard Shad	*Dorosoma cepedianum*
Threadfin Shad	*Dorosoma petense*

Sturgeon

Lake Sturgeon	*Acipenser fulvescens*
Shovelnose Sturgeon	*Scaphirohynchus platorhychus*

Sunfish

Bluegill	*Lepomis macrochirus*
Pumpkinseed	*Lepomis gibbosus*
Green Sunfish	*Lepomis cyanellus*
Longear Sunfish	*Lepomis megalotis*
Orangespotted Sunfish	*Lepomis humilis*
Redear Sunfish	*Lepomis microlophus*
Warmouth	*Lepomis gulosus*

Oceanic (Freshwater Tolerant)

Coho Salmon	*Oncorhynchus kisutch**
Atlantic Rainbow Smelt	*Osmerus mordax*
Sea Trout	*Salmo trutta**

The Atchafalaya River Basin covers more than 3,600 km^2 of south-central Louisiana. Although it is much smaller than the other rivers that are the subject of proposed HK projects, the Atchafalaya River normally receives 30% of the combined flows from the Mississippi and Red Rivers, and can receive up to one half of the Mississippi River discharge when needed to prevent flooding (Troutman et al. 2007). Halloran (2010) identified 26 taxa of juvenile fish from seasonally inundated backwaters of the Atchafalaya River and 12 taxa of icthyoplankton (fish eggs and larvae; Tables 3 and 4), but it is likely that the total fish assemblage of the river includes all the species found in the lower Mississippi River as well as many estuarine species.

Not all of the fish species listed in Tables 1-4 are likely to encounter HK projects. For example, among the many species found in the Mississippi River (Table 1), Schramm (2004) considers 31 to utilize the main channel (where HK projects would be located), including various sturgeon, paddlefish, gar, shad, minnows, suckers and catfish. Other species are likely to be found in the channel border between the main channel and the riverbank, and thus may interact with HK projects. Many species that orient toward structures, such as members of the bass and sunfish family, are more likely to be found in low-velocity backwater habitats. Most fish in the main channel are likely to be found near the bottom, where water velocities are lower and cover is available, rather than higher in the water column where HK rotors would be sited.

Table 3. Juvenile fishes collected in seasonally inundated backwaters of the Atchafalaya River Basin during 2005-2006. From Halloran (2010).

	2005							2006					
Taxa	Feb	Mar	Apr	May	Jun	Jul	Aug	Feb	Mar	Apr	May	Jun	Jul
Aphredoderidae													
Aphredoderus sayanus	1		7	1									
Ameiuridae													
Ameiurus natalis												1	
Atherinidae													
Labidesthes sicculus													1
Catostomidae			1										
Centrarchidae													
Centrarchus macropterus				5									
Lepomis cyanellus			1	3							2	7	
Lepomis gulosus						2	1					12	13
Lepomis macrochirus	3		1	9	12	19	5						1
Lepomis marginatus													1
Lepomis miniatus					1		3						1
Lepomis spp.				1	3	1	3	1					
Lepomis symmetricus												9	29
Micropterus punctulatus											1		
Micropterus salmoides			8	137	1					15		2	
Micropterus spp.			7	24	2				63	1			
Pomoxis annularis				1								2	
Pomoxis nigromaculatus			6	3						2			
Pomoxis spp.			7	1					4				
Clupeidae													
Dorosoma cepedianum						1						1	
Cyprinidae													
Lythrus fumeus							2		5				
Notropis spp.							1						
Esocidae													
Esox americanus americanus	2	1											
Fundulidae													
Fundulus spp.									1			7	1
Percidae			253	4	2	4							
Syngnathidae													
Syngnathus scovelli			5	3		1							
Monthly total	6	1	296	192	21	28	15	1	73	18	3	41	47

Table 4. Icthyoplankton collected during 2005-2006 in the Atchafalaya River Basin. From Halloran (2010).

	2005								2006						
Taxa	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Feb	Mar	Apr	May	Jun	Jul	Aug
Aphredoderidae															
Aphredoderus sayanus															
Atherinidae															
Labidesthes sicculus													1		
Menidia beryllina				2											
Catostomidae	1		11	5	10				18	21	20				
Centrarchidae															
Ambloplites spp.									4						
Lepomis spp.	1		39	177	384	266	190	3	3	2	63	40	900	145	12
Micropterus spp.		3		1					8	9	1		1		
Pomoxis spp.	2	6	38	1			3		48	68	38	3			
Clupeidae															
Dorosoma spp.	1		336	650	119	102	5	1	1	325	8365	680	3768	268	3
Cyprinidae		1	4		21				6	3	29	46			
Fundulidae															
Fundulus spp.															
Hidonidae															
Hidon spp.												1			
Moronidae															
Morone spp.															
Percidae		2	39	2						1	1				1
Sciaenidae															
Aplodinotus grunniens			11	1	1							3	1		
Unknown											1				

4. Potential Effects on Fish Movements and Distributions

The numerous floating and submerged structures, mooring lines, and electrical transmission cables associated with large HK projects could interfere with the long-distance migrations of fish (e.g., juvenile and adult salmonids, paddlefish, sturgeon) if they are sited along migration corridors. Anadromous fish (e.g., green sturgeon, salmon, steelhead) and catadromous fish (e.g., eels) migrate through both rivers and oceans and therefore may encounter both hydrokinetic devices in the rivers and ocean energy projects (Dadswell et al. 1987).

Anchors and other permanent structures on the bottom will create new habitats. Artificial reefs are often constructed in marine systems in order to increase fish production, but some studies suggest that they may be less effective than natural reefs (Carr and Hixon 1997) and that they may even have deleterious effects on reef fish populations by stimulating overfishing and overexploitation (Grossman et al. 1997). In freshwater, Creque et al. (2006) studied an artificial reef constructed of granite rubble in southwestern Lake Michigan. Compared to a nearby reference site, the reef attracted more smallmouth bass (*Micropterus dolomieui*) and rock bass (*Amblopites rupestris*), but other fish species (freshwater drum, gizzard shad, yellow perch, and salmonines) were commonly found at both locations. For all of the fish, use of the artificial reef was seasonal, related to water temperature. Wills et al. (2004) examined the effects of artificial habitat structures on fish abundance in four Michigan reservoirs. Some structures (half-log habitat enhancement structures) attracted significantly greater numbers of smallmouth bass than reference areas or other artificial habitat structures. Other fish groups displayed few significant differences in abundance or nesting frequency between areas with or without structures or before and after structure placement.

The cover provided by woody debris, undercut banks, boulders, artificial structures, etc. serves three main functions: protection against predators, reduction of competition by visual isolation, and hydraulic shelter (Fausch 1993). In a review of cover for riverine fish, Allouche (2002) concluded that fish attraction to cover is largely influenced by the architectural arrangement of the cover structure (i.e., complexity, cavity space) and also the diversity of other associated habitat features generated by the structure (e.g., hydraulic heterogeneity, light intensity). Although the relationships between fish and cover are extremely complex, often fish diversity and abundance are increased. Habitat enhancement structures are also commonly employed in rivers to increase fish production. For example, Proboszcz and Guy (2006) found that constructed wooden half-logs were selected habitat by spotted bass (*Micropterus punctulatus*). Hartman and Titus (2009) reported that artificial dikes were beneficial to centrarchids (black bass and sunfish), cyprinids, and catostomids by providing velocity shelters and cover; these fish were more abundant near the dikes than at reference areas. Abundance and species richness of juvenile fishes were high near pile fields in the lower Hudson River estuary, but low under large piers (Able et al. 1998). Barko et al. (2004b) reported that wing dikes in the upper Mississippi River contained more species of adult and juvenile fishes than the nearby main channel. Among adult fish, cyprinids (minnows), clupeids (shads), and centrarchids (bass and sunfish) were generally more abundant in wing dike habitats, whereas catostomids (suckers) and some ictalurids (catfishes) were more abundant in the main channel physical habitats.

Niles and Hartman (2010) pointed out that the main channels of large rivers have swift flows, and the homogeneous habitat offers few areas of cover or low flows. High-velocity flows increase the energy that fish must expend to maintain position, and cause smaller fish, especially larvae and juveniles, to be swept downstream. Consequently, areas of low velocity like artificial dike structures provide valuable habitat in large rivers. Compared to low quality natural reference areas in the Kanawha River, WV, artificial dikes supported greater larval abundance and taxonomic richness of most fish families.

New structures in the pelagic zone of oceans and lakes (e.g., pilings or mooring cables for floating devices) will create habitat that may act as fish aggregation or attraction devices (FADs), and similar effects might occur in large rivers. These devices are extremely effective in concentrating fish and making them susceptible to harvest (Dempster and Tacquet 2004). Fish are attracted to FADs as physical structure/shelter, and they may feed on organisms attached to the structures. Artificial lighting used to distinguish structures at night may also attract aquatic organisms. If HK projects result in an aggregation of predators, they may adversely affect juvenile salmonids moving through the project area.

In marine waters, Wilhelmsson et al. (2006) found that fish abundance in the vicinity of monopiles that supported offshore wind turbines was greater than in surrounding areas, although species richness and diversity were similar. Most of the fish they observed near the structure were small (juvenile gobies), which may in turn attract commercially important fish looking for prey. Dempster (2005) observed considerable temporal variability in the abundance and diversity of fish associated with marine FADs moored between 3 and 10 km offshore. The variability was often related to the seasonal appearance of large schools of juvenile fish. Fish assemblages differed between times when predators were present or absent; few small fishes were observed near the FADs when predators were present, regardless of the season. Using FADs as an experimental tool, Nelson (2003) found that fish formed larger, more species-rich assemblages around large FADs compared to small ones, and they formed larger assemblages around FADs with fouling biota. Devices enriched with fish accumulated additional recruits more quickly than those in which fish were removed. Although there have been numerous studies of FADs in marine systems and artificial habitat structures in lakes (e.g., review of Viavant 1995), comparable information from freshwater rivers is lacking.

Fish and other aquatic organisms might also be repelled by HK projects in rivers. The visual and auditory stimuli caused by moving structures and the electromagnetic fields (EMF) associated with submerged generators and transmission cables might all conceivably invoke avoidance responses. The scientific literature relevant to possible avoidance of riverine HK projects by freshwater fish from these mechanisms is virtually non-existent, although the effects of noise and EMF are also being investigated in ongoing studies (e.g., Cada et al. 2010; Bevelhimer et al. 2010). Gurgens et al. (2000) found that paddlefish avoided 2.54-cm diameter aluminum rods in a laboratory tank, but not plastic or plastic-coated aluminum rods. The authors speculated that part of the reason why migrating paddlefish congregate below navigation locks in the Mississippi River is electrosensory aversion to the metal gates (although they conceded that high water velocities through partially opened gates might also be influential). In any case, the highly developed electrosensitivity of the paddlefish rostrum may cause them to avoid large or uncharacteristic electrical fields associated with submerged metal structures (Wilkens et al. 1997). Potentially, this sensitivity could result in avoidance of submerged pilings, generators, and electrical transmission cables associated with HK projects. If the project is large enough, fish migrations might be affected.

Regarding sound-related avoidance, it is known that fish avoid the loud, concussive noises of underwater pile driving (DOE 2009), but different species react differently even to pile-driving noises (Nedwell et al. 2006). The sounds from boats have been shown to cause stress in largemouth bass (Graham and Cooke 2008) and avoidance behavior in migrating salmon (Xie et al. 2008) and a variety of lake and reservoir fishes (Drastik and Kubecka 2005). In both studies, avoidance was not a problem at distances of over 10 m. Wysocki et al. (2006) exposed freshwater fish to comparable sound pressure levels of fluctuating (discontinuous) underwater ship noises and continuous Gaussian (white) noise. Stress (measured as elevated cortisol secretion) increased in response to the ship noise but not the continuous white noise. The noise levels produced by operating HK projects have not been measured; however, the results of the Wysocki et al. (2006) experiment suggest that fish may be less affected by continuous noise produced by the HK rotors and generators than by periodic noises from boat traffic or construction. That is, fish may become habituated to a consistent noise, even though a dynamic, unpredictable noise at the same sound pressure levels may cause avoidance reactions. These types of responses to anthropogenic sounds in freshwater environments are presently being investigated (Bevelhimer et al. 2010).

5. Conclusions

There have been few studies of fish attraction to artificial structures like HK in large rivers, but some useful Before-After, Control-Impact (BACI) studies of artificial reefs in freshwater reservoirs have been published (Wills et al. 2004; Creque et al. 2006). Based on these limited studies, the attraction of freshwater fish to HK structures is likely to be seasonal rather than constant; the use of the structure may be related to water temperature or seasonal movements/migrations. Attraction to HK structures will certainly be species-specific. Some freshwater fish species show little interest in mid-water structures, whereas others such as smallmouth bass are more likely to be attracted, especially to overhead cover (Creque et al. 2006). Numerous studies have shown that black bass (*Micropterus* spp.) and other members of the Family Centrarchidae (bass and sunfish) have an affinity for structures throughout summer and during the nesting season. But the depth at which structures are placed and the complexity of nearby natural habitats will also influence the attractiveness of artificial structures (Wills et al. 2004).

Schramm (2004) listed 172 resident, freshwater fish species in the Mississippi River. Many of these species are found in the lower segments of the river and its larger tributaries, where the bulk of the HK projects have been proposed. However, a number of these species will likely have little interaction with HK structures in the main channels of the rivers. Of the 137 species that Schramm was able to assign to preferred habitat zones, none is expected to reside in main channel habitats throughout their life cycle, 24 are expected to occupy one or more channel border habitats throughout their life cycle, and 50 species are expected to reside in one or more backwater habitats throughout their lifecycle. Those species that prefer backwater habitats (characterized by slow currents, shallow water, fine sediments and vegetation) will not normally encounter HK structures. Among the 31 main channel- and 77 channel border-occupying species, some prefer open waters and would not necessarily be attracted to project structures. Many of the 77 channel border species are small minnows, dace, and shiners (Family Cyprinidae) that are weak swimmers and unlikely to venture into the high-velocity channel for long. Based on a consideration of habitat preferences, size/swim speed, and behavior, fish species that are most likely to be attracted to HK structures in the main channel include carps, suckers, catfish, white bass, striped bass, smallmouth bass, spotted bass, and sauger.

For fish in marine, lake, and reservoir systems at least, the average number of individuals and species attracted increases with the structural complexity, volume, size, and surface area of habitat enhancement structures (Wills et al. 2004). The same effect might be expected near HK projects in large rivers. However, compared to dikes and other artificial habitats that are purposely placed in rivers to support fish, HK structures are less likely to provide desirable habitat. For example, Niles and Hartman (2010) noted that incorporation of natural components (to make them attractive to a wider variety of species) and provision of low flow areas, cover, and foraging habitats are important qualities of effective habitat enhancement structures in large rivers. These are not likely to be important elements of HK project structures, and thus their attractiveness to fish will be limited. In general, the additional habitat created by HK structures may not be significant in the context of numerous other man-made structures in large rivers such as bridges, piers, docks, wing dikes, and revetments.

In the ocean, FADs attract fish because they provide food and shelter (Castro et al. 2002); subsequently, they also attract predators (Dempster 2005) that can in turn attract commercial and sport fisheries. Without well-designed monitoring, it will be difficult to determine whether an HK project will enhance populations of aquatic organisms (by providing more habitat to support more fish), will have no overall effect (because it simply draws fish from other, nearby areas), or will decrease fish populations (by facilitating harvest by predators and fishermen). Kingsford (1999) pointed out that the determination of the effects of FADs at a particular location is complicated by the influence of non-independent factors: proximity of other FADs, interconnection of multiple FADs to provide routes for the movement of associated fishes, and temporal dependence (the number of fish present at one sampling date influencing the number at the next sampling date due to fish becoming residents). He described statistical approaches that could be applied to experiments on the effects of FADs on fish populations and solutions to the independent factor problems.

Allouche (2002) noted that whether the addition of cover structures really increases the carrying capacity of a stream or simply causes a redistribution of the existing capacity still remains controversial. Compared to nearby reference areas without structures, a greater abundance and diversity of certain riverine fish species can be expected near HK structures, unless the fish are repelled by other aspects of the device (noise, electromagnetic fields, and rotor movements). Although a possible “FAD effect” has not been studied for HK installations in large rivers, temporary/seasonal attraction of fish to structures that are less valuable than natural habitats is unlikely to alter fish populations or aquatic communities.

Avoidance of MHK projects by fish may result from adverse stimuli presented by movements of the rotors, noise, and EMF emitted by the generating and electrical transmission cables. As with structures, the possible effects on fish of noise from and motions of the HK devices would have to be placed in the context of other such stimuli in the main channels of rivers, especially recreational and commercial boat traffic. Little is known about these effects, although the noise study of Wysocki et al. (2006) suggests that fish may be repulsed by the aperiodic, startling stimuli from boats and become habituated to constant, low-level stimuli from HK machines. Some freshwater fish are known to be sensitive to electromagnetic fields (e.g., sturgeon and paddlefish), and studies are being carried out to determine the sensitivity of these and other freshwater species to the levels of magnetic fields that are expected to be produced by HK projects (Cada et al. 2010).

Monitoring Potential Interference with Animal Movements and Migrations

Because there is insufficient information about the likely effects of structures associated with large energy conversion projects on the movements and migrations of aquatic animals, monitoring of attraction or avoidance will be needed, at least initially. With regard to the local movements, the new structures may act as FADs and increase the local abundance of fish. Changes in numbers and relative abundances of fish populations could be monitored before and after project installation, using control and impacted sites (i.e., a BACI experimental design). Determining the effects of FADs at a particular location is complicated by the influence of non-independent factors including the proximity of other FADs (i.e., other HK units), the interconnection of multiple FADs to provide routes for the movement of associated fishes, and temporal dependence (where the number of fish present at one time influences the number at the next time due to fish becoming residents). Kingsford (1999) described statistical approaches that could be applied to experiments on the effects of FADs on fish populations and solutions to the independent factor problems.

Changes in the abundance of fish in the area of the project could be assessed with acoustic monitoring techniques. For example, Mueller et al. (2006) described the use of visual and acoustic cameras to determine fish presence, behavior, and habitat associations in rivers. Brehmer et al. (2003) were able to monitor fish aggregations, fish behaviors, diel variations, and interactions with artificial structures (vertical longlines suspended between anchors and buoys) using multi-beam side scan sonar. De Leeuw et al. (2007) reviewed techniques for assessing the fish communities of large floodplain rivers, including the use of both hydroacoustic methods and more traditional trawling and netting methods. These techniques could be adapted to the particular circumstances and sampling needs of the HK project.

Effects on long distance movements and migrations are more difficult to assess, and will depend initially on telemetry studies of animals migrating in the vicinity of the energy project. Once the species of interest are determined, active tracking of individuals marked with electronic tags may provide the most useful information about whether or not the HK project interferes with migrations. Ransom et al. (2008), Tripp and Garvey (2009), and Lindley et al. (2011) provided recent examples of the application of acoustic tag monitoring in large rivers.

Mitigating Attraction/Avoidance Effects of Riverine HK Projects

If attraction to or avoidance of HK projects proves to be an issue, the most reliable impact mitigation measure is likely to be proper siting of the energy project in order to avoid sensitive fish populations, habitat areas, and fish migration corridors. For example, it may be prudent to avoid siting the HK project near the entrance of backwaters that serve as nursery habitat for juvenile fish or backwater-dependent adult fish because this location would expose a greater number of species to project effects. Positioning the HK project in the main channel of highest water velocities and least diverse habitats would greatly reduce the amount of interaction with riverine fish. Sound insulation may be needed if noises produced by the generators repel fish or interfere with migrations. Mitigation of EMF effects from freshwater HK projects may be easier than in oceans because rivers are likely to support fewer EMF-sensitive organisms and need shorter cables to transmit electricity from the HK generator to shore. Exposure to EMF can be reduced by burying the transmission cables in the sediments, thereby increasing the separation between the source of the field and any aquatic organisms in the open water.

6. References

Able, K.W., J.P. Manderson, and A.L. Studholme. 1998. The distribution of shallow water juvenile fishes in an urban estuary: The effects of manmade structures in the lower Hudson River. Estuaries 21(4B):731-744.

Allouche, S. 2002. Nature and functions of cover for riverine fish. Bull. Fr. Peche Piscic. 365/366:297-324.

Barko, V.A., M.W. Palmer, D.P. Herzog, and B.S. Ickes. 2004a. Influential environmental gradients and spatiotemporal patterns of fish assemblages in the unimpounded upper Mississippi River. American Midland Naturalist 152:369-385.

Barko, V.A., D.P. Herzog, R.A. Hrabik, and J.S. Scheibe. 2004b. Relationship among fish assemblages and main-channel-border physical habitats in the unimpounded upper Mississippi River. Transactions of the American Fisheries Society 133:371-384.

Bevelhimer, M., G. Cada, M. Johnson, and W. Bonness. 2010. Potential Effects of Noise from Hydrokinetic Devices on Aquatic Organisms. FY2010 Annual Progress Report to the Wind and Water Power Program, U.S. Department of Energy, Washington, DC. 26 p.

Brehmer, P., F. Gerlotto, J. Guillard, F. Sanguinede, Y. Guennegan, and D. Buestel. 2003. New applications of hydroacoustic methods for monitoring shallow water aquatic ecosystems: the case of mussel culture grounds. Aquatic Living Resources 16:333-338.

Cada, G., M. Bevelhimer, K. Riemer, and J. Turner. 2010. Effects on Freshwater Organisms of Magnetic Fields Associated with Instream Hydrokinetic Turbines. FY2010 Annual Progress Report to the Wind and Water Power Program, U.S. Department of Energy, Washington, DC. 35 p.

Carr, M.H. and M.A. Hixon. 1997. Artificial reefs: The importance of comparisons with natural reefs. Fisheries 22(4):28-33.

Castro, J.J., J.A. Santiago, and A.T. Santana-Ortega. 2002. A general theory on fish aggregation to floating objects: An alternative to the meeting point hypothesis. Reviews in Fish Biology and Fisheries 11:255-277.

Creque, S.M., M.J. Raffenberg, W.A. Brofka, and J.M. Dettmers. 2006. If you build it, will they come? Fish and angler use at a freshwater artificial reef. North American Journal of Fisheries Management 26:702-713.

Dadswell, M.J., R.J. Klauda, C.M. Moffitt, R.L. Saunders, R.A. Rulifson, J.E. Cooper. 1987. Common Strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1, Bethesda, MD.

De Leeuw, J.J., A.D. Buijse, G. Haidvogl, M. Lapinska, R. Noble, R. Repecka, T. Virbickas, W. Wisniewolski, and C. Wolter. 2007. Challenges in developing fish-based ecological assessment methods for large floodplain rivers. Fisheries Management and Ecology 14:483-494.

Dempster, T. and M. Taquet. 2004. Fish aggregation device (FAD) research: gaps in current knowledge and future directions for ecological studies. Reviews in Fish Biology and Fisheries 14:21-42.

Dempster, T. 2005. Temporal variability of pelagic fish assemblages around fish aggregation devices: biological and physical influences. Journal of Fish Biology 66:1237-1260.

DOE (U.S. Department of Energy). 2009. Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies. Prepared in response to the Energy Independence and Security Act of 2007, Section 633(b). Wind and Hydropower Technologies Program, U.S. Department of Energy, Washington, DC. 89 p. + appendices.

Drastik, V. and J. Kubecka. 2005. Fish avoidance of acoustic survey boat in shallow waters. Fisheries Research 72(2005):219-228.

Fausch, K.D. 1993. Experimental analysis of microhabitat selection by juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) in a British Columbia stream. Canadian Journal of Fisheries and Aquatic Sciences 50:1198-1207.

Fremling, C.R., J.L. Rasmussen, R.E. Sparks, S.P. Cobb, C.F. Bryan, and T.O. Claflin. 1989. Mississippi River fisheries: A case history. P. 309-351 In D.P. Dodge (ed). *Proceedings of the International Large River Symposium*. Department of Fisheries and Oceans, Ottawa, Canada.

Graham, A.L. and S.J. Cooke. 2008. The effects of noise disturbance from various recreational boating activities common to inland waters on the cardiac physiology of a freshwater fish, the largemouth bass (*Micropterus salmoides*). Aquatic Conservation: Marine and Freshwater Ecosystems 18:1315-1324.

Grossman, G.D., G.P. Jones, and W.J. Seaman, Jr. 1997. Do artificial reefs increase regional fish production? A review of existing data. Fisheries 22(4):17-23.

Gurgens, C., D.F. Russell, and L.A. Wilkens. 2000. Electrosensory avoidance of metal obstacles by the paddlefish. Journal of Fish Biology 57:277-290.

Halloran, B. T. 2010. Early life history dynamics of the fish community in the Atchafalaya River Basin. Ph.D. Dissertation, School of Renewable Natural Resources, Louisiana State University, Baton Rouge, LA. 115 p.

Hartman, K.J. and J.L. Titus. 2009. Fish use of artificial dike structures in a navigable river. River Research and Applications (2009).

Kingsford, M.J. 1999. Fish attraction devices (FADs) and experimental designs. Scientia Marina 63(3-4):181-190.

Lindley, S.T., D.L. Erickson, M.L. Moser, G. Williams, O.P. Langness, B.W. McCovey, Jr., M. Belchik, D. Vogel, W. Pinnix, J.T. Kelly, J.C. Heublein, and A.P. Klimley. 2011. Electronic tagging of green sturgeon reveals population structure and movement among estuaries. Transactions of the American Fisheries Society 140(1):108-122.

Mueller, R.P., R.S. Brown, H . Hop, and L. Moulton. 2006. Video and acoustic camera techniques for studying fish under ice: a review and comparison. Reviews in Fish Biology and Fisheries 16:213:226.

Nedwell, J.R., A.W.H. Turnpenny, J.M. Lovell, and B. Edwards. 2006. An investigation into the effects of underwater piling noise on salmonids. Journal of the Acoustic Society of America 120(5):2550-2554.

Nelson, P.A. 2003. Marine fish assemblages associated with fish aggregating devices: Effects of fish removal, FAD size, fouling communities, and prior recruits. Fishery Bulletin 101(4):835-850.

Niles, J.M. and K.J. Hartman. 2010. Temporal distribution and taxonomic composition differences of larval fish in a large navigable river: A comparison of artificial dike structures and natural habitat. River Research and Applications (2010).

Normandeau Associates, Inc. (2009). An Estimation of Survival and Injury of Fish Passed Through the Hydro Green Energy Hydrokinetic System, and a Characterization of Fish Entrainment Potential at the Mississippi Lock and Dam No. 2 Hydroelectric Project (P-4306), Hastings, Minnesota. Final Report prepared for Hydro Green Energy, LLC, Houston, Texas. 82 p.

Proboszcz, S.L. and C.S. Guy. 2006. Evaluation of habitat enhancement structure use by spotted bass. The Prairie Naturalist 38(4):223-238.

Ransom, B.H., T.W. Steig, M.A. Timko, and P.A. Nealson. 2008. Basin-wide monitoring of salmon smolts at US dams. Hydropower & Dams 3:2-7.

Schlosser, I.J. 1991. Stream fish ecology: A landscape perspective. Bioscience 41(10):704-712.

Schramm, H.L. Jr. 2004. Status and management of Mississippi River fisheries. Available at http://mekonginfo.org/mrc Mekong River Commission. 34 p.

Troutman, J.P., D.A. Rutherford, and W.E. Kelso. 2007. Patterns of habitat use among vegetation-dwelling littoral fishes in the Atchafalaya River Basin, Louisiana. Transactions of the American Fisheries Society 136:1063-1075.

Tripp, S. and J. Garvey. 2009. Fish Passage in the Upper Mississippi River System. Annual Report. Fisheries and Illinois Aquaculture Center, Southern Illinois University, Carbondale, IL. November 6, 2009. 95 p.

Viavant, T. 1995. Fish attraction to artificial structure in Chena Lakes, Alaska. Fishery Data Series No. 95-6, Alaska Department of Fish and Game, Anchorage, AK. 14 p.

Wilhelmsson, D., T. Malm, and M.C. Ohman. 2006. The influence of offshore windpower on demersal fish. ICES Journal of Marine Science 63:775-784.

Wilkens, L.A., D.F. Russell, X. Pei, and C. Gurgens. 1997. The paddlefish rostrum functions as an electrosensory antenna in plankton feeding. Proceedings of the Royal Society of London B. 264:1723-1729.

Wills, T.C., M.T. Bremigan, and D.B. Hayes. 2004. Variable effects of habitat enhancement structures across species and habitats in Michigan reservoirs. Transactions of the American Fisheries Society 133:399-411.

Wysocki, L.E., J.P. Dittami, and F. Ladich. 2006. Ship noise and cortisol secretion in European freshwater fishes. Biological Conservation 128:501-508.

Xie, Y., C.G.J. Michielsens, A.P. Gray, F.J. Martens, and J.L. Boffey. 2008. Observation of avoidance reactions of migrating salmon to a mobile survey vessel in a riverine environment. Canadian Journal of Fisheries and Aquatic Science 65:2178-2190.

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