APPENDIX K: ENDANGERED AND PROTECTED SPECIES SUPPORTING DOCUMENTS

Contents:

Bald Eagle Management Guidelines

NATIONAL BALD EAGLE MANAGEMENT GUIDELINES

U.S. Fish and Wildlife Service

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INTRODUCTION

The bald eagle (*Haliaeetus leucocephalus*) is protected by the Bald and Golden Eagle Protection Act (Eagle Act) and the Migratory Bird Treaty Act (MBTA). The MBTA and the Eagle Act protect bald eagles from a variety of harmful actions and impacts. The U.S. Fish and Wildlife Service (Service) developed these National Bald Eagle Management Guidelines to advise landowners, land managers, and others who share public and private lands with bald eagles when and under what circumstances the protective provisions of the Eagle Act may apply to their activities. A variety of human activities can potentially interfere with bald eagles, affecting their ability to forage, nest, roost, breed, or raise young. The Guidelines are intended to help people minimize such impacts to bald eagles, particularly where they may constitute “disturbance,” which is prohibited by the Eagle Act.

The Guidelines are intended to:

(1) Publicize the provisions of the Eagle Act that continue to protect bald eagles, in order to reduce the possibility that people will violate the law,

(2) Advise landowners, land managers and the general public of the potential for various human activities to disturb bald eagles, and

(3) Encourage additional nonbinding land management practices that benefit bald eagles (see Additional Recommendations section).

While the Guidelines include general recommendations for land management practices that will benefit bald eagles, the document is intended primarily as a tool for landowners and planners who seek information and recommendations regarding how to avoid disturbing bald eagles. Many States and some tribal entities have developed state-specific management plans, regulations, and/or guidance for landowners and land managers to protect and enhance bald eagle habitat, and we encourage the continued development and use of these planning tools to benefit bald eagles.

Adherence to the Guidelines herein will benefit individuals, agencies, organizations, and companies by helping them avoid violations of the law. However, the Guidelines themselves are not law. Rather, they are recommendations based on several decades of behavioral observations, science, and conservation measures to avoid or minimize adverse impacts to bald eagles.

The U.S. Fish and Wildlife Service strongly encourages adherence to these guidelines to ensure that bald and golden eagle populations will continue to be sustained. The Service realizes there may be impacts to some birds even if all reasonable measures are taken to avoid such impacts. Although it is not possible to absolve individuals and entities from liability under the Eagle Act or the MBTA, the Service exercises enforcement discretion to focus on those individuals, companies, or agencies that take migratory birds without regard for the consequences of their actions and the law, especially when conservation measures, such as these Guidelines, are available, but have not been implemented. The Service will prioritize its enforcement efforts to focus on those individuals or entities who take bald eagles or their parts, eggs, or nests without implementing appropriate measures recommended by the Guidelines.

The Service intends to pursue the development of regulations that would authorize, under limited circumstances, the use of permits if "take" of an eagle is anticipated but unavoidable. Additionally, if the bald eagle is delisted, the Service intends to provide a regulatory mechanism to honor existing (take) authorizations under the Endangered Species Act (ESA).

During the interim period until the Service completes a rulemaking for permits under the Eagle Act, the Service does not intend to refer for prosecution the incidental "*take*" of any bald eagle under the MBTA or Eagle Act, if such take is in full compliance with the terms and conditions of an incidental take statement issued to the action agency or applicant under the authority of section 7(b)(4) of the ESA or a permit issued under the authority of section 10(a)(1)(B) of the ESA.

The Guidelines are applicable throughout the United States, including Alaska. The primary purpose of these Guidelines is to provide information that will minimize or prevent violations only of *Federal* laws governing bald eagles. In addition to Federal laws, many states and some smaller jurisdictions and tribes have additional laws and regulations protecting bald eagles. In some cases those laws and regulations may be more protective (restrictive) than these Federal guidelines. If you are planning activities that may affect bald eagles, we therefore recommend that you contact both your nearest U.S. Fish and Wildlife Service Field Office (see the contact information on p.16) and your state wildlife agency for assistance.

LEGAL PROTECTIONS FOR THE BALD EAGLE

The Bald and Golden Eagle Protection Act

The Eagle Act (16 U.S.C. 668-668c), enacted in 1940, and amended several times since then, prohibits anyone, without a permit issued by the Secretary of the Interior, from "taking" bald eagles, including their parts, nests, or eggs. The Act provides criminal and civil penalties for persons who "take, possess, sell, purchase, barter, offer to sell, purchase or barter, transport, export or import, at any time or any manner, any bald eagle ... [or any golden eagle], alive or dead, or any part, nest, or egg thereof." The Act defines "take" as "pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb." "Disturb'' means:

> "Disturb means to agitate or bother a bald or golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available, 1) injury to an eagle, 2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior, or 3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior."

In addition to immediate impacts, this definition also covers impacts that result from human-induced alterations initiated around a previously used nest site during a time when eagles are not present, if, upon the eagle=s return, such alterations agitate or bother an eagle to a degree that injures an eagle or substantially interferes with normal breeding, feeding, or sheltering habits and causes, or is likely to cause, a loss of productivity or nest abandonment.

A violation of the Act can result in a criminal fine of $100,000 ($200,000 for organizations), imprisonment for one year, or both, for a first offense. Penalties increase substantially for additional offenses, and a second violation of this Act is a felony.

The Migratory Bird Treaty Act
The MBTA (16 U.S.C. 703-712), prohibits the taking of any migratory bird or any part, nest, or egg, except as permitted by regulation. The MBTA was enacted in 1918; a 1972 agreement supplementing one of the bilateral treaties underlying the MBTA had the effect of expanding the scope of the Act to cover bald eagles and other raptors. Implementing regulations define "take" under the MBTA as "pursue, hunt, shoot, wound, kill, trap, capture, possess, or collect."

Copies of the Eagle Act and the MBTA are available at: http://permits.fws.gov/ltr/ltr.shtml.

State laws and regulations
Most states have their own regulations and/or guidelines for bald eagle management. Some states may continue to list the bald eagle as endangered, threatened, or of special concern. If you plan activities that may affect bald eagles, we urge you to familiarize yourself with the regulations and/or guidelines that apply to bald eagles in your state. Your adherence to the Guidelines herein does not ensure that you are in compliance with state laws and regulations because state regulations can be more specific and/or restrictive than these Guidelines.

NATURAL HISTORY OF THE BALD EAGLE

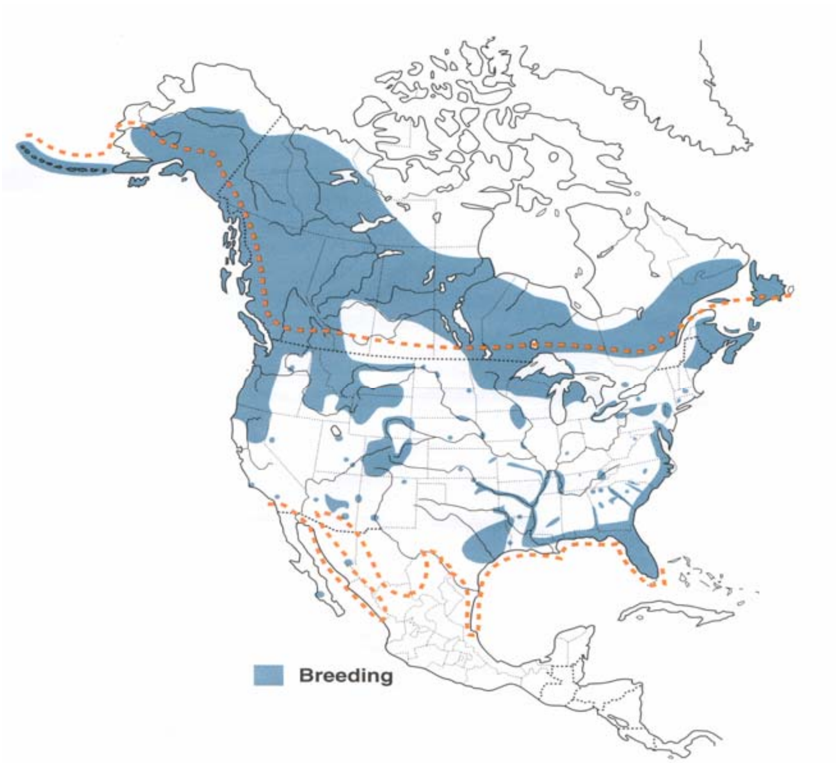
Bald eagles are a North American species that historically occurred throughout the contiguous United States and Alaska. After severely declining in the lower 48 States between the 1870s and the 1970s, bald eagles have rebounded and re-established breeding territories in each of the lower 48 states. The largest North American breeding populations are in Alaska and Canada, but there are also significant bald eagle populations in Florida, the Pacific Northwest, the Greater Yellowstone area, the Great Lakes states, and the Chesapeake Bay region. Bald eagle distribution varies seasonally. Bald eagles that nest in southern latitudes frequently move northward in late spring and early summer, often summering as far north as Canada. Most eagles that breed at northern latitudes migrate southward during winter, or to coastal areas where waters remain unfrozen. Migrants frequently concentrate in large numbers at sites where food is abundant and they often roost together communally. In some cases, concentration areas are used year-round: in summer by southern eagles and in winter by northern eagles.

Juvenile bald eagles have mottled brown and white plumage, gradually acquiring their dark brown body and distinctive white head and tail as they mature. Bald eagles generally attain adult plumage by 5 years of age. Most are capable of breeding at 4 or 5 years of age, but in healthy populations they may not start breeding until much older. Bald eagles may live 15 to 25 years in the wild. Adults weigh 8 to 14 pounds (occasionally reaching 16 pounds in Alaska) and have wingspans of 5 to 8 feet. Those in the northern range are larger than those in the south, and females are larger than males.

Where do bald eagles nest?

Breeding bald eagles occupy "territories," areas they will typically defend against intrusion by other eagles. In addition to the active nest, a territory may include one or more alternate nests (nests built or maintained by the eagles but not used for nesting in a given year). The Eagle Act prohibits removal or destruction of both active and alternate bald eagle nests. Bald eagles exhibit high nest site fidelity and nesting territories are often used year after year. Some territories are known to have been used continually for over half a century.

Bald eagles generally nest near coastlines, rivers, large lakes or streams that support an adequate food supply. They often nest in mature or old-growth trees; snags (dead trees); cliffs; rock promontories; rarely on the ground; and with increasing frequency on human-made structures such as power poles and communication towers. In forested areas, bald eagles often select the tallest trees with limbs strong enough to support a nest that can weigh more than 1,000 pounds. Nest sites typically include at least one perch with a clear view of the water where the eagles usually forage. Shoreline trees or snags located in reservoirs provide the visibility and accessibility needed to locate aquatic prey. Eagle nests are constructed with large sticks, and may be lined with moss, grass, plant stalks, lichens, seaweed, or sod. Nests are usually about 4-6 feet in diameter and 3 feet deep, although larger nests exist.



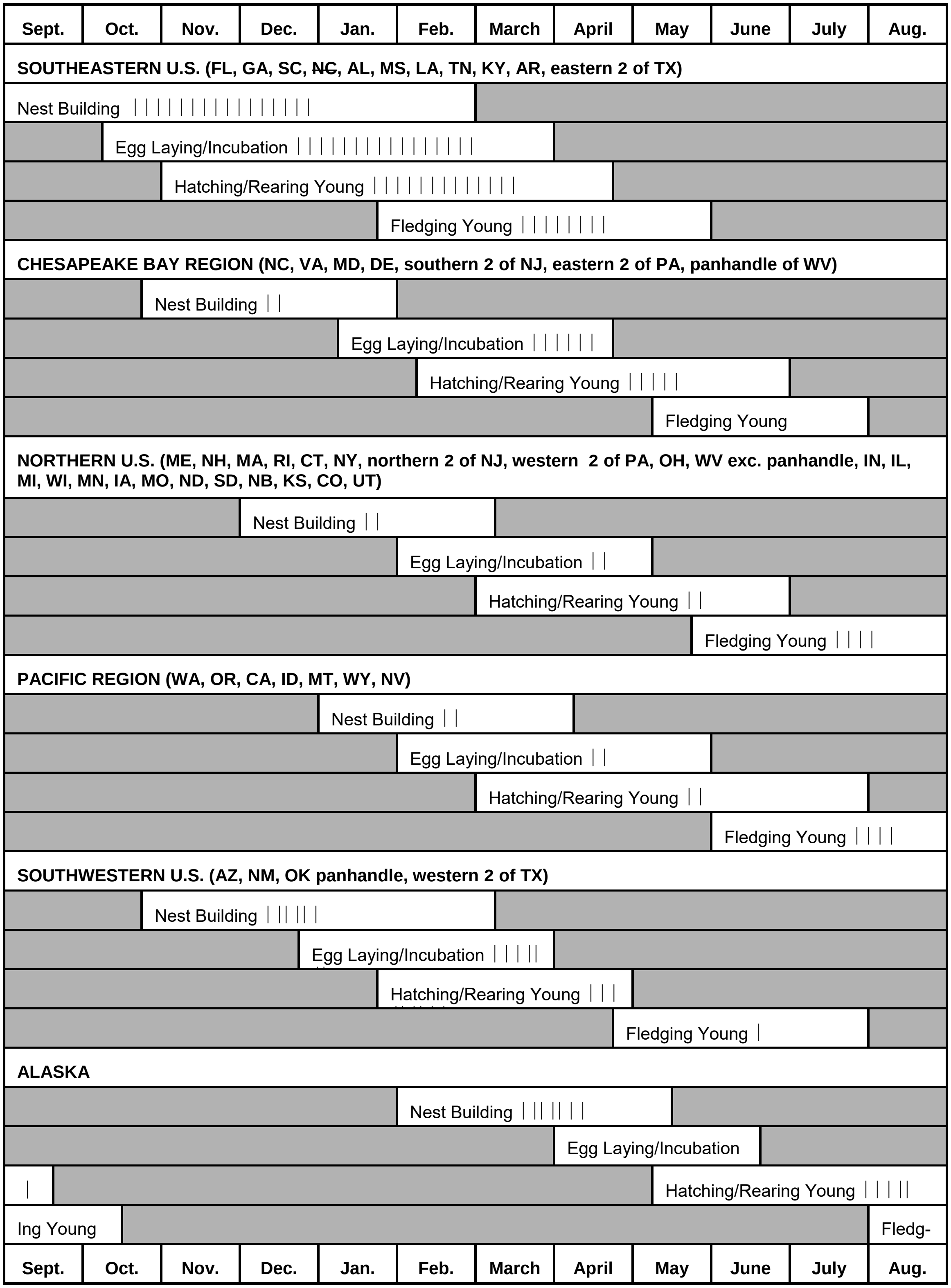
The range of breeding bald eagles in 2000 (shaded areas). This map shows only the larger concentrations of nests; eagles have continued to expand into additional nesting territories in many states. The dotted line represents the bald eagle's wintering range.

When do bald eagles nest?

Nesting activity begins several months before egg-laying. Egg-laying dates vary throughout the U.S., ranging from October in Florida, to late April or even early May in the northern United States. Incubation typically lasts 33-35 days, but can be as long as 40 days. Eaglets make their first unsteady flights about 10 to 12 weeks after hatching, and fledge (leave their nests) within a few days after that first flight. However, young birds usually remain in the vicinity of the nest for several weeks after fledging because they are almost completely dependent on their parents for food until they disperse from the nesting territory approximately 6 weeks later.

The bald eagle breeding season tends to be longer in the southern U.S., and re-nesting following an unsuccessful first nesting attempt is more common there as well. The following table shows the timing of bald eagle breeding seasons in different regions of the country. The table represents the range of time within which the majority of nesting activities occur in each region and does not apply to any specific nesting pair. Because the timing of nesting activities may vary within a given region, you should contact the nearest U.S. Fish and Wildlife Service Field Office (see page 16) and/or your state wildlife conservation agency for more specific information on nesting chronology in your area.

Chronology of typical reproductive activities of bald eagles in the United States.



How many chicks do bald eagles raise?

The number of eagle eggs laid will vary from 1-3, with 1-2 eggs being the most common. Only one eagle egg is laid per day, although not always on successive days. Hatching of young occurs on different days with the result that chicks in the same nest are sometimes of unequal size. The overall national fledging rate is approximately one chick per nest, annually, which results in a healthy expanding population.

What do bald eagles eat?

Bald eagles are opportunistic feeders. Fish comprise much of their diet, but they also eat waterfowl, shorebirds/colonial waterbirds, small mammals, turtles, and carrion. Because they are visual hunters, eagles typically locate their prey from a conspicuous perch, or soaring flight, then swoop down and strike. Wintering bald eagles often congregate in large numbers along streams to feed on spawning salmon or other fish species, and often gather in large numbers in areas below reservoirs, especially hydropower dams, where fish are abundant. Wintering eagles also take birds from rafts of ducks at reservoirs and rivers, and congregate on melting ice shelves to scavenge dead fish from the current or the soft melting ice. Bald eagles will also feed on carcasses along roads, in landfills, and at feedlots.

During the breeding season, adults carry prey to the nest to feed the young. Adults feed their chicks by tearing off pieces of food and holding them to the beaks of the eaglets. After fledging, immature eagles are slow to develop hunting skills, and must learn to locate reliable food sources and master feeding techniques. Young eagles will congregate together, often feeding upon easily acquired food such as carrion and fish found in abundance at the mouths of streams and shallow bays and at landfills.

The impact of human activity on nesting bald eagles

During the breeding season, bald eagles are sensitive to a variety of human activities. However, not all bald eagle pairs react to human activities in the same way. Some pairs nest successfully just dozens of yards from human activity, while others abandon nest sites in response to activities much farther away. This variability may be related to a number of factors, including visibility, duration, noise levels, extent of the area affected by the activity, prior experiences with humans, and tolerance of the individual nesting pair. The relative sensitivity of bald eagles during various stages of the breeding season is outlined in the following table.

Nesting Bald Eagle Sensitivity to Human Activities

Phase	Activity	Sensitivity to Human Activity	Comments
I	Courtship and Nest Building	Most sensitive period; likely to respond negatively	Most critical time period. Disturbance is manifested in nest abandonment. Bald eagles in newly established territories are more prone to abandon nest sites.
II	Egg laying	Very sensitive period	Human activity of even limited duration may cause nest desertion and abandonment of territory for the breeding season.
III	Incubation and early nestling period (up to 4 weeks)	Very sensitive period	Adults are less likely to abandon the nest near and after hatching. However, flushed adults leave eggs and young unattended; eggs are susceptible to cooling, loss of moisture, overheating, and predation; young are vulnerable to elements.
IV	Nestling period, 4 to 8 weeks	Moderately sensitive period	Likelihood of nest abandonment and vulnerability of the nestlings to elements somewhat decreases. However, nestlings may miss feedings, affecting their survival.
V	Nestlings 8 weeks through fledging	Very sensitive period	Gaining flight capability, nestlings 8 weeks and older may flush from the nest prematurely due to disruption and die.

If agitated by human activities, eagles may inadequately construct or repair their nest, may expend energy defending the nest rather than tending to their young, or may abandon the nest altogether. Activities that cause prolonged absences of adults from their nests can jeopardize eggs or young. Depending on weather conditions, eggs may overheat or cool too much and fail to hatch. Unattended eggs and nestlings are subject to predation. Young nestlings are particularly vulnerable because they rely on their parents to provide warmth or shade, without which they may die as a result of hypothermia or heat stress. If food delivery schedules are interrupted, the young may not develop healthy plumage, which can affect their survival. In addition, adults startled while incubating or brooding young may damage eggs or injure their young as they abruptly leave the nest. Older nestlings no longer require constant attention from the adults, but they may be startled by loud or intrusive human activities and prematurely jump from the nest before they are able to fly or care for themselves. Once fledged, juveniles range up to ¼ mile from the nest site, often to a site with minimal human activity. During this period, until about six weeks after departure from the nest, the juveniles still depend on the adults to feed them.

The impact of human activity on foraging and roosting bald eagles

Disruption, destruction, or obstruction of roosting and foraging areas can also negatively affect bald eagles. Disruptive activities in or near eagle foraging areas can interfere with feeding, reducing chances of survival. Interference with feeding can also result in reduced productivity (number of young successfully fledged). Migrating and wintering bald eagles often congregate at specific sites for purposes of feeding and sheltering. Bald eagles rely on established roost sites because of their proximity to sufficient food sources. Roost sites are usually in mature trees where the eagles are somewhat sheltered from the wind and weather. Human activities near or within communal roost sites may prevent eagles from feeding or taking shelter, especially if there are not other undisturbed and productive feeding and roosting sites available. Activities that permanently alter communal roost sites and important foraging areas can altogether eliminate the elements that are essential for feeding and sheltering eagles.

Where a human activity agitates or bothers roosting or foraging bald eagles to the degree that causes injury or substantially interferes with breeding, feeding, or sheltering behavior and causes, or is likely to cause, a loss of productivity or nest abandonment, the conduct of the activity constitutes a violation of the Eagle Act's prohibition against disturbing eagles. The circumstances that might result in such an outcome are difficult to predict without detailed site-specific information. If your activities may disturb roosting or foraging bald eagles, you should contact your local Fish and Wildlife Service Field Office (see page 16) for advice and recommendations for how to avoid such disturbance.

RECOMMENDATIONS FOR AVOIDING DISTURBANCE AT NEST SITES

In developing these Guidelines, we relied on existing state and regional bald eagle guidelines, scientific literature on bald eagle disturbance, and recommendations of state and Federal biologists who monitor the impacts of human activity on eagles. Despite these resources, uncertainties remain regarding the effects of many activities on eagles and how eagles in different situations may or may not respond to certain human activities. The Service recognizes this uncertainty and views the collection of better biological data on the response of eagles to disturbance as a high priority. To the extent that resources allow, the Service will continue to collect data on responses of bald eagles to human activities conducted according to the recommendations within these Guidelines to ensure that adequate protection from disturbance is being afforded, and to identify circumstances where the Guidelines might be modified. These data will be used to make future adjustments to the Guidelines.

To avoid disturbing nesting bald eagles, we recommend (1) keeping a distance between the activity and the nest (distance buffers), (2) maintaining preferably forested (or natural) areas between the activity and around nest trees (landscape buffers), and (3) avoiding certain activities during the breeding season. The buffer areas serve to minimize visual and auditory impacts associated with human activities near nest sites. Ideally, buffers would be large enough to protect existing nest trees and provide for alternative or replacement nest trees.

The size and shape of effective buffers vary depending on the topography and other ecological characteristics surrounding the nest site. In open areas where there are little or no forested or topographical buffers, such as in many western states, distance alone must serve as the buffer. Consequently, in open areas, the distance between the activity and the nest may need to be larger than the distances recommended under Categories A and B of these guidelines (pg. 12) if no landscape buffers are present. The height of the nest above the ground may also ameliorate effects of human activities; eagles at higher nests may be less prone to disturbance.

In addition to the physical features of the landscape and nest site, the appropriate size for the distance buffer may vary according to the historical tolerances of eagles to human activities in particular localities, and may also depend on the location of the nest in relation to feeding and roosting areas used by the eagles. Increased competition for nest sites may lead bald eagles to nest closer to human activity (and other eagles).

Seasonal restrictions can prevent the potential impacts of many shorter-term, obtrusive activities that do not entail landscape alterations (e.g. fireworks, outdoor concerts). In proximity to the nest, these kinds of activities should be conducted only outside the breeding season. For activities that entail both short-term, obtrusive characteristics and more permanent impacts (e.g., building construction), we recommend a combination of both approaches: retaining a landscape buffer *and* observing seasonal restrictions.

For assistance in determining the appropriate size and configuration of buffers or the timing of activities in the vicinity of a bald eagle nest, we encourage you to contact the nearest U.S. Fish and Wildlife Service Field Office (see page 16).

Existing Uses
Eagles are unlikely to be disturbed by routine use of roads, homes, and other facilities where such use pre-dates the eagles' successful nesting activity in a given area. Therefore, in most cases *ongoing* existing uses may proceed with the same intensity with little risk of disturbing bald eagles. However, some *intermittent, occasional, or irregular* uses that pre-date eagle nesting in an area may disturb bald eagles. For example: a pair of eagles may begin nesting in an area and subsequently be disturbed by activities associated with an annual outdoor flea market, even though the flea market has been held annually at the same location. In such situations, human activity should be adjusted or relocated to minimize potential impacts on the nesting pair.

ACTIVITY-SPECIFIC GUIDELINES

The following section provides the Service=s management recommendations for avoiding bald eagle disturbance as a result of new or intermittent activities proposed in the vicinity of bald eagle nests. Activities are separated into 8 categories (A – H) based on the nature and magnitude of impacts to bald eagles that usually result from the type of activity. Activities with similar or comparable impacts are grouped together.

In most cases, impacts will vary based on the visibility of the activity from the eagle nest and the degree to which similar activities are already occurring in proximity to the nest site. Visibility is a factor because, in general, eagles are more prone to disturbance when an activity occurs in full view. For this reason, we recommend that people locate activities farther from the nest structure in areas with open vistas, in contrast to areas where the view is shielded by rolling topography, trees, or other screening factors. The recommendations also take into account the existence of similar activities in the area because the continued presence of nesting bald eagles in the vicinity of the existing activities indicates that the eagles in that area can tolerate a greater degree of human activity than we can generally expect from eagles in areas that experience fewer human impacts. To illustrate how these factors affect the likelihood of disturbing eagles, we have incorporated the recommendations for some activities into a table (categories A and B).

First, determine which category your activity falls into (between categories A – H). If the activity you plan to undertake is not specifically addressed in these guidelines, follow the recommendations for the most similar activity represented.

If your activity is under A or B, our recommendations are in table form. The vertical axis shows the degree of visibility of the activity from the nest. The horizontal axis (header row) represents the degree to which similar activities are ongoing in the vicinity of the nest. Locate the row that best describes how visible your activity will be from the eagle nest. Then, choose the column that best describes the degree to which similar activities are ongoing in the vicinity of the eagle nest. The box where the column and row come together contains our management recommendations for how far you should locate your activity from the nest to avoid disturbing the eagles. The numerical distances shown in the tables are the closest the activity should be conducted relative to the nest. In some cases we have included additional recommendations (other than recommended *distance* from the nest) you should follow to help ensure that your activity will not disturb the eagles.

Alternate nests
For activities that entail permanent landscape alterations that may result in bald eagle disturbance, these recommendations apply to both active and alternate bald eagle nests. Disturbance becomes an issue with regard to alternate nests if eagles return for breeding purposes and react to land use changes that occurred while the nest was inactive. The likelihood that an alternate nest will again become active decreases the longer it goes unused. If you plan activities in the vicinity of an alternate bald eagle nest and have information to show that the nest has not been active during the preceding 5 breeding seasons, the recommendations provided in these guidelines for avoiding disturbance around the nest site may no longer be warranted. The nest itself remains protected by other provisions of the Eagle Act, however, and may not be destroyed.

If special circumstances exist that make it unlikely an inactive nest will be reused before 5 years of disuse have passed, and you believe that the probability of reuse is low enough to warrant disregarding the recommendations for avoiding disturbance, you should be prepared to provide all the reasons for your conclusion, including information regarding past use of the nest site. Without sufficient documentation, you should continue to follow these guidelines when conducting activities around the nest site. If we are able to determine that it is unlikely the nest will be reused, we may advise you that the recommendations provided in these guidelines for avoiding disturbance are no longer necessary around that nest site.

This guidance is intended to minimize disturbance, as defined by Federal regulation. In addition to Federal laws, most states and some tribes and smaller jurisdictions have additional laws and regulations protecting bald eagles. In some cases those laws and regulations may be more protective (restrictive) than these Federal guidelines.

Temporary Impacts
For activities that have temporary impacts, such as the use of loud machinery, fireworks displays, or summer boating activities, we recommend seasonal restrictions. These types of activities can generally be carried out outside of the breeding season without causing disturbance. The recommended restrictions for these types of activities can be lifted for alternate nests within a particular territory, including nests that were attended during the current breeding season but not used to raise young, after eggs laid in another nest within the territory have hatched (depending on the distance between the alternate nest and the active nest).

In general, activities should be kept as far away from nest trees as possible; loud and disruptive activities should be conducted when eagles are not nesting; and activity between the nest and the nearest foraging area should be minimized. If the activity you plan to undertake is not specifically addressed in these guidelines, follow the recommendations for the most similar activity addressed, or contact your local U.S. Fish and Wildlife Service Field Office for additional guidance.

If you believe that special circumstances apply to your situation that increase or diminish the likelihood of bald eagle disturbance, or if it is not possible to adhere to the guidelines, you should contact your local Service Field Office for further guidance.

Category A:
Building construction, 1 or 2 story, with project footprint of ½ acre or less.
Construction of roads, trails, canals, power lines, and other linear utilities.
Agriculture and aquaculture – new or expanded operations.
Alteration of shorelines or wetlands.
Installation of docks or moorings.
Water impoundment.

Category B:
Building construction, 3 or more stories.
Building construction, 1 or 2 story, with project footprint of more than ½ acre.
Installation or expansion of marinas with a capacity of 6 or more boats.
Mining and associated activities.
Oil and natural gas drilling and refining and associated activities.

	If there is no similar activity within 1 mile of the nest	***If there is similar activity closer than 1 mile from the nest***
If the activity will be visible from the nest	660 feet. Landscape buffers are recommended.	660 feet, or as close as existing tolerated activity of similar scope. Landscape buffers are recommended.
If the activity will not be visible from the nest	Category A: 330 feet. Clearing, external construction, and landscaping between 330 feet and 660 feet should be done outside breeding season. Category B: 660 feet.	330 feet, or as close as existing tolerated activity of similar scope. Clearing, external construction and landscaping within 660 feet should be done outside breeding season.

The numerical distances shown in the table are the closest the activity should be conducted relative to the nest.

Category C. Timber Operations and Forestry Practices

- Avoid clear cutting or removal of overstory trees within 330 feet of the nest at any time.

- Avoid timber harvesting operations, including road construction and chain saw and yarding operations, during the breeding season within 660 feet of the nest. The distance may be decreased to 330 feet around alternate nests within a particular territory, including nests that were attended during the current breeding season but not used to raise young, after eggs laid in another nest within the territory have hatched.

- Selective thinning and other silviculture management practices designed to conserve or enhance habitat, including prescribed burning close to the nest tree, should be undertaken outside the breeding season. Precautions such as raking leaves and woody debris from around the nest tree should be taken to prevent crown fire or fire climbing the nest tree. If it is determined that a burn during the breeding season would be beneficial, then, to ensure that no take or disturbance will occur, these activities should be conducted only when neither adult eagles nor young are present at the nest tree (i.e., at the beginning of, or end of, the breeding season, either before the particular nest is active or after the young have fledged from that nest). Appropriate Federal and state biologists should be consulted before any prescribed burning is conducted during the breeding season.

- Avoid construction of log transfer facilities and in-water log storage areas within 330 feet of the nest.

Category D. Off-road vehicle use (including snowmobiles). No buffer is necessary around nest sites outside the breeding season. During the breeding season, do not operate off-road vehicles within 330 feet of the nest. In open areas, where there is increased visibility and exposure to noise, this distance should be extended to 660 feet.

Category E. Motorized Watercraft use (including jet skis/personal watercraft). No buffer is necessary around nest sites outside the breeding season. During the breeding season, within 330 feet of the nest, (1) do not operate jet skis (personal watercraft), and (2) avoid concentrations of noisy vessels (e.g., commercial fishing boats and tour boats), except where eagles have demonstrated tolerance for such activity. Other motorized boat traffic passing within 330 feet of the nest should attempt to minimize trips and avoid stopping in the area where feasible, particularly where eagles are unaccustomed to boat traffic. Buffers for airboats should be larger than 330 feet due to the increased noise they generate, combined with their speed, maneuverability, and visibility.

Category F. Non-motorized recreation and human entry (e.g., hiking, camping, fishing, hunting, birdwatching, kayaking, canoeing). No buffer is necessary around nest sites outside the breeding season. If the activity will be visible or highly audible from the nest, maintain a 330-foot buffer during the breeding season, particularly where eagles are unaccustomed to such activity.

Category G. Helicopters and fixed-wing aircraft.
Except for authorized biologists trained in survey techniques, avoid operating aircraft within 1,000 feet of the nest during the breeding season, except where eagles have demonstrated tolerance for such activity.

Category H. Blasting and other loud, intermittent noises.
Avoid blasting and other activities that produce extremely loud noises within 1/2 mile of active nests, unless greater tolerance to the activity (or similar activity) has been demonstrated by the eagles in the nesting area. This recommendation applies to the use of fireworks classified by the Federal Department of Transportation as Class B explosives, which includes the larger fireworks that are intended for licensed public display.

RECOMMENDATIONS FOR AVOIDING DISTURBANCE AT FORAGING AREAS AND COMMUNAL ROOST SITES

1. Minimize potentially disruptive activities and development in the eagles' direct flight path between their nest and roost sites and important foraging areas.

2. Locate long-term and permanent water-dependent facilities, such as boat ramps and marinas, away from important eagle foraging areas.

3. Avoid recreational and commercial boating and fishing near critical eagle foraging areas during peak feeding times (usually early to mid-morning and late afternoon), except where eagles have demonstrated tolerance to such activity.

4. Do not use explosives within ½ mile (or within 1 mile in open areas) of communal roosts when eagles are congregating, without prior coordination with the U.S. Fish and Wildlife Service and your state wildlife agency.

5. Locate aircraft corridors no closer than 1,000 feet vertical or horizontal distance from communal roost sites.

ADDITIONAL RECOMMENDATIONS TO BENEFIT BALD EAGLES

The following are additional management practices that landowners and planners can exercise for added benefit to bald eagles.

1. Protect and preserve potential roost and nest sites by retaining mature trees and old growth stands, particularly within ½ mile from water.

2. Where nests are blown from trees during storms or are otherwise destroyed by the elements, continue to protect the site in the absence of the nest for up to three (3) complete breeding seasons. Many eagles will rebuild the nest and reoccupy the site.

3. To avoid collisions, site wind turbines, communication towers, and high voltage transmission power lines away from nests, foraging areas, and communal roost sites.

4. Employ industry-accepted best management practices to prevent birds from colliding with or being electrocuted by utility lines, towers, and poles. If possible, bury utility lines in important eagle areas.

5. Where bald eagles are likely to nest in human-made structures (e.g., cell phone towers) and such use could impede operation or maintenance of the structures or jeopardize the safety of the eagles, equip the structures with either (1) devices engineered to discourage bald eagles from building nests, or (2) nesting platforms that will safely accommodate bald eagle nests without interfering with structure performance.

6. Immediately cover carcasses of euthanized animals at landfills to protect eagles from being poisoned.

7. Do not intentionally feed bald eagles. Artificially feeding bald eagles can disrupt their essential behavioral patterns and put them at increased risk from power lines, collision with windows and cars, and other mortality factors.

8. Use pesticides, herbicides, fertilizers, and other chemicals only in accordance with Federal and state laws.

9. Monitor and minimize dispersal of contaminants associated with hazardous waste sites (legal or illegal), permitted releases, and runoff from agricultural areas, especially within watersheds where eagles have shown poor reproduction or where bioaccumulating contaminants have been documented. These factors present a risk of contamination to eagles and their food sources.

CONTACTS

The following U.S. Fish and Wildlife Service Field Offices provide technical assistance on bald eagle management:

Alabama	Daphne	(251) 441-5181
Alaska	Anchorage	(907) 271-2888
	Fairbanks	(907) 456-0203
	Juneau	(907) 780-1160
Arizona	Phoenix	(602) 242-0210
Arkansas	Conway	(501) 513-4470
California	Arcata	(707) 822-7201
	Barstow	(760) 255-8852
	Carlsbad	(760) 431-9440
	Red Bluff	(530) 527-3043
	Sacramento	(916) 414-6000
	Stockton	(209) 946-6400
	Ventura	(805) 644-1766
	Yreka	(530) 842-5763
Colorado	Lakewood	(303) 275-2370
	Grand Junction	(970) 243-2778
Connecticut	(See New Hampshire)	
Delaware	(See Maryland)	
Florida	Panama City	(850) 769-0552
	Vero Beach	(772) 562-3909
	Jacksonville	(904) 232-2580
Georgia	Athens	(706) 613-9493
	Brunswick	(912) 265-9336
	Columbus	(706) 544-6428
Idaho	Boise	(208) 378-5243
	Chubbuck	(208) 237-6975
Illinois/Iowa	Rock Island	(309) 757-5800
Indiana	Bloomington	(812) 334-4261
Kansas	Manhattan	(785) 539-3474
Kentucky	Frankfort	(502) 695-0468
Louisiana	Lafayette	(337) 291-3100
Maine	Old Town	(207) 827-5938
Maryland	Annapolis	(410) 573-4573
Massachusetts	(See New Hampshire)	
Michigan	East Lansing	(517) 351-2555
Minnesota	Bloomington	(612) 725-3548
Mississippi	Jackson	(601) 965-4900
Missouri	Columbia	(573) 234-2132
Montana	Helena	(405) 449-5225
Nebraska	Grand Island	(308) 382-6468
Nevada	Las Vegas	(702) 515-5230
	Reno	(775) 861-6300
New Hampshire	Concord	(603) 223-2541
New Jersey	Pleasantville	(609) 646-9310
New Mexico	Albuquerque	(505) 346-2525
New York	Cortland	(607) 753-9334
	Long Island	(631) 776-1401
North Carolina	Raleigh	(919) 856-4520
	Asheville	(828) 258-3939
North Dakota	Bismarck	(701) 250-4481
Ohio	Reynoldsburg	(614) 469-6923
Oklahoma	Tulsa	(918) 581-7458
Oregon	Bend	(541) 383-7146
	Klamath Falls	(541) 885-8481
	La Grande	(541) 962-8584
	Newport	(541) 867-4558
	Portland	(503) 231-6179
	Roseburg	(541) 957-3474
Pennsylvania	State College	(814) 234-4090
Rhode Island	(See New Hampshire)	
South Carolina	Charleston	(843) 727-4707
South Dakota	Pierre	(605) 224-8693
Tennessee	Cookeville	(931) 528-6481
Texas	Clear Lake	(281) 286-8282
Utah	West Valley City	(801) 975-3330
Vermont	(See New Hampshire)	
Virginia	Gloucester	(804) 693-6694
Washington	Lacey	(306) 753-9440
	Spokane	(509) 891-6839
	Wenatchee	(509) 665-3508
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GLOSSARY

The definitions below apply to these National Bald Eagle Management Guidelines:

Communal roost sites – Areas where bald eagles gather and perch overnight – and sometimes during the day in the event of inclement weather. Communal roost sites are usually in large trees (live or dead) that are relatively sheltered from wind and are generally in close proximity to foraging areas. These roosts may also serve a social purpose for pair bond formation and communication among eagles. Many roost sites are used year after year.

Disturb – To agitate or bother a bald or golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available, 1) injury to an eagle, 2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior, or 3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior.

In addition to immediate impacts, this definition also covers impacts that result from human-caused alterations initiated around a previously used nest site during a time when eagles are not present, if, upon the eagle=s return, such alterations agitate or bother an eagle to a degree that injures an eagle or substantially interferes with normal breeding, feeding, or sheltering habits and causes, or is likely to cause, a loss of productivity or nest abandonment.

Fledge – To leave the nest and begin flying. For bald eagles, this normally occurs at 10-12 weeks of age.

Fledgling – A juvenile bald eagle that has taken the first flight from the nest but is not yet independent.

Foraging area – An area where eagles feed, typically near open water such as rivers, lakes, reservoirs, and bays where fish and waterfowl are abundant, or in areas with little or no water (i.e., rangelands, barren land, tundra, suburban areas, etc.) where other prey species (e.g., rabbit, rodents) or carrion (such as at landfills) are abundant.

Landscape buffer – A natural or human-made landscape feature that screens eagles from human activity (e.g., strip of trees, hill, cliff, berm, sound wall).

Nest – A structure built, maintained, or used by bald eagles for the purpose of reproduction. An **active** nest is a nest that is attended (built, maintained or used) by a pair of bald eagles during a given breeding season, whether or not eggs are laid. An **alternate** nest is a nest that is not used for breeding by eagles during a given breeding season.

Nest abandonment – Nest abandonment occurs when adult eagles desert or stop attending a nest and do not subsequently return and successfully raise young in that nest for the duration of a breeding season. Nest abandonment can be caused by altering habitat near a nest, even if the alteration occurs prior to the breeding season. Whether the eagles migrate during the non-breeding season, or remain in the area throughout the non-breeding season, nest abandonment can occur at any point between the time the eagles return to the nesting site for the breeding season and the time when all progeny from the breeding season have dispersed.

Project footprint – The area of land (and water) that will be permanently altered for a development project, including access roads.

Similar scope – In the vicinity of a bald eagle nest, an existing activity is of similar scope to a new activity where the types of impacts to bald eagles are similar in nature, and the impacts of the existing activity are of the same or greater magnitude than the impacts of the potential new activity. Examples: (1) An existing single-story home 200 feet from a nest is similar in scope to an additional single-story home 200 feet from the nest; (2) An existing multi-story, multi-family dwelling 150 feet from a nest has impacts of a greater magnitude than a potential new single-family home 200 feet from the nest; (3) One existing single-family home 200 feet from the nest has impacts of a lesser magnitude than three single-family homes 200 feet from the nest; (4) an existing single-family home 200 feet from a communal roost has impacts of a lesser magnitude than a single-family home 300 feet from the roost but 40 feet from the eagles' foraging area. The existing activities in examples (1) and (2) are of similar scope, while the existing activities in example (3) and (4) are not.

Vegetative buffer – An area surrounding a bald eagle nest that is wholly or largely covered by forest, vegetation, or other natural ecological characteristics, and separates the nest from human activities.

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Colonial Nesting Bird Avoidance Measures

Colonial Nesting Bird Avoidance Measures

The following guidelines were developed in coordination with Louisiana Department of Wildlife and Fisheries and US Fish and Wildlife Service.

For colonies containing nesting wading birds (i.e., herons, egrets, night-herons, ibis, roseate spoonbills, anhingas, and/or cormorants), all project activity occurring within 300 meters (984 ft) of an active nesting colony should be restricted to the non-nesting period (i.e., September 1 through February 15).

For colonies containing nesting gulls, terns, and/or black skimmers, all project activity occurring within 400 meters (1,312 ft) [700 meters (2,296 ft) for brown pelicans] of an active nesting colony should be restricted to the non-nesting period (i.e., September 16 through April 1).

The following table is an excerpt from page 31 of:

Martin, R.P., and G.D. Lester. 1990. The Atlas and Census of Wading Bird and Seabird Nesting Colonies of Louisiana: 1990. Louisiana Department of Wildlife and Fisheries – Louisiana Natural Heritage Program. Special Publication No. 3 for the U.S. Department of Interior – Fish and Wildlife Service.

Table 8. Nesting chronology for colonial-nesting waterbirds in Louisiana with suggested activity windows.[a]

Species	Incubation Season	Incubation Period (days)	Days to Fledging	Activity[b] Window
Brown Pelican	1 Nov to 15 Jun	28-30	74-76	1 Aug to 31 Oct
Olivaceous Cormorant	15 Mar to 15 Apr	23-26	35-42	1 Jul to 1 Mar
American Anhinga	15 Mar to 15 Apr	25-28	?	1 Jul to 1 Mar
Great Blue Heron	1 Mar to 30 Apr	25-29	58-62	1 Aug to 15 Feb
Great Egret	1 Mar to 31 May	23-24	40-44	1 Aug to 15 Feb
Snowy Egret	16 Mar to 15 Jun	17-19	20-25	1 Aug to 1 Mar
Little Blue Heron	16 Mar to 15 Jun	22-24	28-32	1 Aug to 1 Mar
Tricolored Heron	16 Mar to 15 Jun	20-22	?	1 Aug to 1 Mar
Reddish Egret	16 Mar to 15 Jun	23-26	?	1 Aug to 1 Mar
Cattle Egret	16 Apr to 30 Jun	21-24	35-40	1 Sep to 1 Apr
Green-backed Heron	1 Apr to 30 Jun	19-21	16-17	1 Sep to 15 Mar
Black-crowned Night-Heron	16 Mar to 15 Jun	24-26	40-42	1 Sep to 1 Mar
Yellow-crowned Night-Heron	1 Apr to 15 Jun	?	?	1 Sep to 15 Mar
White Ibis	16 Apr to 30 Jun	21-23	35-42	1 Sep to 1 Apr
Glossy/White-faced Ibis	16 Apr to 30 Jun	21-23	42-49	1 Sep to 1 Apr
Roseate Spoonbill	16 Apr to 15 Jun	23-24	49-56	1 Aug to 1 Apr
Laughing Gull	16 Apr to 15 Jun	23-25	35-45	1 Aug to 1 Apr
Gull-billed Tern	16 May to 15 Jul	22-23	28-35	16 Sep to 1 May
Caspian Tern	1 May to 15 Jul	26-28	36-48	16 Sep to 15 Apr
Royal Tern	1 May to 15 Jul	28-31	36-48	16 Sep to 15 Apr
Sandwich Tern	1 May to 15 Jul	23-25	22-33	16 Sep to 15 Apr
Common Tern	1 May to 15 Jul	21-25	23-27	16 Sep to 15 Apr
Forster's Tern	1 Apr to 31 May	25-29	23-27	1 Aug to 15 Mar
Least Tern	1 May to 15 Jul	20-25	19-23	16 Sep to 15 Apr
Sooty Tern	16 May to 15 Jul	22-23	30-35	16 Sep to 15 Apr
Black Skimmer	16 May to 15 Jul	22-23	30-35	16 Sep to 1 May

[a] Data are compiled from Bent (1921), Bent (1926), Palmer (1962), Harrison (1975), Portnoy (1977) and Terres (1980).

[b] Suggested project initiation and completion dates to minimize disturbance to nesting birds.

Evaluation of Potential Impacts of Diversion on Gulf and Pallid Sturgeon

ERDC/EL TR-08-19

Environmental Laboratory

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Evaluation of Potential Impacts of the Lake Maurepas Diversion Project to Gulf and Pallid Sturgeon

James P. Kirk, K. Jack Killgore, and Jan J. Hoover

June 2008

ERDC/EL TR-08-19
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Evaluation of Potential Impacts of the Lake Maurepas Diversion Project to Gulf and Pallid Sturgeon

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Final report

Prepared for U.S. Environmental Protection Agency, Region 6
Dallas, TX 75202

and U.S. Army Engineer Division, Mississippi Valley
Vicksburg, MS 39181-0080

Abstract: The impacts to Gulf and pallid sturgeon from a proposed Mississippi River water diversion into the swamps bordering Lake Maurepas were evaluated. Gulf sturgeon were unlikely to be affected by the diversion due to characteristics of their life history. Adult and subadult pallid sturgeon were relatively abundant in the proposed project area and could be affected by the proposed diversion. A risk assessment was performed. Juvenile pallid sturgeon were judged to have a "low" entrainment risk due to low likelihood of their occurrence in the project area. Risk of entrainment by adults and subadults was judged "medium" due to their relatively low burst swimming speeds compared to intake velocities. Management recommendations were made to reduce or mitigate chance of their entrainment.

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Figures and Tables

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Preface

The work described in this report was funded by the U.S. Environmental Protection Agency (EPA) and the U.S. Army Engineer Division, Mississippi Valley.

This report was prepared by Dr. James P. Kirk, Dr. Jan J. Hoover, and Dr. K. Jack Killgore, Aquatic Ecology and Invasive Species Branch (AEISB), Ecosystem Evaluation and Engineering Division (EEED), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC). Peer review was provided by Kenneth Teague of the EPA and David Walther of the U.S. Fish and Wildlife Service.

Bradley Lewis, Jay Collins, William Lancaster, Steven George, and Catherine Murphy of AEISB participated in field collections as did R. Timothy Ruth of the Louisiana Department of Wildlife and Fisheries (LDWF). The LDWF provided expedited permitting, telemetry-tagged Gulf sturgeon, and field sampling assistance.

ERDC supervision was provided by Dr. Timothy E. Lewis, Chief, AEISB; Dr. David J. Tazik, Chief, EEED; and Dr. Elizabeth C. Fleming, Director, EL.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Over the past century, flood control in the Mississippi River has reduced freshwater, nutrients, and sediment inputs that maintained swamps bordering Lake Maurepas, Louisiana. A 1,500 to 2,000 cubic feet per second (cfs) diversion from the Mississippi River is proposed to reverse habitat deterioration and improve overall water quality. The diversion from the Mississippi River would use two box culverts at a point near the Hope Canal, near River Mile (RM) 144 (see Figures 1 and 2). The major benefits of this water diversion would be:

1. Increase accretion in the swamps, thus offsetting subsidence, and ameliorate salt stress to cypress-tupelo swamps along the lake's boundaries and
2. Reverse the trend of swamp conversion to open water or marsh.

Before this project can proceed, however, evaluation must be made of its potential impacts on the endangered pallid sturgeon (*Scaphirhynchus albus*) and the threatened Gulf of Mexico (Gulf) sturgeon (*Acipenser oxyrinchus desotoi*), both of which are thought to occur in the project area.

Figure 1. Location of the study area within the State of Louisiana.

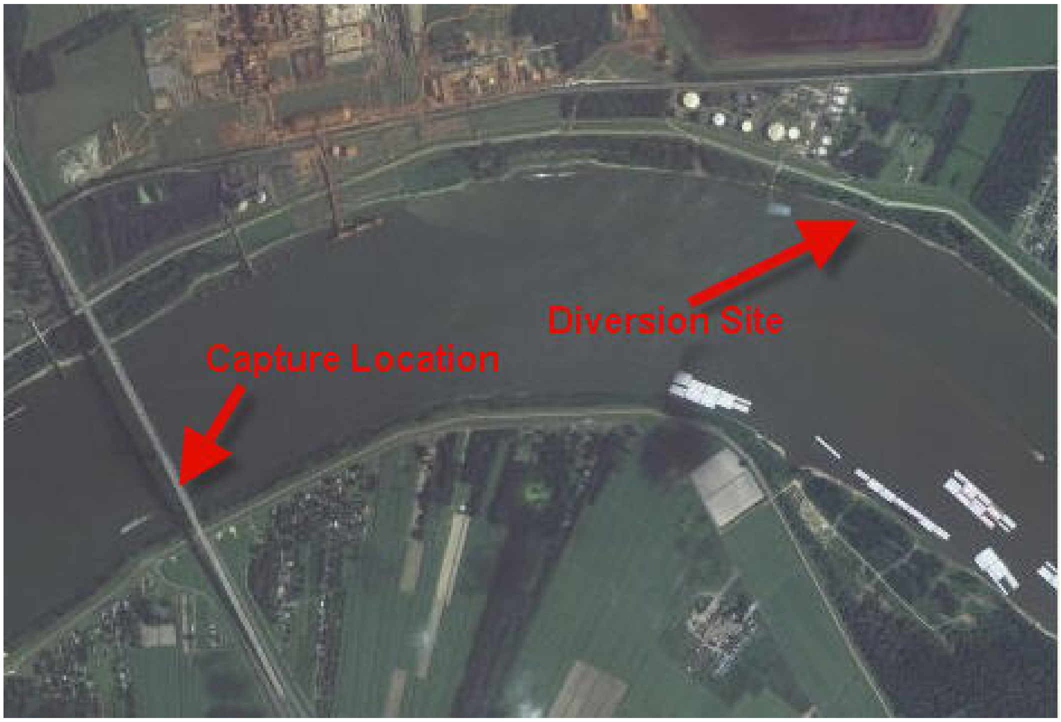

Figure 2. Approximate location of the proposed diversion site and the location where pallid sturgeon were captured.

Gulf sturgeon are diadromous (using both salt and freshwater habitats) and mature between ages 7 to 12 at a fork length (FL) of 1.2 to 1.4 m (Huff 1975). Ranging from Tampa Bay to the Mississippi River (Grunchy and Parker 1980), this fish was listed as threatened in 1991 (USFWS 1991). Exploitation, blockage of migration routes, and declining water quality are thought to be responsible for species decline (Wooley and Crateau 1985; Barkuloo 1988; USFWS and GSMFC 1995). Gulf sturgeon generally spend November through March in saltwater and the rest of the year in freshwater rivers (Wooley and Crateau 1985; Odenkirk 1989; Carr et al. 1996; Foster and Clugston 1997; Fox et al. 2000; Rogillio et al. 2001, 2007; Heise et al. 2004). Gulf sturgeon have been collected in tributary rivers (e.g., the Amite River) flowing into Lake Maurepas. Gulf sturgeon from the Pearl River system in Louisiana-Mississippi may also use Lake Maurepas, and this nearby system has been extensively studied (Davis et al. 1970; Rogillio 1992; Morrow et al. 1996, 1998, 1999; Rogillio et al. 2001, 2007).

The pallid sturgeon was listed as an endangered species in 1990 and occurs in the large rivers in the Mississippi River Basin (Lee et al. 1980; Killgore et al. 2007). The decline of this species is attributed to flood control and navigation projects, pollution, and overexploitation for caviar (Dryer and Sandoval 1993). Populations in the lower Mississippi River are probably stable, but long-term studies are required to fully evaluate population trends and habitat preferences (Killgore et al. 2007). In that regard, the U.S. Army Engineer Research and Development Center (ERDC) is conducting a multi-year study on population status and habitat requirements of pallid sturgeon in the middle and lower Mississippi River. Prior to this study, pallid sturgeon have been documented in the Mississippi River as far south as Donaldsonville, LA, but likely occur below New Orleans albeit at relatively low numbers.

In this study, researchers assessed impacts to Gulf and pallid sturgeon of diverting water from the Mississippi River into swamps around Lake Maurepas. Field studies were conducted with the following objectives:

1. Document habitat characteristics in the proposed diversion site and compare these characteristics to known pallid sturgeon habitat use patterns,
2. Determine relative abundance of both species,
3. Evaluate the impacts to Gulf sturgeon that may periodically be utilizing Lake Maurepas, and
4. Perform a risk assessment of pallid sturgeon entrainment at the proposed water diversion site.

2 Methods

Gulf sturgeon in Lake Maurepas were sampled during November 2005 through June 2006 using 27.4-m experimental monofilament gill nets with stretch mesh panels varying from 102 to 229 mm and 3.1-m otter trawls. Concurrently, mobile sonic telemetry along a systematic grid was used to locate any of approximately 40 Gulf sturgeon telemetry-tagged in the Pearl River system by the Louisiana Department of Wildlife and Fisheries (LDWF) and the ERDC during 2001 through 2006. While sampling, habitat data were collected to describe micro- and macro-habitats. At each sampling site the following water quality parameters were measured: temperature, specific conductance, pH, dissolved oxygen, and turbidity. Likewise, Global Positioning System (GPS) coordinates, distance to shore, depth, bottom slope, water velocities, and substrate were measured.

Pallid sturgeon in the Mississippi River near the proposed diversion site were sampled with trawls and trotlines. Age-0 and juvenile pallid sturgeon were sampled during August 2005 and monthly from April through June 2006 using 3.1- and 4.9-m otter trawls. Replicate trawls approximately 0.6 km in length were made near the diversion site (when river currents were not too high) and at nearby sandbars because age-0 and juvenile sturgeon have been captured at other sandbars in ongoing studies. Habitat data comparable to those described for Gulf sturgeon were recorded at each sampling location.

Abundance was measured in cooler months (December 2005 through April 2006) using trotlines. Once a month, eight trotlines with 60 hooks per line were fished overnight at a variety of sites near the proposed diversion site using night crawlers or crayfish for bait. Sites included: sandy bars above and below the diversion site, in the main channel at the bridge at Gramercy, LA, and near a petroleum loading dock close to the proposed diversion site (Figure 2). Because shovelnose *Scaphirhynchus platorynchus* were also likely to be captured, morphological and meristic data were obtained to separate pallid from shovelnose sturgeon (Murphy et al. 2007). As with trawling sites, water quality and habitat data were collected.

A generic risk assessment for pallid sturgeon entrainment at the diversion site is presented next based on site-specific observations, construction plans, and data from previous studies. Information relevant to entrainment risk of pallid sturgeon is summarized in a format that documents the assessment process. This approach allows re-assessment of risk whenever new information is obtained (e.g., additional data on pallid sturgeon demographics, revised specifications for structure, and studies of pallid sturgeon behavior).

Protocol includes assessment of the probability of pallid sturgeon entrainment adapted from methodology used to assess probability of non-native fish establishment (Courtenay and Williams 2004; Nico et al. 2005). Elements representing a temporal sequence in the movement of the organism are identified, evaluated, and rated to determine overall risk within the pathway (ANSTF 1996). For pallid sturgeon entrainment, elements (Figure 3) are defined below.

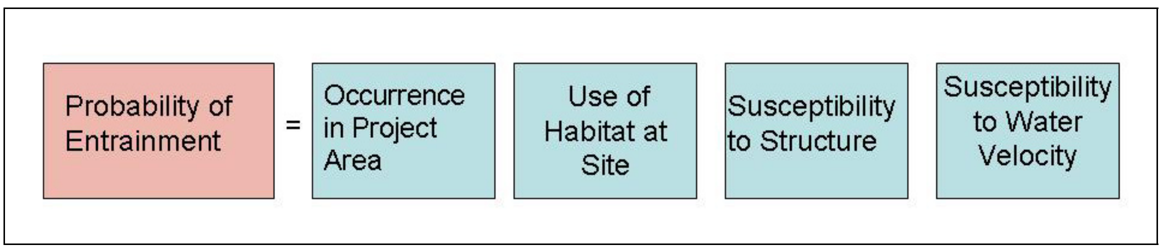

Figure 3. Elements for pallid sturgeon entrainment.

“Occurrence within the project area” is evaluated based on a single characteristic: distribution of the fish within the reach where construction and operation of the project will take place. “Use of habitat at site” is also evaluated on a single characteristic: occurrence of the fish at the location where the structure will be placed and/or in habitat similar to that in which the structure will be constructed. “Susceptibility to structure” is based on multiple characteristics of the completed structure: its suitability as a unique habitat for pallid sturgeon and the creation of flows at the same position in the water column as those occupied by the fish. “Susceptibility to water velocity” is based on swimming performance of the fish in water velocities created by diverted water considering rheotaxis (movement in response to the flow of a current), swim speeds, and station-holding behaviors. Because swimming performance of smaller sturgeon is substantially lower than that of larger sturgeon (Peake et al. 1997), juvenile fish are evaluated separately from subadult and adult fish.

Elements are rated qualitatively on a 3-point scale for risk: low, medium, or high. Probability of entrainment is assigned the value of the element with the lowest risk rating. This estimate of risk is considered conservative since each of the elements must take place for entrainment to occur and since a combined series of probabilities results in a cumulative probability that is in reality lower than any probability of a single event (ANSTF 1996). For each element, ratings of risk were evaluated on a 5-point scale for uncertainty: very certain, reasonably certain, moderately certain, reasonably uncertain, and very uncertain. These evaluations identify elements for which more information is required for greater accuracy in risk assessment. Probability of entrainment was assigned the value with the highest degree of uncertainty as a conservative measure of confidence in the overall risk of entrainment.

3 Results

No Gulf sturgeon were detected (via telemetry) nor captured using trawls or experimental gill nets in Lake Maurepas. Likewise, extensive trawling captured no age-0 or juvenile pallid sturgeon at any location in the Mississippi River near the proposed water diversion site. A total of 10 pallid and 24 shovelnose sturgeon were captured using trotlines from early December of 2005 through April 2006 (see Table 1). These fish were captured at a single location: at the edge of the main channel of the Mississippi River at the Gramercy Bridge (see Figure 2). No pallid or shovelnose sturgeon were captured using similarly set trotlines near the proposed diversion site or from sand bars above and below the diversion site.

The catch per unit effort (CPUE) and pallid to shovelnose sturgeon ratio were compared with previous data for this section of the Mississippi River (Killgore et al. 2007). The established CPUE of pallid sturgeon in the Mississippi River at RM 154 to 507 was 0.31 per trotline, and the pallid to shovelnose ratio was 1:6. Based upon trotlines, the pallid sturgeon CPUE was 0.28 per trotline and not different from the value reported by Killgore et al. (2007). The ratio of pallid to shovelnose sturgeon was 1:2.4.

The habitat near the bridge was at the edge of the main channel in depths of 17.5 to 22.6 m—current velocities ranged from 0.3 to 1.3 m/sec and water temperatures ranged from of 8.2 to 16.6 °C. The sloping bottom was predominately sand with some gravel. The habitat near the proposed diversion site was deep (approximately 10 to 25 m), not in the main channel, and had a bottom comprised of sand and mud.

Table 1. Pallid and shovelnose sturgeon captures in main channel of Mississippi River near Gramercy Bridge, LA, during 2005 and 2006.

Date	Species	Total length, mm	Depth, m	Water Temperature, °C
1 Dec 05	shovelnose	600	17.5	13.6
		621		
	pallid	788		
25 Jan 06	shovelnose	535	22.7	8.4
		514		
		479		
		543		
		563		
	pallid	831		
		823		
		860		
		735		
2 Mar 06	shovelnose	623	20.6	8.2
		600		
		700		
		523		
		547		
		589		
		450		
		430		
		552		
		683		
		593		
		565		
		597		
		561		
		542		
		470		
	pallid	773		
		623		
		709		
13 April 06	shovelnose	545	15.3	16.6
	pallid	762		
		713		

4 Discussion

A risk assessment for entrainment of Gulf sturgeon was not performed, since this species is unlikely to be in this reach of the Mississippi River and thus unlikely to be entrained (Douglas 1974; Ross 2001). Instead, temperature and salinity impacts caused by diverting water from the Mississippi River were evaluated for the Gulf sturgeon in and near Lake Maurepas.

No Gulf sturgeon were captured nor detected using telemetry in Lake Maurepas. However, Gulf sturgeon are likely to use or move through Lake Maurepas from tributary rivers on their annual migration to and from marine habitats (where they feed). In that regard, a review of the literature of Gulf sturgeon movements in Mississippi, Alabama, and Florida is instructive in understanding when Gulf sturgeon are likely to use Lake Maurepas and thus be influenced by project impacts (i.e., decreasing salinity and lower water temperatures).

Movements of Gulf sturgeon out of the Suwannee River in Florida were reported for October to November by Carr et al. (1996) and mid-September through November by Foster and Clugston (1997). Movements out of the Pascagoula River system were reported to be during mid-October through late November (Heise et al. 2004).

Gulf sturgeon in the nearby Pearl River system used winter habitat in the Mississippi Sound between November and March. Starting in April, fish were located at the Rigolets Pass and mouth of the Pearl River. Movements into the Bogue Chitto and Pearl rivers began in April (Rogillio et al. 2007). In the Suwannee River, Gulf sturgeon return ranged from late February through May (Carr et al. 1996; Foster and Clugston 1997) at temperatures of approximately 22 °C. Similar chronologies were found in the Apalachicola River. Wooley and Crateau (1985) found fish moved back into the river during April and May, and Odenkirk (1989) tracked return movements during March and April. Gulf sturgeon returned to the Choctawhatchee River system during March through May (Fox et al. 2000).

Thus, although some Gulf sturgeon may reside in Lake Maurepas – as they are known to do in Lake Pontchartrain – their use of the lake is likely to be during October or November and again during their return from marine habitats in the Mississippi Sound during February through April. Since these fish are moving into or out of saline habitats and are not feeding, changes in temperature or salinity caused by the diversion of water from the Mississippi River seem unlikely to adversely impact their populations.

A risk assessment of pallid sturgeon potentially entrained by all proposed diversion sites from the Mississippi River into the brackish waters in nearby Lake Maurepas was performed. While no direct literature on salt water tolerance of pallid sturgeon was located, it was deemed that diversion from fresh to brackish water could be lethal. Further, if the salinity levels were not lethal, the entrained pallid sturgeon would still be a loss to the Mississippi River population.

Pallid sturgeon probability of entrainment

Entrainment risk was "low" for juveniles due to low likelihood of occurrence in the project area, and "medium" for subadults and adults due to presumed lower limits on swimming capabilities of some individual fish (Table 2). Pallid sturgeon occur throughout the Mississippi River, including reaches above and below the sites of all proposed diversions (Killgore et al. 2007) and thus entrainment risks apply equally to all sites including the one near the Hope Canal. Subadult and adult pallid sturgeon are relatively abundant in the project area (see Table 1), but no small sturgeon (< 623 mm FL) were collected. The occurrence of subadults and adults within the project area can be accepted as "very certain," but the apparent absence of juveniles is less certain. Juvenile pallid sturgeon are rarely collected, even during spatially and temporally extensive surveys of naturally reproducing populations. Low numbers of juveniles is presumably due to specialized habitat requirements and very rapid growth of young fish. Spawning habitat of pallid sturgeon (i.e., gravel beds in swift water) was not apparent in the project area, and it is possible that juveniles do not occur in the area because spawning is taking place elsewhere. Surveys for potential spawning habitat and additional sampling using gear with higher selectivity for juvenile sturgeon (e.g., trawling, small mesh gillnets) during periods of likely occurrence (e.g., late spring, early summer) could confirm or refute their presence in the project area.

Table 2. Risk of entrainment of pallid sturgeon by a water diversion structure at Lake Maurepas.

Element	Characteristics	Juveniles		Subadults & Adults	
		Rating	Uncertainty	Rating	Uncertainty
Occurrence in Project Area	Distribution of sturgeon	Low	Reasonably uncertain	High	Very certain
Use of Habitat at Site	Abundance of sturgeon	Low	Reasonably uncertain	High	Very certain
Susceptibility to Structure	Suitability of habitat for sturgeon Vertical position of withdrawal	High	Moderately certain	High	Reasonably certain
Susceptibility to Velocity	Swimming performance of sturgeon	High	Very certain	Medium	Reasonably certain
Risk	All of the above	Low	Moderately certain	Medium	Reasonably certain

Adult pallid sturgeon were collected at one location, the Gramercy Bridge, within 2,000 m of the proposed diversion structure (Figure 2). Also, it is not uncommon to collect adult pallid sturgeon near steep, vertical banks (sandbar “reefs”) similar to the littoral habitat of the proposed site. Consequently, the probability of use of the site where the structure will be constructed is “high” and “very certain” for subadult and adult fish. Juvenile fish are not documented from the area so use of habitat is presumed “low.” Pending targeted sampling for small fish, this rating is “reasonably uncertain.”

Susceptibility of fish to the proposed culvert is “high” for juveniles and for subadults and adults. Pallid sturgeon in the Mississippi River are frequently found in the vicinity of man-made structures (e.g., dikes). Such structures provide attractive areas of shelter from main channel water velocities. They also provide hard, permanent substrates for benthic invertebrates (e.g., common net spinning caddisflies, Hydropsychidae) and fishes (e.g., chubs, *Macrhybopsis* spp.) eaten by pallid sturgeon (Hoover et al. 2007). The likelihood that pallid sturgeon of any size would exploit a culvert (and any associated embayment) as a refugium and/or feeding ground is “high.” Flows in the culvert will be controlled by vertical lift gates and water diverted through the bottom of the structure (Dr. Patricia Taylor, U.S. Environmental Protection Agency [EPA], personal communication). Consequently, sturgeon attracted to the culvert seeking shelter or food will be placed in direct proximity to potentially entraining flows diverted through the structure. This rating is only “moderately certain” because it is largely conjectural for juveniles (due to limited empirical data). It is “reasonably certain” for subadults and adults since these fish have been frequently confirmed near similar structures.

Susceptibility to water velocities in the culvert is “high” for juveniles, but only “medium” for subadults and adults due to greater swimming capabilities of larger fish. Pallid sturgeon of all sizes are conspicuously rheotactic and exhibit complex station-holding behaviors. Swimming speeds, based on endurance, however, are highly variable among (and within) age classes. Escape speeds (i.e., swimming speeds that can be maintained for up to 1 min) have been measured for juvenile pallid sturgeon 74–205 mm FL and range from 35–75 cm/s (Adams et al. 1999; Hoover et al. 2005). Escape speeds for subadult and adult pallid sturgeon have not been measured but are probably in excess of 120 cm/s (pallid sturgeon were captured in this study in currents as fast as 130 cm/s). This estimate is based on data for shovelnose sturgeon, which have nearly identical swimming endurance to pallid sturgeon (Adams et al. 1997). Shovelnose sturgeon >530 mm SL are capable of swimming at 49–71 cm/s for 60 min (Parsons et al. 2003) and 65–116 cm/s for 15 min (Adams et al. 2003). An extrapolated swim speed of 120–150 cm/s for 1 min would be conservative. Projected flows through the culvert could be 100–150 cm/s (EPA, preliminary communication). If flows approach this range however, entrainment of most juveniles and some of the slower-swimming larger fish would be likely. Rating is “very certain” for juveniles because of data from multiple laboratory studies. Rating is “reasonably certain” for subadults and adults since shovelnose sturgeon data served as surrogates for pallid sturgeon and since trends in swimming performance were extrapolated from observed values of endurance.

Management implications

Risk assessment indicates several critical information needs and possible mitigation actions. Uncertainty in risk ratings for several elements could be reduced with data on pallid sturgeon demographics (i.e., occurrence of juveniles in project area), flow fields around the culvert (i.e., water velocities at varying distances and depths from gate), and frequency of entrainment of riverine species by diversion structures (i.e., sturgeons and suckers that have passed through large culverts). Additional field studies at the site for the planned Lake Maurepas structure and the existing Caernarvon and Davis Pond structures are warranted.

Risk of pallid sturgeon entrainment could be reduced in several ways. Withdrawal of water from near the surface of the river (based upon river stage and season) would make entrainment less likely since pallid sturgeon swim close to the river bottom and rarely approach the water's surface. Also, larger or a greater number of gates to distribute flow (and reduce velocity of exiting water through any single gate) would make it possible for sturgeon to resist flow by creating water velocities lower than escape speeds of most fish. Rough or complex substrates (e.g., scarified concrete, rip rap, etc.) directly in front of the gates (as currently envisioned by the designers) would also enable pallid sturgeon to resist entraining flows by providing low-velocity boundary layers and by enabling alternative low-energy station-holding behaviors such as creeping, hunkering, and tail-bracing to be used by fish (Hoover et al. 2005). Seasonal restrictions on diversion, or "windows," could minimize likelihood of entraining spawning adults (e.g., early spring) or juveniles (e.g., late spring, early summer).

Since some entrainment of pallid sturgeon is possible, mitigation strategies should at least be considered and studied. Culture and release of pallid sturgeon should be a last option for a number of reasons. Brood stock availability, genetic and behavioral considerations, as well as lack of understanding of pallid sturgeon demographics are reasons sufficient to presently recommend against this approach. Thus, mitigation resources would better be used in gaining an enhanced understanding of the pallid sturgeon demographics, swimming capabilities, and the hydraulic characteristics of the diversion structure.

The population status of pallid sturgeon in this reach should be better understood, not only for the evaluation of this project but also future lower Mississippi River water diversion projects. If the local population is robust, then some incidental entrainment losses will likely have very little impact upon the population. If the population is depressed, however, then any losses could be consequential. A local study conducted over several fall and winter periods could determine acceptable levels of entrainment using estimates of abundance, mortality, and recruitment in age-structure population models. A longer study (about 4 years and using multiple sampling gears), could be conducted within a reach perhaps 60 to 80 km above

New Orleans to evaluate the impacts of existing as well as future water diversions to the local pallid sturgeon population.

With water diversion speeds potentially reaching 150 cm/sec, studies of the similar box culvert diversion structure are justified. Fine-scale studies of water velocities in the area near diversion are important because pallid sturgeon have complex swimming behaviors. A good start would be a short but intensive study at the existing Caenarvon and Davis Pond structures to determine fine-scale variation in water velocities in a box culvert as well as velocities in the outlet channel. The results could be paired with laboratory swimming studies of adult pallid and/or shovelnose sturgeons. Taken together, these studies could be used to provide input into biologically sound design criteria as well as to refine risk assessment.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The impacts to Gulf and pallid sturgeon from a proposed Mississippi River water diversion into the swamps bordering Lake Maurepas were evaluated. Gulf sturgeon were unlikely to be affected by the diversion due to characteristics of their life history. Adult and subadult pallid sturgeon were relatively abundant in the proposed project area and could be affected by the proposed diversion. A risk assessment was performed. Juvenile pallid sturgeon were judged to have a "low" entrainment risk due to low likelihood of their occurrence in the project area. Risk of entrainment by adults and subadults was judged "medium" due to their relatively low burst swimming speeds compared to intake velocities. Management recommendations were made to reduce or mitigate chance of their entrainment.

15. SUBJECT TERMS

Pallid sturgeon	Risk analysis
Restoration	Water diversion

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Gulf Sturgeon Entrainment Study

ERDC/MVN

NEW ORLEANS DISTRICT/
ERDC ENVIRONMENTAL LABORATORY

US Army Corps of Engineers®

Entrainment Studies of Pallid Sturgeon Associated with Water Diversions in the Lower Mississippi River DRAFT

November 15, 2013

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PREFACE

This study was funded by the U.S. Army Corps of Engineers New Orleans District (MVN) and Mississippi Valley Division (MVD). MVN project managers were Richard Boe and Thomas Parker. MVD project managers were Dave Vigh and Dr. Barb Kleiss and. Individuals assisting with all or part of this study are listed below.

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EXECUTIVE SUMMARY

Water diversions from the Lower Mississippi River (LMR) are used for flood risk reduction, water supply, and habitat restoration. There was concern that existing and proposed diversions can entrain the federally endangered pallid sturgeon (*Scaphiryhnchus albus*), a species that occurs throughout the LMR. Potential entrainment of pallid sturgeon would be considered a "take" under the Endangered Species Act. Consequently, the New Orleans District and the Mississippi Valley Division funded ERDC-EL to monitor potential entrainment of pallid sturgeon in existing diversions and provide information to evaluate the risk of future entrainment. Objectives were to:

- Document and quantify sturgeon entrainment in existing diversions compared to adjacent river reaches.
- Estimate population size of pallid sturgeon in river reaches associated with diversions.
- Develop population viability models of pallid sturgeon to analyze impacts of entrainment-based "take" by water diversions.

The first task was to determine the spatial distribution and relative abundance of sturgeon in the lower 320 miles of the Mississippi River where all of the diversions either currently exist or are proposed. Four hundred and sixty-nine (469) total sampling gears were deployed at 85 sample stations along the 320 river mile reach with 74.1% of the sampling efforts conducted within the reach associated with existing or planned river diversions. A total of 51 pallid sturgeon, 319 shovelnose sturgeon, and 84 young-of-year sturgeon were collected between 2001 and 2011 below RM 320. The most downstream collection of pallid sturgeon was at RM 95.5. Two juvenile shovelnose sturgeon were collected opposite the Caernarvon Diversion at RM 81, which is the most downstream collection of *Scaphiryhnchus.* These data indicate a low risk of entraining pallid sturgeon below New Orleans because of their rarity or absence in the lower 100 miles of the LMR.

The second task was to estimate pallid sturgeon abundance in the lower reach of the LMR. This information was required to evaluate impacts of potential entrainment to population viability. A long-term (1997-2008) sequential mark-recapture survey of pallid sturgeon in the Lower and Middle Mississippi River failed to recapture any of the 241 individuals marked within the Mississippi River itself. Consequently, we used a hypergeometric probability distribution to estimate population size in light of some chosen probability of no recaptures (i.e., nil-recapture method). After accounting for survival, movement, and habitat use, we estimated that the total abundance of age-3+ pallid sturgeon in the Lower and Middle Mississippi River is at least 3,400-4,100 with probability 0.99; 5,900-7,000 with probability 0.95; and 17,000-20,000 with probability 0.75. Assuming fish were distributed in proportion to survey catch-per-unit-effort, the population estimate in the southernmost reach where existing and planned diversions occur was at least 3.8, 6.5, or 19 fish per river kilometer (rkm) for the 0.99, 0.95, and 0.75 probability respectively. These estimates do not account for juvenile sturgeon less than 3 years of age and there is considerable uncertainty in the analysis. However, this is the first estimate of population size of pallid sturgeon in the LMR and is an essential variable in the analysis of viability for the pallid sturgeon.

Existing diversion outlets were sampled for sturgeon from 2009 – 2011 that included Davis Pond Diversion, Violet Siphon, Caernarvon Diversion, White Ditch Siphon, and Naomi Siphon. Additional sampling occurred in the Bonnet Carré spillway after the 2008 and 2011 openings. The Old River Control Structure was not sampled as part of this study. Multiple gears were used to evaluate species composition entrained through the diversions. In total, 113 species were sampled in one or more of the diversions. Of this total, 35 species were relatively common in the Mississippi River but rare or absent in the marsh habitat below the diversions. Entrainment was highest in diversions during or in periods shortly after there were high volumes of flow through the diversions. There was no significant relationship between entrainment and river stage in most diversions because diversion flows were restricted during high river stages. Highest flows through the diversions occurred in the months following the Deepwater Horizon oil spill when they were opened to near their maximum capacity. During the same period, entrainment was generally high in the larger diversions. Sturgeon were found in samples in the two largest diversions, the Bonnet Carré Spillway and the Davis Pond Diversion. In the former, sturgeon were captured in several lakes after the structure was closed and a high degree of entrainment was found in periods following high flows. Additional sampling of the Bonnet Carré is reported below. In the latter, one pallid sturgeon and three shovelnose sturgeon were taken in each quarter of the latter half of 2009 and the first half of 2010. This component of the overall study indicates that entrainment risk is higher for larger diversions (>10,000 cfs) located above New Orleans.

The Bonnet Carré Spillway was intensively sampled after the 2008 and 2011 openings of the structure to evaluate entrainment of pallid sturgeon from the Mississippi River. Morganza floodway was sampled after the structure was closed in 2011. Pallid sturgeon were collected only in the Bonnet Carré floodway after the structure was closed. Sampling during the openings was restricted due to safety concerns. Higher discharge and longer opening in 2011 resulted in greater number of sturgeon caught. In 2008, a total of 14 pallid sturgeon and 41 shovelnose sturgeon were collected over a 4-week period. In 2011, a total of 20 pallid, 78 shovelnose, and one possible intermediate sturgeon were collected over a 1.5-week period. The majority of these fish were relocated back into the Mississippi River; some were retained for taxonomic studies by USFWS. Field surveys indicated that it was unlikely that pallid sturgeon, an obligate riverine species, would be entrained through Morganza because of the long distance between the main channel of the Mississippi River and the structure. Pallid sturgeon entrained through the Bonnet Carré spillway may move downstream into Lake Pontchartrain, although a telemetry study did not detect movement into the Lake. For those pallid sturgeon remaining in the floodway, a slow decline in discharge after closure draws sturgeon towards the structure where they can be rescued and placed back into the Mississippi River.

An age-based population viability model of pallid sturgeon was developed from the field data reported above that included both demographic and environmental stochasticity. Using abundance estimates, projected numbers of entrained fish was translated into per capita entrainment rates to explore the ecological risk posed by episodic and chronic water diversion actions in the southernmost reach of the LMR. Uncertainty was addressed by testing a range of entrainment rates, abundance levels, and spatial structures. Entrainment during episodic diversions characteristic of the Bonnet Carré spillway reduced median local population size by 0-20% in 60 years. Entrainment in chronic annual water diversions, characteristic of those proposed for wetlands nourishment in Louisiana, reduced median local population size by 2-50%. The effect of combined episodic and cumulative entrainment was multiplicative. If the true abundance of pallid sturgeon adults in the LMR is near 5,000 or more, entrainment is not a central factor in the recovery and maintenance of the population. Only the worst-case scenario of low abundance and high entrainment presented an appreciable risk to the population. At the low abundance level, our estimate of chronic diversion was sufficient to induce an IUCN rating of vulnerable if the LMR pallid population was otherwise stable. However, this scenario is unlikely below New Orleans where pallid sturgeon have not been captured.

Model projections revealed that the greatest gains in certainty would come from a more precise population size estimate. Improved understanding of large-scale movements of age-1+ fish would also greatly improve our ability to manage pallid sturgeon in the free-flowing Mississippi River. Based on the Bonnet Carré experience, it is possible that mitigation efforts, such as monitoring and rescue below small diversion structures, could reduce risks posed by wetlands restoration projects in those reaches where pallid sturgeon are known to occur.

Entrainment Studies of Pallid Sturgeon
Associated with Water Diversions in the Lower Mississippi River

Background

The Louisiana Coastal Area (LCA) Program is a systematic approach to restore natural features and ecosystem processes (New Orleans District 2012). As part of the LCA and the Mississippi River and Tributary projects, water diversions are used for flood risk reduction, water supply, and habitat restoration in the Lower Mississippi River (LMR). In 2008, the Bonnet Carré Spillway, which diverts floodwaters from the Mississippi River into a floodway that empties into Lake Pontchartrain to reduce river stages at New Orleans, was open for 27 days. Prior to opening, the federally endangered pallid sturgeon (*Scaphiryhnchus albus*) was captured in the Mississippi River near the Bonnet Carré structure by Louisiana Department of Wildlife and Fisheries (LDWF). Potential entrainment of pallid sturgeon would be considered a "take" under the Endangered Species Act, and therefore, post-closure monitoring of the floodway was warranted. Within a week after the structure was closed in 2008, ERDC and LDWF captured pallid sturgeon in the floodway verifying that entrainment had occurred.

Water diversions from the Mississippi River for marsh habitat restoration will increase as new projects are implemented in the delta. Future floods will necessitate the openings of the Bonnet Carré and Morganza floodways further increasing entrainment risk. Prior to this study, impacts of diversions on imperiled sturgeon populations were unknown. Comprehensive risk assessments for entrainment of sturgeon by water diversions require substantial inputs including field data on local sturgeon populations, life history information, and output from population modeling simulations. These risk assessments, however, can provide probability of entrainment for specific environmental scenarios (e.g., time of year, river stage, and flow fields generated by a structure). Such probabilities can be eliminated or reduced through modified operations of structures (e.g., schedule of operation, rate of diversion, implementation of deterrents). Otherwise, monitoring and rescue programs will be ongoing elements of O&M costs and concerns regarding long-term impacts to endangered sturgeon will go unresolved.

Biological assessments of freshwater diversions on pallid sturgeon are mandated by the Endangered Species Act. Consequently, the New Orleans District funded ERDC-EL to monitor potential entrainment of pallid sturgeon in existing diversions and provide information to evaluate fully the risk of future entrainment. Objectives of this document are to:

- Document and quantify sturgeon entrainment in existing diversions and adjacent river reaches
- Estimate population size of pallid sturgeon in river reaches associated with diversions
- Develop population viability models of pallid sturgeon to analyze impacts of entrainment-based "take" by water diversions

Approach

This document is divided into five chapters that integrate the full study into a comprehensive risk assessment of entraining pallid sturgeon through water diversions in the lower 300 miles of the Mississippi River as illustrated by the Conceptual Model (Figure 1). Chapters address the following questions:

- How many sturgeon occur in this reach of river? (Chapter 1, river sampling; Chapter 2, demographic model of abundance)
- How many sturgeon are entrained through diversions? (Chapter 3, seasonal sampling in existing diversions; Chapter 4, Bonnet Carré /Morganza sampling in 2008 and 2011)
- What are the impacts of entrainment to the population? (Chapter 5, population viability model)

The first chapter summarizes sampling in the lowermost reach of the Mississippi River for pallid sturgeon and includes extant data collected by ERDC over a ten-year period. Chapter 2 presents a demographic model, based on age-structure of populations of sturgeon collected in the river, to evaluate existing status of the pallid sturgeon (e.g., declining, stable, or increasing) within the lower reach of the Mississippi River and provide for the first time an estimate of population size. Chapter 3 describes a comprehensive database of entrained fish collected seasonally in existing diversions by Nicholls State University under contract with ERDC. Chapter 4 summarizes ERDC's efforts to evaluate sturgeon entrainment through the Bonnet Carré Spillway in 2008 and 2011, and Morganza floodway in 2011. Overall, these four chapters provide the baseline to conduct risk analysis. Risk of entrainment and impacts to sturgeon populations were addressed using a Population Viability Model (PVA) in Chapter 5. The PVA quantifies viability as predicted time-to-extinction (or extirpation): greater viability is reflected in longer (or indefinite) time-to-extinction (Akcakaya 2000). PVA has been successfully used to establish causes of extinction (e.g., Turvey and Risley 2006) and to evaluate individual threats to survival (e.g., Brook et al. 2002). PVA was used to compare scenarios of entraining low numbers (e.g., 10) to high numbers (e.g., >>100) of sturgeon, and determine if a threshold is reached that constitutes a jeopardy opinion. Application of these data and models are illustrated in the conceptual model (Figure 1 – Application of Data).

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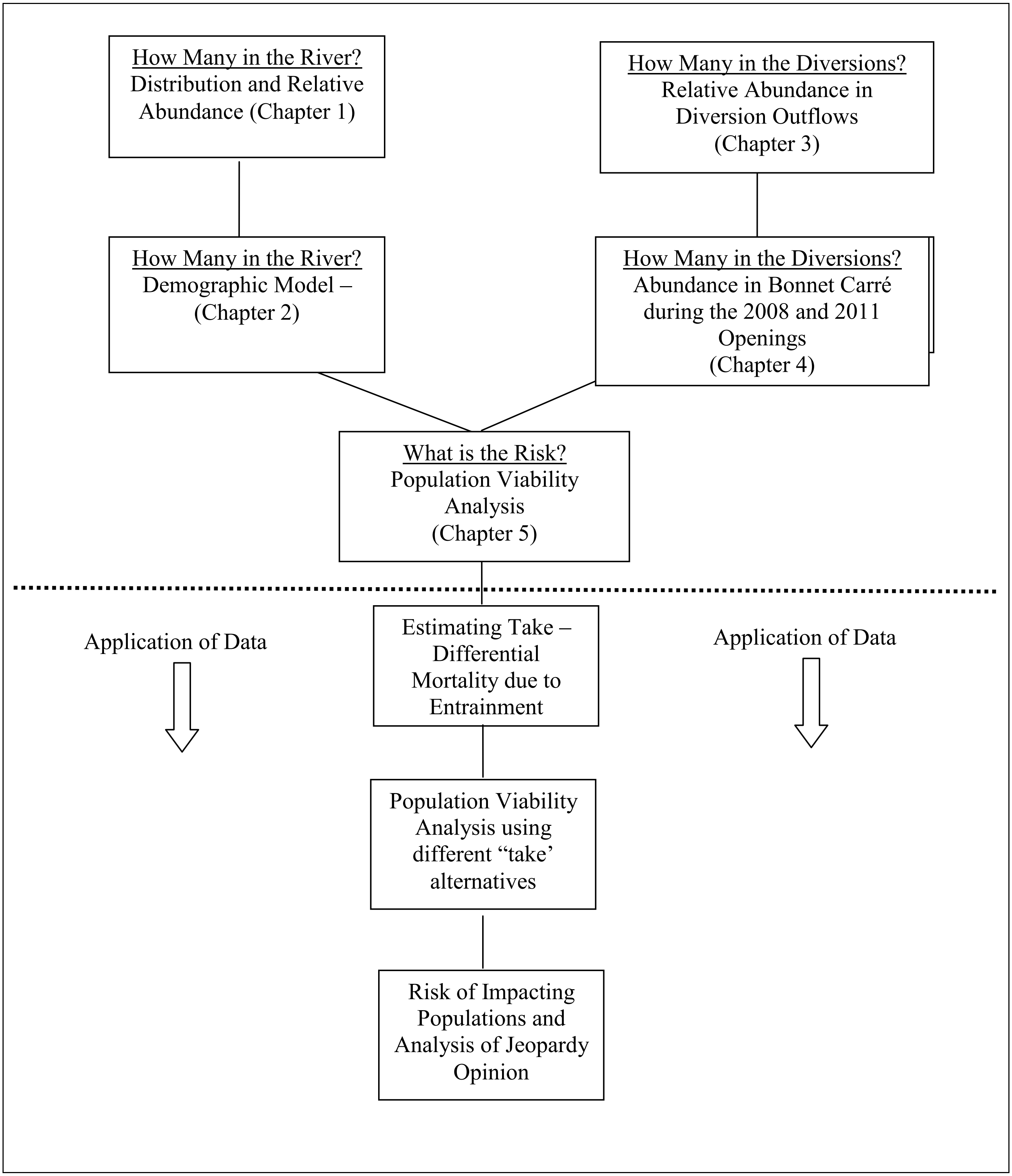

Figure 1. Conceptual Model of Information Acquisition and Application

Chapter 1

Spatial Distribution and Relative Abundance of Sturgeon in the Lower 300 miles of the Mississippi River

by

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Abstract

Field sampling of sturgeon in the lowermost reach of the Mississippi River between river mile (RM) 0 and 320 has been ongoing since 2001. For the Diversion project, additional sampling occurred below New Orleans where the majority of proposed diversions will be located. Three gears were used to sample sturgeon: trotlines, trawl, and gill nets. Four hundred and sixty-nine (469) total sampling gears were deployed at 85 sample stations along the 320 river mile reach with 74.1% of the sampling efforts conducted within the reach associated with existing or planned river diversions. Our sampling documented 61 species of fishes with a total abundance of 13,314 individuals across all samples. A total of 51 pallid sturgeon, 319 shovelnose sturgeon, and 84 young-of-year sturgeon were collected between 2001 and 2010 below RM 320. The most downstream collection of pallid and shovelnose sturgeon was at RM 95.5 and 81, respectively. Consequently, we assume that entrainment risk of pallid sturgeon declines substantially below New Orleans and is unlikely below RM 50.

Introduction

Field sampling of pallid sturgeon, shovelnose sturgeon, and associated species were conducted in the lower reaches of the Mississippi River at sites corresponding to proposed and existing diversions (Table 1.1). Sampling was conducted according to standard protocols established in previous field assessments (Killgore et al. 2007; Miranda and Killgore 2013). The purpose of river sampling was to determine the spatial distribution and most downstream limit of occurrence in the lowermost reach of the Mississippi River. Both shovelnose and pallid sturgeon were considered since the presence of shovelnose sturgeon may imply the presence of the rarer pallid sturgeon. Field collections were used to develop a population model of pallid sturgeon to estimate absolute abundance in the river (see Chapter 2).

Methods

Sampling efforts summarized in this chapter include efforts in the Lower Mississippi River proper between river mile (RM) 0 and 320, all within the operational boundaries of the U.S. Army Corps of Engineers, New Orleans District. Although the primary study reach (i.e., diversion reach) ranges between RM 45 and 160 (Table 1.1, Figure 1.1), the inclusion of comparable upriver sampling efforts was necessary to provide comparisons on relative abundance of both pallid and shovelnose sturgeon within the immediate study zone.

Three gears were used to sample sturgeon. Trotlines (61 m long, 60 dropper lines spaced every 0.9 m tied to 2/0 hooks) were be baited with worms (Canadian night crawlers), fished overnight along the bottom, and retrieved the following morning. Up to eight trotlines were deployed per night at each site, each fishing approximately 16 hours. Trotlines were evenly distributed between littoral and channel border locations. Experimental mesh gill nets (27.4 m by 1.8 m, six mesh panels ranging from 23 to 76 cm) were set in littoral locations and adjacent to diversion inflow areas only. Usually two gill nets were set at each site in the late afternoon and retrieved the following morning, usually over a 16-hour period. A 3.0-m Missouri benthic trawl, based on the design by Herzog et al. (2005), was used to sample smaller benthic fishes. The distance traveled, average speed, and depth range were recorded during each trawling event. Number of trawls per site was dependent on available locations conducive for this type of gear (i.e., relatively un-obstructed river bottom in waters ranging from 1-15 m). Water quality (temperature, dissolved oxygen, pH, conductivity, turbidity) and hydraulic (depth, velocity) variables were measured at each sampling location. GPS coordinates of sampling locations were also recorded. All data were entered into ERDC's Mississippi River long-term database.

All fish captured were identified to species, enumerated, and total length (also fork length for sturgeon) was measured. Additional morphometric measurements and meristic counts were taken on pallid sturgeon to verify species designation *a posteriori* as described by Murphy et al. (2007). Prior to release, shovelnose and pallid sturgeon were externally tagged with t-anchor bar spaghetti tags. In addition, all pallid sturgeon specimens were scanned for the presence of a Passive Integrated Transponder (PIT) tag, and if no tag was detected, a non-encrypted PIT tag was inserted at the base of the dorsal fin. All pallid sturgeon were also scanned for coded wire tags to determine if individuals were of hatchery origin.

Results and Discussion

Four hundred and sixty-nine (469) total sampling gears (e.g., trotline, trawl, gillnet) were deployed at 85 sample stations along the 320 river mile reach (Figure 2.1) with 74.1% of the sampling efforts conducted within the reach associated with existing or planned river diversions. Trotline and trawl were the predominant gear types utilized for all sampling efforts (Figure 3.1; 87.5%) because both are very effective gears for targeting river sturgeon, but each gear type generally targets individuals of different size ranges (Killgore et al. 2007; Phelps et al. 2009). Total sampling efforts included in this summary have been stratified across several years (Figure 4.1) with 57.8 % of the analyzed efforts occurring within the past 5 years, and occurring primarily within the study reach associated with the river diversions. Sampling within the river occurred year-round (Figure 5.1) with 73.1% of all efforts occurring during the cooler months of spring, fall and winter. The depicted monthly pattern is typical and generally reflects gear recruitment by river sturgeon. Our primary gears are very effective in catching sturgeon but catch rates, particularly with trotlines, are temperature dependent (Killgore et al. 2007; Phelps et al. 2009) and are minimally effective during months associated with warmer water temperatures. In contrast, sampling for young-of-year (YOY) with trawls is effective during all months.

The spatial distribution of all sampled gears for the Lower Mississippi River are illustrated in Figure 6.1, which adequately depicts extensive sampling above, below and within the reach containing existing and planned river diversions. Our sampling documented 61 species of fishes with a total abundance of 13,314 individuals across all samples (Table 2.1). A total of 51 pallid sturgeon, 319 shovelnose sturgeon, and 84 young-of-year sturgeon were collected between 2001 and 2010 below RM 320. Seven species composed over 90% of the relative abundance with *Ictalurus furcatus* being the most abundant species and followed in descending order by *Anchoa mitchilli*, *Dorosoma cepedianum*, *Aplodinotus grunniens*, *Ictalurus punctatus*, *Scaphirhynchus platorynchus* and *Mugil cephalus*. *Scaphirhynchus albus* ranked 16th and represented 0.4% of the total relative abundance.

Sturgeon were generally distributed from RM 319 downstream to RM 81 (Figure 7.1) with abundances for each species varying throughout the sampled reach (Figure 8.1). Pallid sturgeon size ranged 405-964 mm FL and shovelnose sturgeon size ranged 231-852 mm FL. Adult pallid and shovelnose sturgeon, as well as YOY, are present within the upper portion (RM 80-160) of the diversion reach, providing evidence of recruitment within this region (Table 2.1, Figure 10.1). Post-larval sturgeon (i.e., YOY) have been documented from RM 128 to 245, and have been represented by numerous specimens (not limited to a single individual in a single effort), over multiple years and during both spring and fall sampling events. Recently spawned sturgeon ranged in size from 17 to 268 mm TL, which is the reported size ranges of pallid and shovelnose sturgeon YOY (Harrison et al. 2014) (Figure 11.1). These data provide additional support for fall spawning in *Scaphirhynchus* species and confirm spawning in the lower extent of the Mississippi River. In addition, the shovelnose sturgeon occurring near the Caernarvon diversion (Figure 10.1) further suggests upriver spawning and/or downstream drift from a favorable upriver site (i.e., Donaldsonville, White Castle). Regardless of the scenario of choice, these data provide support for increased potential of entrainment of small sized sturgeon in nearby diversion areas (e.g., Violet Siphon, Caernarvon).

Killgore et al. (2007) compared CPUE of pallid and shovelnose sturgeon in reaches of the Middle and Lower Mississippi River using only catch from trotlines. In their study (Killgore et al. 2007), effort was considered as an "overnight set" such that a single 100', 60 hook trotline (ca. 16 hour soak period) was treated as a single effort and catch per unit effort (CPUE) of both pallid and shovelnose sturgeon were tabulated based on that set. For this evaluation, we followed the same methodology to compute CPUE and comparisons were restricted to only trotline captures. All but one pallid sturgeon (51 total individuals) and 14 shovelnose sturgeon (319 total) were captured by trotlines. CPUE of both pallid and shovelnose sturgeon varied across the study area with CPUE of shovelnose sturgeon generally exceeding that of pallid sturgeon when compared across stations sampled with trotlines (Figure 12.1). Condensing these data into a river mile category (Table 3.1) illustrates that shovelnose sturgeon were more prevalent in the upstream reach. Although the ratio of pallid to shovelnose sturgeon varied across river mile categories, values for both species were fairly consistent between RM 120-180 with pallid/shovelnose ratios ranging from 1:1 to 1:2.85. Downstream of this area, abundances of both species declined to minimal numbers.

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Table 1.1. List of proposed and existing diversions in the Lower Mississippi River that were sampled by ERDC Fish Ecology Team during the entrainment study.

Water Diversion	River Mile	Status	Mississippi River Sampling	Outflow Channel Sampling	Latitude	Longitude
Convent/Blind River	160.0	Proposed	YES		30.036780	-90.838990
Hope Canal	145.0	Proposed	YES		30.051230	-90.657120
Bonnet Carré	128.0	Existing	YES	YES	30.002430	-90.441470
Davis Pond	119.0	Existing	YES	YES	29.932010	-90.321650
Violet Siphon	83.8	Existing	YES	YES	29.898210	-89.902960
Caernarvon	81.5	Existing	YES	YES	29.862830	-89.912000
White Ditch	64.5	Existing	YES	YES	29.711650	-89.979140
Naomi Siphon	63.9	Existing	YES	YES	29.701360	-89.983520
Myrtle Grove	59.0	Proposed	YES		29.639720	-89.949190
Magnolia (Myrtle Grove No. 2)	45.0	Proposed	YES		29.541650	-89.761730

Table 2.1. Total species occurrence by 20 river mile delineation as documented by ERDC sampling efforts in the Lower Mississippi River during the 2001-2010 sample period. River reaches containing existing or proposed diversion are highlighted with Convent/Blind River (RM 179-160) and White Ditch (RM79-60) noted in red.

Taxa	Common Name	River Mile																	
		301-320	319-300	299-280	279-260	259-240	239-220	219-200	199-180	179-160	159-140	139-120	119-100	99-80	79-60	59-40	39-20	19-0	SUM
Acipenseriformes																			
Acipenseridae																			
Scaphirhynchus albus	Pallid sturgeon	--	9	---		1		---	14	12	11	3		1					**51**
Scaphirhynchus platorynchus	Shovelnose sturgeon	--	201	---	4	7		---	36	31	29	6	2	3					**319**
Scaphirhynchus sp.	YOY sturgeon	--		---		5		---	51	23	2	3							**84**
Polyodontidae																			
Polyodon spathula	Paddlefish	--		---				---		4		37							**41**
Semionotiformes																			
Lepisosteidae																			
Lepisosteus oculatus	Spotted gar	--		---				---				24					9		**33**
Lepisosteus osseus	Longnose gar	--		---				---								1			**1**
Amiiformes																			
Amiidae																			
Amia calva	Bowfin	--		---				---	3					1					**4**
Osteoglossiformes																			
Hiodontidae																			
Hiodon alosoides	Goldeye	--		---	7	3	1	---				1							**12**
Anguilliformes																			
Anquillidae																			
Anguilla rostrata	American eel	--	1	---				---		8	12	16	4	17	1		1		**60**
Ophichthidae																			
Myrophis punctatus	Speckled worm eel	---		---				---								1			**1**
Ophichthus gomesii	Shrimp eel	---		---				---						1					**1**

Clupeiformes																			
Engraulidae																			
Anchoa mitchilli	Bay anchovy	---		---			82	---		16	50			148	43	3040			**3379**
Clupeidae																			
Alosa chrysochloris	Skipjack herring	---		---				---				122		2		1			**125**
Brevoortia patronus	Gulf menhaden	---		---				---						4					**4**
Dorosoma cepedianum	Gizzard shad	---		---	1			---		25		1184	17		23	2	47	4	**1303**
Dorosoma petenense	Threadfin shad	---		---				---	3		24	27	3			2			**59**
Cypriniformes																			
Cyprinidae																			
Ctenopharyngodon idella	Grass carp	---		---				---				2							**2**
Cyprinus carpio	Common carp	---		---				---		2		14				1			**17**
Hypophthalmichthys molitrix	Silver carp	---		---				---				3		1					**4**
Macrhybopsis aestivalis hyostoma	Shoal chub	---		---			4	---	1	9	5			6					**25**
Macrhybopsis storeriana	Silver chub	---	3	---			2	---	1	4	9	147							**166**
Notropis blennius	River shiner	---		---				---				2							**2**
Notropis shumardi	Silverband shiner	---		---				---			6	46							**52**
Notropis wickliffi	Channel shiner	---		---				---				1							**1**
Catostomidae																			
Carpiodes carpio	River carpsucker	---		---				---				7							**7**
Ictiobus bubalus	Smallmouth buffalo	---		---				---	1	2		53	1	3					**60**
Ictiobus cyprinellus	Bigmouth buffalo	---		---				---				4							**4**
Ictiobus niger	Black buffalo	---		---				---	2	1				1					**4**
Siluriformes																			
Ictaluridae																			
Ictalurus furcatus	Blue catfish	---	342	---	344	77	300	---	251	639	438	1277	36	433	157	39	329	73	**4735**
Ictalurus punctatus	Channel catfish	---	18	---				---	33	110	307	224	21	133	3	40	36	1	**926**
Noturus sp.	Unidentified madtom	---		---				---				1							**1**
Pylodictis olivaris	Flathead catfish	---	2	---	1			---	41	26	12	26	4	15	7				**134**

Mugiliformes																			
Mugilidae																			
Mugil cephalus	Striped mullet	---		---				---				10	6				240	1	**257**
Atheriniformes																			
Atherinidae																			
Menidia sp.	Unidentified silverside	---		---				---				10							**10**
Beloniformes																			
Belonidae																			
Strongylura marina	Atlantic needlefish	---		---				---				7							**7**
Cyprinodontiformes																			
Fundulidae																			
Lucania parva	Rainwater killifish	---		---				---				1							**1**
Perciformes																			
Moronidae																			
Morone chrysops	White bass	---		---			3	---			1	9	2				3		**18**
Morone mississippiensis	Yellow bass	---		---				---									1		**1**
Morone saxatilis	Striped bass	---		---				---				7		1			1	4	**13**
Perciformes																			
Centrarchidae																			
Lepomis cyanellus	Green sunfish	---		---				---				6							**6**
Lepomis gulosus	Warmouth	---		---				---				13							**13**
Lepomis humilis	Orangespotted sunfish	---		---				---				5							**5**
Lepomis macrochirus	Bluegill	---		---				---			1	32							**33**
Lepomis marginatus	Dollar sunfish	---		---				---				9							**9**
Lepomis megalotis	Longear	---		---				---				5							**5**
Lepomis microlophus	Redear	---		---				---				1							**1**
Lepoms sp.	Unidentified sunfish	---		---				---			1								**1**
Micropterus salmoides	Largemouth bass	---		---				---		1		58							**59**
Pomoxis annularis	White crappie	---		---				---				28							**28**
Pomoxis nigromaculatus	Black crappie	---		---				---				20					1		**21**

Percidae																			
Sander canadensis	Sauger	---		---				---		2	2	10							**14**
Sciaenidae																			
Aplodinotus grunniens	Freshwater drum	---	1	---	47	18	36	---	11	138	202	616	1	33	3	3	17		**1126**
Cynoscion nebulosus	Spotted seatrout	---		---				---									9		**9**
Pogonias cromis	Black drum	---		---				---									5		**5**
Sciaenops ocellatus	Red drum	---		---				---									2		**2**
Cichlidae																			
Oreochromis sp.	Unidentified tilapia	---		---				---									25		**25**
Gobiidae																			
Gobionellus shufeldti	Freshwater goby	---		---				---						1					**1**
Unidentified goby	unidentified goby	---		---				---						3					**3**
Pleuronectiformes																			
Paralichthyidae																			
Paralichthys lethostigma	Southern flounder	---		---				---						2		1	2		**5**
Achiridae																			
Trinectes maculatus	Hogchoker	---		---				---				5		14	2				**21**
TOTAL			**577**		**404**	**111**	**428**		**448**	**1053**	**1112**	**4082**	**97**	**821**	**239**	**3131**	**728**	**83**	**13314**
NUMBER OF DIVERSIONS										1	1	1	1	2	1	2			
Graptemys pseudogeographica kohnii	Mississippi map turtle									2	2								4
Trachemys scripta elegans	Red-eared slider											1							1
Macrobrachium ohione	Ohio River shrimp								400		1000	2922		3					4325
Orconectes palmeri longimanus	Western painted crayfish											5							5
Procambarus clarkii	Red swamp crayfish											1							1

Table 3.1. Ratio of pallid/shovelnose sturgeon by river mile category based on CPUE from trotlines within each category.

RM	Abundance		Diversions	CPUE		Pallid:Shovelnose	
	Pallid	Shovelnose		Pallid	Shovelnose	proportion	ratio
>320	0	0					
319-300	9	201		0.18	4.02	0.04	1:22.33
299-280	0	0					
279-260	0	0					
259-240	0	0					
239-220	0	0					
219-200	0	0					
199-180	13	37		0.57	1.61	0.35	1:2.85
179-160	12	29	1	0.23	0.56	0.41	1:2.42
159-140	12	29	1	0.29	0.71	0.41	1:2.45
139-120	3	3	1	0.08	0.08	1.00	1:1
119-100	0	2	1		0.20	0.00	
99-80	1	1	2	0.03	0.03	1.00	1:1
79-60	0	0	1				
59-40	0	0	2				
39-20	0	0	0				
19-0	0	0	0				

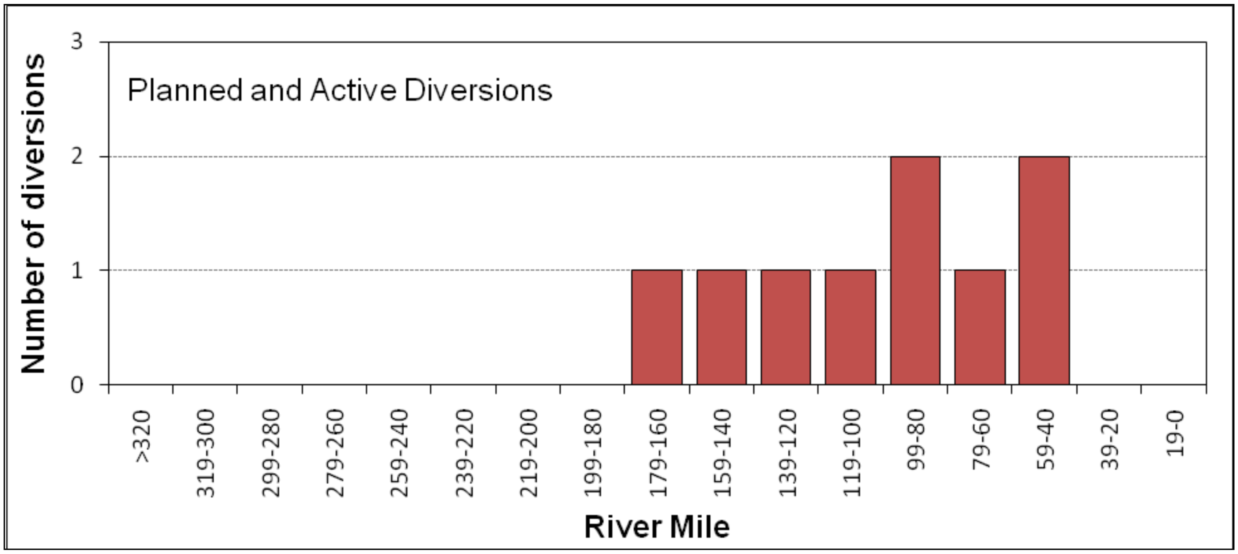

Figure 1.1. Number of planned and active diversions occurring on the Lower Mississippi River within 20 river mile delineations.

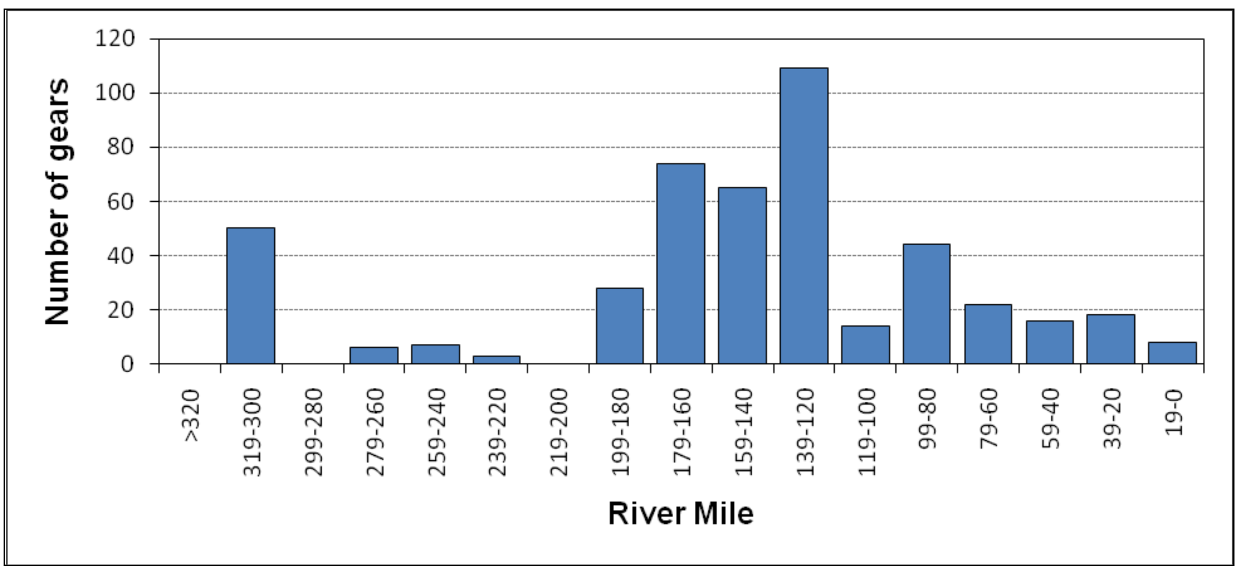

Figure 2.1. Total sampling effort by ERDC Fish Ecology team per river mile category on the Lower Mississippi River (RM 320-0), 2001-2010.

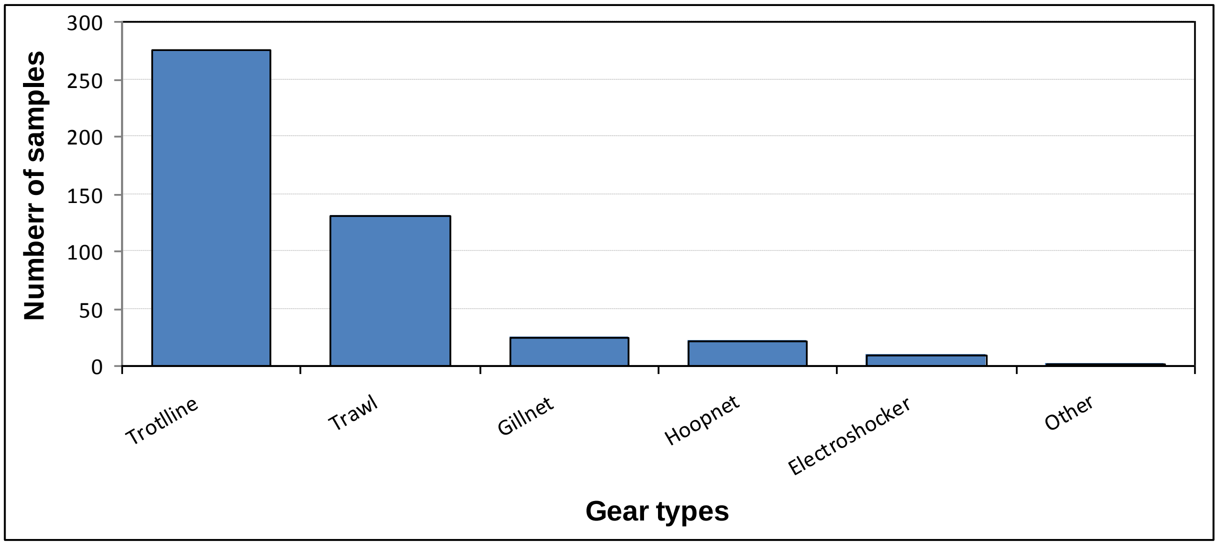

Figure 3.1. Breakdown of gears deployed during fish sampling efforts on the Lower Mississippi River (RM 320-0) (total N = 469), 2001-2010.

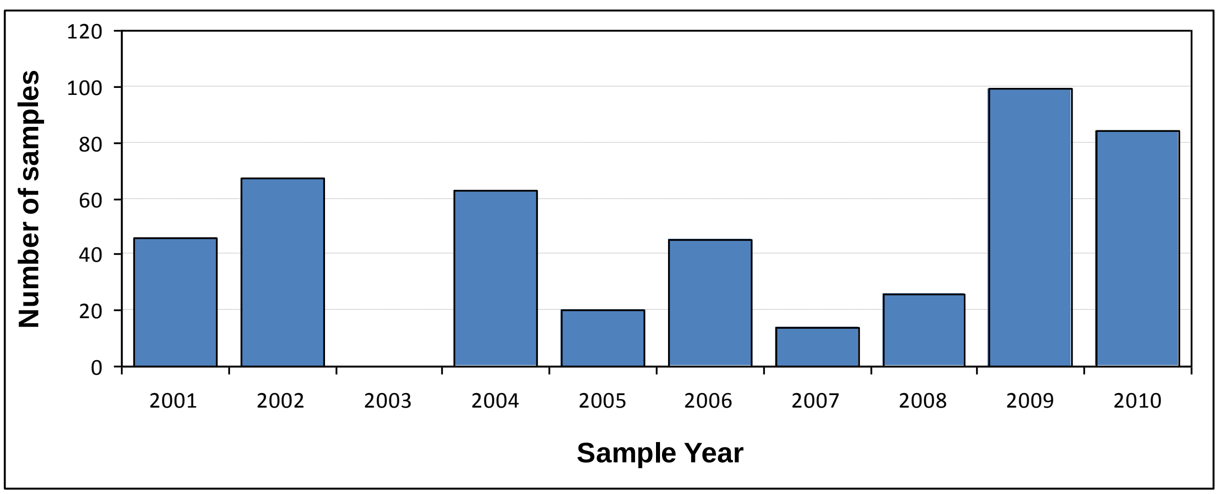

Figure 4.1. Breakdown of sampling effort on the Lower Mississippi River (RM 320-0) by year (total N = 469).

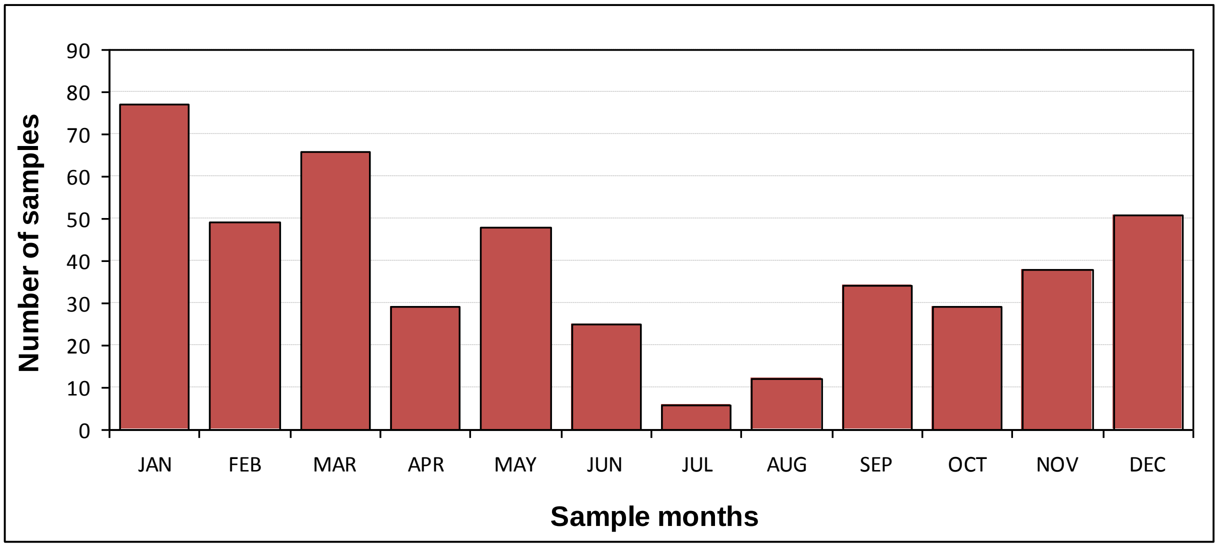

Figure 5.1. Distribution of sampling efforts in Lower Mississippi River (RM 320-0) across months the sample occurred (total N = 469), 2001-2010.

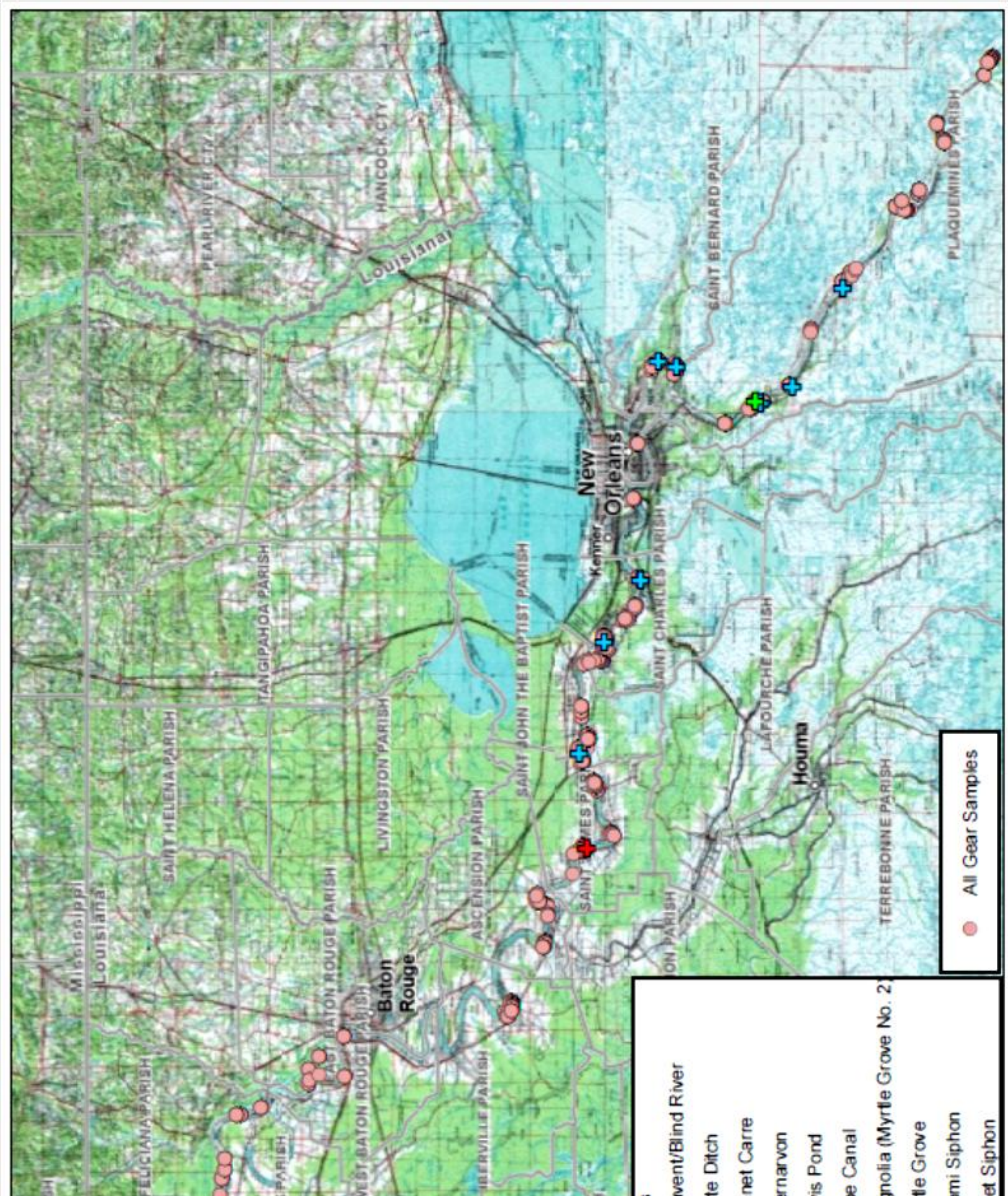

Figure 6.1. Spatial distribution of all sampled gears in the Lower Mississippi River (RM 320-0) and location of existing and proposed diversions within the study reach.

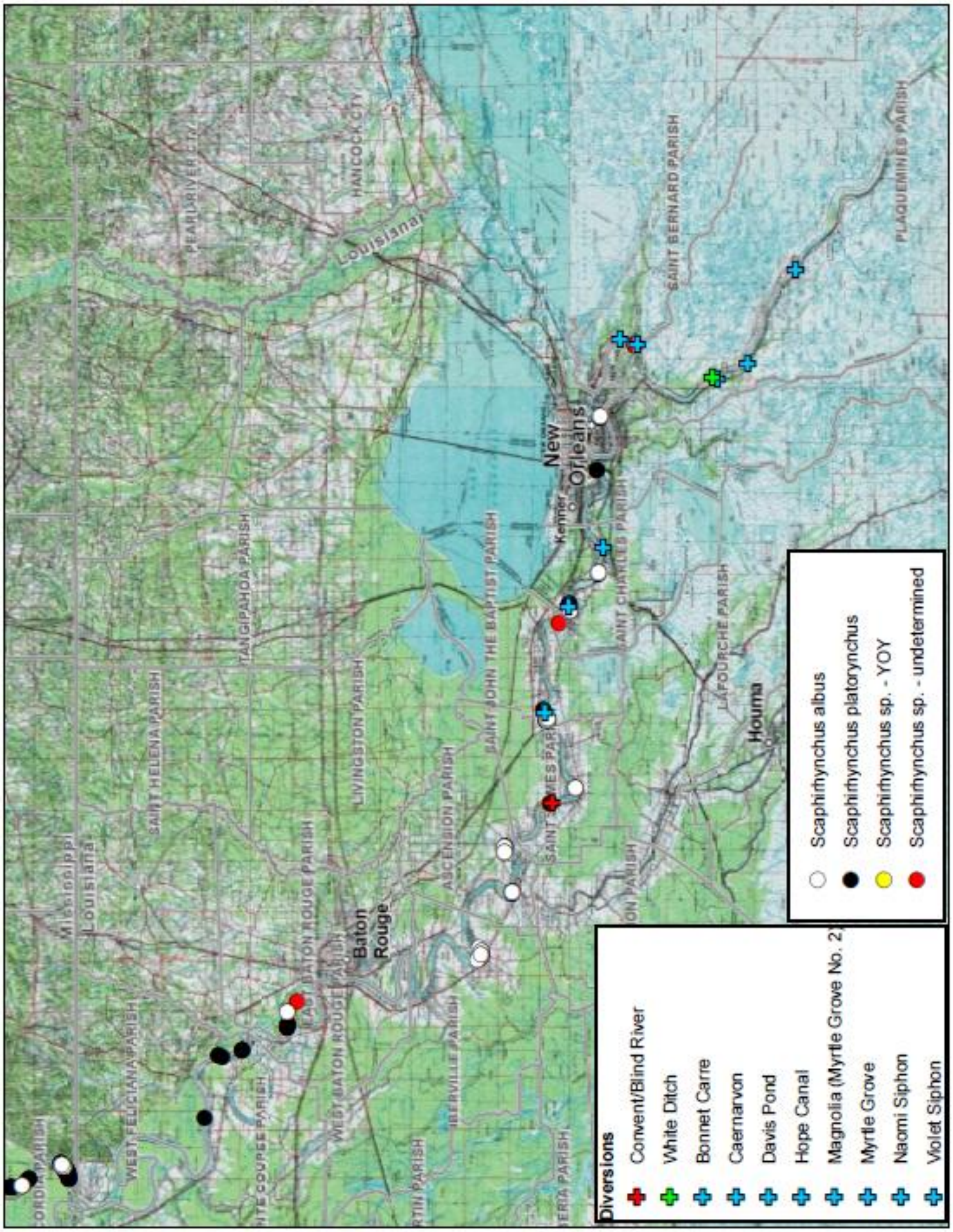

Figure 7.1. Spatial distribution of sturgeon catches along the Lower Mississippi River (RM 320-0).

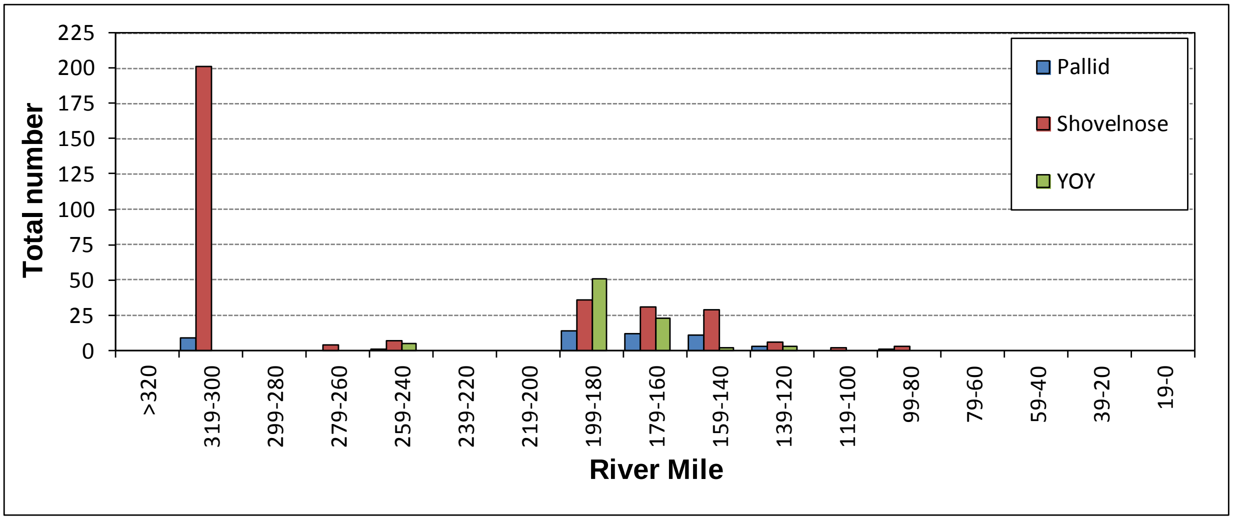

Figure 8.1. Breakdown of all sturgeon catch (all gears combined) by river mile category from 2001-2010.

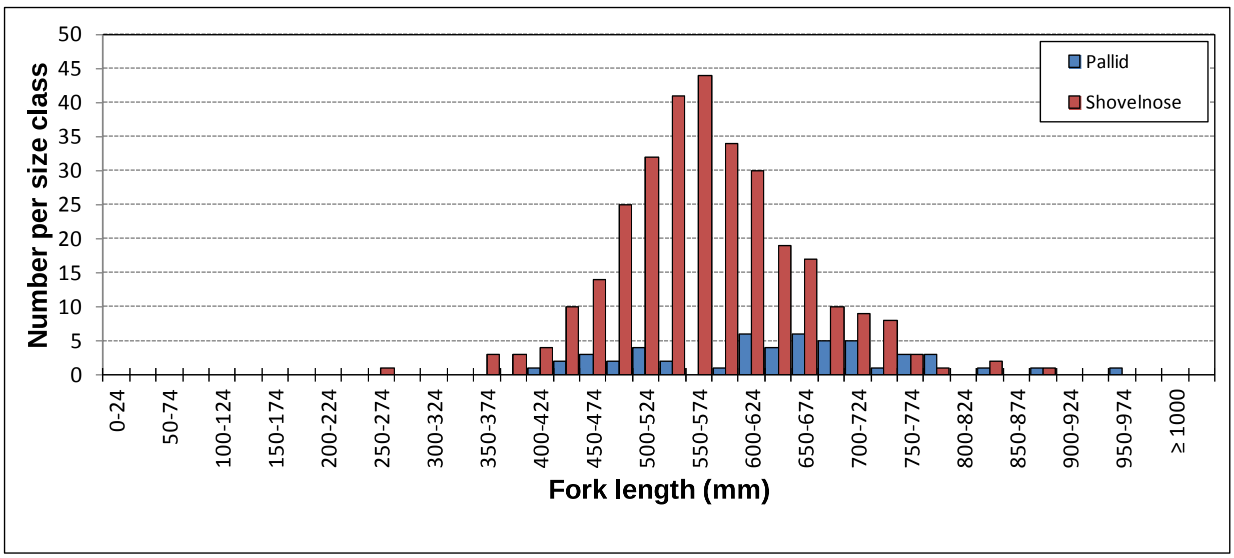

Figure 9.1. Size range and number per size class for pallid and shovelnose sturgeon processed during sampling of Lower Mississippi River (RM 320-0), 2001-2010.

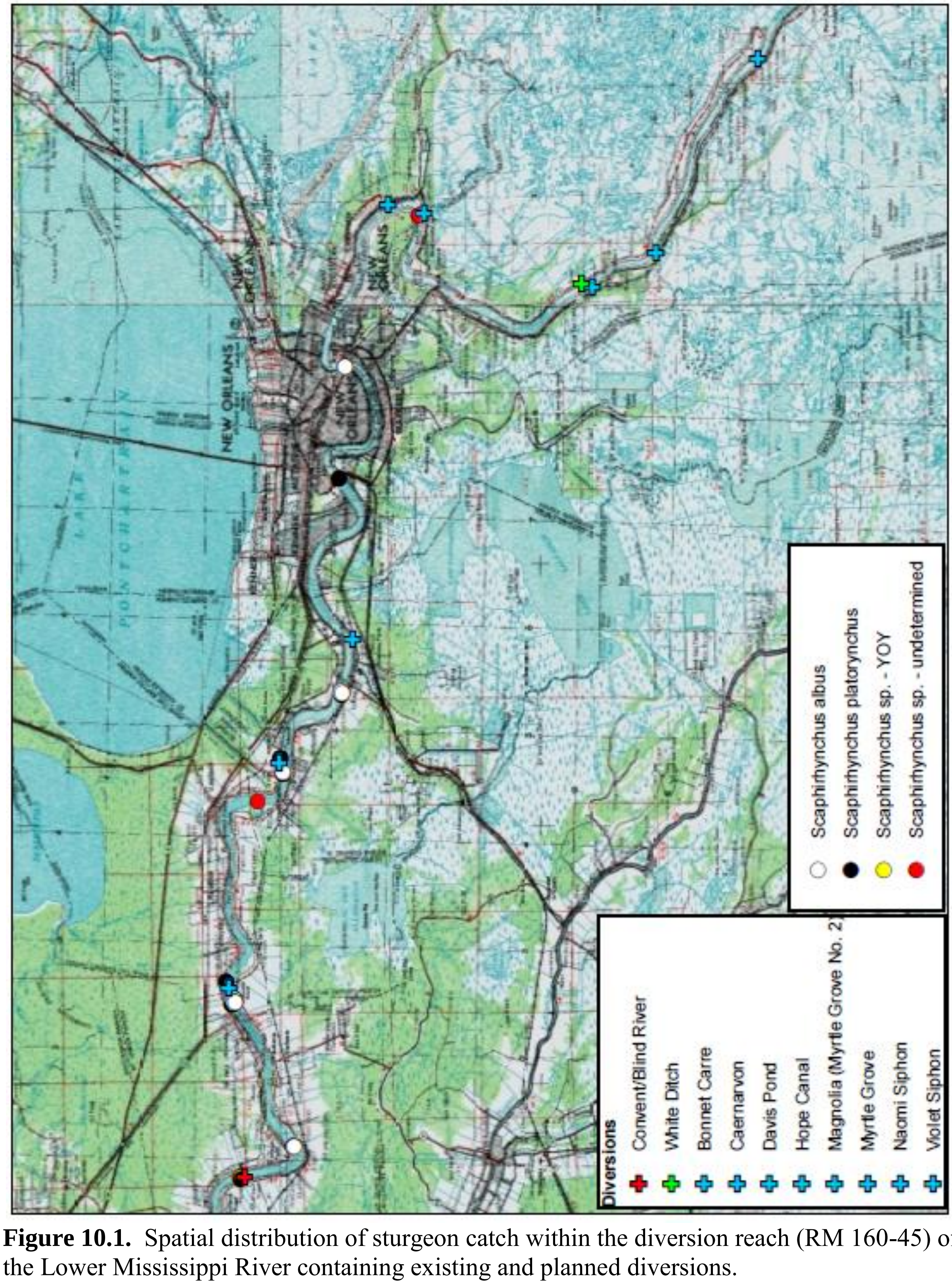

Figure 10.1. Spatial distribution of sturgeon catch within the diversion reach (RM 160-45) of the Lower Mississippi River containing existing and planned diversions.

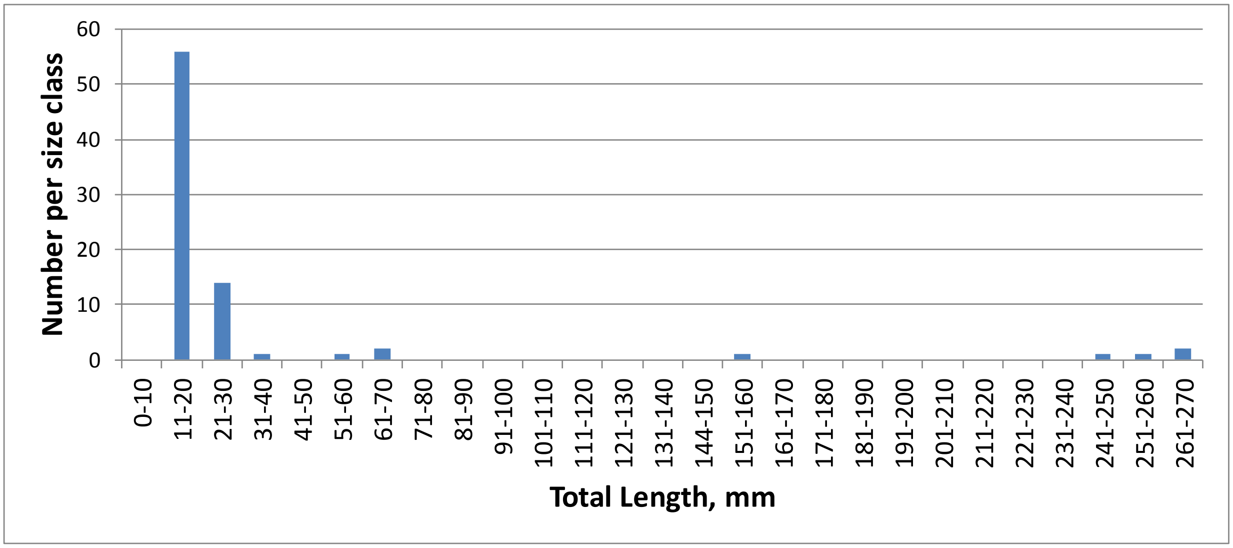

Figure 11.1. Length-frequency histogram for *Scaphirhynchus* young-of-the-year (YOY) processed while sampling the Lower Mississippi River (RM 320-0), 2001-2010.

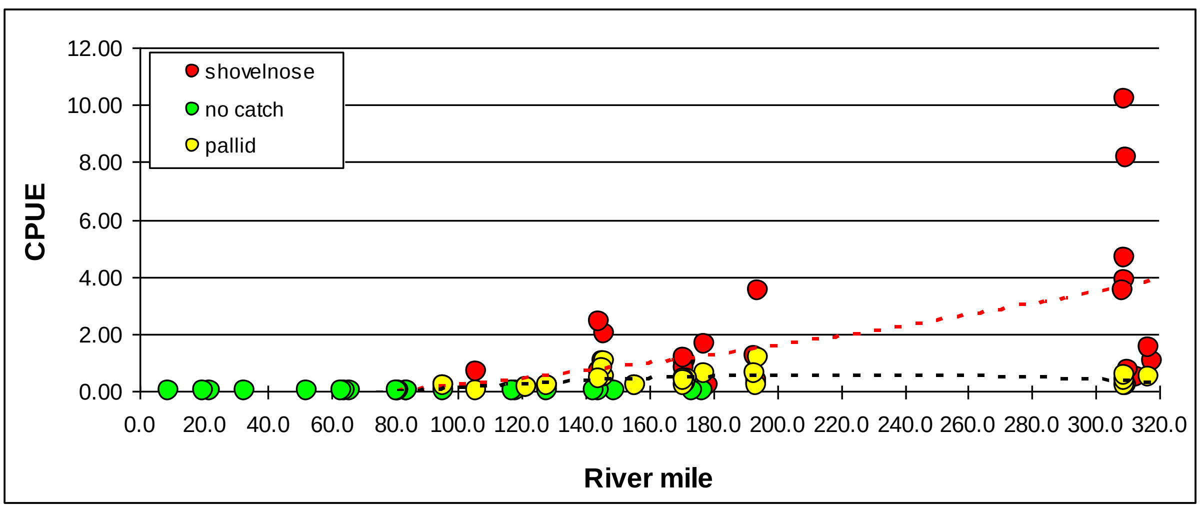

Figure 12.1. Plot of CPUE of pallid and shovelnose sturgeon by river mile for trotlines sampled in the Lower Mississippi River (RM 320-0). Dashed line represents best fit line (2nd order polynomial) through respective data points. Shovelnose sturgeon equation: $y = 3E\text{-}05x^2 - 0.0062x - 0.6581$, $R^2 = 0.3183$; pallid sturgeon equation: $y = -9E\text{-}06x^2 + 0.0042x - 0.1969$, $R^2 = 0.1527$.

Chapter 2

Estimating Pallid Sturgeon (*Scaphirhynchus albus*) Abundance in the Lower and Middle Mississippi River from the Absence of Recaptures

by

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Abstract

Abundance estimates are essential for estimating the viability of populations and the risks posed by alternative management actions. A long-term (1997-2008) sequential mark-recapture survey of pallid sturgeon in the Lower and Middle Mississippi River failed to recapture any of the 241 individuals marked within the Mississippi River itself. We demonstrate that the data are still useful insofar as they suggest lower bounds on abundance consistent with some probability of no recaptures. After accounting for survival, movement, and habitat use, we estimated that the total abundance of age-3+ pallid sturgeon in the Lower and Middle Mississippi River is at least 3,400-4,100 with probability 0.99; 5,900-7,000 with probability 0.95; and 17,000-20,000 with probability 0.75. The latitudinal pattern of reach-level abundance was driven by our assumption about population density along the river. If we assumed fish were distributed in proportion to survey catch-per-unit-effort, then the southernmost reach in the survey, which is thought to lack spawning habitat, hosted at least 3.8, 6.5, or 19 fish per river kilometer (rkm), whereas the remainder of the reaches in the lower and middle Mississippi River hosted at least 1.8-2.3, 3.0-3.9, or 8.7-11.3 fish rkm^{-1}. If we instead assumed a uniform population density over the length of the survey area, the three lower-bound estimates were at least 2.1, 3.7, and 10.7 fish rkm^{-1}. The Lower Mississippi River as a whole comprised over 80% of the Mississippi River population with an average density of 2.0-12.4 age-3+ pallid sturgeon rkm^{-1}. While highly uncertain, our estimates of abundance provide objective initial inputs for what remains an elusive variable in the analysis of viability for the Mississippi River population of pallid sturgeon.

Introduction

Understanding, in absolute terms, the risks facing populations of concern requires an estimate of abundance. As with most of the information we need to know about rare species, however, an abundance estimate may not be available through traditional means, even after extended periods of study. Such is the case with the population of pallid sturgeon, *Scaphirhynchus albus*, in the Mississippi River. The species was listed as endangered in 1990 (55 Federal Register 36641-36647) with presumed low population sizes and recruitment due to overfishing, habitat modifications, pollution, and hybridization (Dryer and Sandvol 1993). The range of the pallid sturgeon includes the Missouri River as well as the Middle and Lower Mississippi River. Pallid sturgeon do not occupy the Upper Mississippi River above the mouth of the Missouri River due to impoundment and are thought to be rare in the lowermost 160 km of the river below New Orleans (Dryer and Sandvol 1993). Pallid sturgeon were historically considered common in the Middle Mississippi River (MMR) between the mouths of the Missouri and Ohio Rivers. Little was known about population density in the Lower Mississippi River (LMR) and the species was thought to be rare there (Duffy et al. 1996). However, the abundance of pallid sturgeon relative to its sister species, *S. platorynchus*, has long been observed to increase southward (Forbes and Richardson 1905; Bailey and Cross 1954), and a more recent study of the LMR indicated higher relative abundances of pallid sturgeon than previously thought (Killgore et al. 2007a).

A long-term survey effort to elucidate abundance and distribution within the Mississippi River captured and marked hundreds of individuals between New Orleans, LA, and the mouth of the Missouri River (Hoover et al. 2007; Killgore et al. 2007a, b)). None of the marked individuals were recaptured in the Mississippi River (Killgore et al. 2007a). The absence of recaptures presents a challenge for traditional mark-recapture methods of abundance estimation but is far from novel. A similar problem arises in risk analysis whenever an event of interest (e.g., an oil spill or pharmaceutical side effect) has not yet been observed (Louis 1981; Hanley and Lippman-Hand 1983; Smith and Winkler 1999; Winkler et al. 2002). The probability of such occurrence is seldom zero. For the mark-recapture problem, Bell (1974a) suggested the use of the hypergeometric probability distribution to estimate population size in light of some chosen probability of no recaptures. Edwards (1974) noted that such an approach can only offer lower bounds on abundance and suggested the use of likelihood ratios for statistical inference. Combined, these methods are easily generalized to sequential mark-recapture studies that might typically be analyzed using the Schnabel estimator (Schnabel 1938; Chapman 1952). The results are highly uncertain and honestly confront the unbounded nature of the problem; the most likely population given no recaptures is always infinite in size. At best, we can only suggest an approximate probability distribution for abundance (Edwards 1992) from which any point estimate is arbitrary.

In this paper we briefly describe our extension of Bell's (1974a) nil-recapture concept to spatially-structured sequential mark-recapture data. We then use the method to find a range of abundance estimates for the pallid sturgeon population in the LMR and MMR under contrasting assumptions about its distribution.

Methods

Survey Overview

A thorough explanation of the survey, study area, and reach delineations can be found in Killgore et al. (2007a). Briefly, the survey dataset covered 12 years (1997 through 2008) of catching and marking pallid sturgeon in the LMR and MMR. The river was divided into six reaches, A-F (Figure 1.2), corresponding to geomorphic differences and river management activities for navigation and flood control. Reach A, the 153 river kilometers (rkm) of river south of New Orleans, yielded no pallid sturgeon and was not considered in this study. Reach B extended 349 rkm from New Orleans to the mouth of the Atchafalaya River, near the southwestern corner of Mississippi. Reach C included the next 433 rkm to the mouth of the Arkansas River. Reach D extended the next 598 rkm to the mouth of the Ohio River, the northern limit of the LMR. Reach E comprised the 314 rkm of the MMR to the mouth of the Missouri River and included the Chain of Rocks, which was separately designated reach F. In the current study, reaches E and F were combined and called reach E+F.

Sampling locations were largely driven by access and the allocation of effort across reaches changed over time with the greatest effort expended in the first half of the survey. All sampling bouts deployed trotlines in a consistent manner throughout the study period. Each trotline was 61 m long, with 60 hooks baited with worms, and deployed for approximately 16 h from late afternoon until the following morning.

Likelihood Function

Each sampling event in the survey consisted of up to eight trotlines and multiple individuals were sometimes caught. Strictly, then, each bout of sampling was conducted without replacement (i.e., the number of fish available to the second hook was one less than the number available to the first hook), indicating the use of a hypergeometric probability distribution to model the likelihood of not catching a marked fish in the sample. In practice, the hypergeometric, binomial, and Poisson distributions gave identical results because the number of fish caught was small relative to estimated total abundance. Hence, we describe the likelihood function generically as proportional to the probability that the number of recaptured fish, r, was zero given c captures and m marked individuals in a population of N fish (sensu Edwards 1992) and provide the hypergeometric expression as only one example of specific functions that could be used. That is,

$$L(N|r=0,c,m) \propto \Pr(r=0|c,m,N), \quad \text{Eq. 1a}$$

$$\Pr(r=0|c,m,N) = \frac{(N-m)!(N-c)!}{N!(N-m-c)!}, \quad \text{Eq. 1b}$$

where L denotes likelihood and Pr denotes probability. Eq. 1b is the hypergeometric probability of no recaptures.

Repeated sampling and marking add three complexities to the inference described in Eqs. 1. First, the number of marked individuals changes in time. Second, an assumption must be made about change in total population size over time. Third, the likelihood of no recaptures must be expressed as the conditional probability of no recaptures in any of the sampling events.

While it is common to make closed-population assumptions [constant population size, no emigration or immigration, no mortality (sensu Gazey and Staley 1986; Yang and Pal 2010)], we assumed the population was open but at birth-death-immigration-emigration equilibrium. Because we were lacking the multiple recapture data necessary for open population estimation methods (Seber 2002), we accounted for immigration, emigration, and survival of marked individuals using an independent demographic model described in the next section (see Estimating Marked Individuals*)*.

We assumed that samples were independent over time. Thus, given no recaptures after repeated sampling and marking events, the likelihood of N is proportional to the joint probability of no recaptures in any sample (Schnabel 1938; Otis et al. 1978; Gazey and Staley 1986), computed as the product of Eq. 1b over all samples.

We also assumed that river reaches were independent. Hence, the joint probability that no individuals were recaptured in any of the locations sampled was taken as the product of Eq. 1b over reaches. Modeling spatial structure is appropriate when it is unlikely that the population is well-mixed at the spatial scale of the entire survey (Kareiva 1990). With T sample dates and R river reaches in the study, the number of individuals caught was recorded in matrix $\boldsymbol{C}$ with T rows and R columns. In the Mississippi River survey, not all reaches were sampled on the same date because sampling locations were separated by hundreds of kilometers and sampling effort varied geographically over the survey period. If reach i was not sampled on date t, $\boldsymbol{C}_{ti}$ was given a value of zero, which has no effect on the estimate of abundance. The number of marked individuals projected to occupy each reach was recorded in matrix $\boldsymbol{M}$, which was the same size as $\boldsymbol{C}$. The resulting hyperbolic likelihood function for total abundance, N, was

$$L(N|r=0,\boldsymbol{C},\boldsymbol{M}) \propto \prod_{i=1}^{R}\prod_{t=1}^{T}\frac{(N_i-\boldsymbol{M}_{ti})!(N_i-\boldsymbol{C}_{ti})!}{N_i!(N_i-\boldsymbol{M}_{ti}-\boldsymbol{C}_{ti})!} = \prod_{i=1}^{R} L_i, \qquad \text{Eq. 2}$$

where L_i is the likelihood of the reach-level estimate of abundance, N_i.

We explored two possible spatial structures of the population. The first assumed uniform population density along the length of the survey area. The second assumed that spatial variation in population density was described by the reach-specific catch per unit effort (CPUE) observed during the survey. The proportion of the total population expected to occupy each reach, denoted w_i, based on either reach length or reach length and CPUE, was then used to determine the local population sizes for any total abundance, such that $N_i = Nw_i$. We explored two spatial structures because it was not clear whether CPUE measured relative abundance, detectability, or the degree of aggregation at nonrandomly-selected sampling locations.

One cost of including spatial structure was that it required assumptions not only about how to apportion abundance over space but also about the degree of dispersal among locations (Hilborn 1990). Observations of pallid sturgeon movement include individuals with high site fidelity (Bramblett and White 2001) as well as dramatic, long distance relocations (Mayden and Kuhajda 1997; Killgore et al. 2007a). A recent telemetry study in the MMR(Koch et al. 2012) observed a maximum 300 km movement among 84 tagged pallid sturgeon, with seven individuals dispersing out of the reach in a year, yielding a dispersal rate estimate of 0.083 with a 95% confidence interval of (0.024, 0.143). We explored two levels of dispersal rates enclosing the 95% confidence interval for exchange between neighboring reaches: no dispersal and 15% annual dispersal from reach E+F to reach D. In the latter case, dispersal rates between other neighboring reaches were adjusted to maintain either the uniform or CPUE spatial structure by accounting for total relative abundance and relative survival rates (described in more detail in the next section).

We also considered a model in which the entire Mississippi River population of pallid sturgeon was panmictic such that any marked individual could conceivably be caught at any location. While formally free of spatial structure, this model implicitly assumed uniform density and high dispersal rates. Such assumptions lead to the most conservative estimate of abundance.

Estimating Marked Individuals

To employ Eq. 2, it was necessary to project the number of marked fish in each reach on each sampling date (Chapman 1954), producing the matrix, $\boldsymbol{M}$. We did this deterministically by decrementing the cumulative number of fish marked during the survey to account for daily mortality and emigration. Classified by the age-length relationship for LMR pallid sturgeon (Killgore et al. 2007b), the youngest fish caught was age three. The annual survival of adult pallid sturgeon in the LMR has been estimated to be 0.93 by catch curve analysis (Killgore et al. 2007b). This same survival rate was used for age-3+ individuals in a previous population model for pallid sturgeon (Bajer and Wildhaber 2007) and is near the rate of 0.92 estimated by mark-recapture methods for age-1+ hatchery-reared pallid sturgeon in the Missouri River (Steffensen et al. 2010). Survival in the MMR (reach E+F) was set to 0.70 based on an estimate from catch curve analysis (Killgore et al. 2007b). The higher mortality rate in the MMR reflects that the survey was conducted before the moratorium there on commercial fishing for *S. platorynchus*, which impacted pallid sturgeon through the species' similarity of appearance. For the panmictic model, we averaged reach-specific survivals, weighting by reach length, to obtain a river-wide survival rate of 0.887. We further assumed that the population was open; 10% of fish emigrated from the system annually and never returned (sensitivity to emigration rate was also explored).

Dispersal between reaches (when non-zero) was estimated using relative abundance expected from uniform or CPUE patterns of population density, *w*, and reach-specific survival rates, *s*, using the formula,

$$d_{ij} = \frac{w_j s_j}{w_i s_i} d_{ji}, \qquad \text{Eq. 3}$$

where d_{ij} is the dispersal rate from reach i to reach j. We solved Eq. 3 for each reach in turn starting with the assumption of 15% dispersal from reach E+F to reach D and working southward. We assumed reaches C and D exchanged individuals with both their upstream and downstream neighbors; in the terminal reaches, B and E+F, all dispersers moved toward the interior of the survey area. Table 1.2 gives the resulting dispersal rates for the two spatial structures we explored.

All rates, including dispersal, were converted to a daily time scale based on 365 days per year and applied to the number of days between sampling events. While all calculations were carried out with double-precision floating point numbers, the number of marked fish was rounded to the nearest integer when entered into the likelihood function. Rounding had the effect of delaying demographic changes in the short term (one fish does not become 0.999 fish the next day). We assumed that survival, emigration, and population size remained constant over the survey period, tagging did not affect survival or detectability, tags were not lost, and populations were well mixed within reaches.

Detectability

It is unlikely that all individuals were detectable during sampling bouts. Hence, the number of marked individuals available to the sampling gear was smaller than the total number projected. Trotlines were deployed along the channel border and near-shore areas but the main channel could not be sampled due to towboat traffic. Pallid sturgeon may spend about 40% of their time in the main channel (Hurley et al. 2004). While this behavior was measured in the MMR and is likely to differ over space, we assumed only 60% of the marked individuals were detectable during any given sampling bout. This assumption had the net effect of reducing total abundance estimates by 40%.

Cumulative Probabilities

The right side of Eq. 2 is a probability mass function. Every point on the function is the probability of no recaptures given $\boldsymbol{C}$, $\boldsymbol{M}$, r, and N (Edwards 1974). The function is unbounded, such that the maximum likelihood estimate of N is infinity. The most accurate way to communicate the abundance estimate is to report the entire probability mass function. If required, a point estimate or a finite range of abundance can be selected from the mass function, but this selection is necessarily subjective. Bell (1974a; 1974b; 1977) suggested that a practical method for point estimation is to report the abundance for which the probability of no recaptures was 0.5. His reasoning was that such a point estimate is neither so large that recaptures were unlikely nor so small that the absence of recaptures was unlikely. However, Bell's method does not allow the user to assign a probability to the estimate of abundance itself.

Likelihood theory provides an approximate basis for the assignment of probabilities to nil-recapture estimates of abundance. Eq. 2 can be used to generate relative likelihoods for finite abundance estimates. The probability that the true abundance is *at least* as great as the estimate is then approximated by the χ^2 distribution and one degree of freedom (Edwards 1992). Because the maximum likelihood given by Eq. 2 is $L(N = \infty) = 1$, the relative likelihood of any finite abundance estimate is simply $1/L(N)$ and its probability as a lower bound on abundance is χ^2 [-2ln$L(N)$, 1]. We chose to find point estimates of abundance for which the probability of the true abundance exceeding our estimates was 0.99, 0.95, and 0.75. These lower confidence limits correspond approximately to probabilities of no recaptures of 0.036, 0.147, and 0.516, respectively. We chose the least conservative lower bound for its near equivalence to Bell's (1974) suggested target probability of 0.5.

Results

In total, 50, 64, 70, and 57 pallid sturgeon were caught and marked in reaches B, C, D, and E+F, respectively, from 1997 through 2008. Figure 2.2 illustrates the projected number of marked fish in each reach over time with the assumed rates of survival and emigration from the Mississippi River and no dispersal. The projected number of marked individuals was used to parameterize Eq. 2 for the estimation of total and reach-level abundance. Alternate projections with dispersal between neighboring reaches (rates given in Table 1.2) led to an increase in the number of marked pallid sturgeon expected in the largest reach, D, for both uniform and CPUE population structures. Dispersal consistent with the CPUE pattern of population density reduced the projected number of marked fish in reach C.

Abundance estimates were robust to the assumptions made about spatial structure and dispersal. All models led to estimates of similar magnitude. Figure 3.2 shows the probability mass and cumulative probability for total population size given no recaptures derived using the uniform and CPUE assumptions without dispersal, as well as the panmictic assumption. The three relative likelihoods evaluated provided a range of lower bounds on total abundance from roughly 3,400 to 20,000 age-3+ fish across models (Table 2.2). The CPUE-based estimate was 10% higher than that gained from the uniform density assumption. Limited dispersal between neighboring reaches increased uniform abundance estimates by 1% and CPUE abundance estimates by 0-2%. Panmixia decreased the estimate of abundance 7% relative to the uniform model with limited dispersal.

The spatial pattern imposed on reach-level population densities had the greatest effect on abundance in the southernmost reach, B (Figure 4.2). The uniform model led to a spatial structure with 21% of the total population in reach B, yielding a lower 95% (99%-75%) bound on local abundance of 1,300 (750-3,800) age-3+ fish (Figure 4.2b). In contrast, the CPUE model suggested that 33% of the population resides in reach B, with a lower bound on abundance of 2,300 (1,300-6,600) age-3+ fish (Figure 4.2b). Under a panmictic model (no spatial structure), the lower bound on river-wide population density was 3.5 (2.0-10.1) age-3+ fish rkm^{-1}. Under the uniform model, density was similarly at least 3.7 (2.1-10.7) age-3+ fish rkm^{-1} (Figure 4.2a). Under the CPUE model, the density of age-3+ fish varied among reaches. Reach B had the highest density, 6.5 (3.8-18.9) rkm^{-1}, while reach C had the lowest, 3.0 (1.8-8.7) rkm^{-1}. Density in reach D was 3.9 (2.3-11.3) rkm^{-1}. Reach E+F had a population density of 3.4 (2.0-9.8). The river-wide average density with the CPUE spatial structure was at least 4.2 (2.4-11.9) age-3+ pallid sturgeon rkm^{-1}.

Uncertainty in the distribution of the population among reaches had only a small effect on the relative sizes of the LMR and MMR populations. While the lower river accounted for 81% of the survey area's length, the CPUE distribution assigned it 85% of the total abundance. Mean population density in the LMR was 4.3 (2.5-12.4) age-3+ fish rkm^{-1} compared with 3.4 (2.0-9.8) age-3+ fish rkm^{-1} in the MMR.

Abundance estimates were sensitive to the emigration rate used to project the number of marked individuals (Table 3.2). The only recapture of a pallid sturgeon marked during the survey was made by a commercial fisherman in the Obion River, TN (Killgore et al. 2007a), providing evidence that some marked individuals could have permanently emigrated from the study area and would thereby become undetectable. The results in Table 2.2 assumed a 10% annual rate of emigration. Reduction of annual emigration to 0% decreased abundance 13%. Increasing emigration to 20% increased abundance 16%. Sensitivity to annual survival would be identical.

The efficiency of sampling gear varies among age or size classes of fish (Anderson 1995). Killgore et al. (2007a) noted that pallid sturgeon did not fully recruit to trotlines until age 11. We explored the sensitivity of the abundance estimate to the reduced detectability of younger age classes using a panmictic model. Captured, marked fish were initially assigned to age classes based on their length using the von Bertalanffy growth model of Killgore et al. (2007b). Age-specific detectabilities for age classes 3-10 were calculated as the number of fish per age class relative to the number expected by backward-interpolation of survival based on age-11 fish. The abundance, length, and detectability of these fish were then projected using our demographic model in combination with the growth model and age-specific detectability. These projections resulted in a modified number of detectable marked fish per sampling bout. We found that the apparent bias of trotlines toward larger age classes could lead to a 12% overestimate of abundance.

Discussion

The abundance of pallid sturgeon is a critical factor in the estimation of the species' viability. The most conservative of our four spatially structured models, the uniform density estimate without dispersal between reaches, suggested there was a 1-25% chance that the Mississippi River between New Orleans and the mouth of the Missouri River contains fewer than 3,700-18,000 age-3+ pallid sturgeon, respectively. The statistical confidence expressed for these estimates is overstated; abundance was slightly sensitive to unquantified uncertainty about spatial structure and dispersal and moderately sensitive to uncertainty about survival, emigration, and gear bias. Additional uncertainty in the projection of the marked population due to environmental variation and demographic stochasticity could be captured by stochastic simulation. However, our goal was to find a first approximation of abundance consistent with the survey data to guide models and management of the MMR and LMR populations. In this respect, we can generally conclude it is 25 times more likely that total abundance is less than 20,000 age-3+ individuals than that it is less than 4,000 individuals. Our exploration of model sensitivities suggests that the error in these probabilistic estimates is less than one order of magnitude.

Our range of lower bounds is inclusive of independent estimates of pallid sturgeon abundance. An unpublished genetic analysis has estimated an effective population size in the LMR of about 20,000 individuals (Rob Wood, pers. comm.). The effective population size is likely conservative (Hartl and Clark 2007), although its geographic scope is also likely to exceed the LMR due to gene flow. A mark-recapture experiment utilizing a greater diversity of sampling gear and greater effort focused on the MMR estimated 1,600 pallid sturgeon (Garvey et al. 2009), a number close to our 95% lower bound estimate of 1,100-1,200 age-3+ fish for reach E+F and likely to address similar age classes. Our lower bounds also encompass the IUCN Red List species assessment for the entire geographic range (Krentz 2004), 6,000-21,000 individuals, taken from Duffy et al. (1996). Our estimate differs from Duffy et al. (1996) in that the interval 1) describes only the lower bound on abundance, 2) is restricted to the Mississippi River portion of the species range, and 3) explicitly includes only age-3+ individuals. Due to recruitment in the Mississippi River, the total abundance including younger age classes may be substantially higher. We are currently developing a demographic model for the Mississippi River population of pallid sturgeon that will help extrapolate abundance to include age-1 and -2 fish.

Comparison of wild adult pallid sturgeon in one reach of the Lower Missouri River, where natural recruitment is considered rare or absent, appear to exist at a density of 5.4 to 8.9 fish rkm^{-1} (Steffensen et al. 2012), a level that falls between our 95% and 75% lower bounds for the uniform Mississippi River population density of 3.7-10.7 age-3+ fish rkm^{-1}, with the obvious difference that the former counts only adults (fork length > 589 mm).

The nil-recapture estimates may be inflated. Closed population models tend to have overestimation bias (Evans and Bonnet 1994; Fewster and Jupp 2009) and this bias can be large in cases with few or no recaptures, in which case even typical bias corrections are insufficient (Chapman 1952). In addition, the assumption that all detectable fish in a reach are sampled by an overnight trotline is an obvious simplification. Finally, the sensitivity to gear bias demonstrated that our lower bounds could be inflated by 12%.

There is also a chance that the nil-recapture estimates are conservative. We made the broad assumption that 40% of marked fish were undetectable based on a telemetry study of habitat use in the MMR (Hurley et al. 2004). A more recent study (Koch et al. 2012) found a similar 44% chance that individuals were in main channel habitat, out of the reach of sampling gear deployed in the river margins. However, the same reported individual movements ranging from 0.5 to 6.6 km per week, suggesting that pallid sturgeon frequently move throughout the river. Hence, our assumption about detectability may have been too conservative. The 16 h deployment of trotlines in the survey could be sufficient to allow substantial turnover of individuals between main channel and margin habitats. Finally, the sensitivity of our estimates to the emigration rate was substantial. While movement of pallid sturgeon between the Mississippi River and its tributaries has been observed (Killgore et al. 2007a; Koch et al. 2012), the annual emigration rate, whether that rate differs among reaches, and whether those individuals are likely to return is not clear. Our use of 10% emigration was intended to be conservative.

The distribution of the Mississippi River population is of potential importance to its viability because reach B lacks hard substrates (Baker et al. 1991) that are thought to serve as spawning habitat (Dryer and Sandvol 1993). While there was evidence from body condition measured during the survey that adults in the lower LMR make upstream spawning migrations (Hoover et al. 2007), such inferences may be confounded with seasonal variation in sampling effort as well as latitudinal gradients in morphology (Murphy et al. 2007). Large seasonal movements of pallid sturgeon have been observed in other parts of the range (Bramblett and White 2001; Koch et al. 2012). It remains unclear whether reach B represents a rearing habitat for immature individuals, the non-spawning home range of an actively-recruiting population, or a sink population (Holt 1985; Pulliam 1988) sustained by larval drift. Such hypotheses also affect the perceived role of reaches C and D, which may comprise the best remaining habitat for pallid sturgeon due to their relatively low channelization and absence of impoundments or major diversions (Baker et al. 1991). While the combined abundance of fish in reaches C and D was insensitive to our assumptions about spatial structure, the population growth rate necessary for persistence would differ greatly between the uniform and CPUE spatial patterns of abundance if reach B is a sink.

Population estimates for the MMR and LMR reported herein, along with published estimates from the Missouri River (Steffensen et al. 2012), provide the first range-wide perspective on pallid sturgeon populations in the free-flowing Missouri-Mississippi river system. Together, these studies suggest population sizes of adult wild pallid sturgeon ranging from approximtely 2 to 12 fish/km. Hatchery fish in the Missouri River were considerbly more abundant (28.6 to 32.3 fish/km Steffensen et al. 2012) than wild fish in either the Missouri or Mississippi rivers. While establishment of a large and reproductive population is a primary recovery goal (U.S. Fish and Wildlife Service 2013), stocking above the carrying capacity of specific reaches carries the risk of depressing demographic rates due to negative density dependent effects (Braaten et al. 2009). Management activities for pallid sturgeon can now consider population estimates of wild fish as part of recovery plans throughout the range of this species.

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Table 1.2. Proportion of each reach population dispersing to neighboring reaches consistent with either uniform population density or the pattern of catch per unit effort (CPUE) observed during the survey. Assumes dispersal from reach E+F was 0.15 for both spatial structures. We assumed fish in the central reaches, C and D, moved both up- and downstream. We assumed fish in the terminal reaches, B and E+F, moved only toward their neighboring reach.

Reach	Uniform	CPUE
B	0.1	0.05
C	0.16	0.18
D	0.12	0.1
E+F	0.15	0.15

Table 2.2. Lower-bound estimates of the abundance of age-3+ pallid sturgeon in the middle and lower Mississippi River. Five model variations and their averages are shown.

	Abundance[a]		
Model[b]	$P \approx 0.99$	$P \approx 0.95$	$P \approx 0.75$
panmictic	3,400	5,900	17,000
uniform	3,600	6,300	18,000
uniform, dispersal	3,700	6,400	18,000
CPUE	4,000	7,000	20,000
CPUE, dispersal	4,100	7,000	20,000
average of models	3,800	6,500	19,000

[a]Column headings give the approximate probability that the true abundance is not less than the estimates. Abundance rounded to nearest 100.

[b]Model variations described in Methods.

Table 3.2. Sensitivity of pallid sturgeon abundance estimates to the assumption of annual emigration rate. Estimates assume uniform population density and no dispersal among reaches.

	Abundance[a]		
Emigration	$P \approx 0.01$	$P \approx 0.05$	$P \approx 0.25$
0%	4,200	7,300	21,100
10%	3,600	6,300	18,000
20%	3,200	5,400	15,700

[a]As in Table 2.2.

Figure 1.2. A map of the survey area illustrating the locations of reaches A-F on the lower and middle Mississippi River. Reproduced from Killgore et al. (2007).

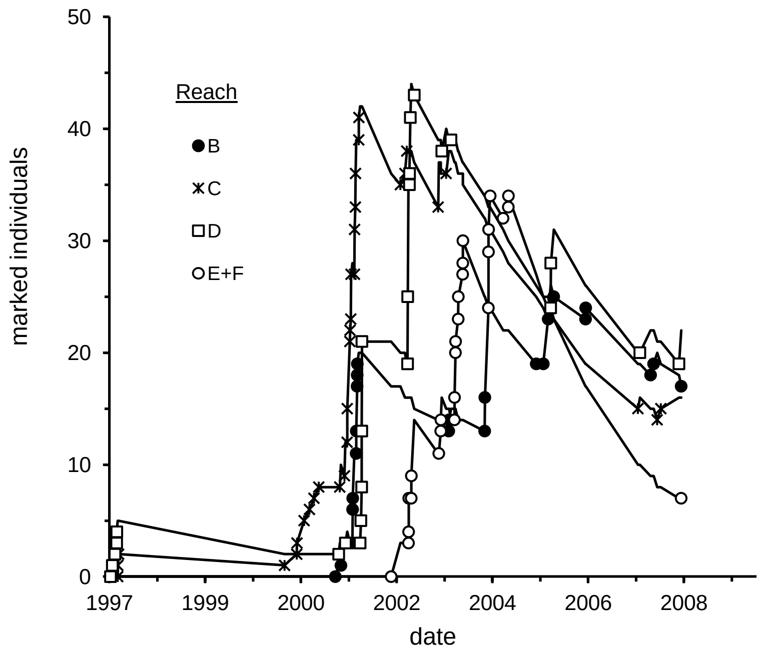

Figure 2.2. Projected numbers of marked pallid sturgeon in four reaches of the middle and lower Mississippi River from 1997 through 2008. Symbols indicate dates on which individuals were caught and marked during the survey period (with the exception of the final symbol for reach E+F, which was added to help identify the curve). Details of projections are given in Methods. The total number of individuals caught and marked was 50, 64, 70, and 57 in reach B, C, D, and E+F, respectively.

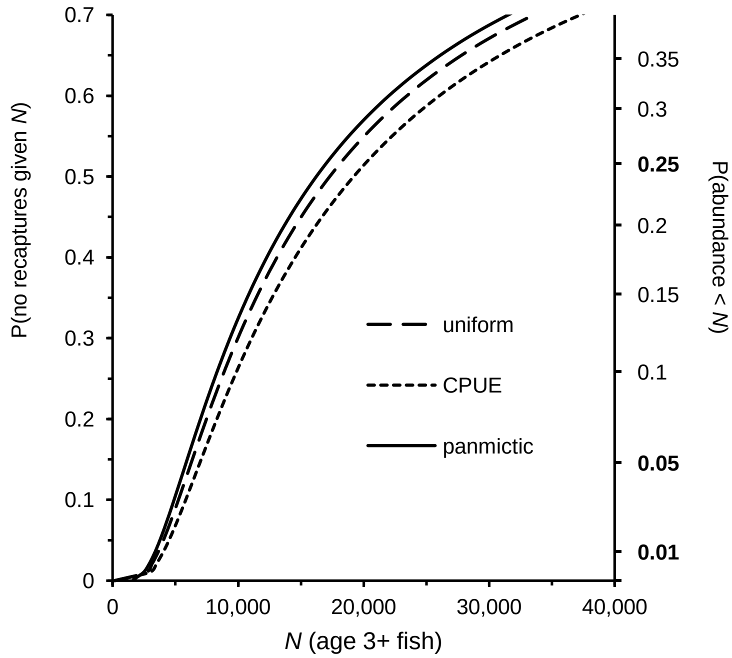

Figure 3.2. The probability of not recapturing any marked individuals during the 1997-2008 Mississippi River survey as a function of hypothetical total population size (left axis) and the associated cumulative probability based on the likelihood ratio test (right axis). The three curves demonstrate the effect of spatial structure model on the estimate. For uniform and CPUE models, curves indicate the estimate assuming no dispersal between reaches. Curves derived assuming dispersal are omitted for clarity.

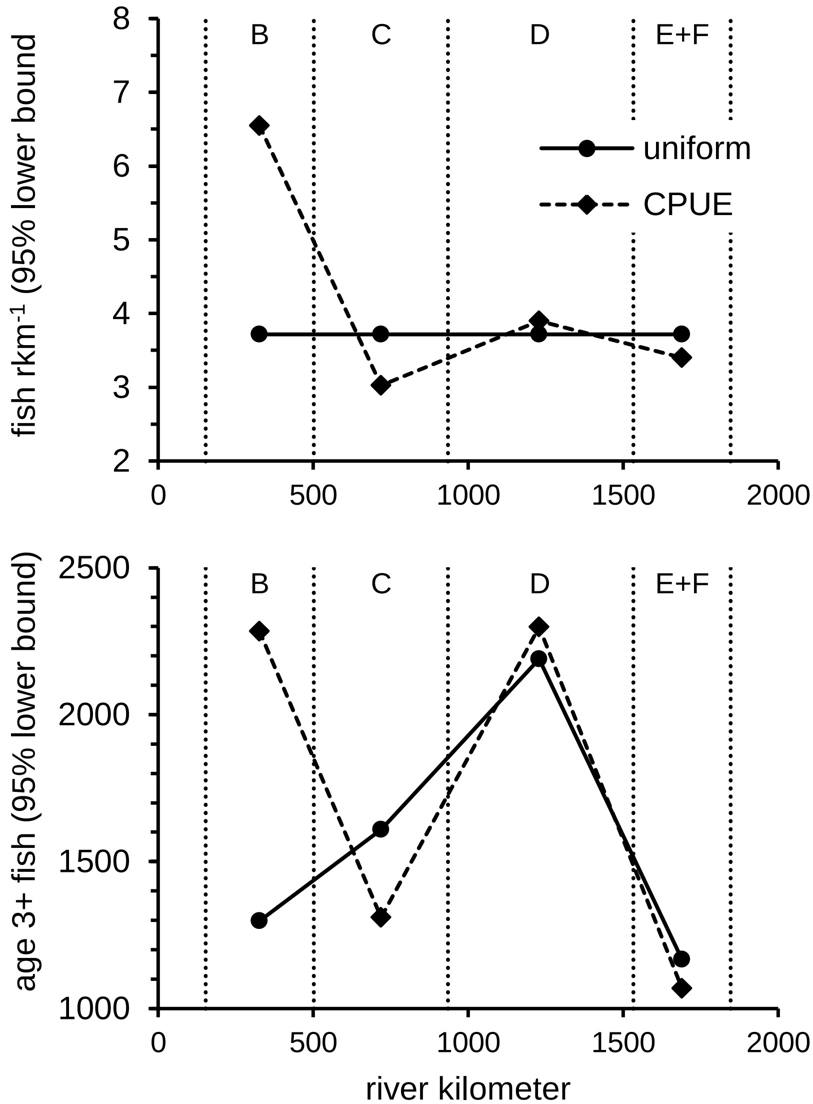

Figure 4.2. Spatial structure of pallid sturgeon population density in the lower and middle Mississippi River. The two series in each panel reflect different spatial structure models. Top panel: the 95% lower bound on population density. Bottom panel: the 95% lower bound on abundance.

Chapter 3

Fish Entrainment by Freshwater Diversions of the Lower Mississippi River.

by

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Abstract

Freshwater diversions in the Lower Mississippi River will likely entrain riverine species and introduce them into new habitats where they may flourish or fail to persist. The pallid sturgeon is endangered and may be entrained in diversions. This study used a variety of collection methods to document the degree to which species are being entrained by six freshwater diversions located in south Louisiana, Bonnet Carré Spillway, Davis Pond Diversion, Violet Siphon, Caernarvon Diversion, White Ditch Siphon, and Naomi Siphon. Special effort was devoted to documenting the occurrence of pallid and shovelnose sturgeon. The amount of entrainment was quantified by identifying 35 species that are relatively common in the river but rare or absent in the marshes below the diversion outflows. In total, 113 species were sampled in one or more of the diversions. Entrainment was highest in diversions during or in periods shortly after there were high volumes of flow through the diversions. There was little relationship between entrainment and river stage in most diversions likely because diversion flows were greatly restricted during high river stages. Highest flows were seen in the months following the Deepwater Horizon oil spill when the diversions were opened to near their maximum capacity. During the same period, entrainment was generally high in the larger diversions. Sturgeon were found in samples in the two largest diversions, the Bonnet Carré Spillway and the Davis Pond Diversion. In the former, the occurrence of sturgeon and a high degree of entrainment was found in periods following high flows. In the latter, one pallid sturgeon and three shovelnose sturgeon were taken in each quarter of the latter half of 2009 and the first half of 2010.

Introduction

Freshwater diversions of the Mississippi River have been constructed for habitat restoration, reduction of saltwater intrusion, sediment introduction and land building, and flood control (Rasi and Steller 1999; USACE 2013a, b). Land loss due to subsidence and sea level rise is motivating plans for more and larger freshwater diversions in southern Louisiana (CPRA 2012). The impact that diversions have on fish species and communities has not been documented but should be considered in the placement and design of diversions, especially where federally listed species may be impacted.

Although most of the freshwater diversions are not intended to modify fish habitat or change the abundance of any fish species, they have changed the habitat downstream from the diversion and this has been documented to have negative impacts on some species and positive impacts on others (Sable and Villarubia 2011). It should be expected that species that prefer low-flow backwater habitats and those that prefer brackish water will likely be displaced and move downstream or into backwaters out of the main flow of water from the river. Introduction of river water will likely improve and expand habitat for many other species, especially those that prefer cooler, flowing, or well-oxygenated waters. Such species may move from areas downstream into waters closer to the diversion or they may be entrained by the diversion and then reside in the diversion channel. Freshwater diversions will potentially negatively impact riverine species that specialize on the high-flow and open-water habitats of the river because many will be entrained by the diversions and either concentrated in the relatively narrow channel downstream from diversions or move further downstream into slower and shallower water bodies where they will likely experience reduced food and oxygen availability.

The purpose of this project was to document the fish species that are found in freshwater diversions of the Lower Mississippi River (LMR). Special effort was devoted to documenting the occurrence of the endangered pallid sturgeon (*Scaphirhynchus albus*) and its congener, the shovelnose sturgeon (*S. platorynchus)*, by diversions. In addition, because many species common in the Mississippi River are uncommon in habitats away from the river (Troxler 2011), the relative potential of each of the diversions to entrain riverine fish species can be estimated. This potential to entrain some riverine species may relate more broadly to the overall entrainment potential of the diversions.

Study Sites

Six freshwater diversions were sampled in the course of this study, the Bonnet Carré Spillway, the Davis Pond Diversion, the Violet Siphon, the Caernarvon Diversion, the White Ditch Siphon, and the Naomi Siphon (Figure 1.3). These diversions differ widely in physical structure, capacity, operation, and potential for entrainment of riverine fishes.

The Bonnet Carré Spillway, located on the east bank of the Mississippi River at river mile (RM) 133, was constructed in response to the Great Mississippi Flood of 1927 and was completed in 1931. Its purpose is to divert water during flood stages to reduce risk of flooding of New Orleans and nearby communities. The spillway structure consists of 2.1 km of concrete weir, partitioned as 350 bays with removable wooden "pins." When river levels rise above the level of the concrete weir water can flow through gaps between the pins. The gaps vary in size but are usually less than 5 cm. Leakage flow is commonly seen in late winter and spring when river levels tend to rise. When river levels approach flood stage, flow through the structure can be increased by removing the pins. The design capacity of the structure is 7100 m^3/s (250,000 cfs). Water flow downstream of the structure is constrained by earthen guide levees that direct water for a distance of 9.5 km into Lake Pontchartrain. The structure has been opened to varying degrees since its construction but has been opened on average about every eight years (USACE 2012). Its last opening was in May 2011. The potential of the Bonnet Carré Spillway to entrain fish is expected to be high when the structure is open. During normal high-water leakage, the potential for entrainment of fish is moderate since only relatively small individuals can pass through the gaps between the pins and the overall volume of flow is low.

The Davis Pond Diversion is located at RM 119 on the west bank of the Mississippi River. The diversion, which is under the management of Office of Coastal Protection and Restoration Authority (OCPRA) New Orleans division, was completed in 2001 and began operating in the summer of the following year. The diversion consists of four 4.3 by 4.3-m concrete box culverts with a maximum discharge of 301.57 m^3s^{-1} (10,650 cfs) and is projected to benefit 13,354 hectares of wetlands and 314,441 hectares of marshes and bays over a 50 year period (USACE 2013b). The main channel of this diversion empties into a ponding area and then into Lake Cataouatche and then farther south into Lake Salvador. The potential for this structure to entrain fish when it is open is expected to be high.

The Violet Siphon Diversion is located on the east bank of the Mississippi River at RM 83.8 and is intended to offset increasing salinity in nearby wetlands through freshwater input from the Mississippi River. The Violet Siphon is operated and maintained by the OCPRA New Orleans division, and consists of two siphon pipes with a maximum capacity of 14.16 m^3s^{-1} (500 cfs). This structure was completed in 1979 and has been operated intermittently since (Rasi and Steller 1999). The Violet Siphon channel flows eastward into the Mississippi River Gulf Outlet and Lake Borgne. Because the capacity of this diversion is low, it is also expected to have low fish entrainment.

The Caernarvon Diversion is located at RM 81.5 and was constructed in 1991 with the intention to restore marsh habitat through freshwater input (USACE 2013a). The OCPRA is in charge of the operation and maintenance of Caernarvon Diversion. The structure contains five 4.6 x 4.6-m box culverts along the inflow and outflow channels and has a maximum discharge rate of 226.53 m^3s^{-1} (8,000 cfs; USACE 2013a). Mississippi River water flows through the Caernarvon Diversion into a lake referred to as Big Mar then farther southeastward through marshland and empties into the Breton Sound. The drainage area of this diversion is 15,556 acres and is projected to benefit 802 acres of wetlands by the year 2013. As with the Davis Pond Diversion, it is expected that this diversion will have a high potential to entrain fish when it is open.

The White Ditch Siphon (also known as White's Ditch Siphon) is located at RM 64.5 on the east side of the river (CPRA 2012). The main channel of this diversion flows through private land and therefore operation of this diversion is almost entirely governed by the landowner. The diversion was built in 1960s to enhance muskrat habitat. Two 127-cm siphon pipes deliver as much as 250 cfs of fresh water eastward towards the Breton Sound. Because the capacity of this diversion is low, its potential for fish entrainment is expected to be low.

The Naomi Siphon Diversion is located at RM 63.9 on the west bank of the river. It has a maximum discharge of 59.47 m3s-1 (2,100 cfs) and was completed in 1992 (CPRA 2012). Eight 1.83-m diameter siphon pipes deliver water from the Mississippi River westward toward a lake called The Pen, and then through marsh and bayous in Barataria Bay, influencing 10,765.9 hectares of wetlands. The Naomi Siphon is managed by the Plaquemines Parish government. Because this siphon has a much higher capacity than the other two, it is expected to have higher fish entrainment.

Methods

Fish were sampled by five methods, including: trawling, gillnetting, electrofishing, seining, and trotlining. Trawl sampling was conducted by deploying a 3-m wide otter trawling fitted with a 3-mm mesh cod end bag. The trawl was pulled off the bow of the boat by propelling the boat in reverse. Trawls were pulled downstream in flowing water, just slightly faster than the current. A hand-held GPS was used to record the beginning and ending coordinates of each trawl pull. If there was sufficient clearance, the trawl was pulled for approximately 300 m. If the trawl could not be pulled for 300 m, it was pulled to the maximum extent possible with beginning and ending coordinates recorded. The fish taken in each trawl were identified to species and counted. When fish could not be identified in the field, specimens were taken to the Marine Biology laboratory at Nicholls State University and identified. Trawl data are expressed as total numbers of each species taken by trawl and mean catch per km (CPUE). In larger diversions, like Davis Pond and Caernarvon, multiple trawls were taken in different reaches of the outfall on each day of sampling. In smaller diversions, like White Ditch and Naomi, fewer trawl samples were taken on each day so as not to sample one area multiple times. Where possible, one or more trawl samples were taken near the outfall, and one or more samples were taken downstream from the outfall.

Gillnet sampling was conducted by deploying one or two 60-m experimental gillnets that each consisted of 8 equal length panels of mesh of sizes 2.5 cm, 5 cm, 7.5 cm, and 10 cm. Gillnets were deployed in various locations within each diversion but eddies and deeper holes were targeted when possible. Gillnet deployments were for various lengths of time but a minimum of 2 hours was targeted. When gillnets were retrieved all fish captured were identified to species and counted. Gillnet sample data are expressed as total numbers of each species taken and mean catch per hour (CPUE).

Electrofishing was conducted using a Smith-Root GPP 5.0 using a prod-pole anode. A pulsating current of 4-8 amperes was applied using a foot-pedal switch. A counter recorded the total time current was applied. Each electrofishing station consisted of 500 seconds application of current as the boat was moved along the shoreline. Three people were required for electrofishing, a boat driver, a netter, and a shocker. An attempt was made to net all fish stunned by the current. Netted fish were placed into a livewell and when a station was completed, each was identified to species and counted. Electrofishing sample data are expressed as total number of fish and the mean number of fish captured per 500-second electrofishing station (CPUE).

Seine samples were taken where the shoreline was relatively unobstructed. This was only true in the Bonnet Carré Spillway. The seine used was 18 m long, 2 m high, with 9 mm mesh. In most cases the seine was deployed by boat approximately 30 m from shore. Bridle lines on either end of the seine were used to bring the seine to shore. Data was recorded only from seine pulls that retained their contents through the length of the pull.

Trotline samples were taken with four trotlines each with 60 hooks spaced at 2 m intervals and baited with earthworms. The lines were weighted to keep them on the bottom.

Trotlines were deployed in the late afternoon and retrieved the next morning. Trotline samples were only taken in the Davis Pond Diversion and the Caernarvon Diversion.

Because fish entrainment is likely to be influenced by the velocity and volume of water taken from the river into the diversion, flow rate was measured once every sample day just below the surface and just above the bottom of the water column by a Flo-Mate flow meter (Frederick, MD). Average daily discharge of the Davis Pond Diversion and the Caernarvon Diversion are available from the USGS National Water Information System (http://waterdata.usgs.gov/la/nwis/uv) and are used for comparison. The other diversions either have no monitoring of discharge (Violet, White Ditch) or the monitoring equipment was not functioning during much of the period of this study (Naomi). Entrainment may also be influenced by river stage. River stage data is available from National Weather Service River Forecast Center (http://www.srh.noaa.gov/lmrfc/). For this report, river stage as recorded in New Orleans at the Carrolton gauge at noon on each day was used.

Entrainment estimates were made by comparing species that are only commonly found in riverine habitats to the total sample, or total number of species in the sample. The total number of individuals that were deemed likely to have been entrained divided by the total catch (each expressed as CPUE) gave the percentage of the catch that was entrained. The total number species that were likely to have been entrained divided by the total number of species sampled gives the percentage of entrained species in samples. Preston (1948) argued and showed with a series of data sets of animal communities that rarer species are only likely to be taken in large samples. Thus, an estimate of the taxonomic breadth of entrainment by diversions could be reflected in the ratio of number of entrained species to the total catch per unit effort. This is the entrained species per unit catch.

Results

Fishing Effort

Table 1.3 details fishing effort by method during each quarter from July 2009 through September 2011. One-hundred-thirty days were spent in the field. Gillnet sets averaged over three per day, as did trawling stations. Electrofishing stations averaged almost two per day. On average, in each quarter, there were over 14 days of effort. Figure 2.3 displays the sampling dates of each diversion over the course of the study.

Table 2.3 details fishing effort at the Bonnet Carré Spillway in each quarter. There was substantial sampling effort in the spillway at the beginning of this study because of the possibility of sturgeon remaining resident in the spillway following the 2008 opening. Sampling was also concentrated at the end of this study following the opening in the spring of 2011. In 2009, because there were large pools on the river side of the spillway, some effort was devoted to sampling in those pools because of the possibility that sturgeon may have been trapped there.

Table 3.3 details fishing effort in the Davis Pond Diversion. More days were spent sampling in Davis Pond than in any other diversion. It is larger than all diversions except the

Bonnet Carré Spillway and it flowed to various degrees throughout the period of this study. Much of the effort was devoted to trawl sampling.

Table 4.3 details sampling effort in the Violet Siphon. Sampling was restricted during late 2009 and early 2010 because of low flow and maintenance dredging in the Violet Siphon. Debris in the outflow channel just below the siphon outfall also made trawling near the diversion impossible. Electrofishing and gillnet samples were taken both near and away from the siphon's outfall.

Table 5.3 details sampling effort in the Caernarvon Diversion. Caernarvon was sampled almost as often as Davis Pond. Fewer trawl samples were taken in Caernarvon because of the narrow outflow channel and large amount of debris on the sides of the channel. A single trotline sample was taken in early 2010.

Table 6.3 details sampling effort in the White Ditch Siphon. Only 5 days of sampling were conducted in White Ditch. White Ditch is privately owned and a legal agreement with the landowner had to be reached before sampling could begin. Operation of the White Ditch Siphon is controlled by the landowner. During most of this study the siphon was not operating. The channel downstream of the siphon is small and shallow. Gillnetting was only practical in the outfall pool and trawling was difficult in general. A single day was spent sampling in August 2010 when the siphon was not operating. At that point, it was deemed unproductive to sample if the siphon was not flowing. The siphon did not operate for the remainder of the study.

Table 7.3 details sampling effort in the Naomi Siphon. The Naomi Siphon was initially chosen as an alternative to the White Ditch Siphon because of difficulties with sampling and the intermittent nature of the operation of the White Ditch Siphon. The Naomi Siphon was sampled regularly during 2010 and early 2011. The small size of channel downstream of the siphon limited trawl sampling effort. In May 2011, the siphon was stopped in preparation for maintenance dredging.

Diversion Flows and River Stage

Figure 3.3a shows the river stage at New Orleans, taken at the Carrolton gauge at noon on each of the days samples were taken in one of the diversions. River stage was highest in spring and early summer of 2011 at the time that the Bonnet Carré Spillway was opened. River stage was high enough to allow some water to leak at the Bonnet Carré Spillway intermittently from late 2009 until summer of 2010. The lowest river stage was seen in late 2010 and early 2011. Figure 3.3b and 3.3c show the average daily discharge of the Davis Pond Diversion and Caernarvon Diversion on each of the dates sampling was conducted. Maximum discharge was seen during the spring and summer of 2010. The high flow in each diversion during this period was a response to the Deepwater Horizon oil spill. During this time of high diversion discharge, the Mississippi River stage was moderate and falling. Otherwise, at the highest river stages the Davis Pond Diversion and Caernarvon Diversion were operated with relatively low discharge on most dates. Figure 3.3d shows the surface current at midday at each of the diversions sampled on the day they were sampled. The periods of high and low discharge in the Davis Pond Diversion and Caernarvon Diversion roughly correspond to field measurements of surface flow. Data on discharge at the other diversions is not available, but measured flow rates at the other diversions, although lower, are roughly correlated with those seen in the Davis Pond Diversion and Caernarvon Diversion and appear to reflect river stage only weakly.

Species Sampled

Over the course of this study, 92,301 fish representing 113 species were sampled (Table 8.3). Many of the species in the samples are found generally throughout south Louisiana. A considerable number of species in the samples are euryhaline species of marine or brackish water origin. At least 35 of the species are likely to have been entrained into the diversion as water flowed from the river. These species are listed in boldface in Table 8.3 and will be referred to henceforth as species likely to have been entrained. All of the species indicated are seldom found in habitats downstream from the diversions (Troxler 2011) and most are relatively common in the river or in flowing water elsewhere in Louisiana. The two sturgeon species, *Scaphirhynchus albus, and S. platorynchus*, are riverine species as is the paddlefish, *Polyodon spathula*. Two gar species, *Lepisosteus osseus*, and *Lepisosteus platostomus* are rarely found in non-riverine habitats in south Louisiana. The two *Hiodon* species are also riverine species. Some minnow species (Family Cyprinidae) are common in non-riverine habitats but those in boldface in Table 8.3 (*Cyprinella lutrensis, Cyprinella venusta, Hybognathus hayi, Hybognathus nuchalis, Hybopsis amnis, Lythrurus fumeus, Macrhybopsis aestivalis, Macrhybopsis storeriana, Notropis atherinoides, Notropis shumardi, Notropis volucellus, Opsopoeodus emiliae,* and *Pimephales vigilax*) are uncommon in non-riverine habitats in south Louisiana (Troxler 2011). Likewise, some sucker species (Family Catostomidae) are common in non-riverine habitats but those in boldface in Table 8.3 (*Carpiodes carpio, Carpiodes cyprinus, Carpiodes vellifer, Cycleptus elongatus, Ictiobus bubalus, Ictiobus cyprinellus, Ictiobus niger,* and *Minytrema melanops*) are uncommon in non-riverine habitats in south Louisiana. Members of the family Moronidae can be found in a range of habitats in south Louisiana but the majority of striped bass (*Morone saxatilis*) taken in this study were large and taken just below the outfall of the diversions. Thus, striped bass are considered species indicative of entrainment. Most sunfish species (Family Centrarchidae) can be found throughout south Louisiana but the spotted bass (*Micropterus punctulatus*) prefers flowing water and likely came into the diversions by entrainment. Members of the perch family (Family Percidae) that were sampled in this study (*Etheostoma asprigene, Percina caprodes, Percina maculata,* and *Sander canadensis*) are rarely taken away from the river in south Louisiana. Sleepers (Family Eleotridae) are common in south Louisiana, but the bigmouth sleeper, *Gobiomorus dormitor*, is only common in south Louisiana in the Mississippi River in Plaquemines Parish. In addition to the species listed in boldface in Table 8.3, there are many other species that are much more common in the Mississippi River than in non-riverine habitats in south Louisiana including *Atractosteus spatula, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis, Ictalurus furcatus, Ictalurus punctatus, Pylodictis olivaris* and *Aplodinotus grunniens.* Several of these species were abundant in our samples, but because each could have entered the diversion from downstream areas, these species are less suitable and were not used as indicators of entrainment.

In the Bonnet Carré Spillway, 11,808 fish representing 72 species were sampled (Table 9.3). Twenty-five of the 35 species likely to have been entrained were found in the Bonnet Carré Spillway. Three of the 35 species that are likely to have been entrained were only taken at the Bonnet Carré Spillway (*Hiodon tergisus, Percina caprodes,* and *Percina maculata*). Three additional species were only taken at the Bonnet Carré Spillway, *Hypophthalmichthys nobilis, Erimyzon oblongus,* and *Herichthys cyanoguttatum.* Of the methods used, seine sampling produced the most species rich samples (60), followed by electrofishing (49) and gillnetting (42). Both sturgeon species were taken in our samples. All but one of the sturgeon sampled were taken by gillnet. The other was taken by seine.

In the Davis Pond Diversion, 26,969 fish representing 77 species were sampled (Table 10.3). Twenty-seven of the 35 species likely to have been entrained were found in the Davis Pond Diversion. Three of the 35 species likely to have been entrained were only taken at the Davis Pond Diversion (*Macrhybopsis aestivalis, Minytrema melanops,* and *Gobiomorus dormitor*). Two additional species were only taken at the Davis Pond Diversion, *Lepomis marginatus,* and *Lutjanus griseus.* Sixty-nine species were sampled by electrofishing, 42 by trawling, and 28 by gillnetting. Only three species were sampled by trotlining. Four sturgeon were taken, three *S. platorynchus*, and one *S. albus*. One of each sturgeon species was taken in trawl samples and the other two sturgeon were taken in gillnets.

In the Violet Siphon, 16,873 fish representing 61 species were sampled (Table 11.3). Six of the 35 species likely to have been entrained were found in the Violet Siphon. None of the species likely to have been entrained were taken only at the Violet Siphon. Six species were only taken at the Violet Siphon, *Bagre marinus, Oligoplites saurus, Bairdiella chrysoura, Pogonias cromis, Gobionellus oceanicus,* and *Citharichthys spilopterus*. All of these species are euryhaline marine species. Fifty-three species were taken by electrofishing, 43 by trawling and 28 by gillnetting.

In the Caernarvon Diversion, 26,001 fish representing 67 species were sampled (Table 12.3). Eighteen of the 35 species likely to have been entrained were found in the Caernarvon Diversion. One of the species likely to have been entrained was taken only at the Caernarvon Diversion, *Etheostoma asprigene*. Two species were only taken at the Caernarvon Diversion, *Ameiurus nebulosus* and *Caranx hippos.* Sixty species were taken by electrofishing, 34 by trawling and 34 by gillnetting. Only 3 species were taken in trotline samples.

In the White Ditch Siphon, 3,481 fish representing 47 species were sampled (Table 13.3). Five of the 35 species likely to have been entrained were found in the White Ditch Siphon. None of the species likely to have been entrained were only taken at the White Ditch Siphon. Two species were only taken at the White Ditch Siphon, *Ctenogobius boleosoma* and *Gobiosoma bosc.* Both of these are euryhaline marine species. Forty-one species were taken by electrofishing, 23 by trawling and 20 by gillnetting.

In the Naomi Siphon, 7,169 fish representing 58 species were sampled (Table 14.3). Twelve of the 35 species likely to have been entrained were found in the Naomi Siphon. None of the species likely to have been entrained were taken only at the Naomi Siphon. One species was only taken at the Naomi Siphon, *Megalops atlanticus*. Fifty-three species were taken by electrofishing, 31 by trawling and 29 by gillnetting.

Overall CPUE and Entrainment Estimates

Table 15.3 compares the CPUE and entrainment estimates for each of the diversions. Entrainment is expressed as the percentage of the total catch that consisted of individuals of species that were likely entrained, the percentage of species captured that were likely to have been entrained and the number of entrained species per unit catch. High CPUE percent catch entrainment is due to large numbers of individuals of species that were likely to have been entrained and could consist of relatively few or many species having been entrained. Entrainment could be selective of a few species or relatively broad due entrainment of a large number of species. In trawl samples, high percent catch entrainment is seen in Davis Pond samples due to a relatively large number of individuals of a wide variety of species while high percent catch entrainment is seen in Naomi samples due to a relatively large number individuals of a few species. Caernarvon Diversion trawl samples had relatively low percent catch entrainment in spite of having a relatively large number of species entrained. High percentage entrainment due to many individuals of a relatively large number of species can be seen in Bonnet Carré gillnet and electrofishing samples while high percentage entrainment due to large numbers of a relatively few species can be seen in Naomi gillnet and electrofishing samples. High total numbers of entrained species can be due to broad entrainment of many species or due to higher fish densities, and thus larger samples, which would be expected to have a higher proportion of rare species. The last column of Table 15.3 presents the entrained species per unit catch. High values of entrained species per unit catch are likely to due to relatively unselective and broad entrainment of species. There is a consistent pattern in entrained species per unit catch among diversions and sampling methods. The highest values of species entrainment are for either the Bonnet Carré Spillway or the Davis Pond Diversion in all samples. The lowest values are for the Violet Siphon or the White Ditch Siphon in all samples.

Species richness in trawl samples within each diversion ranged from a high of 43 in the Violet Siphon to a low 23 in the White Ditch Siphon (Table 15.3). Species richness in the Davis Pond Diversion was a close second (42) while the other diversions ranged from 30 to 34 species. The proportion of those species that were likely to have been entrained was very different however. Thirty-five percent of the species taken in the Davis Pond Diversion were among those deemed likely to have been entrained. Among the species taken in the White Ditch Siphon and Violet Siphon, less than 5% were likely to have been entrained. The Naomi Siphon was higher at 12% while the Caernarvon Diversion and the Bonnet Carré Spillway each had approximately 20% entrained species.

In samples taken by gillnet, species richness ranged from 42 in the Bonnet Carré Spillway to 20 in the White Ditch Siphon (Table 15.3). In the other diversions, species richness ranged from 28 to 34. The White Ditch Siphon and Violet Siphon samples had 15% or fewer species that were likely to have been entrained while the samples from the Bonnet Carré Spillway and Davis Pond Diversion had 32% or more species that were likely to have been entrained.

In samples taken by electrofishing, species richness ranged from 69 in the Davis Pond Diversion to 41in the White Ditch Siphon (Table 15.3). The other diversions in order of decreasing species richness were Caenarvon (60), Naomi Siphon (53), Violet Siphon (50), and Bonnet Carré Spillway (48). The Davis Pond Diversion also had the highest percentage of species that were likely to have been entrained (35%), followed by Caernarvon (28%), Bonnet Carré (27%), Naomi (17%), Violet (10%), and White Ditch (10%).

The percentage of the fish fauna that was likely to have been entrained was consistently smallest in the two smallest siphons (Table 15.3). This was not due to low overall species richness in these siphons. The Violet Siphon had the highest species richness in trawl samples and had intermediate richness in gillnet and electrofishing samples. The percentage of the fish fauna that was likely to have been entrained was consistently more than 32% in Davis Pond for all sampling methods. The other diversions varied in position. The Bonnet Carré Spillway had a relatively high percentage of entrained species in gillnet samples (33%) but a moderate percentage in trawl samples (20%).

Trawl Catch Per Unit Effort and Entrainment Estimates by Quarter

Eighteen of the 35 species likely to have been entrained were taken by trawling in one or more diversions. Except for the first trawl sample of the Bonnet Carré Spillway, where most of the catch was *Aplodinotus grunniens* and *Ictalurus punctatus*, the most productive trawling in terms of species richness (24 spp.) and overall abundance (Table 16.3) was taken the last quarter of sampling. Only six species of those most likely to have been entrained were taken in the Bonnet Carré Spillway by trawling. Five of the six were taken in the last two quarters of sampling after the 2011 opening of the Bonnet Carré Spillway. The highest number of entrained species per unit catch (0.06) was also seen in the second quarter of 2011.

The Davis Pond Diversion had the highest catch per unit effort (CPUE) in the first quarter of sampling in 2010 (1266, Table 17.3). More than half that catch was *Ictalurus furcatus* and *Aplodinotus grunniens*. The highest species richness (23) was seen in the first quarter of 2010, the third quarter of 2010, and the second quarter of 2011. All of these periods were times of moderate to high river stage and low to moderate diversion discharge (Figure 3.3). The highest number of entrained species (11) was also found in the first quarter of 2010 when entrained species represented 47% of the catch. The lowest CPUE and highest number of entrained species per unit catch were seen in the second quarter of 2010, when flow rates were high in the diversion. The single *Scaphirhynchus albus* caught in the Davis Pond Diversion was caught by trawling in the last quarter of 2009 when the river stage was relatively high (13.28 ft), the diversion's discharge and surface flow were moderate (3325 cfs, 0.32 m/s, Figure 3.3). The single *S. platorynchus* caught by trawling in the Davis Pond Diversion was taken in the first quarter of 2010 when the river stage was moderate (9.9 ft), the Davis Pond discharge and surface current were low (1230 cfs, 0.17 m/s).

Trawling in the Violet Siphon yielded relatively high CPUE (over 700 in 3 of the 6 quarters sampled) with *Ictalurus furcatus* making up a majority of many catches (Table 18.3). The highest CPUE (740) was found in the first quarter of 2011. That quarter had the highest species richness (36) and many euryhaline marine species were sampled. During this period, river stage and flow were low. Just two of the likely entrained species were caught by trawling in the Violet Siphon, *Ictiobus bubalus* in the first quarter of 2011 and *Polyodon spathula* in the second quarter of 2011.

Trawling in the Caernarvon Diversion yielded the highest CPUE in the fourth quarter of 2010 (1082). The same quarter had the highest species richness (25) when many euryhaline species were taken and three of the species likely to have been entrained (Table 19.3). In that quarter, the river stage and flows within the diversion were low. One to four of the likely entrained species were taken by trawl in each quarter. As in the Davis Pond Diversion, the highest number entrained species per unit catch was seen in the second quarter of 2010 when flow rates in the diversion were high (Figure 3.3).

Trawl sampling in the White Ditch Siphon yielded mean CPUEs between 131 and 152 in each quarter (Table 20.3). The highest species richness was found in the third quarter of 2010 (17). During that quarter and the previous quarter, the river stage was moderate and flow rates in the diversion were approximately 0.3 m/s. In those two periods, one likely entrained species, *Ictiobus bubalus,* was taken.

The fourth quarter of 2010 yielded the highest CPUE by trawling in the Naomi Siphon (656; Table 21.3). The same quarter had the highest species richness (26) and the highest number of likely entrained species (3). There was no water flowing in the siphon during this time. The lowest CPUE (77) and the lowest species richness was found in the second quarter of 2010 when flow rates in the diversion were at their highest (0.3 to 0.45 m/s). Two or three of the species likely to have been entrained were taken in each quarter.

Gillnet Catch Per Unit Effort and Entrainment Estimates by Quarter

Seventeen of the 35 species likely to have been entrained were taken by gillnetting in one or more diversions. In the Bonnet Carré Spillway, overall CPUE was highest in the second quarter of 2011 (30.2) as was species richness (33) (Table 22.3). The same quarter yielded the highest number of species likely to have been entrained (10). Included in those samples were one of each of the sturgeon species. In the succeeding quarter, another *S. platorynchus* was taken. The lowest CPUE (5.7) was found in the third quarter of 2010 when only 4 species likely to have been entrained were taken. The number of entrained species per unit catch was relatively high in all quarters.

In the Davis Pond Diversion, overall CPUE was highest in the third quarter of 2009 (12.0) (Table 23.3). Species richness was highest in the second quarter of 2010 (20). The highest number of species likely to have been entrained (6) was also seen in the second quarter of 2010, when flow rates in the diversion were high. In the second and third quarter of 2011, when discharge and water flow in the diversion were low only two species likely to have been entrained were taken.

In the Violet Siphon, CPUE was highest in the fourth quarter of 2009 (10.2) (Table 24.3). The highest species richness (18) was found in the third quarter of 2009, which was also when all four of the species likely to have been entrained there were taken. Euryhaline marine species were taken in most quarters.

In the Caernarvon Diversion, seven species likely to have been entrained were taken. CPUE was highest in the first quarter of 2011 (21.9) when the river stage and diversion discharge were both low (Table 25.3). Species richness was highest in the fourth quarter of 2009 (20) when five of the seven species likely to have been entrained were taken. At that time, the river stage was relatively high while diversion discharge and surface flow was low.

In the White Ditch Siphon, only three species likely to have been entrained were taken. They were all *Ictiobus* species (Table 26.3). All three species were all taken in the second quarter of 2010. CPUE did not vary greatly among quarters (8.7 to 12.8) and species richness did not vary greatly either (11 to 14).

In the Naomi Siphon, seven species likely to have been entrained were taken by gillnet. The highest CPUE was in the first quarter of 2010 (14.9; Table 27.3). Highest species richness (22) was found in the first quarter of 2011. Five species likely to have been entrained were taken in the first quarter of 2010, and in the first and second quarter of 2011. In each of those periods flow in the Naomi Siphon was low to moderate (0 to .3 m/s).

Electrofishing Catch Per Unit Effort and Entrainment Estimates by Quarter

Twenty-eight of the 35 species likely to have been entrained were taken by electrofishing in one or more diversions. In the Bonnet Carré Spillway, 13 of the species likely to have been entrained were taken by electrofishing (Table 15.3). The highest CPUE (339) was during the third quarter of 2010 (Table 28.3). The highest species richness (37) was found in the third quarter of 2009 and the highest number of species likely to have been entrained were taken in the third and fourth quarter of 2009. Low CPUE, low species richness, high percent catch entrained, and high entrained species per unit catch was found in late 2009 and early 2010 when the Bonnet Carré Spillway leaked sporadically for several months.

Twenty-four of the species likely to have been entrained were taken in electrofishing samples at the Davis Pond Diversion (Table 15.3). The highest CPUE (322.9), species richness (44) and number of species likely to have been entrained (11) were taken in the third quarter of 2009 (Table 29.3). The same number of species likely to have been entrained were taken in the third quarter of 2010. The former period was during a period of relatively low discharge and the latter was during a period of high discharge. During the latter period, CPUE was lower and this produced the largest value of entrained species per unit catch. Minnow species made up many of the likely entrained species and none of those minnows occurred consistently among quarters.

In the Violet Siphon, only five of the species likely to have been entrained were taken. Only one or two of those species were taken in any quarter (Table 30.3). CPUE was at or close to 200 in several quarters. Species richness was highest (37) the third quarter of 2009. Relatively high species richness was seen the second and third quarters of 2011 where euryhaline marine species were commonly taken.

Seventeen of the species likely to have been entrained were taken in the Caernarvon Diversion. The largest CPUE (755), species richness (42), and number of species likely to have been entrained were found in the third quarter of 2009 (Table 31.3). High numbers of entrained species were also found in the second and third quarters of 2010, and the third quarter of 2011. This is similar to what was seen in the Davis Pond Diversion and as in Davis Pond an assortment of minnows was found in those quarters. The highest number of entrained species per unit catch was found in the second quarter of 2010 when the diversion discharge and flow rates were high.

In the White Ditch Siphon, only four species likely to have been entrained were taken and at most two were taken in any quarter (Table 32.3). These were the two *Ictiobus* species and two *Hybognathus* species. The highest CPUE (686) and species richness (33) were seen in the second quarter of 2010. The high CPUE was due to a very large number of *Dormitator maculatus*. The high species richness was due to a large number of euryhaline marine species in the samples.

In the Naomi Siphon, eight of the species likely to have been entrained were taken (Table 33.3). Seven of those were taken in the third quarter of 2010 when surface flow was relatively high (0.3 to 0.4 m/s). During the same quarter, the highest value of entrained species per unit catch in the Naomi Siphon was seen. In all but the first quarter of 2010, species richness ranged from 30 to 37. The highest CPUE (206) was seen the first quarter of 2011 when flow rates varied between 0 and 0.3 m/s.

Discussion

Guillory (1982) documented that 121 species of fish can be found in the LMR in Louisiana near St. Francisville. He used a variety of collection methods, published literature and observations of fishermen’s catches to compile this estimate. In this study, 113 species were sampled. Three recently introduced freshwater species, *Hypophthalmichthys molitrix, H. molitrix,* and *Herichthys cyanoguttatum* were not reported by Guillory but were taken in this study. In addition, many euryhaline marine species were not taken by Guillory but were taken in this study. Byrne (2013) used the samples taken by electrofishing in the Davis Pond Diversion, the Violet Siphon, the Caernarvon Diversion, and the Naomi Siphon, in which 87 total species were taken, and five different mathematical techniques to estimate that the total number of species available for sampling by electrofishing in those diversions is between 92 and 101. Thus, it is likely that different sampling methods and increased sampling would increase the list of species that are entrained by or enter the freshwater diversions sampled in this study by 10% or more.

There was not a consistent relationship between the number of species found in the diversions and the capacity of the diversions among the different sampling techniques. The Violet Siphon had the largest number of species represented in trawl samples (43) in spite of having a small capacity (Table 15.3). The Davis Pond Diversion had the largest number of species taken by electrofishing (69), followed by Caernarvon (60), the Violet Siphon (50), and the Bonnet Carré Spillway (49). In gillnet samples, the Bonnet Carré Spillway had the largest number of species (42) followed by the Caernarvon Diversion (34). When all species taken by all sampling methods are combined the Davis Pond Diversion had the largest number species (77), followed by the Bonnet Carré Spillway (72). The remaining diversions had overall species richness correlated with their capacity.

Broad entrainment, in terms of species per unit catch, was seen in the Bonnet Carré Spillway throughout late 2009 and early 2010 in gillnet and electrofishing samples. During this period the Mississippi River stage was high (Figure 3.3a) and leakage at the spillway was intermittent. Broad entrainment was evident in trawl samples in the second quarter of 2011, just after the closing of the spillway. The only sturgeon taken in the Bonnet Carré Spillway during this study were taken in the second and third quarters of 2011. It is not surprising that the Bonnet Carré Spillway entrains species broadly when the river is high enough to allow water to leak or flow over the weirs. High volume and high velocity flow over the spillway weir will likely convey any fish in the water column.

Entrainment was greatest in the Davis Pond Diversion, Caernarvon Diversion, and Naomi Siphon in trawl and electrofishing samples during second and third quarters of 2010 when flow within these diversions were high. The same pattern was seen the White Ditch Siphon for gillnet and electrofishing samples. Entrainment was greatest in gillnet samples in the Davis Pond Diversion and Caernarvon Diversion early in 2010 when the river stage was high but flow within the diversions were relatively low. Thus, both river stage and flow within the diversions each may have positive effects on entrainment.

In general, there was low entrainment in both the Violet Siphon and White Ditch Siphon. The low volume of water flowing through these structures likely allows many species to avoid being entrained. The contrast of these two siphons with the Naomi Siphon suggests it is siphon size, and not the presence of siphons that result in differences in entrainment.

There appears to be little relationship between river stage and entrainment except in the Bonnet Carré Spillway. High river stage is required for flow in the Bonnet Carré Spillway and when it was flowing, there was broad entrainment. In the other diversions, flow was usually restricted during high river stage. This probably reduced the likelihood of species entering the diversions from the river. There was an almost inverse relationship between river stage and the volume of flow in the other diversions. Entrainment was clearly associated with the high flow through the diversions in the second and third quarters of 2010, when the river stage was moderate and falling. Thus, there may be potential for higher entrainment if the volume of flow through the diversions is allowed to be high when the river stage is high.

Studies that have examined the relationship between environmental variability and fish community structure have generally found that variable flow regimes result in lower community diversity and stability (Bain et al. 1988; Koel and Sparks 2002). None of the diversions in this study have had stable or natural flow regimes (Figure 3.3). In spite of this environmental variability, the fish communities sampled have remained diverse with 47 to 77 species taken in the diversions over the course of the study (Table 8.3). Thirty-one species were found in every one of the diversion in at least one of the samples. These included two gar species, American eel, bay anchovy, three clupeids, three catostomids, three ictalurids, striped mullet, inland silverside, western mosquitofish, white bass, nine centrarchids, freshwater drum, fat sleeper, freshwater goby, and hogchoker and many of these were taken in most samples. This consistency probably reflects continual entrainment of some of these species from larger and stable riverine populations and likely does not reflect self-perpetuating populations of each species in the outfall area of each diversion. Others in the list are likely to have moved into the diversion from stable populations downstream. Euryhaline marine species could enter the diversion through entrainment but for many, access is likely easier from areas downstream of the diversion.

The focus of this study was to attempt to document entrainment of the pallid sturgeon (*Scaphirhynchus albus)* by freshwater diversions. Two pallid sturgeon were captured: one in the Bonnet Carré Spillway and one in the Davis Pond Diversion. Shovelnose sturgeon (*S. platorynchus*) were also taken in the same two diversions: fifteen were taken in the Bonnet Carré Spillway and three in the Davis Pond Diversion. Sampling effort was highest at the Davis Pond Diversion (35 days) but nearly as high at the Caernarvon Diversion (29) days where no sturgeon were taken, in spite of similar flow regimes throughout this study. Sampling effort was highest in the Bonnet Carré Spillway when it was leaking or had recently had significant flow. Thus, is it is not surprising the overall entrainment (Table 15.3) and sturgeon entrainment was relatively high there. Overall entrainment of riverine fishes by the Davis Pond Diversion was as high or higher than that of the Bonnet Carré Spillway even though sampling was conducted in all quarters, during high and low river stages and high and low diversion discharge. The relative ability of diversions to entrain sturgeon specifically cannot be estimated due to the lack of sturgeon in most of the diversions. However, it is clear that smaller diversions have an overall lower degree of entrainment of species that are exclusively riverine and are probably less likely to entrain sturgeon.

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Table 1.3. Total sampling effort by period, days sampling and method. Gillnet effort is gillnet sets which averaged 4.2 hours. Trawl effort is number of trawl pulls, which averaged .29 km in length. Seine effort is the number of seine samples taken. Electrofish effort is the number of electrofishing stations sampled. Each electrofishing station consisted of 500 seconds of charge applied to the water. Trotline effort is the number of trotline sets. Each trotline set consisted of 4 lines with 60 baited hooks each left overnight.

Total Sampling Effort						
		Methods				
Period	**Days**	**Gillnet**	**Trawl**	**Seine**	**Electrofish**	**Trotline**
Jul-Sep-09	24	60	11	4	35	0
Oct-Dec-09	12	35	14	3	23	0
Jan-Mar-10	11	29	20	3	12	2
Apr-Jun-10	18	40	42	6	33	1
Jul-Sep-10	15	30	46	1	32	0
Oct-Dec-10	15	30	61	0	28	0
Jan-Mar-11	12	24	53	0	23	1
Apr-Jun-11	16	35	56	3	28	0
Jul-Aug-11	7	25	35	0	11	0
Total	130	308	338	20	225	4

Table 2.3. Bonnet Carré Spillway Sampling Effort. Sampling effort began July 10 2009 and ended August 16 2011.

Bonnet Carré Spillway Sampling Effort						
		Methods				
Period	**Days**	**Gillnet**	**Trawl**	**Seine**	**Electrofish**	**Trotline**
Jul-Sep-09	6	16	0	4	6	0
Oct-Dec-09	3	9	1	3	6	0
Jan-Mar-10	1	2	1	3	1	0
Apr-Jun-10	3	10	4	6	3	0
Jul-Sep-10	1	2	0	1	2	0
Oct-Dec-10	0	0	0	0	0	0
Jan-Mar-11	0	0	0	0	0	0
Apr-Jun-11	4	11	8	3	3	0
Jul-Aug-11	6	23	29	0	9	0
Total	24	73	43	20	30	0

Table 3.3. Davis Pond Diversion Sampling Effort. Sampling effort began July 9 2009 and ended August 13 2011.

Davis Pond Diversion Sampling Effort						
		Methods				
Period	Days	Gillnet	Trawl	Seine	Electrofish	Trotline
Jul-Sep-09	6	16	4	0	10	0
Oct-Dec-09	3	8	6	0	4	0
Jan-Mar-10	5	12	14	0	4	1
Apr-Jun-10	5	10	21	0	7	1
Jul-Sep-10	3	6	13	0	8	0
Oct-Dec-10	5	10	26	0	12	0
Jan-Mar-11	4	8	23	0	8	1
Apr-Jun-11	3	6	18	0	6	0
Jul-Aug-11	1	2	6	0	2	0
Total	35	78	131	0	61	3

Table 4.3. Violet Siphon Sampling Effort. Sampling effort began July 6 2009 and ended June 9 2011.

Violet Siphon Sampling Effort						
		Methods				
Period	Days	Gillnet	Trawl	Seine	Electrofish	Trotline
Jul-Sep-09	5	13	2	0	9	0
Oct-Dec-09	1	4	0	0	4	0
Jan-Mar-10	1	1	0	0	1	0
Apr-Jun-10	3	8	4	0	8	0
Jul-Sep-10	3	6	11	0	5	0
Oct-Dec-10	3	6	13	0	3	0
Jan-Mar-11	3	6	12	0	7	0
Apr-Jun-11	3	6	12	0	6	0
Jul-Aug-11	0	0	0	0	0	0
Total	22	50	54	0	43	0

Table 5.3. Caernarvon Diversion Sampling Effort. Sampling effort began July 1 2009 and ended June 14 2011.

Caernarvon Diversion Sampling Effort

		Methods				
Period	**Days**	**Gillnet**	**Trawl**	**Seine**	**Electrofish**	**Trotline**
Jul-Sep-09	7	15	5	0	10	0
Oct-Dec-09	3	8	5	0	4	0
Jan-Mar-10	2	6	3	0	3	1
Apr-Jun-10	3	4	6	0	7	0
Jul-Sep-10	3	6	8	0	6	0
Oct-Dec-10	4	8	15	0	6	0
Jan-Mar-11	3	6	13	0	3	0
Apr-Jun-11	4	8	12	0	7	0
Jul-Aug-11	0	0	0	0	0	0
Total	29	61	67	0	46	1

Table 6.3. White Ditch Siphon Sampling Effort. Sampling effort from October 22 2009 through August 11, 2010.

White Ditch Sampling Effort

		Methods				
Period	**Days**	**Gillnet**	**Trawl**	**Seine**	**Electrofish**	**Trotline**
Jul-Sep-09	0	0	0	0	0	0
Oct-Dec-09	1	4	1	0	2	0
Jan-Mar-10	0	0	0	0	0	0
Apr-Jun-10	2	4	4	0	3	0
Jul-Sep-10	2	4	6	0	3	0
Oct-Dec-10	0	0	0	0	0	0
Jan-Mar-11	0	0	0	0	0	0
Apr-Jun-11	0	0	0	0	0	0
Jul-Aug-11	0	0	0	0	0	0
Total	5	12	11	0	8	0

Table 7.3. Naomi Siphon Sampling Effort. Sampling effort from January 1 2010 through May 31 2011.

Naomi Siphon Sampling Effort						
		Methods				
Period	**Days**	**Gillnet**	**Trawl**	**Seine**	**Electrofish**	**Trotline**
Jul-Sep-09	0	0	0	0	0	0
Oct-Dec-09	0	0	0	0	0	0
Jan-Mar-10	2	8	2	0	3	0
Apr-Jun-10	2	4	3	0	5	0
Jul-Sep-10	3	6	8	0	8	0
Oct-Dec-10	3	6	7	0	7	0
Jan-Mar-11	2	4	5	0	5	0
Apr-Jun-11	2	4	6	0	6	0
Jul-Aug-11	0	0	0	0	0	0
Total	14	32	31	0	34	0

Table 8.3. Species Sampled at Freshwater Diversions of the Lower Mississippi. Species are listed in systematic order following Nelson (2006). Species in boldface are most likely to have been entrained in water that flowed into the diversion. Species marked with a dagger (†) are euryhaline marine species.

Species	Common Name	Bonnet Carré Spillway	Davis Pond Diversion	Violet Siphon	Caernarvon Diversion	White Ditch Siphon	Naomi Siphon	Total
Dasyatis sabina†	Atlantic stingray		4	1	4	1		10
Scaphirhynchus albus	pallid sturgeon	1	1					2
Scaphirhynchus platorynchus	shovelnose sturgeon	15	3					18
Polyodon spathula	paddlefish	23	38	1	6		7	75
Atractosteus spatula	alligator gar	2	1	29	16	7	30	85
Lepisosteus oculatus	spotted gar	84	279	452	244	136	583	1778
Lepisosteus osseus	longnose gar	18	125	3	93		84	323
Lepisosteus platostomus	shortnose gar	67	10		6		2	85
Amia calva	bowfin	1	13				23	37
Hiodon alosoides	goldeye	21	22		1		2	46
Hiodon tergisus	mooneye	1						1
Anguilla rostrata	American eel	11	71	25	44	1	9	161
Elops saurus†	ladyfish	5	35	93	164	29	1	327
Megalops atlanticus†	tarpon						2	2
Anchoa mitchilli†	bay anchovy	106	387	835	6456	217	124	8125
Alosa chrysochloris†	skipjack herring	639	36	339	104	14		1132
Brevoortia patronus†	Gulf menhaden	445	97	2257	1100	267	79	4245
Dorosoma cepedianum	gizzard shad	1760	1422	630	998	139	388	5337
Dorosoma petenense	threadfin shad	2316	490	65	223	40	179	3313
Ctenopharyngodon idella	grass carp		2				4	6
Cyprinella lutrensis	red shiner		1		1			2
Cyprinella venusta	blacktail shiner		2		1			3
Cyprinus carpio	carp	84	114	6	21		22	247

Hybognathus hayi	cypress minnow		1			1		2
Hybognathus nuchalis	silvery minnow	1	11		8	11	1	32
Hybopsis amnis	pallid shiner	1	2					3
Hypophthalmichthys molitrix	silver carp	91	21	4	23		9	148
Hypophthalmichthys nobilis	bighead carp	3						3
Lythrurus fumeus	ribbon shiner	4	6	1	8			19
Macrhybopsis aestivalis	speckled chub		3					3
Macrhybopsis storeriana	silver chub	4	87		1		1	93
Notemigonus crysoleucas	golden shiner	1	3		1		8	13
Notropis atherinoides	emerald shiner	1	16		13			30
Notropis shumardi	silverband shiner	1			4			5
Notropis volucellus	mimic shiner	5	2					7
Opsopoeodus emiliae	pugnose minnow	7	1		4		4	16
Pimephales vigilax	bullhead minnow	4						4
Carpiodes carpio	river carpsucker	107	4					111
Carpiodes cyprinus	quillback	10	1					11
Carpiodes vellifer	highfin carpsucker	1						1
Cycleptus elongatus	blue sucker		1				1	2
Erimyzon oblongus	creek chubsucker	1						1
Ictiobus bubalus	smallmouth buffalo	281	772	10	206	27	307	1603
Ictiobus cyprinellus	bigmouth buffalo	67	46	18	42	11	154	338
Ictiobus niger	black buffalo	40	10	6	16	1	80	153
Minytrema melanops	spotted sucker		1					1
Ameiurus melas	black bullhead			2	1			3
Ameiurus natalis	yellow bullhead		2		10	1	3	16
Ameiurus nebulosus	brown bullhead				1			1
Ictalurus furcatus	blue catfish	759	10554	5085	6051	331	794	23574
Ictalurus punctatus	channel catfish	426	1030	208	1297	28	93	3082
Pylodictis olivaris	flathead catfish	85	174	17	42	6	18	342
Bagre marinus†	gafftopsail catfish			9				9
Aphredoderus sayanus	pirate perch	9	21					30
Mugil cephalus†	striped mullet	427	1093	1557	529	64	891	4561

Mugil curema†	white mullet		29		3			32
Membras martinica†	rough silverside	41	1		51			93
Menidia beryllina	inland silverside	131	133	120	109	49	6	548
Strongylura marina†	Atlantic needlefish	5	2	10	53	1		71
Fundulus chrysotus	golden topminnow		1	1			4	6
Fundulus grandis†	Gulf killifish			103		1	2	106
Lucania parva	rainwater killifish			514		3	4	521
Gambusia affinis	western mosquitofish	151	53	492	3	63	43	805
Heterandria formosa	least killifish	2		1		1	2	6
Poecilia latipinna	sailfin molly		3	99			17	119
Cyprinodon variegatus†	sheepshead minnow	1		220				221
Morone chrysops	white bass	113	333	42	152	3	53	696
Morone mississippiensis	yellow bass	65	77	6	60		17	225
Morone saxatilis	striped bass	3	19		19		1	42
Morone saxatilis x M. chrysops	hybrid striped bass		2		1		2	5
Chaenobryttus gulosus	warmouth sunfish	112	1022	188	92	4	107	1525
Lepomis cyanellus	green sunfish	30	335	18	33	1	3	420
Lepomis humilis	orangespotted sunfish	441	19	1	3		3	467
Lepomis macrochirus	bluegill sunfish	881	1761	769	1034	105	965	5515
Lepomis marginatus	dollar sunfish		13					13
Lepomis megalotis	longear sunfish	436	745	27	51	2	67	1328
Lepomis microlophus	redear sunfish	41	37	50	1208	46	397	1779
Lepomis miniatus	redspotted sunfish	25	154	58	727	68	331	1363
Lepomis symmetricus	bantam sunfish	6	1	1			1	9
Micropterus punctulatus	spotted bass		4		13			17
Micropterus salmoides	largemouth bass	640	1367	119	1263	19	358	3766
Pomoxis annularis	white crappie	159	65	2	36	2	39	303
Pomoxis nigromaculatus	black crappie	286	701	85	239	17	357	1685
Etheostoma asprigene	mud darter				1			1
Percina caprodes	logperch	3						3
Percina maculata	blackside darter	1						1
Sander canadensis	sauger	4	12		1			17

Caranx hippos†	crevalle jack				4			4
Oligoplites saurus†	leatherjacket			7				7
Lutjanus griseus†	gray snapper		1					1
Aplodinotus grunniens	freshwater drum	260	2453	381	2394	69	122	5679
Bairdiella chrysoura†	silver perch			1				1
Cynoscion arenarius†	sand seatrout			76	5	19		100
Leiostomus xanthurus†	spot			32	1			33
Micropogonias undulatus†	Atlantic croaker	14		1521	6	57		1598
Pogonias cromis†	black drum			1				1
Sciaenops ocellatus†	red drum			3		2		5
Herichthys cyanoguttatum	Rio Grande cichlid	1						1
Dormitator maculatus†	fat sleeper	1	280	180	489	1605	324	2879
Eleotris pisonis†	spinycheek sleeper		15	3	1	2	1	22
Gobiomorus dormitor	bigmouth sleeper		1					1
Ctenogobius boleosoma†	darter goby					1		1
Ctenogobius shufeldti	freshwater goby	2	16	58	51	1	30	158
Gobionellus oceanicus†	highfin goby			3				3
Gobiosoma bosc†	naked goby					1		1
Citharichthys spilopterus†	bay whiff			3				3
Paralichthys lethostigma†	southern flounder	1		13	5	1	6	26
Trinectes maculatus†	hogchoker	17	299	12	154	6	4	492
	Total sampled	11808	26969	16873	26001	3481	7169	92301
	Total species	72	77	61	67	47	58	108

Table 9.3. Species sampled at the Bonnet Carré Spillway with each sampling method. Species are listed in systematic order following Nelson (2006).

		Sampling Method				
Species	**Common Name**	**Gillnet**	**Trawl**	**Seine**	**Electrofish**	**Total**
Scaphirhynchus albus	pallid sturgeon	1				1
Scaphirhynchus platorynchus	shovelnose sturgeon	14		1		15
Polyodon spathula	paddlefish	5	3	14	1	23
Atractosteus spatula	alligator gar	1		1		2
Lepisosteus oculatus	spotted gar	43	2	10	29	84
Lepisosteus platostomus	shortnose gar	56		3	8	67
Lepisosteus osseus	longnose gar	11	2	2	3	18
Amia calva	bowfin	1				1
Hiodon tergisus	mooneye	1				1
Hiodon alosoides	goldeye	20		1		21
Anguilla rostrata	American eel	1	3	1	6	11
Elops saurus	ladyfish	1		2	2	5
Anchoa mitchilli	bay anchovy		32	34	40	106
Alosa chrysochloris	skipjack herring	579		11	49	639
Brevoortia patronus	Gulf menhaden	31	7	220	187	445
Dorosoma cepedianum	gizzard shad	855	7	363	535	1760
Dorosoma petenense	threadfin shad	62	27	1389	838	2316
Cyprinus carpio	carp	61	6	7	10	84
Hybognathus nuchalis	silvery minnow			1		1
Macrhybopsis storeriana	silver chub		1	3		4
Lythrurus fumeus	ribbon shiner				4	4
Notemigonus crysoleucas	golden shiner				1	1
Hybopsis amnis	pallid shiner			1		1
Notropis atherinoides	emerald shiner			1		1
Notropis shumardi	silverband shiner			1		1
Notropis volucellus	mimic shiner			5		5

Opsopoeodus emiliae	pugnose minnow		2	1	4	7
Pimephales vigilax	bullhead minnow			2	2	4
Hypophthalmichthys molitrix	silver carp	12		24	55	91
Hypophthalmichthys nobilis	bighead carp	1		2		3
Ictiobus bubalus	smallmouth buffalo	90	10	76	105	281
Ictiobus cyprinellus	bigmouth buffalo	43		5	19	67
Ictiobus niger	black buffalo	19		13	8	40
Carpiodes carpio	river carpsucker	47	5	28	27	107
Carpiodes vellifer	highfin carpsucker	1				1
Carpiodes cyprinus	quillback	6		1	3	10
Erimyzon oblongus	creek chubsucker			1		1
Ictalurus furcatus	blue catfish	416	283	26	34	759
Ictalurus punctatus	channel catfish	118	164	138	6	426
Pylodictis olivaris	flathead catfish	47	31	3	4	85
Aphredoderus sayanus	pirate perch			9		9
Mugil cephalus	striped mullet	73	1	53	300	427
Membras martinica	rough silverside			41		41
Menidia beryllina	inland silverside			31	100	131
Strongylura marina	Atlantic needlefish			2	3	5
Gambusia affinis	western mosquitofish			4	147	151
Heterandria formosa	least killifish			2		2
Cyprinodon variegatus	sheepshead minnow				1	1
Morone chrysops	white bass	12	16	70	15	113
Morone mississippiensis	yellow bass	31	18	13	3	65
Morone saxatilis	striped bass	1		1	1	3
Lepomis cyanellus	green sunfish			10	20	30
Chaenobryttus gulosus	warmouth sunfish	10	7	58	37	112
Lepomis humilis	orangespotted sunfish	3	26	341	71	441
Lepomis macrochirus	bluegill sunfish	17	96	215	553	881
Lepomis megalotis	longear sunfish	9	42	111	274	436
Lepomis microlophus	redear sunfish	5	1	1	34	41
Lepomis miniatus	redspotted sunfish			6	19	25

Lepomis symmetricus	bantam sunfish				6	6
Micropterus salmoides	largemouth bass	38		409	193	640
Pomoxis annularis	white crappie	10	47	96	6	159
Pomoxis nigromaculatus	black crappie	20	117	135	14	286
Percina caprodes	logperch			3		3
Sander canadensis	sauger			4		4
Percina maculata	blackside darter				1	1
Aplodinotus grunniens	freshwater drum	40	93	102	25	260
Micropogonias undulatus	Atlantic croaker	1	13			14
Herichthys cyanoguttatus	Rio Grande cichlid				1	1
Dormitator maculatus	fat sleeper			1		1
Ctenogobius shufeldti	freshwater goby		1	1		2
Paralichthys lethostigma	southern flounder				1	1
Trinectes maculatus	hogchoker		14	2	1	17

Table 10.3. Species sampled at the Davis Pond Diversion with each sampling method. Species are listed in systematic order following Nelson (2006).

		Sampling Method				
Species	**Common Name**	**Gillnet**	**Trawl**	**Electrofish**	**Trotlines**	**Total**
Dasyatis sabina	Atlantic stingray	1	3			4
Scaphirhynchus albus	pallid sturgeon		1			1
Scaphirhynchus platorynchus	shovelnose sturgeon	2	1			3
Polyodon spathula	paddlefish		37	1		38
Atractosteus spatula	alligator gar	1				1
Lepisosteus oculatus	spotted gar	37	153	89		279
Lepisosteus osseus	longnose gar	53	44	28		125
Lepisosteus platostomus	shortnose gar		1	9		10
Amia calva	bowfin	2		11		13
Hiodon alosoides	goldeye	6	2	14		22
Anguilla rostrata	American eel			71		71
Elops saurus	ladyfish			35		35
Anchoa mitchilli	bay anchovy		19	368		387
Alosa chrysochloris	skipjack herring	22	1	13		36
Brevoortia patronus	Gulf menhaden		4	93		97
Dorosoma cepedianum	gizzard shad	245	728	449		1422
Dorosoma petenense	threadfin shad	11	17	462		490
Ctenopharyngodon idella	grass carp			2		2
Cyprinella lutrensis	red shiner			1		1
Cyprinella venusta	blacktail shiner			2		2
Cyprinus carpio	common carp	13	10	91		114
Hybognathus hayi	cypress minnow			1		1
Hybognathus nuchalis	silvery minnow			11		11
Hybopsis amnis	pallid shiner			2		2
Hypophthalmichthys molitrix	silver carp	9	2	10		21
Lythrurus fumeus	ribbon shiner			6		6
Macrhybopsis aestivalis	speckled chub		3			3
Macrhybopsis storeriana	silver chub		83	4		87
Notemigonus crysoleucas	golden shiner			3		3
Notropis atherinoides	emerald shiner		2	14		16
Notropis volucellus	mimic shiner			2		2
Opsopoeodus emiliae	pugnose minnow			1		1
Carpiodes carpio	river carpsucker		2	2		4
Carpiodes cyprinus	quillback			1		1
Cycleptus elongates	blue sucker			1		1
Ictiobus bubalus	smallmouth buffalo	65	643	64		772
Ictiobus cyprinellus	bigmouth buffalo	17	8	21		46
Ictiobus niger	black buffalo	2	4	4		10

Minytrema melanops	spotted sucker	1				1
Ameiurus natalis	yellow bullhead		1	1		2
Ictalurus furcatus	blue catfish	1333	8594	543	84	10554
Ictalurus punctatus	channel catfish	177	679	144	30	1030
Pylodictis olivaris	flathead catfish	54	56	64		174
Aphredoderus sayanus	pirate perch		20	1		21
Mugil cephalus	striped mullet	8		1085		1093
Mugil curema	white mullet			29		29
Membras martinica	rough silverside			1		1
Menidia beryllina	inland silverside			133		133
Strongylura marina	Atlantic needlefish			2		2
Fundulus chrysotus	golden topminnow			1		1
Gambusia affinis	western mosquitofish			53		53
Poecilia latipinna	sailfin molly			3		3
Morone chrysops	white bass	71	40	222		333
Morone mississippiensis	yellow bass	7	48	22		77
Morone saxatilis	striped bass	3	2	14		19
Morone saxatilis x M. chrysops	hybrid striped bass	2				2
Chaenobryttus gulosus	warmouth sunfish	1	49	972		1022
Lepomis cyanellus	green sunfish			335		335
Lepomis humilis	orangespotted sunfish		1	18		19
Lepomis macrochirus	bluegill sunfish		78	1683		1761
Lepomis marginatus	dollar sunfish			13		13
Lepomis megalotis	longear sunfish		7	738		745
Lepomis microlophus	redear sunfish			37		37
Lepomis miniatus	redspotted sunfish			154		154
Lepomis symmetricus	bantam sunfish			1		1
Micropterus punctulatus	spotted bass			4		4
Micropterus salmoides	largemouth bass		1	1366		1367
Pomoxis annularis	white crappie		29	36		65
Pomoxis nigromaculatus	black crappie	17	283	401		701
Sander canadensis	sauger	4	5	3		12
Lutjanus griseus	gray snapper			1		1
Aplodinotus grunniens	freshwater drum	199	2209	41	4	2453
Dormitator maculatus	fat sleeper		1	279		280
Eleotris pisonis	spinycheek sleeper			15		15
Gobiomorus dormitor	bigmouth sleeper			1		1
Ctenogobius shufeldti	freshwater goby		6	10		16
Trinectes maculatus	hogchoker		299			299

Table 11.3. Species sampled at the Violet Siphon with each sampling method. Species are listed in systematic order following Nelson (2006).

Species	Common Name	Sampling Method			Total
		Gillnet	Trawl	Electrofish	
Dasyatis sabina	Atlantic stingray	1			1
Polyodon spathula	paddlefish		1		1
Atractosteus spatula	alligator gar	20	6	3	29
Lepisosteus oculatus	spotted gar	203	140	109	452
Lepisosteus osseus	longnose gar	2		1	3
Anguilla rostrata	American eel			25	25
Elops saurus	ladyfish	11	5	77	93
Anchoa mitchilli	bay anchovy		230	605	835
Alosa chrysochloris	skipjack herring	241	59	39	339
Brevoortia patronus	Gulf menhaden	29	85	2143	2257
Dorosoma cepedianum	gizzard shad	264	89	277	630
Dorosoma petenense	threadfin shad	43	9	13	65
Cyprinus carpio	carp	6			6
Hypophthalmichthys molitrix	silver carp		3	1	4
Lythrurus fumeus	ribbon shiner			1	1
Ictiobus bubalus	smallmouth buffalo	4	2	4	10
Ictiobus cyprinellus	bigmouth buffalo	5		13	18
Ictiobus niger	black buffalo	4		2	6
Ameiurus melas	black bullhead		2		2
Ictalurus furcatus	blue catfish	56	5008	21	5085
Ictalurus punctatus	channel catfish	24	166	18	208
Pylodictis olivaris	flathead catfish	4	13		17
Bagre marinus	gafftopsail catfish	7	2		9
Mugil cephalus	striped mullet	7	407	1143	1557
Menidia beryllina	inland silverside		19	101	120
Strongylura marina	Atlantic needlefish			10	10
Fundulus chrysotus	golden topminnow			1	1
Fundulus grandis	Gulf killifish		15	88	103
Lucania parva	rainwater killifish		360	154	514
Gambusia affinis	western mosquitofish		1	491	492
Heterandria formosa	least killifish		1		1
Poecilia latipinna	sailfin molly		9	90	99
Cyprinodon variegatus	sheepshead minnow		140	80	220
Morone chrysops	white bass	35	4	3	42
Morone mississippiensis	yellow bass	3	3		6
Chaenobryttus gulosus	warmouth sunfish	1	74	113	188
Lepomis cyanellus	green sunfish		2	16	18
Lepomis humilis	orangespotted sunfish			1	1
Lepomis macrochirus	bluegill sunfish	11	541	217	769
Lepomis megalotis	longear sunfish			27	27

Lepomis microlophus	redear sunfish		45	5	50
Lepomis miniatus	redspotted sunfish		57	1	58
Lepomis symmetricus	bantam sunfish		1		1
Micropterus salmoides	largemouth bass	15	2	102	119
Pomoxis annularis	white crappie		2		2
Pomoxis nigromaculatus	black crappie	2	61	22	85
Oligoplites saurus	leatherjacket			7	7
Aplodinotus grunniens	freshwater drum	13	344	24	381

Table 12.3. Species sampled at the Caernarvon Diversion with each sampling method. Species are listed in systematic order following Nelson (2006).

		Sampling Method				
Species	**Common Name**	**Gillnet**	**Trawl**	**Electrofish**	**Trotlines**	**Total**
Dasyatis sabina	Atlantic stingray	3	1			4
Polyodon spathula	paddlefish		6			6
Atractosteus spatula	alligator gar	13	2	1		16
Lepisosteus oculatus	spotted gar	76	77	91		244
Lepisosteus osseus	longnose gar	36	29	28		93
Lepisosteus platostomus	shortnose gar	2	1	3		6
Hiodon alosoides	goldeye	1				1
Anguilla rostrata	American eel			44		44
Elops saurus	ladyfish	1		163		164
Anchoa mitchilli	bay anchovy		5	6451		6456
Alosa chrysochloris	skipjack herring	61		43		104
Brevoortia patronus	Gulf menhaden		13	1087		1100
Dorosoma cepedianum	gizzard shad	181	57	760		998
Dorosoma petenense	threadfin shad	1	4	218		223
Cyprinella lutrensis	red shiner			1		1
Cyprinella venusta	blacktail shiner			1		1
Cyprinus carpio	carp	2	5	14		21
Hybognathus nuchalis	silvery minnow			8		8
Hypophthalmichthys molitrix	silver carp	15		8		23
Lythrurus fumeus	ribbon shiner			8		8
Macrhybopsis storeriana	silver chub			1		1
Notemigonus crysoleucas	golden shiner			1		1
Notropis atherinoides	emerald shiner			13		13
Notropis shumardi	silverband shiner			4		4
Opsopoeodus emiliae	pugnose minnow			4		4
Ictiobus bubalus	smallmouth buffalo	81	89	36		206
Ictiobus cyprinellus	bigmouth buffalo	29	3	10		42
Ictiobus niger	black buffalo	13	1	2		16
Ameiurus melas	black bullhead			1		1
Ameiurus natalis	yellow bullhead			10		10
Ameiurus nebulosus	brown bullhead	1				1
Ictalurus furcatus	blue catfish	1318	4489	230	14	6051
Ictalurus punctatus	channel catfish	163	949	153	32	1297
Pylodictis olivaris	flathead catfish	9	21	12		42
Mugil cephalus	striped mullet	6		523		529
Mugil curema	white mullet			3		3
Membras martinica	rough silverside			51		51
Menidia beryllina	inland silverside			109		109
Strongylura marina	Atlantic needlefish	1		52		53
Gambusia affinis	western mosquitofish			3		3

Morone chrysops	white bass	70	9	73		152
Morone mississippiensis	yellow bass	19	26	14	1	60
Morone saxatilis	striped bass	6	1	12		19
Morone saxatilis x M. chrysops	hybrid striped bass	1				1
Chaenobryttus gulosus	warmouth sunfish	1	2	89		92
Lepomis cyanellus	green sunfish		1	32		33
Lepomis humilis	orangespotted sunfish			3		3
Lepomis macrochirus	bluegill sunfish	12	297	725		1034
Lepomis megalotis	longear sunfish			51		51
Lepomis microlophus	redear sunfish	21	251	936		1208
Lepomis miniatus	redspotted sunfish	1	5	721		727
Micropterus punctulatus	spotted bass			13		13
Micropterus salmoides	largemouth bass	8	6	1249		1263
Pomoxis annularis	white crappie		16	20		36
Pomoxis nigromaculatus	black crappie	12	102	125		239
Etheostoma asprigene	mud darter			1		1
Sander canadensis	sauger			1		1
Caranx hippos	crevalle jack			4		4
Aplodinotus grunniens	freshwater drum	420	1919	55		2394
Cynoscion arenarius	sand seatrout		5			5
Leiostomus xanthurus	spot	1				1
Micropogonias undulatus	Atlantic croaker		3	3		6
Dormitator maculatus	fat sleeper		5	484		489
Eleotris pisonis	spinycheek sleeper			1		1
Ctenogobius shufeldti	freshwater goby		5	46		51
Paralichthys lethostigma	southern flounder	4		1		5
Trinectes maculatus	hogchoker		148	6		154

Table 13.3. Species sampled at the White Ditch Siphon with each sampling method. Species are listed in systematic order following Nelson (2006).

Species	Common Name	Sampling Method: Gillnet	Trawl	Electrofish	Total
Dasyatis sabina	Atlantic stingray		1		1
Atractosteus spatula	alligator gar	4		3	7
Lepisosteus oculatus	spotted gar	82	3	51	136
Anguilla rostrata	American eel			1	1
Elops saurus	ladyfish	1	4	24	29
Anchoa mitchilli	bay anchovy		199	18	217
Alosa chrysochloris	skipjack herring	14			14
Brevoortia patronus	Gulf menhaden		32	235	267
Dorosoma cepedianum	gizzard shad	18		121	139
Dorosoma petenense	threadfin shad		3	37	40
Hybognathus hayi	cypress minnow			1	1
Hybognathus nuchalis	silvery minnow			11	11
Ictiobus bubalus	smallmouth buffalo	15	9	3	27
Ictiobus cyprinellus	bigmouth buffalo	8		3	11
Ictiobus niger	black buffalo	1			1
Ameiurus natalis	yellow bullhead			1	1
Ictalurus furcatus	blue catfish	189	110	32	331
Ictalurus punctatus	channel catfish	11	8	9	28
Pylodictis olivaris	flathead catfish	5		1	6
Mugil cephalus	striped mullet	4	3	57	64
Menidia beryllina	inland silverside			49	49
Strongylura marina	Atlantic needlefish			1	1
Fundulus grandis	Gulf killifish			1	1
Lucania parva	rainwater killifish			3	3
Gambusia affinis	western mosquitofish			63	63
Heterandria formosa	least killifish			1	1
Morone chrysops	white bass		1	2	3
Chaenobryttus gulosus	warmouth sunfish		1	3	4
Lepomis cyanellus	green sunfish			1	1
Lepomis macrochirus	bluegill sunfish		12	93	105
Lepomis megalotis	longear sunfish			2	2
Lepomis microlophus	redear sunfish	1	2	43	46
Lepomis miniatus	redspotted sunfish			68	68
Micropterus salmoides	largemouth bass	1		18	19
Pomoxis annularis	white crappie	1	1		2
Pomoxis nigromaculatus	black crappie	3	4	10	17
Aplodinotus grunniens	freshwater drum	29	36	4	69
Cynoscion arenarius	sand seatrout		12	7	19
Micropogonias undulatus	Atlantic croaker	4	17	36	57

Sciaenops ocellatus	red drum	1		1	2
Dormitator maculatus	fat sleeper		6	1599	1605
Eleotris pisonis	spinycheek sleeper		1	1	2
Ctenogobius boleosoma	darter goby			1	1
Ctenogobius shufeldti	freshwater goby		1		1
Gobiosoma bosc	naked goby			1	1
Paralichthys lethostigma	southern flounder	1			1
Trinectes maculatus	hogchoker		5	1	6

Table 14.3. Species sampled at the Naomi Siphon with each sampling method. Species are listed in systematic order following Nelson (2006).

		Sampling Method			
Species	**Common Name**	**Gillnet**	**Trawl**	**Electrofish**	**Total**
Polyodon spathula	paddlefish	7			7
Atractosteus spatula	alligator gar	20	5	5	30
Lepisosteus oculatus	spotted gar	249	67	267	583
Lepisosteus osseus	longnose gar	33	26	25	84
Lepisosteus platostomus	shortnose gar	1		1	2
Amia calva	bowfin	2		21	23
Hiodon alosoides	goldeye			2	2
Anguilla rostrata	American eel			9	9
Elops saurus	ladyfish			1	1
Megalops atlanticus	tarpon	2			2
Anchoa mitchilli	bay anchovy		53	71	124
Brevoortia patronus	Gulf menhaden		1	78	79
Dorosoma cepedianum	gizzard shad	208	48	132	388
Dorosoma petenense	threadfin shad	1	143	35	179
Ctenopharyngodon idella	grass carp	1		3	4
Cyprinus carpio	carp	4	3	15	22
Hybognathus nuchalis	silvery minnow			1	1
Hypophthalmichthys molitrix	silver carp	5		4	9
Macrhybopsis storeriana	silver chub		1		1
Notemigonus crysoleucas	golden shiner			8	8
Opsopoeodus emiliae	pugnose minnow			4	4
Cycleptus elongatus	blue sucker	1			1
Ictiobus bubalus	smallmouth buffalo	79	85	143	307
Ictiobus cyprinellus	bigmouth buffalo	82		72	154
Ictiobus niger	black buffalo	41	3	36	80
Ameiurus natalis	yellow bullhead		1	2	3
Ictalurus furcatus	blue catfish	105	547	142	794
Ictalurus punctatus	channel catfish	18	53	22	93
Pylodictis olivaris	flathead catfish	5	3	10	18
Mugil cephalus	striped mullet	118	221	552	891
Menidia beryllina	inland silverside			6	6
Fundulus chrysotus	golden topminnow			4	4
Fundulus grandis	Gulf killifish			2	2
Lucania parva	rainwater killifish			4	4
Gambusia affinis	western mosquitofish		2	41	43
Heterandria formosa	least killifish			2	2
Poecilia latipinna	sailfin molly			17	17
Morone chrysops	white bass	38	6	9	53
Morone mississippiensis	yellow bass	5	2	10	17

Morone saxatilis	striped bass			1	1
Morone saxatilis xM. chrysops	hybrid striped bass		2		2
Chaenobryttus gulosus	warmouth sunfish		31	76	107
Lepomis cyanellus	green sunfish			3	3
Lepomis humilis	orangespotted sunfish			3	3
Lepomis macrochirus	bluegill sunfish	15	353	597	965
Lepomis megalotis	longear sunfish		7	60	67
Lepomis microlophus	redear sunfish	7	68	322	397
Lepomis miniatus	redspotted sunfish			331	331
Lepomis symmetricus	bantam sunfish			1	1
Micropterus salmoides	largemouth bass	8	2	348	358
Pomoxis annularis	white crappie	2	22	15	39
Pomoxis nigromaculatus	black crappie	28	124	205	357
Aplodinotus grunniens	freshwater drum	15	100	7	122
Dormitator maculatus	fat sleeper		8	316	324
Eleotris pisonis	spinycheek sleeper			1	1
Ctenogobius shufeldti	freshwater goby		15	15	30
Paralichthys lethostigma	southern flounder	5		1	6
Trinectes maculatus	hogchoker		2	2	4

Table 15.3. Overall CPUE, and entrainment estimates for each method at each Diversion. CPUE for trawling is catch per km. CPUE for gillnetting is catch per hour. CPUE for electrofishing is catch per 500 second electrofishing station. Entrained CPUE is the catch of species most likely to have been entrained. Percent catch entrained is the ratio of entrained CPUE to total CPUE multiplied by 100. Percent entrained species is the percentage of species taken that were likely to have been entrained. Entrained species per unit catch is the ratio of total entrained species to total CPUE.

Method/ Diversion	Total CPUE	Entrained CPUE	Percent Catch Entrained	Total Species	Total Entrained	Percent Entrained Species	Entrained Species per Unit Catch
Trawl							
Bonnet Carré	106.8	2.3	2.14	30	6	20.0	0.056
Davis Pond	352.3	20.8	5.91	42	15	35.7	0.043
Violet	590.8	0.2	0.03	43	2	4.7	0.003
Caernarvon	410.0	6.2	1.52	34	7	20.6	0.017
White Ditch	137.1	2.6	1.91	23	1	4.3	0.007
Naomi	331.4	19.0	5.74	31	4	12.9	0.012
Gillnet							
Bonnet Carré	11.8	1.3	11.2	42	14	33.3	1.19
Davis Pond	5.8	0.4	6.5	28	9	32.1	1.55
Violet	5.9	0.1	1.5	28	4	14.3	0.68
Caernarvon	9.0	0.6	6.5	34	7	20.6	0.78
White Ditch	8.5	0.5	6.1	20	3	15.0	0.35
Naomi	8.1	1.8	22.1	29	7	24.1	0.87
Electrofish							
Bonnet Carré	126.9	6.2	4.89	49	13	26.5	0.102
Davis Pond	169.0	3.5	2.05	69	24	34.8	0.142
Violet	146.8	0.5	0.33	50	5	10.0	0.034
Caernarvon	322.0	3.2	0.99	60	17	28.3	0.053
White Ditch	327.1	2.3	0.69	41	4	9.8	0.012
Naomi	123.5	8.5	6.86	52	8	15.4	0.065

Table 16.3. CPUE of species sampled by trawling at the Bonnet Carré Spillway. CPUE is the mean number (± standard error) of fish taken per km of trawl. N is the number of trawls. Species are listed in systematic order following Nelson (2006).

Period	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Apr-Jun 2011**	**Jul-Aug 2011**
N	1	1	4	8	29
Mean CPUE	758.6	7.1	64.6	46.7	104.6
Entrained CPUE	37.8	0.0	2.6	2.9	0.5
Percent Catch Entrained	4.98	0.00	4.07	6.11	0.46
Total Species	11	2	12	18	24
Total Entrained	2	0	2	3	3
Percent Entrained Species	18.2	0.0	16.7	16.7	12.5
Entrained Species per Unit Catch	0.003	0.00	0.03	0.06	0.03
Species					
Polyodon spathula	0	0	0	1.39±1.39	0
Lepisosteus oculatus	0	0	0	0	0.28±0.28
Lepisosteus osseus	0	0	1.62±1.62	0	0.15±0.15
Anguilla rostrata	3.15	0	0	0	0.26±0.18
Anchoa mitchilli	0	0	0	0.57±0.57	3.97±2.86
Brevoortia patronus	0	0	0	0.44±0.44	0.73±0.51
Dorosoma cepedianum	0	3.57	0	0.93±0.61	0.83±0.66
Dorosoma petenense	0	0	6.12±4.77	0	2.94±0.94
Cyprinus carpio	0	0	0	1.38±0.95	0.45±0.34
Macrhybopsis storeriana	0	0	0	0	0.18±0.18
Opsopoeodus emiliae	0	0	0	1.02±1.02	0
Carpiodes carpio	12.59	0	1±1	0	0
Ictiobus bubalus	25.18	0	0	0.44±0.44	0.15±0.15
Ictalurus furcatus	6.3	3.57	0	10.91±2.95	40.93±10.98
Ictalurus punctatus	412.33	0	1.62±1.62	4.1±2.11	3.58±1.21
Pylodictis olivaris	0	0	0	0.51±0.51	4.9±1.81
Mugil cephalus	0	0	0	0.42±0.42	0

Morone chrysops	0	0	2.11±2.11	0	2.35±1.51
Morone mississippiensis	0	0	1.62±1.62	0.51±0.51	2.53±0.99
Chaenobryttus gulosus	0	0	0	0	0.94±0.4
Lepomis humilis	3.15	0	1.62±1.62	5.04±2.13	2.2±0.91
Lepomis macrochirus	47.21	0	4.86±4.86	7.37±2.92	7.96±4.17
Lepomis megalotis	3.15	0	0	1.43±0.71	4.78±3.03
Lepomis microlophus	3.15	0	0	0	0
Pomoxis annularis	0	0	2.63±1.6	1.88±0.72	6.03±1.61
Pomoxis nigromaculatus	3.15	0	37.13±27.16	5.86±1.86	13.04±2.4
Aplodinotus grunniens	239.21	0	0	0	2.78±1.06
Micropogonias undulatus	0	0	0	0	1.66±1.21
Ctenogobius shufeldti	0	0	2.11±2.11	0	0
Trinectes maculatus	0	0	2.1±1.22	2.51±1.15	0.93±0.43

Table 17.3. CPUE of species sampled by trawling at the Davis Pond Diversion. CPUE is the mean number (± standard error) of fish taken per km of trawl. N is the number of trawls. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**	**Jul-Aug 2011**
N	4	6	14	21	13	26	23	18	6
Mean CPUE	197.3	40.1	1266.0	14.1	718.9	269.2	224.7	400.6	24.1
Entrained CPUE	7.7	3.9	118.2	1.3	1.4	17.0	21.5	2.5	0.6
Percent Catch Entrained	3.88	9.60	9.33	9.41	0.20	6.32	9.59	0.62	2.53
Total Species	6	10	23	13	13	23	19	23	3
Total Entrained	2	2	11	3	2	5	5	4	1
Percent Entrained Species	33.3	20.0	47.8	23.1	15.4	21.7	26.3	17.4	33.3
Entrained Species per Unit Catch	0.01	0.05	0.009	0.21	0.003	0.02	0.02	0.01	0.04
Species									
Dasyatis Sabina	0	1.63±1.63	0	0	0	0	0	0	0
Scaphirhynchus albus	0	0.48±0.48	0	0	0	0	0	0	0
Scaphirhynchus platorynchus	0	0	0.19±0.19	0	0	0	0	0	0
Polyodon spathula	6.97±6.08	3.37±2.17	4.95±2.36	0.13±0.13	0	0	0	0	0
Lepisosteus oculatus	0	0.4±0.4	26.05±12.08	0	0.86±0.46	0.87±0.44	0	6.34±2.49	0
Lepisosteus osseus	0	0	0.5±0.34	1.09±0.36	0.99±0.63	3.09±1.22	0	1.76±0.82	0.61±0.61
Lepisosteus platostomus	0	0	0.22±0.22	0	0	0	0	0	0
Hiodon alosoides	0	0	0	0	0.41±0.31	0	0	0	0
Anchoa mitchilli	0	1.32±1.32	0	0	0	2.56±1.96	0	0	0
Alosa chrysochloris	0	0	0	0	0	0	0	0.2±0.2	0
Brevoortia patronus	0	0	0	0	0	0.62±0.5	0	0	0
Dorosoma cepedianum	0	0	52.16±28.76	0.15±0.15	0	37.03±22.42	34.96±17.04	0.41±0.28	0
Dorosoma petenense	0	0	0.19±0.19	0.13±0.13	0.11±0.11	0.14±0.14	0	2.64±2.44	0
Cyprinus carpio	0	0	0	0.15±0.15	0	0	0.49±0.36	1.27±0.62	0
Hypophthalmichthys molitrix	0	0	0	0.17±0.17	0	0	0	0.18±0.18	0
Macrhybopsis aestivalis	0	0	0	0	0	0	0.17±0.17	0.39±0.27	0
Macrhybopsis storeriana	0	0	1.14±0.54	0	0	8.52±3.64	1.74±0.91	0	0

Notropis atherinoides	0	0	0.19±0.19	0	0	0.12±0.12	0	0	0
Carpiodes carpio	0	0	0.44±0.44	0	0	0	0	0	0
Ictiobus bubalus	0	0	107.72±61.55	0	0	5.16±2.04	19.14±8.06	0.18±0.18	0
Ictiobus cyprinellus	0.7±0.7	0	1.38±0.72	0.1±0.1	0	0	0	0	0
Ictiobus niger	0	0	0.47±0.32	0	0	0	0.33±0.23	0	0
Ameiurus natalis	0	0	0	0.13±0.13	0	0	0	0	0
Ictalurus furcatus	98.38±43.35	25.57±1.86	783.69±244.9	9.87±2.04	635.96±325.53	91.5±22.41	28.05±8.1	322.85±82.09	21.01±7.2
Ictalurus punctatus	0	2.63±2.63	59.01±20.46	0.21±0.21	0.82±0.38	12.87±4.18	41.99±15.55	7.77±2.26	0
Pylodictis olivaris	0	1.09±0.71	4.3±1.32	1.25±0.42	0.2±0.2	0.58±0.36	0.98±0.49	1.82±0.78	2.47±0.78
Aphredoderus sayanus	0	0	0	0	0	0	0	4.05±2.34	0
Morone chrysops	0.7±0.7	0	2.7±2.42	0	0	1.43±0.65	2.45±1.49	0.29±0.29	0
Morone mississippiensis	0	0	0.22±0.22	0	0	2.3±1.42	3.32±2.02	1.62±0.78	0
Morone saxatilis	0	0	0	0	0	0.11±0.11	0	0.14±0.14	0
Chaenobryttus gulosus	0	0	0	0	3.91±2.08	0.29±0.29	0.17±0.17	4.11±2	0
Lepomis humilis	0	0	0	0	0.29±0.29	0	0	0	0
Lepomis macrochirus	0	0	0	0	1.33±0.95	3.05±0.97	4.26±1.99	3.8±3.03	0
Lepomis megalotis	0	0	0	0	0	1.04±0.68	0.16±0.16	0	0
Micropterus salmoides	0	0	0	0	0	0.15±0.15	0	0	0
Pomoxis annularis	0	0	0.66±0.66	0	0	2.64±1.39	0.33±0.23	1.1±0.44	0
Pomoxis nigromaculatus	0	0	5.82±5.27	0.1±0.1	7.74±4.31	9.88±3.22	7.63±2.74	15.88±8.87	0
Sander canadensis	0	0	0.96±0.43	0	0	0	0.17±0.17	0	0
Aplodinotus grunniens	89.75±62.57	3.2±1.62	212.81±71.88	0	64.07±35.73	57.81±28.84	77.24±36.27	6.18±1.55	0
Dormitator maculatus	0.84±0.84	0	0	0	0	0	0	0	0
Ctenogobius shufeldti	0	0	0	0	0	0	0	1.2±0.51	0
Trinectes maculatus	0	0.44±0.44	0.22±0.22	0.58±0.27	2.15±1.73	27.4±14.79	1.17±0.66	16.4±12.28	0

Table 18.3. CPUE of species sampled by trawling at the Violet Siphon. CPUE is the mean number (± standard error) of fish taken per km of trawl. N is the number of trawls. Species are listed in systematic order following Nelson (2006).

Period	Jul-Sep 2009	Apr-Jun 2010	Jul-Sep 2010	Oct-Dec 2010	Jan-Mar 2011	Apr-Jun 2011
Species **N**	2	4	11	13	12	12
Mean CPUE	53.6	131.5	714.9	366.6	740.4	708.0
Entrained CPUE	0.0	0.0	0.0	0.0	0.5	0.3
Percent Catch Entrained	0.00	0.00	0.00	0.00	0.07	0.05
Total Species	6	10	16	22	36	16
Total Entrained	0	0	0	0	1	1
Percent Entrained Species	0.0	0.0	0.0	0.0	2.8	6.3
Entrained Species per Unit Catch	0.00	0.00	0.00	0.00	0.001	0.001
Species						
Polyodon spathula	0	0	0	0	0	0.34±0.34
Atractosteus spatula	0	0	0	0.24±0.24	1.29±1.02	0
Lepisosteus oculatus	0	0	0	5.49±4.21	32.44±18.33	0.31±0.31
Elops saurus	1.78±1.78	0	1.07±1.07	0	0.31±0.31	0
Anchoa mitchilli	14.08±10.83	28.49±10.93	22.27±6.7	15.79±4.14	0.83±0.44	12.42±5.42
Alosa chrysochloris	0	0	0	0	12.78±12.47	0
Brevoortia patronus	0	0	9.77±6.17	14.48±10.75	0.29±0.29	0
Dorosoma cepedianum	0	0	3.69±2.28	1.88±1.12	15.4±5.56	2.8±1.04
Dorosoma petenense	0	0	0.33±0.33	1.03±0.61	0.51±0.35	0.55±0.37
Hypophthalmichthys molitrix	0	1.74±1.74	0	0	0.32±0.32	0
Ictiobus bubalus	0	0	0	0	0.5±0.35	0
Ameiurus melas	0	0	0	0	0.27±0.27	0.31±0.31
Ictalurus furcatus	0	25.46±13.75	663.85±504.5	142.83±48.82	287.42±159.06	216.44±61.53
Ictalurus punctatus	0	0.93±0.93	0.89±0.89	6.54±3.78	23.28±13.39	8.06±4.54
Pylodictis olivaris	0	0.66±0.66	0	3.65±3.35	0	0
Bagre marinus	1.63±1.63	0	0.36±0.36	0	0	0
Mugil cephalus	0	0	2.4±1.46	0	120.91±74.96	0

Menidia beryllina	0	0	0	0	5.33±3.02	0
Fundulus grandis	0	1.32±1.32	0	0	3.51±3.19	0
Lucania parva	0	0	0	0	80.55±65.78	0
Gambusia affinis	0	0	0	0	0.22±0.22	0
Heterandria formosa	0	0	0	0	0.31±0.31	0
Poecilia latipinna	0	0	0	0.3±0.3	2.29±1.87	0
Cyprinodon variegatus	0	0	0	0	32.86±21.65	0
Morone chrysops	0	0	0.24±0.24	0.17±0.17	0.48±0.33	0
Morone mississippiensis	0	0	0	0.24±0.24	0.62±0.62	0
Chaenobryttus gulosus	0	0	0	16.01±11.33	4.51±1.84	0.32±0.32
Lepomis cyanellus	0	0	0	0	0.51±0.35	0
Lepomis macrochirus	0	0	0	120.29±57.96	36.83±14.12	0
Lepomis microlophus	0	0	0	5.03±3.57	7.19±3.11	0
Lepomis miniatus	0	0	0	14.84±9.68	1.71±0.91	0
Lepomis symmetricus	0	0	0	0	0.22±0.22	0
Micropterus salmoides	0	0	0	0	0.56±0.38	0
Pomoxis annularis	0	0	0.27±0.27	0.31±0.31	0	0
Pomoxis nigromaculatus	0	0	0.45±0.45	10.3±5.41	5.04±2.39	1.2±0.51
Aplodinotus grunniens	0	0	5.46±2.9	6.14±3.79	55.2±27.63	16.5±7.8
Cynoscion arenarius	32.73±9.97	34.75±22.53	2.01±0.87	0	0	0.26±0.26
Leiostomus xanthurus	0	0.81±0.81	0	0.45±0.32	0.67±0.46	5.63±3.14
Micropogonias undulatus	1.63±1.63	36.36±6.78	1.18±0.62	0	0.58±0.58	436.31±119.73
Pogonias cromis	0	0	0	0.29±0.29	0	0
Dormitator maculatus	0	0	0.69±0.46	0.28±0.28	0	0
Ctenogobius shufeldti	0	0.93±0.93	0	0	3.77±2.08	4.34±2
Trinectes maculatus	1.78±1.78	0	0	0	0.86±0.6	2.2±2.2

Table 19.3. CPUE of species sampled by trawling at the Caernarvon Diversion. CPUE is the mean number (± standard error) of fish taken per km of trawl. N is the number of trawls. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**
N	5	5	3	6	8	15	13	12
Mean CPUE	298.3	486.7	53.2	16.3	353.3	1082.1	219.9	195.0
Entrained CPUE	1.1	12.5	3.5	0.9	0.8	15.4	7.8	4.5
Percent Catch Entrained	0.35	2.58	6.59	5.45	0.24	1.42	3.57	2.31
Total Species	7	13	7	7	14	25	20	16
Total Entrained	1	3	2	2	2	3	4	3
Percent Entrained Species	14.3	23.1	28.6	28.6	14.3	12.0	20.0	18.8
Entrained Species per Unit Catch	0.003	0.01	0.04	0.12	0.01	0.00	0.02	0.02
Species								
Dasyatis sabina	0	0	0	0	0	0.23±0.23	0	0
Polyodon spathula	1.05±0.67	0.55±0.55	0	0.33±0.33	0.56±0.56	0	0	0
Atractosteus spatula	0	0	0	0	0	0.42±0.29	0	0
Lepisosteus oculatus	0	22.55±9.11	0	0	0	5.8±3.09	6.92±1.95	0
Lepisosteus osseus	0	5.1±3.37	1.98±1.14	0	0	1.77±0.79	2.17±1.23	1.74±0.78
Lepisosteus platostomus	0	0	0	0	0	0.22±0.22	0	0
Anchoa mitchilli	0	0	0	0	0.28±0.28	0.59±0.41	0	0.24±0.24
Brevoortia patronus	0	0	0	0	0.67±0.45	2.32±1.01	0	0
Dorosoma cepedianum	0	1.51±0.64	0	0	0.56±0.56	5.84±3.64	7±3.32	0.34±0.34
Dorosoma petenense	0	0	0	0	0	0	1.15±0.78	0
Cyprinus carpio	0	0	0	0.56±0.56	0	0.22±0.22	0.69±0.49	0.24±0.24
Ictiobus bubalus	0	6.9±3.22	1.53±1.53	0	0	13.43±6.21	5.05±2.92	2.46±1.84
Ictiobus cyprinellus	0	0	0	0.56±0.56	0.28±0.28	0	0.36±0.36	0
Ictiobus niger	0	0	0	0	0	0	0.26±0.26	0
Ictalurus furcatus	266.12±69.69	90.83±32.54	17.76±7.12	13.13±7.95	267.3±147.43	569.85±175.77	15.83±7.17	152.4±41.8
Ictalurus punctatus	9.97±5.5	93.88±28.75	29.07±26.94	0.56±0.56	0.56±0.56	141.9±81.89	2.42±1.8	9.04±4.17
Pylodictis olivaris	0.7±0.7	1.68±1.68	0.77±0.77	0.42±0.42	1.47±0.97	1.93±0.61	0	1.48±0.82
Morone chrysops	0.41±0.41	1.09±1.09	0	0	0	0.23±0.23	1.7±1.11	0

Morone mississippiensis	0	0	0	0	0	1.3±1.06	6.38±4.26	0.3±0.3
Morone saxatilis	0	0	0	0	0	0	0	0.3±0.3
Chaenobryttus gulosus	0	0.55±0.55	0	0	0	0.45±0.45	0	0
Lepomis cyanellus	0	0	0	0	0	0	0.36±0.36	0
Lepomis macrochirus	0	1.47±1.06	0	0	0	61.39±27.82	21.04±9.36	0
Lepomis microlophus	0	0	0	0	0	54.17±27.67	4.52±1.57	0
Lepomis miniatus	0	0	0	0	0	1.05±1.05	0	0
Micropterus salmoides	0	0	0	0	0	0	1.72±1.09	0
Pomoxis annularis	0	0	0	0	0	2.58±1.49	2.32±1.23	0
Pomoxis nigromaculatus	0	0	0	0	1.4±1.4	14.78±5.75	11.31±4.22	0.96±0.68
Aplodinotus grunniens	19.37±4.96	259.68±104.71	1.42±0.72	0	74.5±49.91	182.79±29.3	128.46±94.25	4.46±1.48
Cynoscion arenarius	0	0	0	0	0.28±0.28	0.19±0.19	0	1.1±0.79
Micropogonias undulatus	0.68±0.68	0	0	0	0.28±0.28	0	0	0.33±0.33
Dormitator maculatus	0	0	0	0	0	1.28±0.69	0	0
Ctenogobius shufeldti	0	0	0	0.72±0.72	0.34±0.34	0	0	0.66±0.45
Trinectes maculatus	0	0.93±0.58	0.66±0.66	0	4.79±2.49	17.35±5.68	0.26±0.26	18.98±5.52

Table 20.3. CPUE of species sampled by trawling at the White Ditch Siphon. CPUE is the mean number (± standard error) of fish taken per km of trawl. N is the number of trawls. Species are listed in systematic order following Nelson (2006).

Period	**Oct-Dec 2009**	**Apr-Jun 2010**	**Jul-Sep 2010**
N	1	4	6
Mean CPUE	150.1	152.0	131.4
Entrained CPUE	0.0	2.5	2.7
Percent Catch Entrained	0.00	1.65	2.08
Total Species	5	14	17
Total Entrained	0	1	1
Percent Entrained Species	0.0	7.1	5.9
Entrained Species per Unit Catch	0.00	0.007	0.008
Species			
Dasyatis sabina	0	0	0.44±0.44
Lepisosteus oculatus	22.52	0	0
Elops saurus	0	0	2.16±1.52
Anchoa mitchilli	30.02	113.02±90.99	24.68±4.19
Dorosoma petenense	0	2.46±2.46	0
Brevoortia patronus	0	2.01±1.23	16.07±10.27
Ictiobus bubalus	0	2.51±2.51	2.73±1.57
Ictalurus punctatus	0	0.63±0.63	3.35±1.32
Ictalurus furcatus	0	4.63±2.15	54.47±11.22
Mugil cephalus	22.52	0	0
Morone chrysops	0	0.63±0.63	0
Pomoxis annularis	0	0	0.54±0.54
Chaenobryttus gulosus	0	0	0.56±0.56
Lepomis microlophus	0	0	1.2±0.77
Pomoxis nigromaculatus	0	0	2.4±1.26
Lepomis macrochirus	67.55	0.77±0.77	1.2±0.77
Cynoscion arenarius	0	7.16±5.34	0.5±0.5
Aplodinotus grunniens	0	0.75±0.75	18.06±5.47
Micropogonias undulatus	7.51	10.44±6.05	0.99±0.63
Eleotris pisonis	0	0	0.44±0.44
Dormitator maculatus	0	4.82±3.13	0
Ctenogobius shufeldti	0	0.75±0.75	0
Trinectes maculatus	0	1.38±0.8	1.53±1.09

Table 21.3. CPUE of species sampled by trawling at the Naomi Siphon. CPUE is the mean number (± standard error) of fish taken per km of trawl. N is the number of trawls. Species are listed in systematic order following Nelson (2006).

Period	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**
N	2	3	8	7	5	6
Mean CPUE	325.4	76.8	131.6	656.0	309.9	247.1
Entrained CPUE	8.0	7.5	6.8	54.1	3.3	4.5
Percent Catch Entrained	2.46	9.74	5.18	8.24	1.07	1.82
Total Species	11	5	19	26	16	13
Total Entrained	2	2	3	3	2	2
Percent Entrained Species	18.2	40.0	15.8	11.5	12.5	15.4
Entrained Species per Unit Catch	0.006	0.026	0.023	0.005	0.006	0.008
Species						
Atractosteus spatula	11.35±6.28	0	0	0.48±0.48	0	0
Lepisosteus osseus	5.07±5.07	4.98±4.98	2.58±1.32	9.21±3.51	0.9±0.9	3.19±2.1
Lepisosteus oculatus	5.07±5.07	0	0.71±0.71	35.93±10.62	5.65±3.56	3.12±1.89
Anchoa mitchilli	0	0	6.12±3.39	5.88±2.6	27.04±16.79	1.54±1.54
Brevoortia patronus	0	0	0.71±0.71	0	0	0
Dorosoma cepedianum	15.21±15.21	0	2.12±2.12	18.5±16.94	0	0.51±0.51
Dorosoma petenense	0	0	6.94±5.61	25.42±9.69	77.09±75.2	0
Macrhybopsis storeriana	0	0	0.71±0.71	0	0	0
Cyprinus carpio	0	0	0	1.58±1.05	0	0
Ictiobus niger	0	0	0	0.48±0.48	0	1.31±1.31
Ictiobus bubalus	2.94±2.94	2.49±2.49	3.53±3.53	44.4±24.1	2.4±2.4	0
Ameiurus natalis	0	0	0	1.53±1.53	0	0
Pylodictis olivaris	0	0	0.67±0.67	0.48±0.48	0	0.76±0.76
Ictalurus punctatus	71.79±60.03	2.11±2.11	4.11±2.93	8.88±4.34	7.21±7.21	0
Ictalurus furcatus	135.17±123.41	60.8±29.75	67.98±32.07	76.47±37.04	77.57±34.61	209.44±95.41
Mugil cephalus	0	0	0	83.14±60.58	50.91±47.19	0
Gambusia affinis	0	0	0	0	1.53±1.53	0

Morone saxatilis x M. chrysops	0	0	0	0.95±0.95	0	0
Morone mississippiensis	0	0	0	0.69±0.69	0.84±0.84	0
Morone chrysops	2.54±2.54	0	1.86±1.26	1.82±0.88	0	0
Micropterus salmoides	0	0	0.71±0.71	0.48±0.48	0	0
Lepomis megalotis	0	0	0	2.11±1.48	2.52±2.52	0
Pomoxis annularis	0	0	4.76±3.19	8.59±1.99	0	0.51±0.51
Chaenobryttus gulosus	0	0	4.62±2.84	17.57±6.31	0	0.51±0.51
Lepomis microlophus	0	0	0	21.36±13.39	25.5±19.51	0
Pomoxis nigromaculatus	2.94±2.94	0	9.44±6.26	60.13±23.71	0.84±0.84	5.69±2.67
Lepomis macrochirus	8.01±2.13	0	0.64±0.64	186.71±116.55	27.26±21.98	0
Aplodinotus grunniens	65.3±0.62	0	8.56±3.16	40.64±14.76	1.77±1.08	9.79±6
Dormitator maculatus	0	0	4.83±3.38	2.64±2.64	0	0
Ctenogobius shufeldti	0	6.4±6.4	0	0	0	8.59±5.66
Trinectes maculatus	0	0	0	0	0.86±0.86	2.1±2.1

Table 22.3. CPUE of species sampled by gillnetting at the Bonnet Carré Spillway. CPUE is the mean number (± standard error) of fish taken per hour of gillnet set. N is the number of gillnet sets. Species are listed in systematic order following Nelson (2006).

Period	Jul-Sep 2009	Oct-Dec 2009	Jan-Mar 2010	Apr-Jun 2010	Jul-Sep 2010	Apr-Jun 2011	Jul-Aug 2011
N	16	9	2	10	2	11	23
Mean CPUE	15.4	10.1	6.7	11.4	5.7	30.2	15.2
Entrained CPUE	1.2	2.2	1.5	0.9	2.7	1.3	1.2
Percent Catch Entrained	7.51	21.83	21.57	8.15	47.94	4.19	7.99
Total Species	30	23	8	20	12	33	29
Total Entrained	9	8	4	6	4	10	9
Percent Entrained Species	30.0	34.8	50.0	30.0	33.3	30.3	31.0
Entrained Species per Unit Catch	0.584	0.790	0.595	0.529	0.698	0.331	0.594
Species							
Scaphirhynchus platorynchus	0	0	0	0	0	0.44±0.16	0.04±0.03
Scaphirhynchus albus	0	0	0	0	0	0.04±0.04	0
Polyodon spathula	0.06±0.05	0	0	0	0	0	0.04±0.03
Lepisosteus oculatus	0.45±0.19	0.21±0.13	0	0.04±0.02	1.06±0.58	0.22±0.13	0.09±0.03
Lepisosteus osseus	0.01±0.01	0.06±0.03	0	0.08±0.07	0	0.04±0.03	0.05±0.03
Lepisosteus platostomus	0.07±0.05	0.34±0.18	0	0	1.79±1.25	0.12±0.05	0.23±0.07
Atractosteus spatula	0	0	0	0	0	0.03±0.03	0
Amia calva	0	0	0	0	0.09±0.09	0	0
Hiodon alosoides	0	0.06±0.06	0	0	0	0.18±0.1	0.22±0.1
Hiodon tergisus	0.04±0.04	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0.12±0.12	0
Elops saurus	0.03±0.03	0	0	0	0	0	0
Dorosoma cepedianum	8.64±2.27	4.54±0.82	5.05±0.48	7.22±3.36	1.08±0.36	1.14±0.43	2.22±0.3
Alosa chrysochloris	0.71±0.31	0	0.07±0.07	1.4±0.6	0	5.25±1.67	7.19±1.94
Dorosoma petenense	0.13±0.05	0	0	0.66±0.39	0	0.66±0.27	0.14±0.08
Brevoortia patronus	0.41±0.13	0	0	0	0	0.34±0.15	0.03±0.02
Cyprinus carpio	0.35±0.25	1.1±0.53	0.07±0.07	0.1±0.09	0.25±0.07	0.05±0.03	0.01±0.01
Hypophthalmichthys molitrix	0.06±0.05	0.08±0.05	0	0.02±0.02	0.08±0.08	0.1±0.06	0.02±0.02

Hypophthalmichthys nobilis	0	0.03±0.03	0	0	0	0	0
Carpiodes carpio	0.21±0.13	0.44±0.25	0.14±0.14	0.61±0.41	0	0.2±0.11	0.15±0.06
Carpiodes cyprinus	0.09±0.05	0.04±0.04	0	0	0	0	0
Carpiodes vellifer	0	0	0	0.01±0.01	0	0	0
Ictiobus bubalus	0.5±0.18	0.69±0.28	0.44±0.13	0.08±0.06	0.59±0.05	0.13±0.07	0.38±0.16
Ictiobus cyprinellus	0.12±0.08	0.52±0.16	0.57±0.57	0.11±0.11	0.27±0.27	0.05±0.03	0.05±0.03
Ictiobus niger	0.06±0.04	0.07±0.04	0.3±0.01	0.03±0.03	0.09±0.09	0.06±0.04	0.06±0.03
Ictalurus furcatus	1.4±0.43	0.18±0.09	0	0	0	10.94±4.49	2.52±0.46
Ictalurus punctatus	0.73±0.25	0.22±0.12	0	0.48±0.13	0.26±0.1	0.72±0.26	0.75±0.16
Pylodictis olivaris	0.14±0.09	0.26±0.22	0.08±0.08	0.2±0.2	0	0.7±0.31	0.28±0.1
Mugil cephalus	0.24±0.14	0.44±0.25	0	0.11±0.08	0.08±0.08	2.63±1.51	0.06±0.06
Morone mississippiensis	0.08±0.05	0.05±0.03	0	0.02±0.02	0	0.53±0.36	0.22±0.06
Morone chrysops	0.07±0.05	0.14±0.08	0	0	0	0	0.07±0.03
Morone saxatilis	0	0	0	0	0	0.02±0.02	0
Micropterus salmoides	0.06±0.04	0	0	0.05±0.05	0	3.11±2.89	0.06±0.04
Pomoxis nigromaculatus	0.17±0.13	0.22±0.11	0	0	0.08±0.08	0.32±0.24	0.03±0.02
Lepomis macrochirus	0.13±0.06	0.06±0.06	0	0.03±0.03	0	0.21±0.12	0
Lepomis megalotis	0	0	0	0.07±0.06	0	0.29±0.24	0.03±0.03
Chaenobryttus gulosus	0.14±0.07	0	0	0	0	0.22±0.22	0.01±0.01
Lepomis humilis	0	0	0	0	0	0.36±0.36	0
Pomoxis annularis	0.04±0.03	0.08±0.06	0	0	0	0.15±0.12	0.04±0.03
Lepomis microlophus	0.05±0.04	0	0	0	0	0.17±0.12	0
Aplodinotus grunniens	0.19±0.1	0.31±0.1	0	0.03±0.03	0	0.71±0.41	0.16±0.06
Micropogonias undulatus	0	0	0	0	0	0	0.02±0.02

Table 23.3. CPUE of species sampled by gillnetting at the Davis Pond Diversion. CPUE is the mean number (± standard error) of fish taken per hour of gillnet set. N is the number of gillnet sets. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**	**Jul-Aug 2011**
N	16	8	12	10	6	10	8	6	2
Mean CPUE	6.7	12.0	2.5	9.5	7.5	5.6	4.6	8.6	8.1
Entrained CPUE	0.0	0.8	0.3	0.3	0.4	1.3	0.2	0.0	0.3
Percent Catch Entrained	0.53	6.61	10.79	2.86	5.27	22.85	3.88	0.37	3.28
Total Species	11	14	16	20	14	12	15	14	6
Total Entrained	2	4	4	6	3	4	4	1	2
Percent Entrained Species	18.2	28.6	25.0	30.0	21.4	33.3	26.7	7.1	33.3
Entrained Species per Unit Catch	0.30	0.33	1.62	0.63	0.40	0.71	0.88	0.12	0.25
Species									
Dasyatis sabina	0	0	0	0	0	0	0	0.03±0.03	0
Scaphirhynchus platorynchus	0.02±0.02	0	0	0.02±0.02	0	0	0	0	0
Lepisosteus osseus	0.02±0.02	0.11±0.07	0.01±0.01	0.09±0.08	0.15±0.07	0.77±0.48	0.02±0.02	0	0
Lepisosteus oculatus	0.02±0.02	0.03±0.03	0.35±0.15	0.02±0.02	0	0	0	0.17±0.11	0
Atractosteus spatula	0	0	0.01±0.01	0	0	0	0	0	0
Amia calva	0	0	0.02±0.02	0	0	0	0.02±0.02	0	0
Hiodon alosoides	0	0	0.05±0.03	0	0.11±0.11	0	0	0	0
Dorosoma cepedianum	0.06±0.04	0.48±0.09	0.84±0.37	0.35±0.11	0.04±0.04	0.14±0.06	2.96±1.59	0.23±0.15	0
Alosa chrysochloris	0.07±0.04	0.05±0.05	0.01±0.01	0.18±0.13	0.1±0.07	0	0.03±0.03	0.06±0.04	0
Dorosoma petenense	0	0	0	0.07±0.06	0	0	0.07±0.07	0.12±0.06	0
Cyprinus carpio	0	0.05±0.03	0.03±0.02	0	0.06±0.04	0.02±0.02	0.1±0.08	0.06±0.04	0
Hypophthalmichthys molitrix	0	0	0	0.15±0.05	0.04±0.04	0	0	0	0
Ictiobus bubalus	0	0.48±0.32	0.22±0.06	0.1±0.05	0.19±0.07	0.43±0.19	0.09±0.07	0	0
Ictiobus cyprinellus	0	0.18±0.1	0	0.04±0.03	0.06±0.04	0.07±0.03	0.05±0.05	0	0.14±0.14
Ictiobus niger	0	0	0	0.02±0.02	0	0.02±0.02	0	0	0
Minytrema melanops	0	0	0.01±0.01	0	0	0	0	0	0
Ictalurus furcatus	4.72±0.88	9.82±3.61	0.38±0.26	5.16±0.9	4.52±1.64	3.01±0.74	0.96±0.21	6.12±0.86	6.61±0.36
Ictalurus punctatus	0.64±0.21	0.08±0.05	0	1.77±0.65	0.5±0.1	0.05±0.03	0	0.89±0.66	0.26±0.01
Pylodictis olivaris	0.19±0.09	0.14±0.08	0.03±0.02	0.31±0.15	0.19±0.06	0.1±0.07	0.03±0.03	0.3±0.1	0.51±0.24
Mugil cephalus	0	0	0	0.13±0.08	0	0	0	0	0

Morone chrysops	0.02±0.02	0.18±0.07	0.19±0.05	0.45±0.13	0.03±0.03	0.37±0.16	0.03±0.03	0.11±0.06	0
Morone mississippiensis	0	0	0	0.02±0.02	0	0	0.04±0.03	0.11±0.11	0
Morone saxatilis	0	0	0	0	0	0	0.02±0.02	0.03±0.03	0.13±0.13
Morone saxatilis x M. chrysops	0.02±0.02	0	0	0.01±0.01	0	0	0	0	0
Pomoxis nigromaculatus	0	0.03±0.03	0.03±0.02	0.09±0.06	0	0.07±0.05	0.07±0.05	0.06±0.04	0
Chaenobryttus gulosus	0	0	0	0	0.03±0.03	0	0	0	0
Sander canadensis	0	0.03±0.03	0.02±0.02	0.01±0.01	0	0	0	0	0
Aplodinotus grunniens	0.89±0.33	0.38±0.09	0.26±0.07	0.55±0.15	1.51±0.42	0.58±0.53	0.08±0.04	0.34±0.21	0.4±0.15

Table 24.3. CPUE of species sampled by gillnetting at the Violet Siphon. CPUE is the mean number (± standard error) of fish taken per hour of gillnet set. N is the number of gillnet sets. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**
N	13	4	1	8	6	6	6	6
Mean CPUE	8.8	10.2	2.1	7.0	5.1	6.4	5.8	5.7
Entrained CPUE	0.3	0.1	0.0	0.0	0.1	0.0	0.1	0.1
Percent Catch Entrained	3.82	0.72	0.00	0.35	1.78	0.00	1.87	1.50
Total Species	18	4	5	13	13	15	14	14
Total Entrained	4	1	0	1	1	0	2	2
Percent Entrained Species	22.2	25.0	0.0	7.7	7.7	0.0	14.3	14.3
Entrained Species per Unit Catch	0.46	0.10	0.00	0.14	0.20	0.00	0.34	0.35
Species								
Dasyatis sabina	0	0	0	0	0.04±0.04	0	0	0
Lepisosteus oculatus	1.16±0.45	3.17±1.74	0.52	0.37±0.12	1.91±0.88	1.9±0.7	1.13±0.76	0.08±0.05
Atractosteus spatula	0.19±0.1	0	0	0.03±0.03	0.34±0.13	0.27±0.09	0	0
Lepisosteus osseus	0.03±0.03	0.07±0.07	0	0	0	0	0	0
Elops saurus	0.06±0.06	0	0	0	0.42±0.19	0	0	0
Dorosoma cepedianum	1.1±0.48	6.84±3.31	0.78	3.84±2.14	0.33±0.13	0.6±0.2	2.89±1.22	1.07±0.59
Alosa chrysochloris	4.44±1.19	0	0	1.14±0.52	0.91±0.31	0.56±0.23	0.07±0.07	2.54±1.44
Dorosoma petenense	0	0	0	0.2±0.2	0	0.08±0.05	0.57±0.38	1.01±0.87
Brevoortia patronus	0.03±0.03	0	0	0	0	1.16±1.12	0	0
Cyprinus carpio	0	0	0	0	0	0	0.22±0.14	0
Ictiobus niger	0.14±0.09	0	0	0	0	0	0.04±0.04	0.04±0.04
Ictiobus cyprinellus	0.09±0.07	0	0	0	0	0	0.07±0.05	0.04±0.04
Ictiobus bubalus	0.08±0.08	0	0	0.02±0.02	0.09±0.06	0	0	0
Ictalurus furcatus	0.83±0.24	0	0	0.48±0.28	0.64±0.21	0.54±0.45	0.04±0.04	0.04±0.04
Ictalurus punctatus	0.12±0.07	0	0	0.13±0.09	0.09±0.06	0.08±0.08	0.07±0.07	0.42±0.23
Pylodictis olivaris	0.03±0.03	0	0	0.09±0.09	0.1±0.06	0	0	0
Bagre marinus	0.19±0.08	0	0	0	0	0	0	0
Mugil cephalus	0	0.07±0.07	0	0	0	0.11±0.08	0	0.12±0.12
Morone chrysops	0.08±0.08	0	0.26	0.54±0.28	0.05±0.05	0.62±0.43	0.07±0.04	0.09±0.05

Morone mississippiensis	0	0	0	0	0	0	0.1±0.1	0
Lepomis macrochirus	0	0	0.26	0	0	0.17±0.17	0.19±0.19	0
Micropterus salmoides	0	0	0	0	0	0.16±0.05	0.36±0.18	0
Pomoxis nigromaculatus	0	0	0	0	0	0.04±0.04	0	0.04±0.04
Chaenobryttus gulosus	0	0	0	0	0	0	0	0.04±0.04
Aplodinotus grunniens	0.14±0.06	0	0.26	0.05±0.03	0.09±0.09	0.04±0.04	0.04±0.04	0.09±0.09
Micropogonias undulatus	0.01±0.01	0	0	0	0	0	0	0.04±0.04
Cynoscion arenarius	0	0	0	0.02±0.02	0	0	0	0
Paralichthys lethostigma	0.05±0.05	0	0	0.03±0.03	0.09±0.06	0.04±0.04	0	0

Table 25.3. CPUE of species sampled by gillnetting at the Caernarvon Diversion. CPUE is the mean number (± standard error) of fish taken per hour of gillnet set. N is the number of gillnet sets. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**
N	15	8	6	4	6	8	6	8
Mean CPUE	5.4	13.4	3.1	5.3	8.5	11.6	21.9	9.2
Entrained CPUE	0.1	0.6	1.2	0.2	0.4	1.6	0.5	0.3
Percent Catch Entrained	1.67	4.10	37.59	4.05	4.77	13.86	2.10	3.13
Total Species	12	20	17	13	14	19	16	17
Total Entrained	2	5	5	2	3	4	3	4
Percent Entrained Species	16.7	25.0	29.4	15.4	21.4	21.1	18.8	23.5
Entrained Species per Unit Catch	0.37	0.37	1.60	0.38	0.35	0.35	0.14	0.44
Species								
Dasyatis sabina	0.02±0.02	0	0	0	0	0.03±0.03	0	0.02±0.02
Atractosteus spatula	0.03±0.03	0.12±0.12	0.06±0.03	0.08±0.08	0	0	0	0
Lepisosteus oculatus	0	0.57±0.49	0.3±0.15	2.8±2.52	0	0	0	0
Lepisosteus osseus	0.05±0.03	0.32±0.22	0.16±0.09	0.07±0.07	0	0.18±0.09	0	0.06±0.04
Lepisosteus platostomus	0	0.02±0.02	0	0	0	0	0	0.03±0.03
Hiodon alosoides	0	0	0.01±0.01	0	0	0	0	0
Elops saurus	0	0	0	0	0.06±0.06	0	0	0
Dorosoma cepedianum	0	0.24±0.12	0.57±0.19	0.33±0.33	0	2.3±1.43	1.29±0.46	0.29±0.16
Alosa chrysochloris	0.35±0.2	0	0	0.21±0.13	0.97±0.47	0.17±0.14	0	0.18±0.11
Dorosoma petenense	0	0	0	0	0	0	0	0.03±0.03
Hypophthalmichthys molitrix	0	0.02±0.02	0.16±0.15	0	0.03±0.03	0	0.21±0.16	0
Cyprinus carpio	0	0	0	0	0.09±0.06	0	0	0
Ictiobus bubalus	0	0.15±0.13	0.87±0.47	0.14±0.08	0.17±0.11	0.86±0.32	0.25±0.12	0.1±0.05
Ictiobus cyprinellus	0.02±0.02	0.02±0.02	0.1±0.06	0	0.14±0.11	0.37±0.1	0.11±0.06	0.05±0.03
Ictiobus niger	0	0.02±0.02	0.05±0.05	0	0.1±0.07	0.19±0.05	0.03±0.03	0
Ictalurus furcatus	4.02±1.24	9.33±4.09	0.37±0.19	0.13±0.08	4.64±1.15	4.87±1.07	9.92±3.95	7.56±1.94
Ictalurus punctatus	0.48±0.18	0.26±0.13	0	0.5±0.5	0.14±0.11	0.23±0.1	2.88±1.67	0.05±0.04
Pylodictis olivaris	0	0.07±0.07	0	0	0.03±0.03	0	0.1±0.07	0.11±0.06

Ameiurus nebulosus	0	0	0.06±0.06	0	0	0	0	0
Mugil cephalus	0	0	0	0.42±0.42	0	0.03±0.03	0	0
Strongylura marina	0	0	0	0.07±0.07	0	0	0	0
Morone chrysops	0.1±0.08	0.66±0.26	0.24±0.08	0.3±0.14	0.09±0.04	0.29±0.17	0.1±0.07	0.06±0.06
Morone mississippiensis	0.02±0.02	0.08±0.05	0.01±0.01	0	0	0.06±0.04	0.1±0.07	0.18±0.14
Morone saxatilis	0.01±0.01	0.02±0.02	0	0	0	0	0.06±0.04	0.05±0.03
Morone saxatilis x M. chrysops	0	0	0.01±0.01	0	0	0	0	0
Lepomis microlophus	0	0.02±0.02	0	0	0	0.48±0.31	0.02±0.02	0
Pomoxis nigromaculatus	0	0.06±0.04	0.07±0.05	0	0.04±0.04	0.05±0.03	0.1±0.07	0.03±0.03
Lepomis macrochirus	0	0.04±0.02	0.01±0.01	0	0.03±0.03	0.18±0.1	0.02±0.02	0
Micropterus salmoides	0	0	0	0.08±0.08	0	0.03±0.03	0.15±0.12	0
Lepomis miniatus	0	0	0	0	0	0.02±0.02	0	0
Chaenobryttus gulosus	0	0.02±0.02	0	0	0	0	0	0
Aplodinotus grunniens	0.28±0.11	1.39±0.9	0.11±0.05	0.14±0.14	1.96±1.12	1.19±0.5	6.54±3.12	0.31±0.2
Leiostomus xanthurus	0	0	0	0	0	0.03±0.03	0	0
Paralichthys lethostigma	0.02±0.02	0	0	0	0	0	0	0.07±0.07

Table 26.3. CPUE of species sampled by gillnetting at the White Ditch Siphon. CPUE is the mean number (± standard error) of fish taken per hour of gillnet set. N is the number of gillnet sets. Species are listed in systematic order following Nelson (2006).

Period	**Oct-Dec 2009**	**Apr-Jun 2010**	**Jul-Sep 2010**
N	4	4	4
Mean CPUE	12.8	9.3	8.7
Entrained CPUE	0.5	0.8	0.3
Percent Catch Entrained	3.91	8.46	3.62
Total Species	14	14	11
Total Entrained	1	3	2
Percent Entrained Species	7.1	21.4	18.2
Entrained Species per Unit Catch	0.08	0.32	0.23
Species			
Atractosteus spatula	0.33±0.33	0.13±0.07	0
Lepisosteus oculatus	7.86±4.03	1.9±1.16	0.22±0.15
Elops saurus	0.17±0.17	0	0
Alosa chrysochloris	0	0.56±0.36	0.28±0.22
Dorosoma cepedianum	1.31±0.61	0.5±0.35	0.05±0.05
Ictiobus niger	0	0.06±0.06	0
Ictiobus cyprinellus	0	0.35±0.21	0.05±0.05
Ictiobus bubalus	0.5±0.5	0.37±0.13	0.26±0.16
Pylodictis olivaris	0.25±0.25	0.06±0.06	0.16±0.1
Ictalurus punctatus	0	0.49±0.3	0.11±0.06
Ictalurus furcatus	0.67±0.47	3.99±1.3	6.5±0.75
Mugil cephalus	0.5±0.5	0.05±0.05	0
Micropterus salmoides	0.08±0.08	0	0
Lepomis microlophus	0.17±0.17	0	0
Pomoxis nigromaculatus	0	0.13±0.07	0.06±0.06
Pomoxis annularis	0.25±0.25	0	0
Sciaenops ocellatus	0.17±0.17	0	0
Micropogonias undulatus	0.29±0.17	0	0.06±0.06
Aplodinotus grunniens	0.25±0.25	0.61±0.47	0.9±0.23
Paralichthys lethostigma	0	0.06±0.06	0

Table 27.3. CPUE of species sampled by gillnetting at the Naomi Siphon. CPUE is the mean number (± standard error) of fish taken per hour of gillnet set. N is the number of gillnet sets. Species are listed in systematic order following Nelson (2006).

Period	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**
N	2	3	8	7	5	6
Mean CPUE	14.9	3.8	2.6	9.3	12.1	3.3
Entrained CPUE	5.0	0.8	0.1	1.3	1.9	1.0
Percent Catch Entrained	33.28	22.30	4.79	14.38	15.76	31.97
Total Species	14	14	13	21	22	15
Total Entrained	5	4	2	4	5	5
Percent Entrained Species	35.7	28.6	15.4	19.0	22.7	33.3
Entrained Species per Unit Catch	0.34	1.07	0.78	0.43	0.41	1.52
Species						
Polyodon spathula	0	0	0	0	0.3±0.19	0.1±0.06
Amia calva	0	0	0	0	0.13±0.13	0
Atractosteus spatula	0.58±0.24	0.11±0.11	0	0.18±0.07	0	0
Lepisosteus oculatus	2.59±0.87	1.16±0.6	0.37±0.2	3.22±1.68	1.16±1.16	0.51±0.44
Lepisosteus osseus	1.32±0.56	0.12±0.07	0	0.1±0.06	0.08±0.05	0
Lepisosteus platostomus	0.03±0.03	0	0	0	0	0
Megalops atlanticus	0	0	0	0.06±0.04	0	0
Dorosoma cepedianum	4.82±1.88	0.61±0.49	0.53±0.25	1.02±0.27	1.97±0.71	0.32±0.11
Dorosoma petenense	0	0.06±0.06	0	0	0	0
Hypophthalmichthys molitrix	0	0.05±0.05	0	0	0.16±0.06	0.05±0.05
Cyprinus carpio	0	0	0	0	0.17±0.1	0.06±0.06
Ctenopharyngodon idella	0	0	0	0	0.04±0.04	0
Ictiobus bubalus	1.47±0.66	0.27±0.14	0	0.53±0.48	0.42±0.22	0.57±0.23
Ictiobus cyprinellus	1.64±0.63	0.06±0.06	0.08±0.05	0.56±0.29	0.54±0.23	0.21±0.09
Ictiobus niger	0.5±0.24	0.39±0.17	0.05±0.05	0.15±0.08	0.57±0.2	0.11±0.11
Cycleptus elongatus	0	0	0	0	0	0.06±0.06
Ictalurus furcatus	0.24±0.16	0.33±0.1	1.03±0.44	1.16±0.87	0.51±0.31	0.53±0.28
Ictalurus punctatus	0.21±0.12	0.05±0.05	0.05±0.05	0.18±0.14	0.14±0.1	0.11±0.06
Pylodictis olivaris	0	0	0	0.07±0.07	0.04±0.04	0.06±0.06

Mugil cephalus	0	0	0.07±0.05	1.57±1.05	3.86±3.26	0
Morone chrysops	0.93±0.59	0.21±0.12	0.12±0.05	0.09±0.09	0.07±0.07	0.22±0.22
Morone mississippiensis	0.04±0.04	0	0.04±0.04	0.03±0.03	0.07±0.07	0.06±0.06
Pomoxis nigromaculatus	0.36±0.25	0.29±0.21	0.03±0.03	0.09±0.05	0.31±0.18	0.32±0.15
Lepomis macrochirus	0	0	0	0.1±0.07	0.58±0.58	0
Micropterus salmoides	0	0	0	0.04±0.04	0.43±0.31	0
Lepomis microlophus	0	0	0	0.05±0.03	0.26±0.26	0
Pomoxis annularis	0	0	0.03±0.03	0.05±0.05	0	0
Aplodinotus grunniens	0.18±0.09	0.05±0.05	0.05±0.05	0.05±0.03	0.32±0.32	0
Paralichthys lethostigma	0	0	0.14±0.14	0.04±0.04	0	0

Table 28.3. CPUE of species sampled by electrofishing at the Bonnet Carré Spillway. CPUE is the mean number (± standard error) of fish taken per electrofishing station (500 seconds). N is the number of electrofishing stations. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Apr-Jun 2011**	**Jul-Aug 2011**
N	7	5	1	3	2	3	9
Mean CPUE	233.6	53.8	24.0	39.3	339.5	143.7	72.2
Entrained CPUE	6.4	7.6	10.0	5.3	30.5	2.3	1.0
Percent Catch Entrained	2.75	14.13	41.67	13.56	8.98	1.62	1.38
Total Species	37	27	8	25	24	29	26
Total Entrained	7	7	4	5	5	5	3
Percent Entrained Species	18.9	25.9	50	20	20.8	17.2	11.5
Entrained Species per Unit Catch	0.03	0.13	0.17	0.13	0.01	0.03	0.04
Species							
Polyodon spathula	0	0	0	0	0.5±0.5	0	0
Lepisosteus oculatus	1±1	0.4±0.24	0	1.33±0.88	2.5±1.5	2±1.15	0.56±0.29
Lepisosteus osseus	0	0	0	0	0	1±1	0
Lepisosteus platostomus	0.14±0.14	0.8±0.58	1	0.33±0.33	0	0	0.11±0.11
Anguilla rostrata	0.14±0.14	0	0	0	0	0.67±0.67	0.33±0.24
Elops saurus	0.14±0.14	0	0	0	0	0	0.11±0.11
Anchoa mitchilli	3.14±1.7	0	0	0	0	0.33±0.33	1.89±1.77
Alosa chrysochloris	0.86±0.86	0	0	1.67±1.67	0	0	4.22±3.01
Brevoortia patronus	7.43±4.44	0	0	0.33±0.33	0	5.33±2.91	13.11±7.25
Dorosoma cepedianum	21.43±7.23	8.4±6.18	7	5.67±5.67	95.5±4.5	6±1.53	12.22±4.03
Dorosoma petenense	67.71±27.8	4.4±2.29	0	2.67±1.67	147±29	5.33±5.33	2.67±1.8
Cyprinus carpio	0.14±0.14	0.4±0.24	0	1.67±0.88	1±1	0	0
Hypophthalmichthys molitrix	0.29±0.29	0.2±0.2	0	0	25±15	0.33±0.33	0.11±0.11
Lythrurus fumeus	0.57±0.43	0	0	0	0	0	0
Notemigonus crysoleucas	0	0	0	0.33±0.33	0	0	0
Opsopoeodus emiliae	0	0.2±0.2	0	0.33±0.33	0.5±0.5	0.33±0.33	0
Pimephales vigilax	0.29±0.18	0	0	0	0	0	0

Carpiodes carpio	0	2.2±1.74	7	2.67±0.88	0	0.33±0.33	0
Carpiodes cyprinus	0.43±0.43	0	0	0	0	0	0
Ictiobus bubalus	4.14±1.68	2.2±0.73	0	1.67±0.67	26.5±9.5	0.33±0.33	0.67±0.24
Ictiobus cyprinellus	0.57±0.3	1±0.77	1	0.33±0.33	2.5±1.5	0.33±0.33	0.22±0.22
Ictiobus niger	0.29±0.18	1±0.45	1	0	0	0	0
Ictalurus furcatus	3±3	0.2±0.2	0	1±0.58	0	0.67±0.33	0.78±0.32
Ictalurus punctatus	0.29±0.18	0	0	0	1±1	0.67±0.67	0
Pylodictis olivaris	0	0.2±0.2	0	0	0	0.33±0.33	0.22±0.15
Mugil cephalus	11±4.48	0.8±0.37	0	1.33±0.33	12±3	7.33±2.91	18.78±3.41
Menidia beryllina	5.86±2.44	0.8±0.58	0	1.67±0.88	2.5±2.5	8±7.02	2.33±1.25
Strongylura marina	0.29±0.18	0	0	0	0	0	0.11±0.11
Gambusia affinis	0.14±0.14	4.2±3.95	0	0.33±0.33	0	41±24.58	0.11±0.11
Cyprinodon variegatus	0	0	0	0	0	0.33±0.33	0
Morone chrysops	1.57±0.69	0.4±0.4	0	0.33±0.33	0	0	0.11±0.11
Morone mississippiensis	0	0	1	0	1±0	0	0
Morone saxatilis	0	0	0	0	0.5±0.5	0	0
Chaenobryttus gulosus	3.86±1.67	0.2±0.2	0	2±1.15	0.5±0.5	0.67±0.67	0
Lepomis cyanellus	1.71±0.71	0	0	0.67±0.67	0.5±0.5	1.67±1.2	0
Lepomis humilis	4.14±1.94	0.2±0.2	0	0.33±0.33	3.5±3.5	11±5.86	0
Lepomis macrochirus	52.57±9.84	18.2±6.79	0	4±2.52	4.5±1.5	14.67±8.57	3.22±1.42
Lepomis megalotis	21.86±8.93	5.2±2.22	0	4.33±3.38	0.5±0.5	19.67±9.06	2.44±0.9
Lepomis microlophus	1.71±0.75	0.8±0.37	0	0	1.5±1.5	1.33±1.33	1.22±0.88
Lepomis miniatus	1±0.44	0	0	0	0	2±2	0.67±0.67
Lepomis symmetricus	0	0	0	0	0	2±1.53	0
Micropterus salmoides	13±2.87	0.4±0.4	0	3.67±2.19	5.5±2.5	9.67±3.93	5.44±1.26
Pomoxis annularis	0.43±0.3	0.2±0.2	0	0	1±0	0	0
Pomoxis nigromaculatus	0.57±0.37	0.4±0.4	4	0.33±0.33	1.5±0.5	0	0
Percina maculata	0	0.2±0.2	0	0	0	0	0
Aplodinotus grunniens	1.57±0.87	0.2±0.2	2	0.33±0.33	2.5±0.5	0.33±0.33	0.44±0.18
Herichthys cyanoguttatus	0.14±0.14	0	0	0	0	0	0
Paralichthys lethostigma	0.14±0.14	0	0	0	0	0	0
Trinectes maculatus	0	0	0	0	0	0	0.11±0.11

Table 29.3. CPUE of species sampled by electrofishing at the Davis Pond Diversion. CPUE is the mean number (± standard error) of fish taken per electrofishing station (500 seconds). N is the number of electrofishing stations. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**	**Jul-Aug 2011**
N	10	4	4	7	8	12	8	6	2
Mean CPUE	322.9	129.5	43.3	262.3	116.3	127.9	85.0	176.0	177.5
Entrained CPUE	4.6	4.5	1.3	5.4	4.4	3.5	0.6	3.3	1.0
Percent Catch Entrained	1.42	3.47	2.89	2.07	3.76	2.74	0.74	1.89	0.56
Total Species	44	38	21	41	38	37	29	36	24
Total Entrained	11	8	4	9	11	7	5	7	2
Percent Entrained Species	25.0	21.1	19.0	22.0	28.9	18.9	17.2	19.4	8.3
Entrained Species per Unit Catch	0.03	0.06	0.09	0.03	0.09	0.05	0.06	0.04	0.01
Species									
Polyodon spathula	0	0	0	0.14±0.14	0	0	0	0	0
Lepisosteus oculatus	2.3±0.56	1±0.71	0.25±0.25	3.43±1.36	1.13±0.74	0.92±0.51	0	2.83±1.54	0
Lepisosteus osseus	0.4±0.22	0.5±0.5	0	0.29±0.18	0.13±0.13	1.33±0.67	0.13±0.13	0.17±0.17	0.5±0.5
Lepisosteus platostomus	0.1±0.1	0.25±0.25	0	0.71±0.29	0	0	0	0.33±0.21	0
Amia calva	0.1±0.1	0	0.25±0.25	0.29±0.29	0	0.08±0.08	0.38±0.26	0.5±0.5	0
Hiodon alosoides	0	0.25±0.25	0	0	1.5±0.5	0.08±0.08	0	0	0
Anguilla rostrata	0.4±0.22	2.25±1.03	0.75±0.48	2.29±1.32	0.88±0.48	0.67±0.28	1.63±0.98	1.67±0.67	0.5±0.5
Elops saurus	3.5±1.59	0	0	0	0	0	0	0	0
Anchoa mitchilli	16.5±6.16	1.75±1.11	0	2.29±1.54	0.75±0.37	10±6.78	0	8.67±3.74	1±0
Alosa chrysochloris	0.3±0.21	0.25±0.25	0	0.86±0.55	0	0.17±0.11	0	0	0.5±0.5
Brevoortia patronus	2.4±1.18	1.25±0.95	0	4.43±4.26	0.13±0.13	1.58±1.41	0	2.17±1.51	0
Dorosoma cepedianum	13.3±3.4	11.75±8.48	8.5±4.09	7.57±2.44	9±2.39	4.67±2.29	5.25±4.26	0.67±0.49	4±4
Dorosoma petenense	17.5±7.54	0.5±0.5	0	32.29±13.86	2.13±1.99	1.17±1.08	0.13±0.13	3±2.45	4.5±1.5
Ctenopharyngodon idella	0	0	0	0	0	0	0	0.33±0.33	0
Cyprinus carpio	0	0.25±0.25	0.5±0.5	7.14±2.52	0.13±0.13	0	2.38±0.94	3±2.61	0
Cyprinella lutrensis	0	0	0	0	0.13±0.13	0	0	0	0
Cyprinella venusta	0	0	0	0	0.13±0.13	0	0	0.17±0.17	0
Hybopsis amnis	0	0	0	0	0.13±0.13	0	0.13±0.13	0	0
Hybognathus hayi	0.1±0.1	0	0	0	0	0	0	0	0

Hybognathus nuchalis	1±0.8	0	0	0	0.13±0.13	0	0	0	0
Hypophthalmichthys molitrix	0.1±0.1	0	0	1.14±0.46	0	0	0	0	0.5±0.5
Lythrurus fumeus	0.6±0.4	0	0	0	0	0	0	0	0
Macrhybopsis storeriana	0	0	0.25±0.25	0	0	0.25±0.18	0	0	0
Notropis atherinoides	0	0.25±0.25	0	0.71±0.36	0.13±0.13	0.58±0.5	0	0	0
Notemigonus crysoleucas	0.1±0.1	0	0	0	0.13±0.13	0	0.13±0.13	0	0
Notropis volucellus	0	0	0	0.29±0.29	0	0	0	0	0
Opsopoeodus emiliae	0	0	0.25±0.25	0	0	0	0	0	0
Carpiodes carpio	0	0	0	0	0.25±0.25	0	0	0	0
Carpiodes cyprinus	0	0	0	0	0	0	0.13±0.13	0	0
Cycleptus elongatus	0	0	0	0.14±0.14	0	0	0	0	0
Ictiobus bubalus	0.8±0.29	1.75±0.85	0.5±0.29	1.43±0.75	1.63±0.56	0.92±0.47	0.13±0.13	1.83±0.98	0.5±0.5
Ictiobus cyprinellus	0.3±0.21	0.25±0.25	0	1.57±1	0.13±0.13	0.17±0.11	0.13±0.13	0.33±0.33	0
Ictiobus niger	0.1±0.1	0	0	0.14±0.14	0	0	0	0.33±0.21	0
Ameiurus natalis	0	0.25±0.25	0	0	0	0	0	0	0
Ictalurus furcatus	2.3±1.12	19±7.14	1±1	35.57±15.89	7.75±2.26	3.83±1.39	1.25±0.62	6.83±2.46	16±3
Ictalurus punctatus	3.3±1	1.5±0.5	0	4.29±2.08	3±1.75	0.67±0.5	0.13±0.13	4±1.95	9±5
Pylodictis olivaris	2.6±0.91	0.25±0.25	0	1.14±0.55	2±1.12	0.25±0.25	0	0.67±0.33	3±3
Aphredoderus sayanus	0	0	0	0	0	0	0.13±0.13	0	0
Mugil cephalus	8.6±3.1	10.75±7.09	5.25±4.92	71±29.08	5±1.51	5.42±1.74	15.25±9.74	34±10.89	3.5±2.5
Mugil curema	1.4±1.4	3.75±3.42	0	0	0	0	0	0	0
Membras martinica	0	0	0	0.14±0.14	0	0	0	0	0
Menidia beryllina	1.2±0.66	0.25±0.25	1±0	1.71±0.64	1.38±0.46	3.5±1.61	5.5±2.75	0.67±0.33	1.5±0.5
Strongylura marina	0	0	0	0	0	0	0	0.33±0.33	0
Fundulus chrysotus	0	0.25±0.25	0	0	0	0	0	0	0
Gambusia affinis	1.5±0.89	1.25±0.95	0	3.71±3.55	0.75±0.49	0.08±0.08	0	0	0
Poecilia latipinna	0	0	0	0	0	0.25±0.18	0	0	0
Morone chrysops	13.8±6.36	3±0.58	1.25±1.25	2.86±1.08	3.75±1.31	0.67±0.67	0.25±0.16	0.33±0.21	2.5±0.5
Morone mississippiensis	0.4±0.31	0	0	0.14±0.14	0	0.58±0.58	0.38±0.26	0.33±0.33	2.5±1.5
Morone saxatilis	0.8±0.51	0.75±0.48	0.25±0.25	0	0.13±0.13	0	0	0.17±0.17	0
Chaenobryttus gulosus	35.8±9.84	7.75±2.59	3±1.22	16.86±3.39	6.75±2.5	11.5±4.98	11.25±3.12	18.17±5.99	31±22
Lepomis cyanellus	13.8±4.49	6±2.86	3±1.78	5.86±1.82	4.38±1.67	4.08±1.71	2.75±1.18	2.17±0.48	0.5±0.5

Lepomis humilis	0.1±0.1	0	0	0.29±0.18	0	0	0.25±0.25	2.17±0.95	0
Lepomis macrochirus	51.3±17.8	7.5±3.88	7±4.02	21.29±5.46	19.25±3.27	35.08±17.79	14.13±3.64	38.17±6.1	23±19
Lepomis marginatus	0	3.25±2.63	0	0	0	0	0	0	0
Lepomis megalotis	17±3.46	2.75±1.11	6±3.72	9.14±1.34	9.75±5.34	17.67±5.11	13.38±6.47	10.67±2.86	4±3
Lepomis microlophus	1.3±0.52	0	0.25±0.25	0.43±0.3	0.5±0.27	0.67±0.51	0.75±0.53	0	1±1
Lepomis miniatus	1.7±0.5	0	0	0.29±0.18	0.88±0.48	1.08±0.26	0.63±0.32	16±7.18	7±7
Lepomis symmetricus	0	0	0	0	0	0	0	0.17±0.17	0
Micropterus punctulatus	0	0.5±0.29	0	0	0	0.17±0.17	0	0	0
Micropterus salmoides	72.6±21.96	8±4.71	0.75±0.48	8.57±2.39	23.38±7.95	15.75±7.8	1.88±0.44	11.17±2.65	43.5±26.5
Pomoxis annularis	0.4±0.22	0.25±0.25	0	1±0.69	0.25±0.16	0.25±0.18	0.25±0.16	1.83±1.83	3±1
Pomoxis nigromaculatus	15.6±7.79	3.5±1.32	3±1.91	8.14±2.57	5.25±2.24	2.92±1	6±1.79	1.33±0.42	14.5±5.5
Sander canadensis	0.3±0.15	0	0	0	0	0	0	0	0
Lutjanus griseus	0	0.25±0.25	0	0	0	0	0	0	0
Aplodinotus grunniens	0	0.5±0.5	0.25±0.25	1.71±0.57	1.75±0.73	0.42±0.42	0.38±0.38	0.67±0.67	0
Dormitator maculatus	16.6±15.27	25.25±25.25	0	0	1.38±0.6	0.08±0.08	0	0	0
Eleotris pisonis	0.3±0.21	0.75±0.48	0	0.14±0.14	0.5±0.27	0.33±0.19	0	0	0
Gobiomorus dormitor	0.1±0.1	0	0	0	0	0	0	0	0
Ctenogobius shufeldti	0.2±0.2	0	0	0.86±0.7	0	0.08±0.08	0	0.17±0.17	0

Table 30.3. CPUE of species sampled by electrofishing at the Violet Siphon. CPUE is the mean number (± standard error) of fish taken per electrofishing station (500 seconds). N is the number of electrofishing stations. Species are listed in systematic order following Nelson (2006).

Period	Jul-Sep 2009	Oct-Dec 2009	Jan-Mar 2010	Apr-Jun 2010	Jul-Sep 2010	Oct-Dec 2010	Jan-Mar 2011	Apr-Jun 2011
N	9	4	1	8	5	3	7	6
Mean CPUE	111.7	46.0	48.0	198.4	200.4	98.3	181.7	153.2
Entrained CPUE	0.2	0.3	0.0	0.0	0.6	0.3	0.1	2.2
Percent Catch Entrained	0.20	0.54	0.00	0.00	0.30	0.34	0.08	1.41
Total Species	37	15	8	31	23	20	24	27
Total Entrained	2	1	0	0	1	1	1	1
Percent Entrained Species	5.4	6.7	0.0	0.0	4.3	5.0	4.2	3.7
Entrained Species per Unit Catch	0.02	0.02	0.00	0.00	0.005	0.01	0.01	0.01
Species								
Atractosteus spatula	0	0	0	0.25±0.16	0	0.33±0.33	0	0
Lepisosteus oculatus	2±0.78	2.75±1.55	15	2±0.93	4.6±1.96	4.67±2.73	1±0.72	0.83±0.48
Lepisosteus osseus	0	0.25±0.25	0	0	0	0	0	0
Anguilla rostrata	0.78±0.43	0	0	0.75±0.31	0.4±0.24	0.67±0.67	0	1.33±0.71
Elops saurus	1.33±0.9	0	0	8±3.67	0.2±0.2	0	0	0
Anchoa mitchilli	3.44±1.11	0.5±0.5	0	4.25±1.01	1.6±1.17	3.33±1.76	70.86±58.31	4±1.03
Alosa chrysochloris	0.22±0.15	0	0	2.63±2.63	0.6±0.6	0	1.43±0.75	0.5±0.34
Brevoortia patronus	49±15.08	0	0	143.25±69.06	72±25.4	1±0.58	8.57±5.95	22.17±18.26
Dorosoma cepedianum	1±0.44	2.25±0.75	9	3.13±0.85	19±13.07	14.33±9.49	1±1	13.33±3.99
Dorosoma petenense	0.11±0.11	0	0	0.25±0.16	0	0	0.14±0.14	1.5±0.96
Hypophthalmichthys molitrix	0	0	0	0.13±0.13	0	0	0	0
Lythrurus fumeus	0.11±0.11	0	0	0	0	0	0	0
Ictiobus bubalus	0	0	0	0	0.6±0.4	0.33±0.33	0	0
Ictiobus cyprinellus	0	0	0	0	0	0	0	2.17±1.42
Ictiobus niger	0.11±0.11	0	0	0	0	0	0.14±0.14	0
Ictalurus furcatus	1.11±0.65	0	0	0.5±0.27	0.4±0.24	0.33±0.33	0.14±0.14	0.5±0.34
Ictalurus punctatus	0	0	0	0.5±0.27	0.4±0.24	1±0.58	0.86±0.86	0.5±0.22
Mugil cephalus	18±4.62	16.25±3.54	3	7.38±1.95	64.6±30.92	16±5.69	1.71±0.78	78.5±39.04

Menidia beryllina	6.78±1.28	0.75±0.75	0	3.38±1.97	0.4±0.4	0	0.14±0.14	1.17±0.75
Strongylura marina	0.11±0.11	0	0	0.75±0.37	0	0	0	0.5±0.34
Fundulus chrysotus	0	0	0	0	0	0.33±0.33	0	0
Fundulus grandis	5.89±2.45	0.25±0.25	3	2.25±1.18	0.8±0.37	0.67±0.67	0.71±0.29	0.33±0.21
Lucania parva	1.22±0.74	1±0.41	4	2.13±0.55	0	0	8.43±4.74	9.83±2.55
Gambusia affinis	0.78±0.46	4±4	5	2±0.85	1.6±0.51	1.33±0.33	62.14±35.39	0
Poecilia latipinna	0	7.25±3.66	0	0	0	19.67±15.39	0.29±0.29	0
Cyprinodon variegatus	0	0.25±0.25	0	0	0	0	11.29±10.46	0
Morone chrysops	0.22±0.15	0	0	0.13±0.13	0	0	0	0
Chaenobryttus gulosus	2.33±0.88	1.25±0.75	0	2.75±1	3.2±0.49	5.67±2.96	1±0.38	4.17±1.49
Lepomis cyanellus	0.44±0.24	0	0	0	0	0	1.14±0.7	0.67±0.33
Lepomis humilis	0	0	0	0	0	0	0.14±0.14	0
Lepomis macrochirus	7.44±1.6	7.75±3.71	8	3.5±0.96	4.2±1.24	4.33±3.38	3.43±2.33	4.17±1.96
Lepomis megalotis	1.56±0.85	0	0	0.38±0.26	0	0.67±0.33	0	1.33±0.42
Lepomis microlophus	0	0	1	0	0	0	0.29±0.18	0.33±0.21
Lepomis miniatus	0	0	0	0	0	0	0	0.17±0.17
Micropterus salmoides	2.56±0.71	1.25±0.63	0	1.88±0.77	2±0.71	1.33±1.33	4.71±1.15	2±0.68
Pomoxis nigromaculatus	0.22±0.22	0	0	1.25±0.56	0.6±0.24	1±1	0	0.67±0.21
Oligoplites saurus	0.78±0.46	0	0	0	0	0	0	0
Aplodinotus grunniens	0.44±0.24	0	0	0.25±0.16	0.6±0.6	0	1.57±1.15	0.67±0.49
Bairdiella chrysoura	0.11±0.11	0	0	0	0	0	0	0
Cynoscion arenarius	0.11±0.11	0	0	0.75±0.49	0	0	0	0
Leiostomus xanthurus	0.22±0.22	0	0	0.63±0.42	0	0	0	0
Micropogonias undulatus	0.33±0.24	0	0	1.88±0.83	0	0	0	1.17±0.31
Sciaenops ocellatus	0.11±0.11	0	0	0.25±0.16	0	0	0	0
Dormitator maculatus	0.44±0.34	0.25±0.25	0	0	21.6±7.51	21.33±18.41	0	0
Eleotris pisonis	0.22±0.22	0	0	0.13±0.13	0	0	0	0
Ctenogobius shufeldti	0.78±0.78	0	0	1.13±0.48	0.6±0.24	0	0.57±0.3	0.5±0.5
Gobionellus oceanicus	0.33±0.17	0	0	0	0	0	0	0
Citharichthys spilopterus	0.33±0.33	0	0	0	0	0	0	0
Paralichthys lethostigma	0.67±0.44	0	0	0	0.2±0.2	0	0	0.17±0.17
Trinectes maculatus	0	0	0	0	0.2±0.2	0	0	0

Table 31.3. CPUE of species sampled by electrofishing at the Caernarvon Diversion. CPUE is the mean number (± standard error) of fish taken per electrofishing station (500 seconds). N is the number of electrofishing stations. Species are listed in systematic order following Nelson (2006).

Period	**Jul-Sep 2009**	**Oct-Dec 2009**	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**
N	10	4	3	7	6	6	3	7
Mean CPUE	754.7	131.0	90.3	84.6	90.5	450.2	253.0	257.3
Entrained CPUE	3.4	3.0	0.3	0.3	0.3	1.8	0.3	0.7
Percent Catch Entrained	0.45	2.29	0.37	0.34	0.37	0.41	0.13	0.28
Total Species	34	21	20	29	29	27	14	30
Total Entrained	9	3	3	7	6	5	1	6
Percent Entrained Species	26.5	14.3	15.0	24.1	20.7	18.5	7.1	20.0
Entrained Species per Unit Catch	0.01	0.02	0.03	0.08	0.07	0.01	0.004	0.02
Species								
Atractosteus spatula	0.1±0.1	0	0	0	0	0	0	0
Lepisosteus osseus	0.7±0.21	0	0.33±0.33	0.86±0.7	0.33±0.21	1.33±0.49	0	0.57±0.57
Lepisosteus platostomus	0	0	0	0.14±0.14	0	0	0	0.29±0.29
Lepisosteus oculatus	1.9±0.66	0.75±0.75	0.67±0.67	4.71±2.42	1.5±0.72	1.33±0.84	0.33±0.33	2.29±1.51
Anguilla rostrata	0.6±0.22	0.75±0.48	4.67±2.73	0.57±0.2	0.17±0.17	0.83±0.31	0	1.57±0.78
Elops saurus	8.2±4.19	0	0	6.14±3.98	5.83±3.23	0.17±0.17	0	0.29±0.29
Anchoa mitchilli	619.3±282.84	3.25±1.97	0.33±0.33	0.14±0.14	1.17±0.83	12.33±10.38	0	23.14±11.32
Alosa chrysochloris	2.5±1.66	0	0	0.71±0.36	0.83±0.65	0.5±0.5	1.67±1.67	0
Dorosoma petenense	6.9±3.51	1±0.71	11.67±11.17	11.57±6.06	0.67±0.49	0	0	3.57±1.51
Dorosoma cepedianum	8.6±3.17	10.5±6.02	1.33±0.88	2.14±0.91	6±2.65	93.83±84.91	0.33±0.33	1.86±0.94
Brevoortia patronus	18±10.15	0	0	5.86±4.56	3.17±0.87	3.17±1.4	0	118.29±62.63
Cyprinus carpio	0	0	0	0.71±0.36	0.17±0.17	0	0	1.14±0.83
Cyprinella lutrensis	0	0	0	0	0.17±0.17	0	0	0
Cyprinella venusta	0.1±0.1	0	0	0	0	0	0	0
Hybognathus nuchalis	0.4±0.4	0	0	0.57±0.37	0	0	0	0
Hypophthalmichthys molitrix	0	0	0	0.29±0.18	0.17±0.17	0.17±0.17	0	0.57±0.57
Lythrurus fumeus	0.8±0.47	0	0	0	0	0	0	0
Macrhybopsis storeriana	0.1±0.1	0	0	0	0	0	0	0
Notropis atherinoides	0	3±2.04	0.33±0.33	0	0	0	0	0

Notemigonus crysoleucas	0	0	0.33±0.33	0	0	0	0	0
Notropis shumardi	0.4±0.4	0	0	0	0	0	0	0
Opsopoeodus emiliae	0	0	0	0.14±0.14	0	0	0	0.43±0.43
Ictiobus cyprinellus	0	0.25±0.25	0	0.29±0.18	0	0.67±0.67	0	0.43±0.43
Ictiobus niger	0	0	0	0	0.17±0.17	0.17±0.17	0	0
Ictiobus bubalus	0.4±0.31	0.25±0.25	0	0.57±0.43	0.5±0.22	1.17±0.98	0	2.43±0.84
Ameiurus melas	0	0	0	0	0	0	0.33±0.33	0
Ameiurus natalis	0	0.25±0.25	2.33±1.86	0	0.17±0.17	0.17±0.17	0	0
Pylodictis olivaris	0.4±0.22	0	0	0.43±0.43	0.5±0.22	0.33±0.21	0	0
Ictalurus punctatus	5.9±2.11	0.75±0.48	0	3.71±1.21	4.67±2.46	5.5±2.29	0	0.57±0.3
Ictalurus furcatus	8.5±3.37	1±0.71	0	3.57±1.13	4±1.24	3.33±1.41	0.67±0.67	10±3.77
Mugil curema	0	0.25±0.25	0	0	0	0.33±0.33	0	0
Mugil cephalus	9.3±4.97	3.5±1.55	0	16.57±5.95	2.33±1.2	14.33±4.2	0.33±0.33	28.43±11.15
Membras martinica	0	0	0	0	0	0	0	7.29±6.79
Menidia beryllina	0.5±0.31	16.25±12.3	11±10.02	0	0	0	0	0.86±0.7
Strongylura marina	0.7±0.4	0.25±0.25	0	0.14±0.14	0	0	0	6.14±4.14
Gambusia affinis	0.1±0.1	0	0	0	0.17±0.17	0.17±0.17	0	0
Morone mississippiensis	0.1±0.1	0	1±1	0.43±0.3	0.33±0.21	0	0	0.71±0.47
Morone saxatilis	0.4±0.22	0	0	0.29±0.18	0.17±0.17	0	0	0.71±0.57
Morone chrysops	2.2±1.01	0.75±0.48	0.33±0.33	2±0.53	2.17±1.25	1.83±1.64	0	1.29±1.29
Lepomis humilis	0	0	0.33±0.33	0	0	0	0.33±0.33	0.14±0.14
Micropterus punctulatus	0	0	0	0	0.17±0.17	1.83±1.83	0.33±0.33	0
Pomoxis annularis	0.1±0.1	0	1.67±0.88	0.43±0.3	0	0	0	1.57±0.43
Lepomis cyanellus	0.8±0.42	1.5±0.65	0.33±0.33	0.29±0.18	0.5±0.5	1.17±0.6	0.33±0.33	0.57±0.3
Lepomis megalotis	1.1±0.8	2.25±1.31	2.33±0.67	0.14±0.14	0.5±0.34	3±1.32	0.33±0.33	0.14±0.14
Pomoxis nigromaculatus	3.4±0.99	1.75±1.75	5.33±3.38	3.14±0.7	2.17±0.7	2.17±0.6	0.33±0.33	2.71±1.27
Chaenobryttus gulosus	1.4±0.4	8.5±3.86	11.67±6.67	0	0	0.17±0.17	0.67±0.33	0.43±0.2
Lepomis macrochirus	17.7±4.09	18.5±5.87	22.33±5.24	3.86±2.13	3.5±1.34	26.33±7.9	42±19.86	10.71±2.11
Lepomis miniatus	1.1±0.41	16.75±6.94	6.33±1.2	0	0.5±0.5	69.33±41.11	62.67±22.24	2.43±1.15
Lepomis microlophus	0	30.5±10.9	3.67±1.86	2.43±2.27	0.83±0.83	94.17±54.53	64±44.02	3.43±1.65
Micropterus salmoides	29.4±9.84	8.25±2.29	0.33±0.33	9.57±5.96	46±20.38	34.33±13.91	78.33±54.17	19.57±8.62
Etheostoma asprigene	0	0	0.33±0.33	0	0	0	0	0

Sander canadensis	0.1±0.1	0	0	0	0	0	0	0
Caranx hippos	0.4±0.27	0	0	0	0	0	0	0
Micropogonias undulatus	0	0	0	0.43±0.3	0	0	0	0
Aplodinotus grunniens	1.3±0.47	0.75±0.48	1.67±0.88	1.29±0.42	1.17±0.48	0.67±0.49	0	2±1.18
Eleotris pisonis	0.1±0.1	0	0	0	0	0	0	0
Dormitator maculatus	0.1±0.1	0	0	0.86±0.46	1±0.45	78.5±71.6	0	0
Ctenogobius shufeldti	0.1±0.1	0	0	2±1.84	0	0	0	4.43±1.51
Paralichthys lethostigma	0.1±0.1	0	0	0	0	0	0	0
Trinectes maculates	0.4±0.22	0	0.33±0.33	0	0	0.17±0.17	0	0

Table 32.3. CPUE of species sampled by electrofishing at the White Ditch Siphon. CPUE is the mean number (± standard error) of fish taken per electrofishing station (500 seconds). N is the number of electrofishing stations. Species are listed in systematic order following Nelson (2006).

Period	**Oct-Dec 2009**	**Apr-Jun 2010**	**Jul-Sep 2010**
N	2	3	3
Mean CPUE	163.5	686.7	76.7
Entrained CPUE	1.5	4.7	0.7
Percent Catch Entrained	0.92	0.68	0.87
Total Species	18	33	20
Total Entrained	1	2	2
Percent Entrained Species	5.6	6.1	10.0
Entrained Species per Unit Catch	0.01	0.003	0.03
Species			
Atractosteus spatula	0	1±1	0
Lepisosteus oculatus	3.5±2.5	12.33±7.31	2.33±1.45
Anguilla rostrata	0	0.33±0.33	0
Elops saurus	0	6.67±6.67	1.33±0.88
Anchoa mitchilli	3.5±1.5	3.67±3.18	0
Brevoortia patronus	1±1	74.67±45.43	3±1.73
Dorosoma cepedianum	4±2	7.33±4.67	30.33±24.92
Dorosoma petenense	17.5±16.5	0.67±0.67	0
Hybognathus hayi	0	0	0.33±0.33
Hybognathus nuchalis	0	3.67±3.67	0
Ictiobus bubalus	1±1	0	0.33±0.33
Ictiobus cyprinellus	0	1±0.58	0
Ameiurus natalis	0.5±0.5	0	0
Ictalurus furcatus	0	5±3.21	5.67±3.18
Ictalurus punctatus	0	2.33±1.2	0.67±0.33
Pylodictis olivaris	0	0.33±0.33	0
Mugil cephalus	26±2	1.67±0.67	0
Menidia beryllina	17.5±6.5	4.67±1.76	0
Strongylura marina	0	0.33±0.33	0
Fundulus grandis	0.5±0.5	0	0
Lucania parva	0	1±1	0
Gambusia affinis	21±5	1±0.58	6±3.06
Heterandria formosa	0.5±0.5	0	0
Morone chrysops	0	0.33±0.33	0.33±0.33
Chaenobryttus gulosus	0	0.67±0.33	0.33±0.33
Lepomis cyanellus	0	0.33±0.33	0
Lepomis macrochirus	34.5±0.5	6±2.65	2±0.58
Lepomis megalotis	0	0	0.67±0.67
Lepomis microlophus	4±0	5±4.51	6.67±6.17
Lepomis miniatus	25.5±4.5	2.67±1.76	3±0.58
Micropterus salmoides	1.5±0.5	0.67±0.33	4.33±1.76

Pomoxis nigromaculatus	0	2.33±1.45	1±0
Aplodinotus grunniens	0	0	1.33±1.33
Cynoscion arenarius	0	2±2	0.33±0.33
Micropogonias undulatus	0	12±12	0
Sciaenops ocellatus	0.5±0.5	0	0
Dormitator maculatus	1±0	525.67±487.37	6.67±2.6
Eleotris pisonis	0	0.33±0.33	0
Ctenogobius boleosoma	0	0.33±0.33	0
Gobiosoma bosc	0	0.33±0.33	0
Trinectes maculatus	0	0.33±0.33	0

Table 33.3. CPUE of species sampled by electrofishing at the Naomi Siphon. CPUE is the mean number (± standard error) of fish taken per electrofishing station (500 seconds). N is the number of electrofishing stations. Species are listed in systematic order following Nelson (2006).

Period	**Jan-Mar 2010**	**Apr-Jun 2010**	**Jul-Sep 2010**	**Oct-Dec 2010**	**Jan-Mar 2011**	**Apr-Jun 2011**
N	3	5	8	7	5	6
Mean CPUE	122.3	67.6	77.6	165.7	206.4	90.3
Entrained CPUE	7.3	7.2	2.4	9.0	16.8	10.2
Percent Catch Entrained	5.99	10.65	3.06	5.43	8.14	11.25
Total Species	16	30	35	38	31	37
Total Entrained	3	4	7	5	5	5
Percent Entrained Species	18.8	13.3	20.0	13.2	16.1	13.5
Entrained Species per Unit Catch	0.02	0.06	0.09	0.03	0.02	0.06
Species						
Atractosteus spatula	0	0.6±0.6	0	0.14±0.14	0.2±0.2	0
Lepisosteus oculatus	9±4	7±0.84	7±1.73	11.71±2.71	7.8±4.37	4.67±1.74
Lepisosteus osseus	0	0	0.25±0.16	1.86±0.83	1.4±1.17	0.5±0.22
Lepisosteus platostomus	0	0.2±0.2	0	0	0	0
Amia calva	0	0	0.25±0.16	1.57±0.2	0.8±0.37	0.67±0.21
Hiodon alosoides	0	0	0.25±0.25	0	0	0
Anguilla rostrata	0	0	0.13±0.13	0.43±0.2	0	0.83±0.48
Elops saurus	0	0	0	0	0	0.17±0.17
Anchoa mitchilli	0	0.4±0.24	1±0.73	6.71±1.98	1.2±0.97	1.33±0.61
Brevoortia patronus	0	0.2±0.2	0.88±0.48	0	0	11.67±6.46
Dorosoma cepedianum	4.33±1.45	2.2±0.73	2.13±0.93	2.57±1.31	2.4±0.51	10.17±3.04
Dorosoma petenense	0	2.2±1.02	1.75±0.75	0.29±0.18	0.8±0.49	0.67±0.33
Ctenopharyngodon idella	0	0.4±0.24	0	0	0.2±0.2	0
Cyprinus carpio	0	0.6±0.6	0.25±0.25	0	1.4±0.75	0.5±0.34
Hybognathus nuchalis	0	0	0	0.14±0.14	0	0
Hypophthalmichthys molitrix	0	0	0	0	0	0.67±0.33
Notemigonus crysoleucas	0	0	0	0.71±0.18	0.4±0.24	0.17±0.17
Opsopoeodus emiliae	0	0	0.13±0.13	0	0.4±0.4	0.17±0.17
Ictiobus bubalus	6.33±3.48	2.6±0.24	1.25±0.62	5±1.63	8.2±3.37	4.17±1.85
Ictiobus cyprinellus	0.67±0.67	2.4±1.94	0.25±0.25	1.71±0.68	4.8±1.39	3.33±1.73
Ictiobus niger	0.33±0.33	2±0.84	0.13±0.13	0.29±0.18	2±1.3	2±0.93
Ameiurus natalis	0	0	0	0	0	0.33±0.21
Ictalurus furcatus	1±1	5.8±3.2	3±1.05	2.14±0.63	5.8±2.87	7±2.97
Ictalurus punctatus	0.67±0.67	1.2±0.58	0.63±0.26	0.57±0.2	0.8±0.2	0.17±0.17
Pylodictis olivaris	0	0.2±0.2	0.13±0.13	0.43±0.3	0	0.83±0.4
Mugil cephalus	0	8.8±4.12	3±2.1	9±1.11	69.2±39.66	12.5±2.4
Menidia beryllina	0	0.2±0.2	0.13±0.13	0.14±0.14	0.4±0.4	0.17±0.17
Fundulus chrysotus	0.33±0.33	0	0	0.43±0.2	0	0
Fundulus grandis	0	0	0	0.29±0.29	0	0
Lucania parva	0	0.4±0.24	0	0	0.2±0.2	0.17±0.17
Gambusia affinis	0	0.2±0.2	1.75±0.94	1.57±0.87	0.4±0.24	2.17±1.64
Heterandria formosa	0	0	0	0.29±0.18	0	0
Poecilia latipinna	0	0	0	2.14±1.16	0.4±0.4	0
Morone chrysops	0.33±0.33	0.4±0.4	0.13±0.13	0.57±0.3	0	0.17±0.17
Morone mississippiensis	0	0	0.13±0.13	0.57±0.2	0.4±0.24	0.5±0.5
Morone saxatilis	0	0	0.13±0.13	0	0	0
Chaenobryttus gulosus	0.33±0.33	2.4±1.03	0.75±0.49	2.57±0.87	5±1.9	2.33±0.84
Lepomis cyanellus	0	0	0	0.29±0.18	0	0.17±0.17
Lepomis humilis	0	0.6±0.4	0	0	0	0
Lepomis macrochirus	61.33±16.5	6.8±3.14	4.63±1.61	33.57±9.48	15.6±2.93	4.83±1.25
Lepomis megalotis	0	0	0	4±1.05	4.4±2.25	1.67±0.56
Lepomis microlophus	3.33±0.88	0.6±0.6	0.5±0.5	25.29±5.76	25.6±15.04	0
Lepomis miniatus	2.67±0.67	3.2±1.59	2.88±1.78	27.29±6.01	14.8±3.73	3.17±1.17
Lepomis symmetricus	0	0	0.13±0.13	0	0	0

Micropterus salmoides	1.67±0.33	3.2±1.16	8.25±3.42	15±4.21	24±13.31	6±2.08
Pomoxis annularis	0	0.6±0.4	0.25±0.16	0.71±0.29	0	0.83±0.48
Pomoxis nigromaculatus	29.67±10.14	6.4±3.75	2.25±0.75	1.57±0.2	6.8±2.52	3.5±1.15
Aplodinotus grunniens	0.33±0.33	0	0.25±0.16	0.14±0.14	0.4±0.24	0.17±0.17
Dormitator maculatus	0	5.6±2.73	32.75±10.5	3.71±1.7	0	0
Eleotris pisonis	0	0.2±0.2	0	0	0	0
Ctenogobius shufeldti	0	0	0.25±0.16	0.14±0.14	0.2±0.2	1.83±1.45
Paralichthys lethostigma	0	0	0	0.14±0.14	0	0
Trinectes maculatus	0	0	0.13±0.13	0	0	0.17±0.17

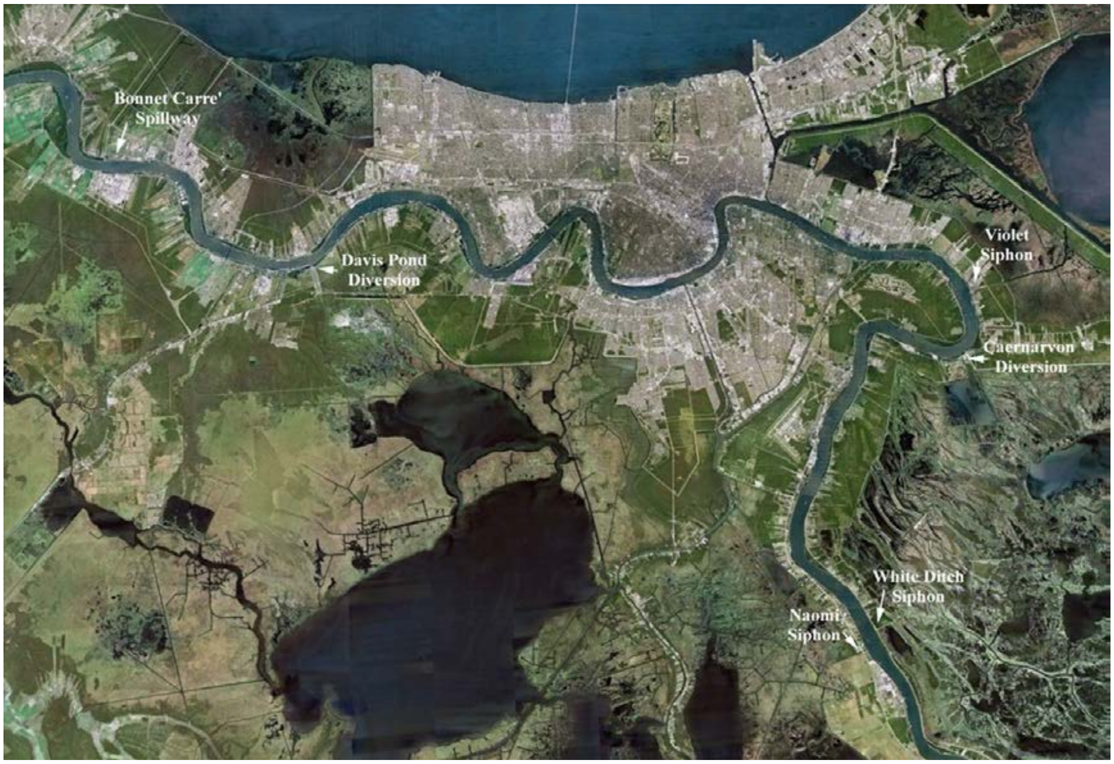

Figure 1.3. Location of the diversions sampled.

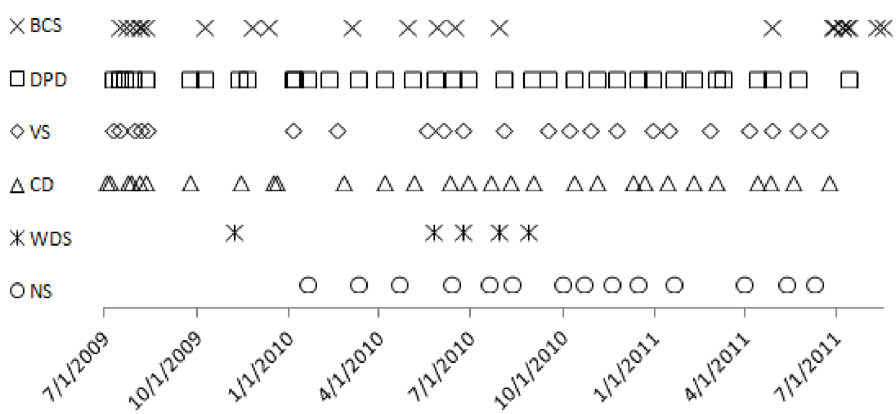

Figure 2.3. Graphical representation of days of sampling effort at each diversion. BCS = Bonnet Carré Spillway, DPD = Davis Pond Diversion, VS = Violet Siphon, CD = Caernarvon Diversion, WDS = White Ditch Siphon, NS = Naomi Siphon.

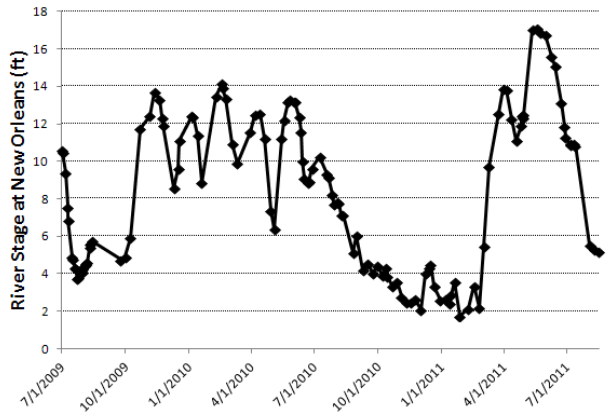

Figure 3.3a. River stage at New Orleans (Carrolton gauge) at 12:00 PM on each date samples were taken in this study.

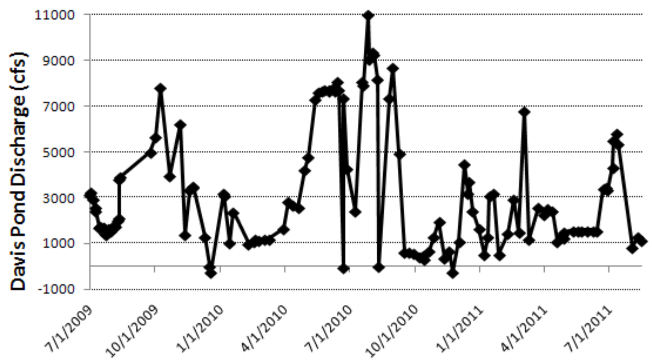

Figure 3.3b. Average daily discharge of the Davis Pond Diversion on each date samples were taken in this study.

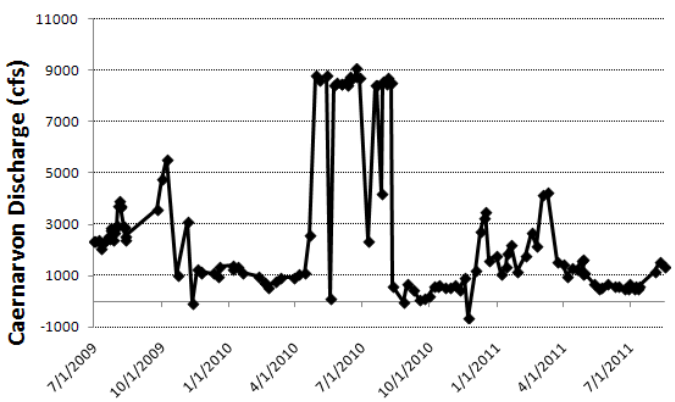

Figure 3.3c. Average daily discharge of the Caernarvon Diversion on each date samples were taken in this study.

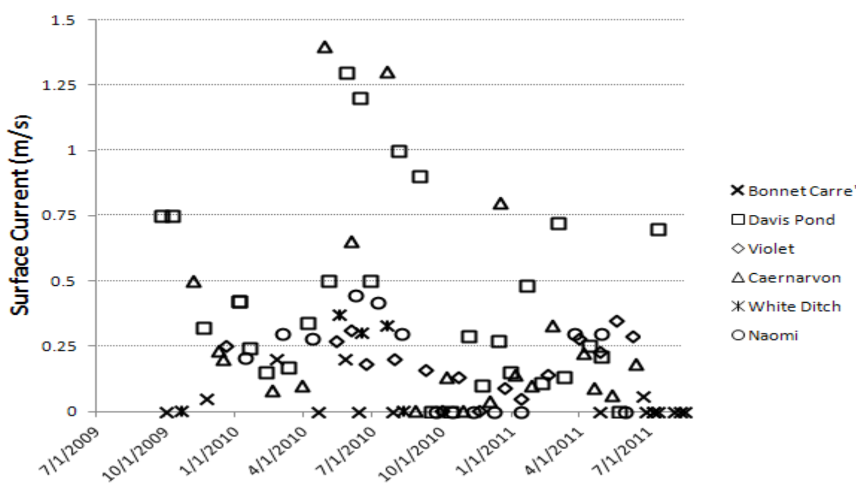

Figure 3.3d. Surface current velocity on sampling days in each diversion.

Chapter 4

Evaluation of Entrainment of Sturgeon Through the Morganza and Bonnet Carré Spillways

by

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Abstract

The Bonnet Carré Spillway, opened in 2008 and 2011, and the Morganza Spillway, opened in 2011, were sampled to evaluate entrainment of pallid sturgeon from the Mississippi River. Pallid sturgeon were collected only in the Bonnet Carré Spillway after the structure was closed. In 2008, a total of 14 pallid sturgeon and 41 shovelnose sturgeon were collected over a 4-week period. In 2011, a total of 20 pallid, 78 shovelnose, and one possible intermediate sturgeon were collected over a 1.5-week period. Higher discharge and longer opening in 2011 resulted in greater numbers of sturgeon caught. The majority of these fish were relocated back into the Mississippi River; some were retained for taxonomic studies by USFWS. Field surveys indicated that it was unlikely that pallid sturgeon, an obligate riverine species, would be entrained through the Morganza Spillway because of the long distance of the floodplain between the main channel of the Mississippi River and the structure.

Introduction

The Bonnet Carré Spillway was constructed in response to the 1927 flood to protect New Orleans. The spillway diverts water from the Mississippi River into a floodway that empties into Lake Pontchartrain to reduce flood stages downstream; design capacity flow is 250,000 cfs. The USACE opened the spillway for the first time in 11 years on April 11, 2008. Within nine days, a total of 160 bays were open diverting a maximum flow of 160,000 cfs from the Mississippi River. The structure was completely closed May 8, 2008 and pallid sturgeon were captured below the structure documenting entrainment of this federally endangered species for the first time.

Based on documented entrainment of pallid sturgeon through the Bonnet Carré Spillway, the New Orleans District made a commitment to monitor entrainment of pallid sturgeon for any future openings of either the Bonnet Carré or Morganza Spillways and attempt rescue efforts to minimize impacts to this endangered species. Both structures were opened during the 2011 flood, and as a result, monitoring and rescue efforts were initiated. This chapter describes field efforts and results of the monitoring/rescue program during the 2008 and 2011 floods.

Each Spillway had unique properties that required modified sampling approaches to effectively capture entrained sturgeon. The Bonnet Carré Spillway empties into Lake

Pontchartrain where detection or capture is difficult and was not sampled during this study. The fate of pallid sturgeon moving into Lake Pontchartrain is uncertain because their salinity tolerance is unknown. The Morganza Spillway empties into the Atchafalaya Basin where fish can widely disperse, and they can move upstream towards the Old River Control Complex where entrainment also occurs. Bonnet Carré and Morganza Spillways do have well-defined, low-flow channels immediately below the structures that form when water recedes and where capture efficiency is highest. However, upstream movement of pallid sturgeon entrained through the Spillways is dependent on rheotactic behaviors possibly disrupted in artificial environments associated with the floodways. Lastly, Morganza has a 7,000-acre forebay that becomes isolated from both the Atchafalaya and Mississippi Rivers at lower stages potentially trapping sturgeon. Despite these challenges, the Spillways were sampled multiple times to document sturgeon entrainment, and if possible, rescue sturgeon after closure of the structures.

Morganza Spillway

The Morganza Spillway, constructed in 1954, is a 4,159-foot structure located along the western bank of the Mississippi River at river mile 280. The structure consists of two sluice gates and 125 gated (bay) openings with a design maximum discharge of 600,000 cfs. During major floods, Mississippi River water is diverted through the gated openings into a floodway 20 miles long and 5 miles wide, which then flows into the Atchafalaya Basin down to the Gulf of Mexico. The spillway has been operated twice, during the 1973 and 2011 floods, to lower Mississippi river stages above and below Baton Rouge and to prevent the Mississippi River from permanently altering course down the Atchafalaya River. During the 2011 flood, Morganza Spillway was operated from 14 May to 7 July with a total of 17 bays opened reaching peaking flows of approximately 180,000 cfs.

ERDC and USACE Rangers with the New Orleans District sampled the Morganza Spillway on July 14 and 18, 2011 for pallid sturgeon. A boat-mounted electroshocker was used to sample the stilling basin below the structure, downstream canal, and the forebay above the structure. Total shocking (pedal) time below the structure was 53 minutes and 19 minutes along the forebay above the structure (Figure 1.4). In addition, a total of six hauls was made with a 20-ft seine in the forebay. Water quality parameters varied below and above the structure, with lower water temperature, dissolved oxygen, and turbidity measured below the structure (Table 1.4). Dissolved oxygen was 5 mg/l below the structure, and since these measurements were taken during early afternoon, hypoxic conditions (<3.0 mg/l) may have occurred during early morning hours. Other areas below the structure were too shallow to sample by boat or had completely dried, but large numbers of dead fish were present. Therefore, two people surveyed these areas by foot for a total combined time of 9.5 hours. Approximately one hour was also expended in the forebay for dead sturgeon. However, no sturgeon were observed or captured below or above the structure.

Because of the massive number of dead fishes present, we only kept track of species and ranked abundance into three categories (abundant, common, and rare). A total of 35 species of fishes comprised of 14 families were observed or collected (Table 2.4). Gar were observed swimming near the structure (Figure 2.4), but most fish were dead (Figures 3.4 – 5.4). The dominant fishes observed were silver carp, gizzard shad, and bigmouth buffalo. Common fishes included gar, catfishes, silversides, and sunfishes. Rare fishes consisted of a few individuals of skipjack herring, mullet and flathead catfish. Most of the fishes observed were backwater species or tolerant of environmental fluctuations, and most rare species are typically found in riverine environments. In addition, five species of freshwater mussels typically found in backwaters were observed (Table 3.4).

The absence of sturgeon is likely due to the position of the Morganza Spillway relative to the Mississippi River. The structure is set back a considerable distance from the River compared to the Bonnet Carré Spillway. In addition, riverine fish originating from the Mississippi River must travel through backwaters in the floodplain and over the potato levee. These barriers likely hamper movement towards the structure. Consequently, it is our opinion that entrainment of pallid sturgeon, which is an obligate riverine fish, through the Morganza Spillway would be a rare event.

Bonnet Carré Spillway

The Bonnet Carré Spillway, constructed in 1931, is located 32.8 miles above New Orleans. The structure consists of 350 bays, each 20 feet wide, for a total width of 7,000 feet at the weir opening. The structure's design flow is 250,000 cfs, which diverts flood waters from the Mississippi River into a 5.7-mile floodway that empties into Lake Pontchartrain to reduce river stages at New Orleans. It has been opened twice over the past four years, although frequency of openings prior to this period was approximately once every 10 years. In 2008, it was open for 27 days beginning April 11th with a maximum of 160 bays in operation creating a maximum discharge through the structure of 160,144 cfs. In 2011, it was open for 42 days beginning May 9th with a maximum of 330 bays in operation creating a maximum discharge of 315,930 cfs, which was twice as high compared to 2008. The structure is closed by placing pins across each bay. However, water continues to seep between the pins for a period of time, creating low flow channels down the floodway.

During both openings, USACE, Louisiana Department of Wildlife and Fisheries (LDWF), and Nicholls State University evaluated entrainment of pallid sturgeon through the structure. Nicholls State University prepared a separate report on their collection efforts (Chapter 3) and these data are not included in this Chapter. The pallid sturgeon is a freshwater, riverine species and it was assumed that any individual entrained and moved into Lake Pontchartrain would not survive in this brackish, lacustrine environment. The floodway could not be sampled during operation because of safety concerns. However, once the structure was closed, USACE and LDWF began sampling the floodway for sturgeon to evaluate entrainment. In both years, sturgeon were captured during the first week after the structure was closed and sampling continued until the floodway became dewatered. Sampling also occurred in the floodway one week prior to the 2011 opening, but no sturgeon were captured.

2008 Opening

Shortly after the Bonnet Carré spillway was open in 2008, a pallid sturgeon was captured by LDWF in the Mississippi River near the structure, suggesting for the first time that this species could be entrained through the spillway. We surmised that the most likely location where entrained sturgeon would occur was in the upper end (closest to the structure) of Barbars Canal, the primary distributary in the floodway where water leaking through the pins after closure would concentrate creating a low flow channel (Figure 6.4). Within one hour of setting a gill net at this location, the first pallid sturgeon was caught.

Multiple gears were used over a five-week period in an attempt to capture pallid sturgeon, including a boat-mounted electroshocker operating at 60 Hz, two types of gill nets (experimental - 90 ft long x 6 ft deep with 6, 15 ft long panels, mesh size ranged from 1 to 3 ½ inches; Trammel - 2 ½ inch mesh), two sizes of hoop nets (3 ft hoops with 1-inch mesh and 4 ft hoops with 4 inch mesh), trotlines (200 ft long with 60 dropper lines baited with worms or shrimp), trawls (10-ft mouth opening with two mesh sizes to retain small fish: exterior was ½ inch and interior was 2 inch), and seines (30 ft in length with ¼ inch mesh; also an experimental gill net retrofitted as a seine). Although species other than sturgeon were recorded during sampling, we did not make a concerted effort to collect every fish because it would jeopardize capture efficiency of pallid sturgeon.

With one exception, all pallid sturgeon were collected by electroshocking (effort=15 hours of pedal time) and gill nets (effort=20 net-sets during the day only, checked every 1-3 hours). One pallid sturgeon was collected at the base of the structure by seining with a gill net. Overall, a total of 14 pallid sturgeon were collected below the structure in Barbars canal during a 3-week period. Other locations were sampled in the floodway, including its confluence with Lake Pontchartrain, but no sturgeon were captured. We assumed that because pallid sturgeon are strongly rheotactic (Adams et al. 1999), individuals displaced downstream oriented into the direction of the flow and moved towards the base of the structure, against the current, until they reached an impassable road crossing where they were susceptible to capture.

Sampling continued for two more weeks, but no additional pallid sturgeon were collected. In addition, 41 shovelnose sturgeon (*S. platorynchus*) were captured below the structure, mostly in the upper end of Barbars canal. All sturgeon were measured, tagged, and released back into the Mississippi River. Water quality and hydraulics in Barbars canal a week after closure was within acceptable limits to support sturgeon (Table 4.4). Water temperature was 23.7 °C, dissolved oxygen was 6 mg/l, and the discharge in the canal was 1,882 cfs. Discharge in Barbars canal gradually decreased in subsequent weeks as the Mississippi River stage elevation dropped below the sill and water stopped leaking between the pins. Five weeks after closure, Barbars canal became dewatered and sampling was discontinued.

2011 Pre-Opening

Several reaches associated with the Bonnet Carré Spillway were sampled on May 4-5, 2011 for the pallid sturgeon. The reaches included the Mississippi River in the vicinity of the spillway structure, the upper portion of Barbars Canal, and the upper portion of Y Canal. Each reach was sampled using a boat-electroshocker operated at 60 Hz. At Barbars Canal and Y Canal, additional sampling gear was deployed which included experimental gillnets, a 2 ½ trammel net, and 3 and 4-ft hoop nets previously described.

A total of 21 species of fish were collected in Barbars and Y Canal (Table 5.4). Many of the species were represented by a single individual. Striped mullet and gizzard shad were the dominant species collected. No sturgeon were observed or collected. The majority of the fish collected were by boat-electroshocking (Shocking time = 1,897 seconds). Gillnets, hoop nets, and trammel nets were fished overnight with limited success. Low catch with these gears was attributed to trash entangled in the nets from floating plant debris displaced by the rising water levels. Most of the species collected during pre-opening are tolerant of fluctuating habitat conditions and tend to exploit newly created waterbodies. These include gar, shad, and sunfishes. As water leaks through the pins into the floodway, resident fish species either move into the canals from the adjacent lakes or from Lake Pontchartrain. Water quality was within acceptable limits for most fish species (Table 4.4). Discharge in Barbars and Y canal was 763 and 502 cfs, respectively. Therefore, the approximate discharge in Barbars Canal below the confluence of Y Canal on May 4, 2011 was 1265 cfs and rising.

Electroshocking was conducted along the Bonnet Carré Spillway (MS River side). Three reaches (each end and the middle) of the spillway was shocked for 300 seconds each and all fish stunned were captured and identified. Additional shocking was conducted in the vicinity of entire spillway structure in search for sturgeon only. That shocking time accounted for 2,256 seconds (Figure 7.4).Water velocity was essentially zero and water temperature was almost 3 degrees higher in the river compared to the floodway 9Table 4.4). No sturgeon were observed or captured.

2011 Opening

Sampling began once the structure was closed on June 20th. Based on the 2008 collections, three primary areas of the floodway were sampled regularly: stilling basin, canals (primarily Barbars and Y), and lakes (Figure 8.4). Over 24 days were expended by three crews working either together or separately representing LDWF, Nicholls State, and USACE. However, after the first week when the structure was closed in 2011, discharge in Barbars canal went from 716 cfs to near zero (Table 4.4), and the majority of sampling occurred in the lakes and stilling basin thereafter.

Higher discharge and longer opening in 2011 resulted in greater number of sturgeon caught. In 2008, a total of 14 pallid and 41 shovelnose sturgeon were collected over a 4-week period. In 2011, a total of 20 pallid, 78 shovelnose, and one possible intermediate sturgeon were collected over a 1.5-week period. Pallid to shovelnose ratio were similar between the two years; 1:3 in 2008 and 1:4 in 2011. Ratio in this reach of the lower Mississippi River is typically 1:3. Mean length of pallid sturgeon collected in 2011 was 773 mm FL, compared to 712 mm FL in 2008. Sizes in 2011 ranged from 449 – 924 mm FL corresponding to ages ranging from three to greater than 15 years. Mean size of shovelnose sturgeon caught in 2011 was slightly smaller (607 mm FL) than in 2008 (665 mm FL).

A notable collection was a tagged pallid sturgeon originally captured in the floodway during 2008 and released back into the Mississippi River. Also, a large adult Paddlefish entrained from the Mississippi River through the Bonnet Carré spillway, injured and underweight, was captured and released back into the Mississippi River. It was re-captured eight months later in north Mississippi, 627 km upriver from where it was released (Hoover et al. 2014). These incidents suggest that entrained fish, trapped for several days in a hyperthermic and hypoxic habitat, can be viable when returned to the river. It also demonstrated that rescue efforts can reduce impacts of spillway operations to fish populations.

Discharge patterns after the structure was closed differed substantially between the two years (Figure 9.4). The 2008 hydrograph exhibited a slow decline over a period of four weeks, whereas the 2011 hydrograph dropped to almost zero discharge in the floodway within a week. Pallid and shovelnose sturgeon catch generally followed the same trend as the hydrograph (Figure 9.4). Sturgeon were caught over a four-week period in 2008, whereas almost all sturgeon captured in 2011 occurred within the first week after closure. The greater magnitude of discharge through the floodway and the abbreviated period of flow in the canals in 2011 displaced sturgeon to a greater extent compared to 2008, and contributed to different sturgeon catch patterns. Both pallid and shovelnose sturgeon are strongly rheotactic and orient into the direction of the flow. As water velocity in the canals below the structure essentially went to zero within a week after the 2011 closure and water levels dropped precipitously throughout the floodway, displaced sturgeon were less likely to move towards the base of the structure as they did in 2008 when discharge persisted for 4-5 weeks in the canals. Rapid drop in water levels in 2011 also hampered physical movement through or over road crossings that crisscross the floodway. In addition, water temperature in Barbars canal was considerably higher in 2011 (28 °C) compared to 2008 (Table 4.4), which likely created stressful conditions for sturgeon necessitating rapid recovery. As water levels declined in the canals after the 2011 opening, sturgeon became stranded in the stilling basin and possibly in floodway lakes that became disconnected with the canals. Numerous sturgeon were caught in the stilling basin, which retained water for weeks with depths approximately 3 feet, but by June 30, 2011, water temperature was over 30 °C and dissolved oxygen averaged 0.9 mg/l. Although no major fish kills were observed in the stilling basin, water quality conditions were degraded and those sturgeon collected at this location were in various stages of stress.

The USFWS issued a non-jeopardy, emergency Biological Opinion for the 2008 opening with an estimated incidental loss of 88 adult pallid sturgeon. A Biological Opinion will likely be issued for the 2011 opening. Differences in hydrograph and catch rates should be considered for future operations. Rapid decreases in discharge below the structure, which happened in 2011, will probably result in more sturgeon becoming stranded and non-recoverable. Gradual decreases in discharges, like 2008, will provide rheotactic cues for sturgeon to move upstream towards the structure, congregate, and become easier to catch. Regardless of the discharge patterns, however, it has been demonstrated twice under different circumstances that rapid rescue of entrained pallid sturgeon can be successfully accomplished to minimize impacts to this endangered species.

Telemetry - 2011

Following the 2011 opening, we used acoustic telemetry to monitor movement of entrained shovelnose sturgeon (*Scaphiryhnchus platorynchus*), a species closely related to and sympatric with pallid sturgeon, within the floodway. Twelve VEMCO VR2Ws (remote receivers) were deployed from the Bonnet Carré floodway down Barbars Canal to Lake Pontchartrain to establish an automated acoustic telemetry array. Eighteen shovelnose sturgeon ranging in size from 501-830 mm FL were captured from upper Barbars, Y-Canal, and the Bonnet Carré stilling basin and equipped with acoustic telemetry tags (V9 coded acoustic transmitters, 289 day battery life) during the period 20-27 June 2011. Tagged fish were then redistributed within the system near telemetry buoys (Barbars 1, 2, 4, 5, 8 and Y-canal 1, see Figure 10.4). The array was deployed from 20 June 2011 through 25 August 2012 and accumulated over 120,000 detections. No mortalities were reported and initially all individuals moved extensively near their original release point. There were no detection patterns to support movement of telemetry tagged individuals from the Bonnet Carré floodway into Lake Pontchartrain after 13 July 2011.

The initial acoustic array within the floodway was deployed on 20 June prior to sampling but the remaining receivers at Lake Pontchartrain were not deployed until 13 July. This created an “open window” for undocumented movement into Lake Pontchartrain (21 June-13 July = 20-32 days depending on when fish were captured, tagged and released). Six individuals were unaccounted for after 13 July suggesting they moved quickly through the floodway and into Lake Pontchartrain before the final receivers were deployed. None were documented returning back to the floodway. Those fish that remained in the system experienced sporadic, localized movement. However, overall movement of telemetry tagged fish began to decrease by early August, as water levels within the floodway decreased, in part creating isolated pools and remnant channels, and as water temperatures increased (31° C). Salinity during this period where the floodway enters Lake Pontchartrain was ≥ 2 ppt; detections during this period on the receivers nearest to Lake Pontchartrain were few to none.

Fish Assemblage of the Bonnet Carre

In addition to sturgeon captured during the 2008 and 2011 openings, a total of 43 species of freshwater and euryhaline fishes were collected (Table 5.4). Catfishes and cluepeids were the most common species, with blue catfish being the most abundant. Sunfishes were the most speciose of all families. Euryhaline species included Gulf menhaden, bay anchovy, Atlantic needlefish, freshwater goby, and hogchocker, all likely originating from Lake Pontchartrain after the structure was opened providing an upstream pathway towards the structure. Species richness doubled after the opening indicating entrainment of riverine fishes, and at least one invasive species, silver carp, from the Mississippi River. American eels were observed at the structure attempting to climb over the sill into the Mississippi River. Schultz (Chapter 3, this document) reported ten additional species not collected by USACE/LDWF. These included smaller individuals primarily captured by seining, and one invasive species (Rio Grande cichlid, *Herichthys cyanoguttatus*). Therefore, total species richness documented in the Bonnet Carre spillway after the 2008 and 2011 openings is 55 including shovelnose and pallid sturgeon.

Estimating Entrainment

Capture of sturgeon in the outflow of diversions verifies entrainment. However, the magnitude of entrainment will remain speculative. Population Viability Models (see next chapter) require input of different "take" levels to properly evaluate the range of alternatives in assessing risk to pallid sturgeon populations. It is likely that a combination of at least three different approaches will be used to determine different take scenarios (Figure 11.4). Examples of the different approaches are presented in Appendix 1. The statistic-based estimate uses predictive models derived from the field study to determine numbers of sturgeon entrained, if any, over a given time period. The hydraulic-based estimate uses the statistical model as an initial starting point, estimate numbers of sturgeon on a volumetric scale (e.g., numbers per cubic meter), and multiply this value by the total volume of water diverted into the marshes. If information is available, volumetric estimates of sturgeon abundance can be supplemented from published rates of entrainment for a given volume of water during dredging or other diversion activities. The biology-based estimate incorporates swimming speeds, rheotactic behavior, and other types of avoidance behavior by sturgeon to modify the hydraulic-based estimates.

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Adams, S.R., J.J. Hoover, and K.J. Killgore. 1999. Swimming endurance of juvenile pallid sturgeon, *Scaphirhynchus albus*. Copeia 1999: 807-807.

Hoover, J. J., S. G. George, and K. J. Killgore. 2013. A Paddlefish Entrained by the 2011 Mississippi River Flood: Rescue, Recapture, and Inferred Swim-Speed. Southeastern Naturalist 12, 5 pages.

Table 1.4. Water quality data for Morganza Spillway, July 5, 2011		
Parameters	Below Structure	Above Structure
Width (ft)	25	-
Depth (ft)	5.98	-
Velocity (ft/s)	0.79	-
Discharge (cfs)	354	-
Water Temperature (ºC)	29.50	31.38
Dissolved oxygen (mg/L)	5.10	7.44
pH	7.36	7.63
Conductivity (mS)	0.344	0.332
Turbidity (NTU)	18.39	49.9

Table 2.4. Fish species documented in the Morganza Spillway, July 2011

Family	Scientific Name	Common Name	Status
Polyodontidae	*Polyodon spathula*	Paddlefish	Common
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	Common
	Lepisosteus osseus	Longnose gar	Common
	Lepisosteus platostomus	Shortnose gar	Common
Amiidae	*Amia calva*	Bowfin	Common
Anguillidae	*Anguilla rostrata*	American eel	Rare
Clupeidae	*Alosa chrysochloris*	Skipjack herring	Common
	Dorosoma cepedianum	Gizzard shad	Abundant
	Dorosoma petenense	Threadfin shad	Common
Cyprinidae	*Cyprinus carpio*	Common carp	Common
	Hypophthalmichthys molitrix	Silver carp	Abundant
	Hypophthalmichthys nobilis	Bighead carp	Abundant
	Ctenopharyngodon idella	Grass carp	Rare
Catostomidae	*Carpiodes carpio*	River carpsucker	Rare
	Ictiobus bubalus	Smallmouth buffalo	Rare
	Ictiobus cyprinellus	Bigmouth buffalo	Common
	Ictiobus niger	Black buffalo	Common
Ictaluridae	*Ameiurus melas*	Black bullhead	Common
	Ameiurus natalis	Yellow bullhead	Common
	Ictalurus furcatus	Blue catfish	Rare
	Ictalurus punctatus	Channel catfish	Common
	Pylodictus olivaris	Flathead catfish	Rare
Belonidae	*Strongylura marina*	Atlantic needlefish	Rare
Atherinopsidae	*Menidia beryllina*	Inland silverside	Common
Moronidae	*Morone chrysops*	White bass	Rare
	Morone mississippiensis	Yellow bass	Rare
Centrarchidae	*Lepomis cyanellus*	Green sunfish	Abundant
	Lepomis gulosus	Warmouth	Common
	Lepomis macrochirus	Bluegill	Common
	Lepomis megalotis	Longear sunfish	Rare
	Micropterus salmoides	Largemouth bass	Common
	Pomoxis annularis	White crappie	Rare
	Pomoxis nigromaculatus	Black crappie	Common
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	Rare
Mugilidae	*Mugil cephalus*	Striped mullet	Rare
Total number of species			35

Table 3.4 Alive and dead freshwater mussels observed above and below the Morganza Spillway.	
Species	Status
Family Unionidae	
Pyganodon grandis, giant floater	Abundant
Utterbackia imbecillis, paper pondshell	Common
Quadrula apiculata, southern mapleleaf	Common
Toxolasmus texasensis, Texas lilliput	Common
Uniomerus tetralasmus, pond horn	Common

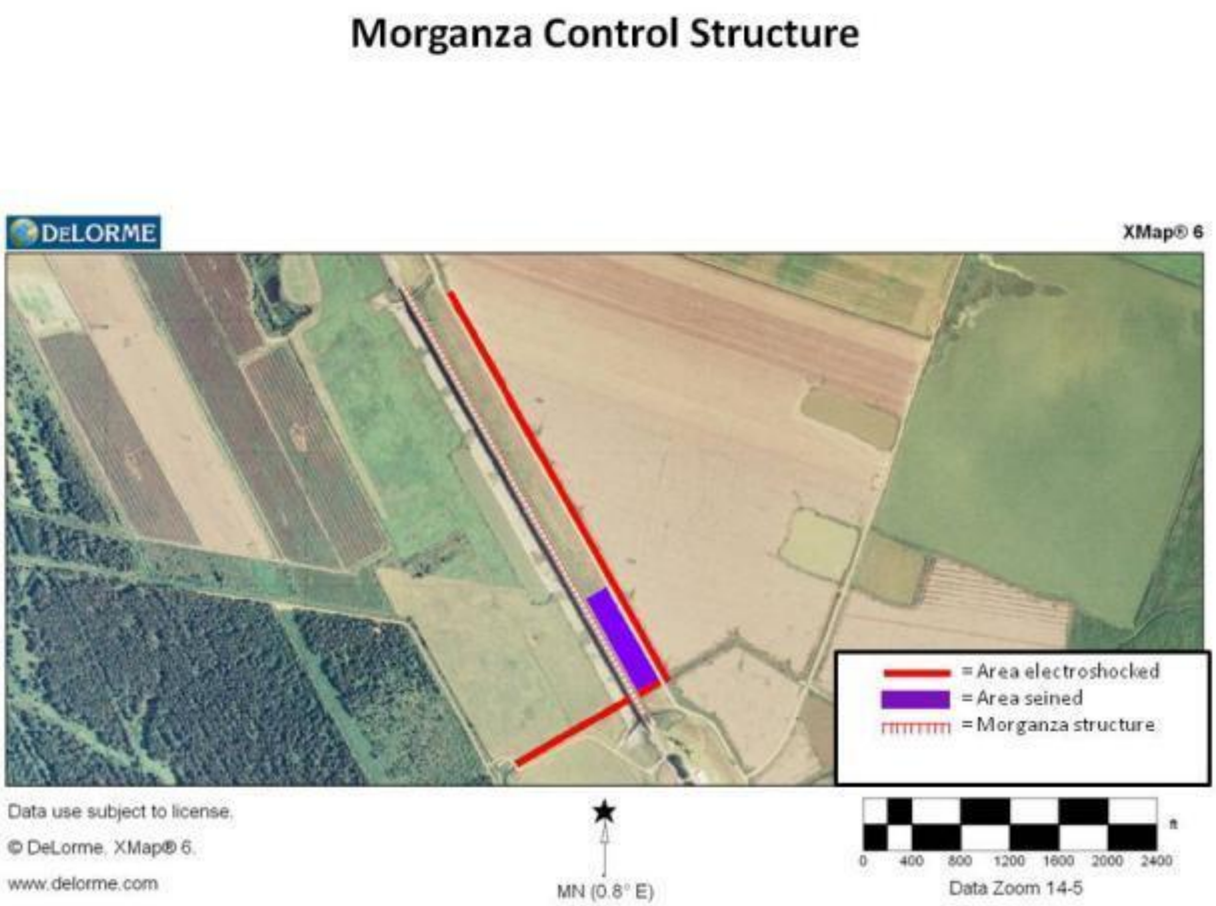


Figure 1.4. Aerial view of the Morganza Spillway showing the areas sampled using electroshocking and seines.

Figure 2.4. Gar species swimming in the current in the outflow sluice gates of the Morganza Spillway.

Figure 3.4. Alive and freshly dead fishes on July 14, 2011 downstream of the sluice gates of the Morganza Spillway. Cause of death is low dissolved oxygen. Most of the fishes (bass and bluegill) are backwater species.

Figure 4.4. Decomposed dead carp and buffalo below the Morganza Spillway structure.

Figure 5.4. Typical scene examined for the presence of sturgeon; however, no sturgeon were found.

Table 4.4. Water quality and hydraulic data for the Bonnet Carré Spillway, 2008 and 2011.									
Site	Water Temperature (ºC)	Conductivity (µmhos/cm)	pH	Dissolved Oxygen (mg/l)	Turbidity (NTU)	Average Depth (ft)	Average Velocity (ft/s)	Width (ft)	Discharge (cfs)
2008 – Barbars Canal	23.7	292	7.44	6.01	48	7.1	3.38	78	1882
May 23, 2008									
Pre-Opening – Barbars Canal	18.39	344	7.12	6.75	47	9	0.83	93	763[1]
May 5, 2011									
Pre-Opening – Y Canal	18.94	344	7.41	8.40	42	6.5	0.71	93	502
May 5, 2011									
Pre-Opening – MS River	22.2	342	7.48	7.06	38	7.4	0	-	-
May 5, 2011									
2011 – Barbars Canal	28.4	393	8.27	6.28	50	8.5	0.88	96	716
June 20, 2011									

[1] – Discharge measured above the confluence of Y Canal.

Table 5.4. Number of fishes captured, excluding sturgeons, and cumulative for all sampling gears, in the Bonnet Carré Spillway after the 2008 and 2011 openings and prior to the 2011 opening (May 4-5).

Family	Scientific Name	Common Name	Number Post-Opening	Number Pre-Opening
Polyodontidae	*Polyodon spathula*	Paddlefish	11	0
Lepisosteidae	*Atractosteus spatula*	Alligator gar	2	0
	Lepisosteus oculatus	Spotted gar	16	0
	Lepisosteus osseus	Longnose gar	7	3
Amiidae	*Amia calva*	Bowfin	1	0
Anguillidae	*Anguilla rostrata*	American eel	50	0
Clupeidae	*Alosa chrysochloris*	Skipjack herring	219	3
	Brevoortia patronus	Gulf menhaden	11	0
	Dorosoma cepedianum	Gizzard shad	102	14
	Dorosoma petenense	Threadfin shad	65	3
Engraulidae	*Anchoa mitchilli*	Bay anchovy	1	0
Hiodontidae	*Hiodon alosoides*	Goldeye	1	0
Cyprinidae	*Cyprinus carpio*	Common carp	5	1
	Hypophthalmichthys molitrix	Silver carp	18	7
	Hypophthalmichthys nobilis	Bighead carp	6	0
	Macrhybopsis hyostomus	Speckled chub	1	0
	Macrhybopsis storeriana	Silver chub	2	0
	Notropis shumardi	Silverband shiner	1	0
	Notropis wickliffi	Channel shiner	5	0
Catostomidae	*Carpiodes carpio*	River carpsucker	3	3
	Ictiobus bubalus	Smallmouth buffalo	18	9
	Ictiobus cyprinellus	Bigmouth buffalo	2	2
	Ictiobus niger	Black buffalo	1	0
Ictaluridae	*Ictalurus furcatus*	Blue catfish	1345	1
	Ictalurus punctatus	Channel catfish	65	2
	Pylodictus olivaris	Flathead catfish	129	1
Belonidae	*Strongylura marina*	Atlantic needlefish	4	0
Poeciliidae	*Gambusa affinis*	Western mosquitofish	10	1
Atherinopsidae	*Menidia beryllina*	Inland silverside	1	0
Moronidae	*Morone mississippiensis*	Yellow bass	2	0
	Morone saxatilis	Striped bass	5	0

Table 5.4. Number of fishes captured, excluding sturgeons, and cumulative for all sampling gears, in the Bonnet Carré Spillway after the 2008 and 2011 openings and prior to the 2011 opening (May 4-5).

Family	Scientific Name	Common Name	Number Post-Opening	Number Pre-Opening
Centrarchidae	*Lepomis gulosus*	Warmouth	1	0
	Lepomis humilis	Orangespotted sunfish	3	0
	Lepomis macrochirus	Bluegill	28	4
	Lepomis megalotis	Longear sunfish	2	1
	Lepomis microlophus	Redear	0	1
	Lepomis miniatus	Redspotted sunfish	135	0
	Lepomis symmetricus	Bantam sunfish	0	1
	Micropterus salmoides	Largemouth bass	3	1
	Pomoxis annularis	White crappie	3	1
	Pomoxis nigromaculatus	Black crappie	2	0
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	30	1
Mugilidae	*Mugil cephalus*	Striped mullet	47	41
Gobiidae	*Ctenogobius shufeldti*	Freshwater goby	5	0
Soleidae	*Trinectes maculatus*	Hogchoker	5	0
Total number of species			43	21

Figure 6.4. Running a large mesh hoopnet in Barbars Canal, notice the silver carp in the net.

Figure 7.4. ERDC personnel sampling for sturgeon using electroshocking in the Mississippi River adjacent to Bonnet Carré Spillway.

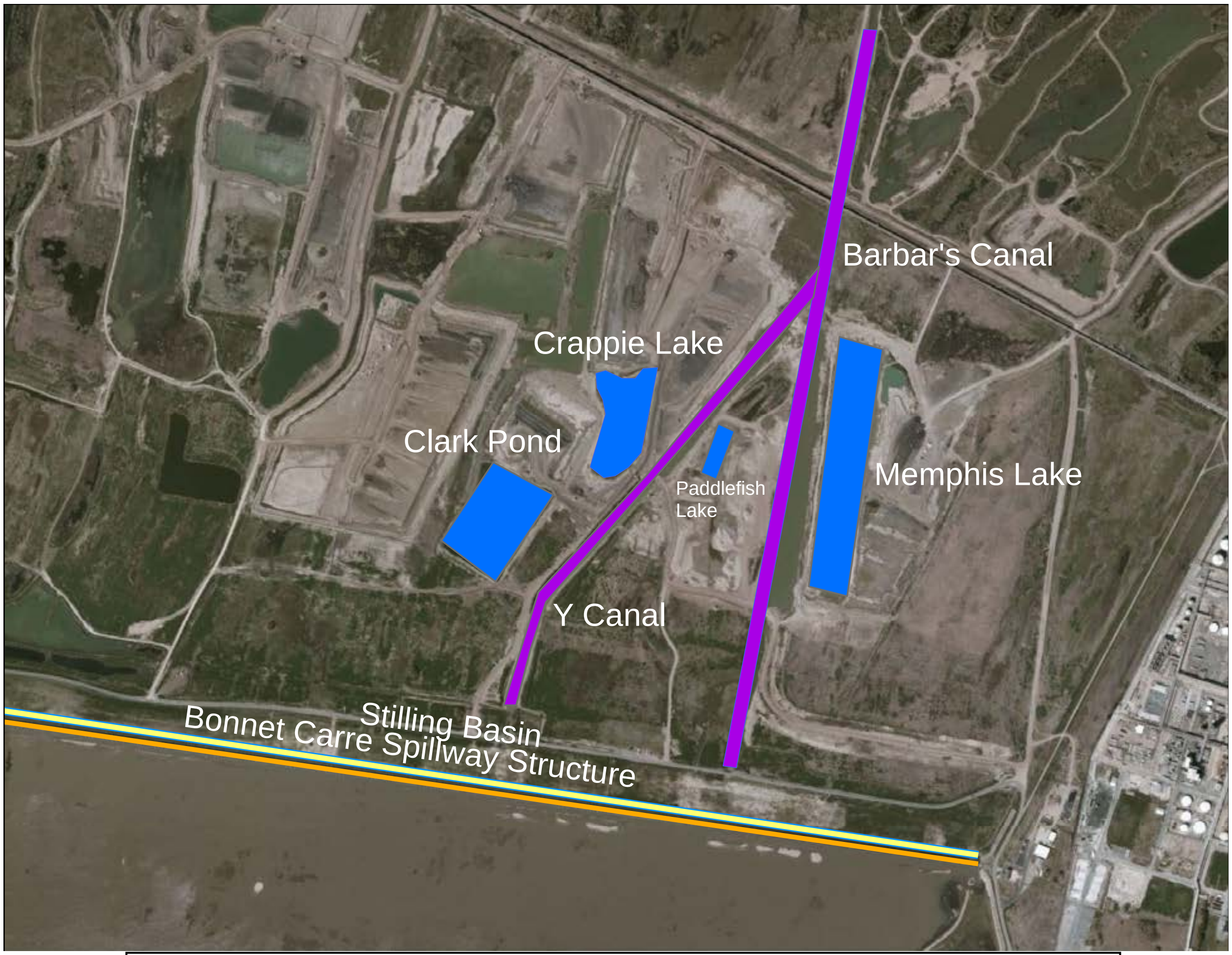


Figure 8.4. Three primary areas where sturgeon were collected in 2011: Stilling Basin, Canals (Barbars and Y), and Lakes.

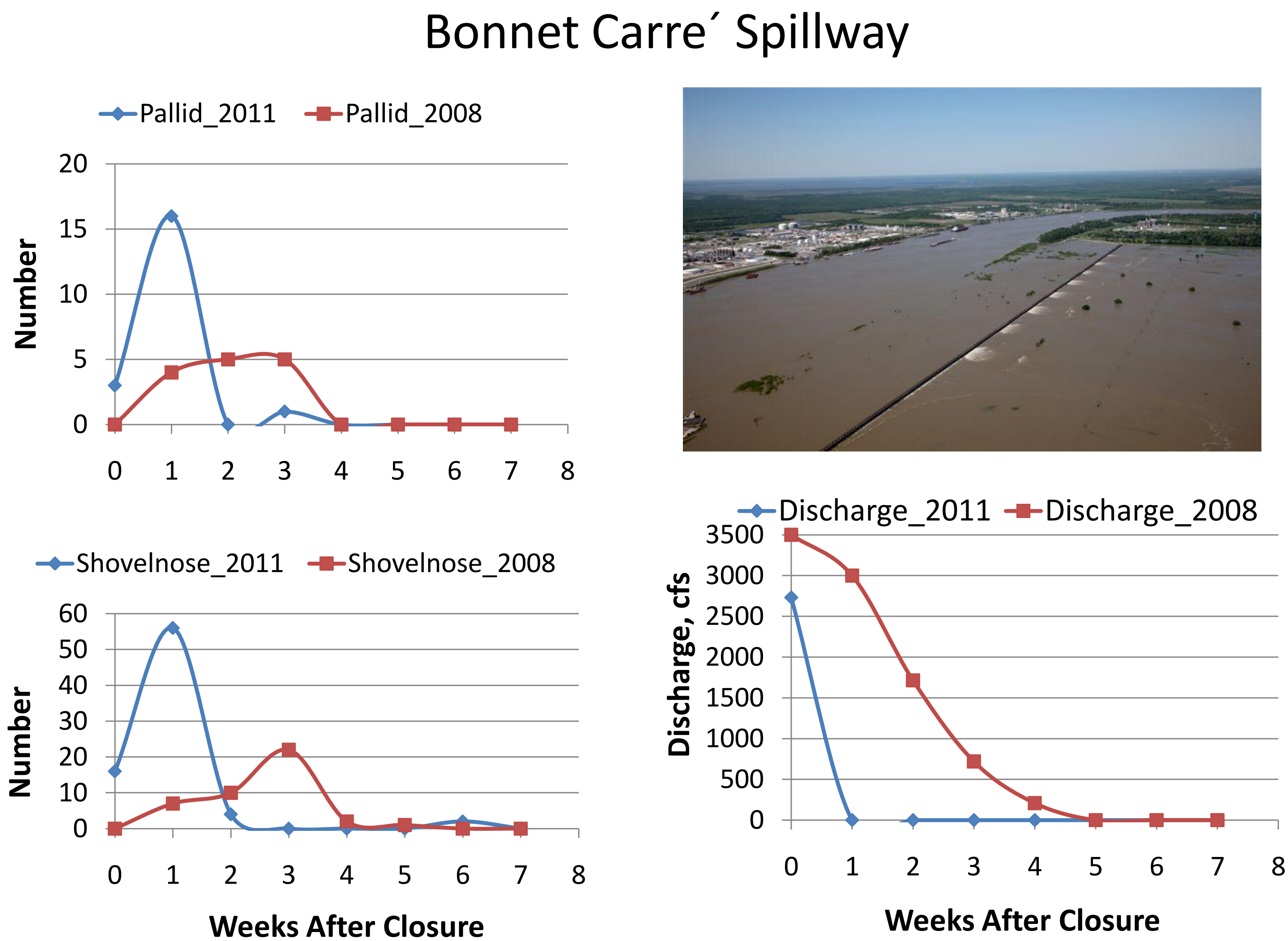


Figure 9.4. A summary of discharge (CFS) in the floodway and sturgeon catch after closure of the Bonnet Carre spillway in 2008 and 2011.

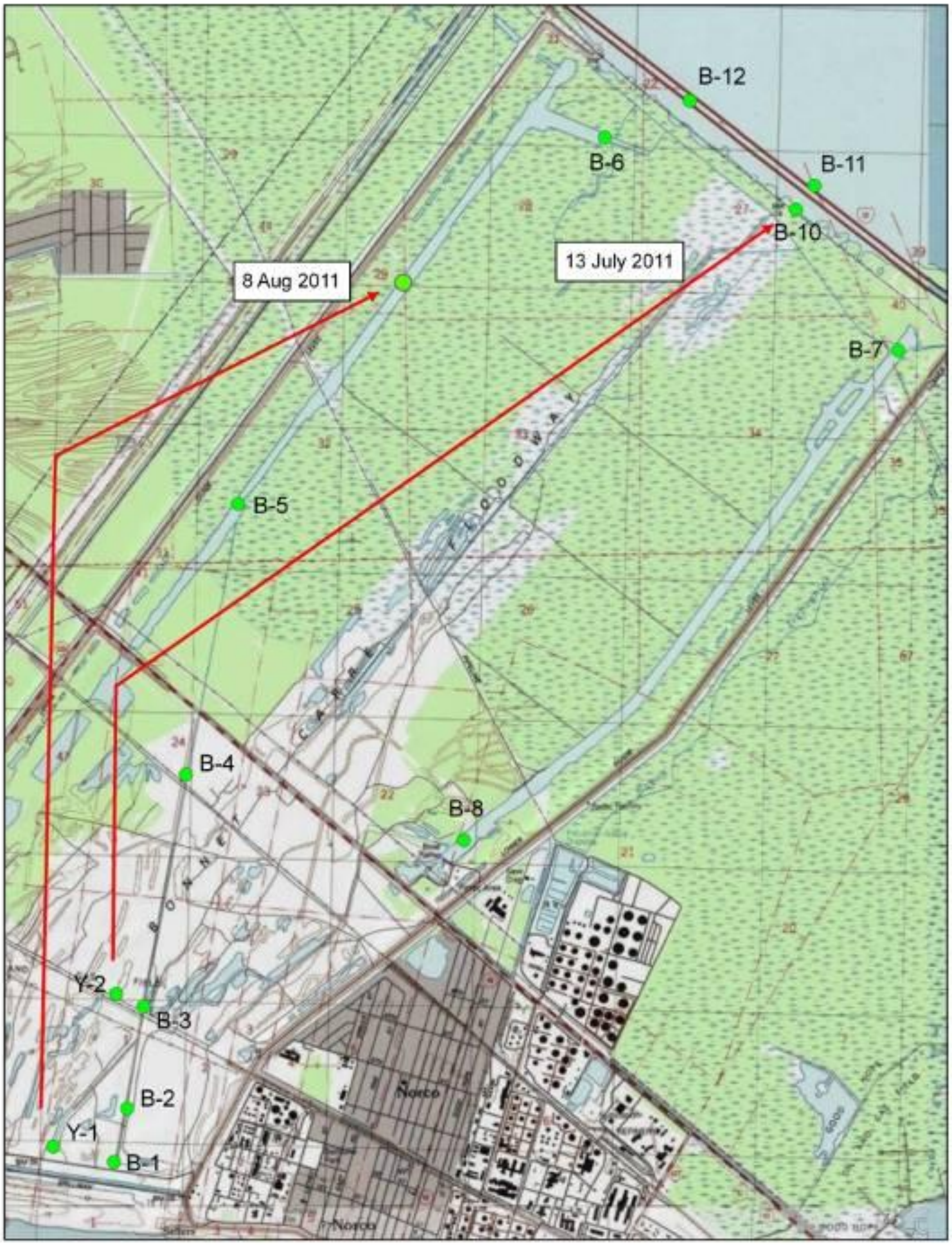


Figure 10.4. Location of 12 VR2Ws (remote receivers, green dots) deployed in the Bonnet Carre Spillway down to Lake Pontchartrain. Red arrows indicate relocation of receivers from waterbodies that became disconnected from primary canals.

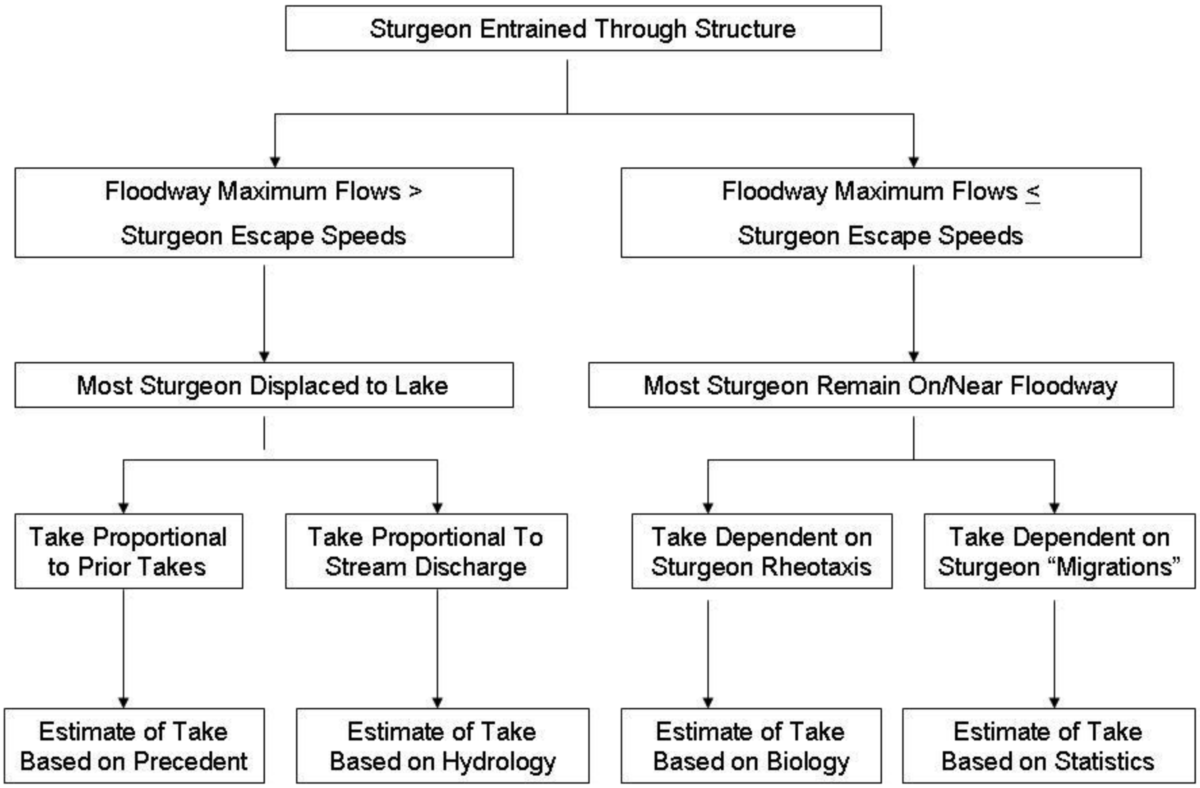


Figure 11.4. Rationale for Sturgeon Take Estimates by Water Diversions

Appendix 1

Estimation of Take
by

Jan J. Hoover
ERDC-EL

This appendix provides rationale for sturgeon take estimates entrained through water diversions based on collections at Bonnet Carré in 2008.

Precedent-Based Estimate

Assumptions:
1. Flows exceed swimming performance of fish; fish are entrained in numbers proportional to discharge
2. There is no upstream movement from fish displaced to lake
3. Numbers of fish entrained can be estimated from previously documented rates of entrainment (other studies) and relative abundance of fish in the river (i.e., Killgore et al., 2007)
4. Fish do not occur in the water column and are entrained only from water occurring very close to the bottom of the river.
5. Fish are entrained only on dates of moderate to high discharge.

Calculations:

For Shovelnose sturgeon:

Precedent used was 2008 Chain-of-Rocks Dredging Data (Nathan Badgett, Ecological Specialists, Inc., 2008): 4 shovelnose sturgeon were entrained in 319,309 m^3 water discharged by dredge.

We assumed that 1% of the Bonnet Carré peak discharge represented bottom water. We also assumed that bottom water was entrained on dates of moderate to high discharge: i.e., dates > 150,000cfs.

Total Number Entrained/Total Volume of Bottom Water =
Previous Number Entrained/Previous Volume of Bottom Water

Total Number Entrained =
Previous Number Entrained*Total Volume of Bottom Water/Previous Volume of Bottom Water

(4 sturgeon)*(0.01)(1.59)(10^{11})m^3/319,309m^3 = 19,918 sturgeon

(This number represents how many shovelnose sturgeon would have been entrained if volume of water pumped at Chain-of-Rocks was equivalent to volume of bottom water diverted through Bonnet Carré)

To estimate number of shovelnose sturgeon that would have been entrained at Bonnet Carré, we “correct” the number based on the ratio of sturgeon abundance near Bonnet Carré to sturgeon abundance at Chain-of-Rocks (Killgore et al., 2007).

19, 918 shovelnose * (1.88 CPUE at New Orleans-Atchaf/22.24 CPUE at Chain-of-Rocks) = 1684 shovelnose

For pallid sturgeon:

To estimate number of pallid sturgeon entrained that would have been entrained at Bonnet Carré, we use the ratio of pallid sturgeon abundance to shovelnose sturgeon abundance in the river near Bonnet Carré:
1684 shovelnose * (1 pallid/6 shovelnose) = 281 pallid sturgeon

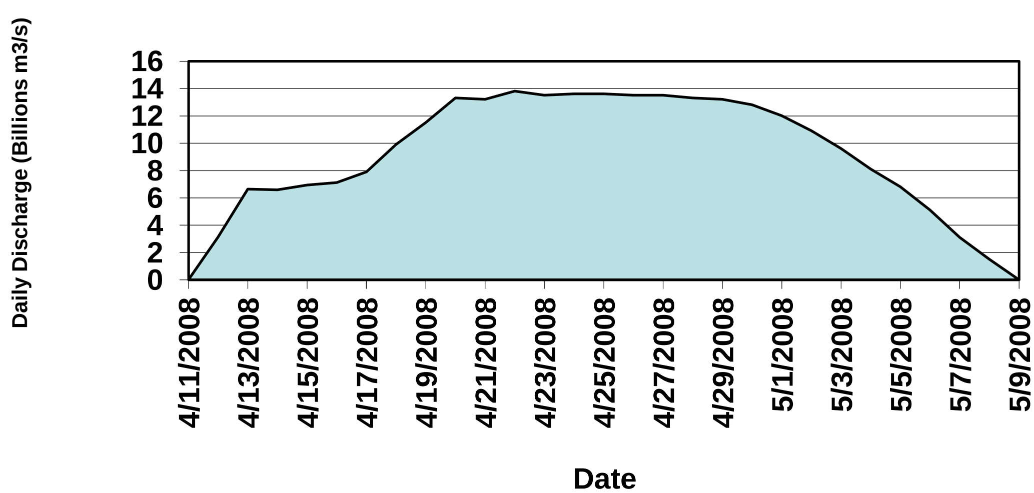
Estimate of Unrecovered Take = 281-14 = 266 pallid sturgeon

<u>Refinements:</u>
We could develop a sliding scale of what represents bottom water (instead of using a fixed value of 1%). Value could be lower during higher stages to represent relatively greater distance of substrates from the surface of the water.

<u>Note:</u>
This number is conservatively high. Whether entrainment rate of a small dredge operating in an area of high sturgeon density can be extrapolated to a large diversion drawing water from an area of moderate sturgeon density would be difficult to resolve.

Hydrology-Based Estimate

<u>Assumptions:</u>
1. Flows exceed swimming performance of fish; fish are entrained in numbers proportional to discharge
2. There is no upstream movement from fish displaced to lake (11 Apr -30 Apr).
3. All fish remaining on floodplain after gate closure were entrained during the declining hydrograph (01-09 May)
4. All fish remaining on floodplain were collected



Calculations:

Total Number Entrained/Total Volume of Water =
Number collected/01-09 May Volume of Water

Total Number Entrained =
Number collected * Total Volume of Water/01-09 May Volume of Water

Total Number Entrained = 14 $(2.64)(10^{11})\text{m}^3$ / $(5.67)(10^{10})$ m^3

Total Number Entrained = 65.2

Estimate of Unrecovered Take = 65 – 14 = 51

Refinements:
Frequency and downstream displacement rates of sturgeon (from Old River Control Structure) could be used to better estimate time interval represented by fish collected post-closure.

Biology-Based Estimate

Assumptions:
1. Flows do not exceed swimming performance of fish.
2. Fish remain on floodplain or in lake near outflow.
3. Non-rheotactic fish drift to lake (or are stranded) and do not return – numbers decrease continuously over time
4. Rheotactic fish seek and remain in flow as water recedes – numbers increase continuously over time
5. Percentage of non-rheotactic fish can be estimated from laboratory studies of swimming performance. Data suggest that it ranges from 0.00 for adult shovelnose sturgeon (ERDC, unpublished data; Adams et al. 1998; Parsons et al. 2003) to 0.27 for some groups of juvenile sturgeon (ERDC, unpublished data; Hoover et al. 2005).

Calculations:

Total Number Entrained =
[Number collected] + [(Number collected)*(Percentage presumed non-rheotactic)]

Total Number Entrained =
14 + 14*(0.27)

Total Number Entrained = 17.8

Estimate of Unrecovered Take = 18-14 = 4

Refinements:
If flow fields could be generated from hydraulic models, we could develop a risk-based analysis (sensu Hoover et al., 2005). We would need data for the following variables:
i.) number of fish in vicinity of gates, or moving through structure

ii) water velocities at bottom of gates
iii) escape speeds of fish (could be extrapolated from ERDC swim tunnel studies)
iv) chronology of gate openings (distribution and linear extent of low and high gates)

Statistics-Based Estimate

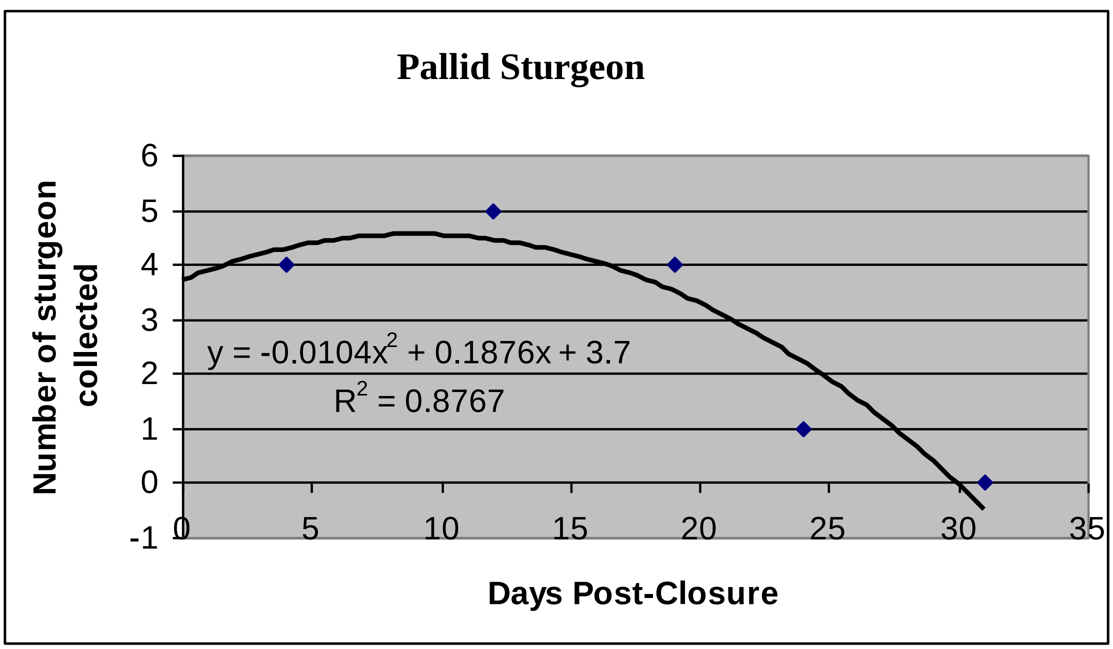
Assumptions:
1. Flows do not exceed swimming performance of fish.
2. Fish remain on floodplain or in lake near outflow.
3. Non-rheotactic fish drift to lake (or are stranded) and do not return: Emigration (E)
4. Rheotactic fish seek and remain in flow as water recedes: Immigration (I)
5. Numbers of fish at any point in time based on net migrations (fish moving upstream – fish moving downstream) – not necessarily continuous over time

Migrations	Number over time	Area Under Curve As Estimate of Take
I > E	Positive correlation	Underestimate (requires extrapolation and forecast)
I = E	No correlation	Underestimate (requires WAG, BPJ)
I > E, then I = E, then I < E	Parabolic correlation	Variable (dependent on fit of model)
I < E	Negative correlation	Underestimate (requires extrapolation and hindcast)

Calculations:

Time series analysis
Best fit model of frequency distribution over time
Total Number Entrained = Area under curve + extrapolations

Area under curve approximated by bar graphs at 1- week sample intervals.



Total Number Entrained = 14 [No extrapolation required]

Estimate of Unrecovered Take = 0*

*** Note:**
If a bell-shaped distribution is assumed, area under curve would be approximately 18 and unrecovered take would be estimated at 4.

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Chapter 5

Water Diversions and Pallid Sturgeon Population Viability in the Lower Mississippi River: Uncertainties and Priorities for Ecological Risk Assessment

by

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Abstract

Management of pallid sturgeon (*Scaphiryhnchus albus*) in the Lower Mississippi River (LMR) should be supported by a region-specific demographic model. Among the challenges faced by this long-lived fish is entrainment in water diversion structures used to manage the hydrology of the river and its surrounding drainage. We developed an age-based model of pallid sturgeon that included both demographic and environmental stochasticity. Using abundance estimates derived in a companion study, we translated projected numbers of entrained fish into per capita entrainment rates to explore the ecological risk posed by episodic and chronic water diversion actions in the southernmost reach of the LMR occupied by pallid sturgeon. Uncertainty was addressed by testing a range of entrainment rates, abundance levels, and spatial structures. Entrainment during episodic diversions characteristic of the Bonnet Carré spillway reduced median local population size by 0-20% in 60 years. Entrainment in chronic annual water diversions, characteristic of those proposed for wetlands nourishment in Louisiana, reduced median local population size by 2-50%. The effect of combined episodic and cumulative entrainment was multiplicative. Model projections revealed that the greatest gains in certainty would come from a more precise population size estimate. Improved understanding of large-scale movements of age-1+ fish would also greatly improve our ability to manage pallid sturgeon in the free-flowing Mississippi River.

Introduction

The pallid sturgeon, *Scaphirhynchus albus*, occupies portions of the Missouri and Mississippi River basins from Montana to Louisiana (Dryer and Sandvol 1993). The species varies dramatically in growth, size, and longevity over its range. While adults in northern populations are large and long-lived (Keenlyne et al. 1992), individuals in the south are smaller, reproduce at an earlier age, have a higher mass-specific fecundity (George et al. 2012), and appear to have shorter lives (Killgore et al. 2007b). The Mississippi River is the only portion of the range in which natural recruitment is apparent (U.S. Fish and Wildlife Service 2013). While populations in the middle and upper Missouri River are well studied and form the "type" reference for the species, the size and reproductive potential of the Mississippi River population is still poorly understood.

Demographic models are essential tools for guiding research priorities and modifying adaptive management plans (Bakker and Doak 2009) and can provide unbiased projections of risk to threatened populations (Brook et al. 2000). Given the geographic variation in pallid sturgeon life history, it is important to develop a population model specific to the Mississippi River. A plan for the recovery of pallid sturgeon from endangered status calls for a quantification of mortality due to entrainment as well as its consequences for population viability.

Several large diversion structures exist in the Lower Mississippi River (LMR). Some, including the Morganza and Bonnet Carré spillways, are only opened episodically at high river stage to protect communities downstream from flooding. Others, such as the Old River Control Complex and smaller diversions, operate on a continual basis either to regulate river flows or nourish wetlands. Entrainment of pallid sturgeon through both episodic and chronic diversion structures has been confirmed by limited monitoring. In this study, we developed a demographic model specific to the LMR population of pallid sturgeon. We used the model to extrapolate abundance estimates from a companion study (Friedenberg et al. 2013) to all age classes. We then used the model in case studies of the effect of episodic and chronic entrainment on future risk of population decline.

Methods

Reproduction

As outlined by the equations in Table 1.5, we estimated age specific egg production, E_t, using a Bertalanffy growth model and allometric relationships of mass-to-length and eggs-to-mass. Growth parameters were specific to the LMR population (Killgore et al. 2007b). The mass-length relationship was fit to the LMR survey samples by log-log ordinary least squares regression. Mass-specific egg production was established using the mean mass and egg counts of two female pallid sturgeon collected in the Atchafalaya River, LA, at the Old River Control Structure on 23 October 2009 (George et al. 2012). The two fish weighed 2.85 kg and 3.20 kg and contained 50,759 and 51,959 eggs, respectively. DeVore et al. (1995) found that white sturgeon egg production scaled as the 0.91 power of mass, slightly less than linearly. Using an allometric relationship of the form $E = aM^b$ with $b = 0.91$, we solved for the intercept, *a,* using the geometric mean of mass, *M*, and number of eggs, *E*, of the two Atchafalaya females. We used the resulting allometry to calculate age-specific egg production from expected age-specific mass (Table 1.5). All individuals age 25 or greater were assigned age-25 fecundity.

Estimates of age of first spawning in the Mississippi River basin range from a high of 15 (Keenlyne and Jenkins 1993) to as low as eight (George et al. 2012). To accommodate this range, we modeled variation in age of first reproduction as the accumulated variance of a normally-distributed developmental rate (sensu Dennehy et al. 2007) with a mean of 9.1% per year and standard deviation of 1%. As illustrated in Figure 1, the inverse of the normal distribution of developmental rates is a skewed distribution of maturation ages with a median of 11, the mean of the two mature Atchafalaya females measured by George et al. (2012). The distribution was conservative in that the earliest age of reproduction was nine rather than eight and some individuals did not mature until age 16. We used a reproductive interval of three years, consistent with the fraction of adult fish caught in the survey that were reproductive (JJH, personal observation). While possibly a low value (Mayden and Kuhajda 1997), any effect of reproductive interval was removed by our method of estimating survival from egg to age-1, as described below.

Fecundity and Survival

Age-specific fecundity, F_t, representing in this case the number of age-1 females produced by a female of age *t*, incorporated sex ratio, reproductive interval, and distribution of age of first reproduction, in addition to our estimate of first-year survival discussed in the next paragraph.

An annual survival rate of 0.93 for age classes 3 through 24 was taken from Killgore et al. (2007b). Survival of age-2 fish, 0.75, was taken from a low observation in mark-recapture experiments in the upper Missouri River basin (Hadley and Rotella 2009) and follows Bajer and Wildhaber (2007). An initial age-0 survival rate of 0.004 (Bajer and Wildhaber 2007) and age-1 survival rate of 0.69 (Steffensen et al. 2010) were subsequently adjusted such that the model projected no change in expected abundance over time for a population at the stable age distribution given by the dominant eigenvector of the transition matrix (i.e., at the population's equilibrium age structure, births balanced deaths) (Caswell 2001). For a deterministic model, this would be equivalent to finding survival rates that give an asymptotic growth rate of 1.0, as indicated by the dominant eigenvalue of the transition matrix (Caswell 2001). In our model, which included environmental and demographic stochasticity, the asymptotic growth rate needed to exceed slightly 1.0 for long-term stability of expected abundance under baseline conditions. Environmental variation in pallid sturgeon demography may be driven by factors such as hydrograph and temperature (Phelps et al. 2010). A four-year study of larval abundance in the Middle Mississippi River (MMR) (Phelps et al. 2010) yielded a mean catch per unit effort of 0.85 (SD 0.51), translating to a 60% coefficient of variation in larval production. This empirical estimate of environmental variation is inflated by measurement error and demographic stochasticity (Akcakaya 2002). We assumed a 50% coefficient of variation around fecundity (the variability of age-0 mortality was subsumed into variation in fecundity). On the premise that a long-lived species will have less variation in survival than in reproduction, we assumed a 10% coefficient of variation around age-1+ survival rates. Environmental variation in vital rates was log-normal. We found final values for age-0 and age-1 survival by iteratively adjusting survival and the attendant stable age distribution and variability until the median 60-year projection of 10,000 simulations changed by less than 0.5%. The use of a longer reproductive interval (or any other age-independent decrease in fecundity, such as fractional spawning success) would lead to a higher estimate of age-0 survival but would not otherwise affect the model. The use of a demographically balanced model allowed us to examine the population-level effects of entrainment in isolation from any existing trends or cumulative stresses affecting population dynamics.

Sensitivity Analysis

We examined the sensitivity of asymptotic population growth rate to small changes in vital rates. While RAMAS Metapop provides elasticities for each entry in the transition matrix, we instead took the approach of examining the effect of a 5% change in vital rates across a range of age classes. Specifically, we measured sensitivity to a change in fecundity of all reproductive classes (age-9 through age-25), survival of all age classes, survival of non-reproductive age classes (age-1 through age-8), and survival of reproductive age classes. Sensitivity was measured as the percent decrease in asymptotic growth rate relative to the percent decrease in vital rate. A sensitivity of 100% would indicate that a 5% decrease in vital rate yields a 5% decrease in population growth rate. Additional calculations showed that the sensitivity for small increases and decreases in vital rates was nearly identical.

Abundance

The population size of pallid sturgeon in the LMR is not known with any precision. Lower bounds on the abundance of pallid sturgeon in the LMR and MMR have been estimated based on the absence of recaptures during the survey (Friedenberg et al. 2013). Various assumptions affected the abundance estimates, but a rough value for the lower 99% confidence limit was 4000 age-3+ individuals in the LMR and MMR combined. The lower 75% confidence limit was 20,000 age-3+ individuals. This five-fold range of abundance served to investigate the sensitivity of population-level impacts to uncertainty in population size. To extrapolate from age-3+ abundance to total abundance, we assumed that the population was initially at the stable age distribution indicated by our estimates of fecundity and survival.

Spatial structure

The water diversion structures we were concerned with lie within a reach of the LMR between New Orleans and the Old River control structure, named reach B by Killgore et al. (2007a). The remainder of the LMR north of reach B originates at the confluence of the Ohio River near Cairo, IN. For our study, we referred to this portion of the river as reach CD because it encompasses the reaches named C and D in Killgore et al. (2007a). The MMR comprises the reach between confluences with the Ohio River and Missouri River. Results of the Mississippi River pallid sturgeon survey were reported separately for sampling locations in the greater part of the MMR and the Chain of Rocks, referred to as reaches E and F, respectively, by Killgore et al. (2007a). Following Friedenberg (Friedenberg et al. 2013), we treated the MMR as a single reach. We only considered the MMR for the purposes of calculating abundance in populations B and CD; the geographic scope of the population model was restricted to the LMR.

Catch per unit effort in the Mississippi River pallid sturgeon survey suggested variation in relative abundance among reaches (Killgore et al. 2007a). However, there is a possibility that such variation was driven by the availability and suitability of sampling locations. We addressed the uncertainty in the spatial structure of abundance by developing two sets of models, one with uniform population density and the other with observed relative abundance. For uniform spatial structure, relative abundance was based on the length of reaches. The lengths of reaches B, C, D, and E are 349, 433, 598, and 314 km, respectively. Hence, uniform relative abundance was 0.21, 0.26, 0.35, and 0.19, respectively, indicating that 21% of the Mississippi River pallid sturgeon population is in reach B, while 61% resides in reaches C and D. In contrast, the observed catch per unit effort among reaches was 0.31, 0.14, 0.18 and 0.16, respectively (Killgore et al. 2007a), giving an index of relative population density of 0.39, 0.18, 0.23, and 0.20, respectively. Weighted by the length of reaches, the observed pattern of population density suggests that reach B contains 33% of the population while 52% resides in reaches C and D. As described below, the two spatial structures led to distinct sets of parameters for relative fecundity and dispersal. We assumed all environmental variability was perfectly correlated across the two populations.

Relative Fecundity and Larval Drift

We assumed uniform age structure among reaches. Given the lack of spawning substrate in reach B, we assumed that relative fecundity in reach B was 0 and that all age-1 individuals were supplied by larval drift from reach CD, a plausible scenario given that pallid sturgeon larvae are likely to drift more than 300 km in the LMR (Kynard et al. 2007). Hence, we adjusted relative fecundity in reach CD upward to produce all age-1 individuals expected in the LMR at the stable age distribution. The dispersal rate of offspring via larval drift was then calculated based on the assumed spatial structure of the population. Under the uniform spatial structure, 21 / (21 + 61) = 25.6% of larvae drifted to reach B. Under the observed spatial structure, drift relocated 33 / (33 + 52) = 38.8% of larvae to reach B.

Dispersal

Telemetry has determined that as many as almost 15% pallid sturgeon emigrate from the MMR in a year (Koch et al. 2012). In calculating dispersal between reaches, we assumed that all emigrants from the MMR move into the LMR. For reaches C and D, we assumed an equal number of emigrants moved upstream and downstream. For reach B, we assumed all emigrants moved upstream. We further assumed that all age classes had the same dispersal probabilities and that survival was the same in all reaches (in contrast with Friedenberg et al. 2013). With these assumptions, it was possible to calculate dispersal rates between neighboring reaches consistent with either the uniform or observed spatial structure of abundance. Given relative abundance and in reaches i and j, w_i *and* w_j, and the rate of dispersal from reach i to reach j, d_{ij}, the balanced reciprocal rate of dispersal is $d_{ji} = d_{ij}w_i / w_j$. For reaches with bi-directional dispersal, the total emigration rate is $2d$. Starting with reach E and working southward, this logic leads to a reach B dispersal rate of 13.5% for the uniform spatial structure and 7% for the observed spatial structure. Using the summed relative abundance of reach CD, dispersal from reach CD to reach B was therefore set to 4.6% and 4.4% for the uniform and observed spatial structures, respectively. All dispersal rates varied annually with a coefficient of variation of 10%.

Density Dependence

In addition to our main analysis using density-independent population growth models, we explored a subset of scenarios using a model with density-dependent fecundity. We used a Ricker density dependence function (Ricker 1954) to maintain a total population growth rate of 1.0 by adjusting relative fecundity in reach CD based on the abundance of age-8+ adults (using the “scramble” option for density dependence in RAMAS Metapop 5.0) (Akcakaya and Root

2005). We assumed a maximum population growth rate, R_{max}, of 1.05 in reach CD. The loss of larvae to downstream drift reduced the local maximum growth rate, $R_{max\ local}$, in reach CD, requiring a carrying capacity, K, that was higher than our target for equilibrium abundance. $R_{max\ local}$ was calculated as the eigenvalue of the transition matrix after relative fecundity was adjusted for larval drift from the value necessary to give R_{max}. An initial value for carrying capacity was then calculated as $K = N^{*}\ln(R_{max}) / \ln(R_{max\ local})$, where N^{*} was our target for equilibrium abundance of age 8+ individuals based on the stable age distribution of the transition matrix with relative fecundity set to 1.0. Given that R_{max} was larger than $R_{max\ local}$, K was larger than N^{*}. We assigned K a 10% annual coefficient of variation. The initial value of K and its standard deviation were adjusted iteratively until stochastic baseline models showed no change in expected abundance over time.

Episodic Entrainment

The level of the Mississippi River is managed by a number of large water diversion structures, including the Bonnet Carré spillway linking the river and Lake Pontchartrain in Louisiana, a location within reach B. From 11 April to 9 May 2008, the spillway diverted an estimated 7.5×10^{9} m^{3} of water. The maximum number of bays in operation was 160 out of 350 and the maximum discharge rate through the structure was 160,144 cfs. Entrainment of pallid sturgeon during operation of the Bonnet Carré diversion was confirmed by sampling in the floodway after the structure was closed. Entrained sturgeon were detected for up to a month after closure using a variety of gear, including a boat-mounted electroshocker, seines, trawls, and gill nets. Sampling detected 14 pallid sturgeon 528-884 mm fork length in addition to 43 shovelnose sturgeon, *Scaphirhynchus platorynchus* 570-841 mm fork length.

A range of rough estimates of the true number of individuals entrained by the Bonnet Carré spillway in 2008 was developed using a variety of approaches. We developed a low estimate using a behavioral justification. If only rheotactic individuals, which can account for as little as 77% of pallid sturgeon (Hoover et al. 2005), remained in the floodplain, then a total of 14 / 0.77 = 18 individuals were entrained. A high estimate followed from a calculation of detectability based on a measurement of shovelnose entrainment rate in dredges in the MMR (Nathan Badgett, Ecological Specialists, Inc., 2008). If we assumed that 10% of the water diverted was from low enough in the water column to entrain sturgeon and applied this volume to the dredge entrainment rate, then 400 shovelnose sturgeon were expected to be entrained, giving a detectability of 43 / 400 = 0.1075. Assuming the same detectability for both species gave an expected entrainment of 130 pallid sturgeon. An intermediate estimate of pallid sturgeon entrainment assumed that peak flow of the water through the floodplain was great enough to wash all individuals out of the study area and that sampling only detected sturgeon entrained during the declining hydrograph from 1-9 May. Of the total volume of water diverted during the 2008 opening of the Bonnet Carré spillway, 21.5% was released from 1-9 May. If entrainment was proportional to the volume of water diverted, then 65 pallid sturgeon were expected to have passed through the spillway over the full course of its operation.

The smallest pallid sturgeon detected in the spillway (528 mm) was smaller than the smallest individual measured during a 6-year survey of the LMR and MMR (540 mm). The youngest individual aged from fin ray sampled taken during the survey was age-3 (Killgore et al. 2007b). Therefore, we treated conservatively the three estimates as representative of per capita episodic entrainment rates of age-3+ fish. We assumed age-1 and age-2 individuals were subject to the same probability of entrainment but were not detectable. We further assumed that half the individuals entrained were female. Final estimates of episodic entrainment rates depended on the abundance level and spatial structure used in each model scenario (Table 2.5).

The Bonnet Carré water diversion was opened 10 times in the 80 years between its completion in 1931 and 2011 (USACE New Orleans District 2013), leading to a conservative estimate of the frequency of episodic entrainment events of once per eight years. Therefore, episodic entrainment events were modeled as random catastrophes in RAMAS Metapop with a probability of 0.125 y^{-1} that affected the abundance of all stages proportionally given the take of 18, 65, or 130 age-3+ individuals.

Chronic Entrainment

A proposed wetlands replenishment project will nourish marshes with Mississippi River water and sediment using diversion structures located both in and south of reach B. Studies below an existing diversion structure, the Davis Pond diversion at rkm 191, detected the entrainment of one pallid and three shovelnose sturgeon (D. Schultz, McNeese University, pers. comm.). Two other structures, the Medium Diversion at White Ditch at rkm 103 and the Small Diversion at Convent Blind River at rkm 262, are proposed for the nourishment project as well. These three structures and others will operate continually, creating a chronic risk of entrainment.

Chronic entrainment rates were estimated by first considering the detectability of sturgeon and the abundance of pallid sturgeon relative to that of shovelnose sturgeon in reach B to determine the number of fish entrained at Davis Pond. The total number of individuals entrained at three sites was then estimated by assuming a constant probability of entrainment per volume of discharge. Planned discharge rates were provided by D. Walter of the U.S. Fish and Wildlife Service (USFWS). Local sampling indicated a detectability of 10% based on previously finding 2 of 20 tagged individuals in the diversion canal (D. Walther, USFWS, pers.comm..). We further assumed that, as in the Mississippi River survey and sampling below the Bonnet Carré spillway, only age-3+ individuals were detectable. Of 271 sturgeon caught in reach B during the Mississippi River survey, 44 were pallid sturgeon (Killgore et al. 2007a), a relative abundance of roughly 1/6. The four sturgeon discovered at Davis Pond suggest the presence of 40 sturgeon given 10% detectability, of which seven would be age-3+ pallid sturgeon based on relative abundance. The volume of water diverted annually through Davis Pond, 2.55×10^9 m^3, translates to a volumetric entrainment rate of one pallid sturgeon per 3.64×10^8 m^3 of discharge. The projected operating volume for the Whites Ditch diversion, 6.31×10^9 m^3, gave an expected 18 age-3+ pallid sturgeon entrained per year. At the proposed Convent Blind River diversion, the projected 1.79×10^9 m^3 annual discharge would entrain an expected 3 age-3+ pallid sturgeon. Lower and upper estimates around the expected total annual entrainment of 28 age-3+ individuals were then produced by developing 80% Clopper-Pearson confidence intervals (Walley 1996) around the observed detectability and relative abundance. Assuming independence, the product of these intervals generated the 98% confidence interval of 8-56 age-3+ pallid sturgeon. As with episodic entrainment, we assumed half the entrained individuals were female. Per capita entrainment probabilities varied with population size and spatial structure and extended to age-1 and age-2 individuals (Table 2.5).

Experimental Design

The effects of episodic or chronic entrainment on the LMR population of pallid sturgeon were investigated separately using three-way factorial designs that crossed population size (low or high), spatial structure (uniform or observed), and the level of entrainment (none, low, medium, or high). Simulations were run for 60 years (approximately 3 generations) and each scenario was replicated 10,000 times to ensure the precision of results. For each scenario, we calculated the probability of declining by at least 0-100% to produce exceedance curves that allow comparison of risk over all possible levels of decline. We further summarized results using the median final population size in each scenario (probability of no decline = 0.5), which provides information on the sensitivity of expected population size to factors in the model. We also chose to monitor the probability of declining by at least 30% to examine sensitivity in the probability of a threshold population size. This threshold was chosen because a projected 30% decline over three generations indicates population vulnerability by IUCN standards (IUCN Standards and Petitions Subcommittee 2010).

Additional Investigations

We performed additional simulations to investigate model behavior under the combination of episodic and chronic entrainment. Only best and worst cases were examined to develop the envelope of risk under the combined stresses. We also explored sensitivity to dispersal rate using only the uniform spatial structure under a scenario of low population size and the intermediate value of either episodic or chronic entrainment. Finally, we used models with density-dependent fecundity in reach CD to examine how spatial structure and population size might interact with compensatory population growth under high episodic or chronic entrainment.

Results

Reproduction

Table 1.5 summarizes the parameters used to calculate age-specific egg production, E_t. Our reanalysis of the updated Mississippi River survey dataset yielded an allometric relationship between mass (kg) and length (mm) of $M = 10^{-9.22}L^{3.42}$ ($r^2 = 0.95$, $F_{1,235} = 4101$, $P < 0.0001$). The geometric mean intercept for the allometry between egg number and mass (kg) was 18,780 eggs. The resulting allometry between length (mm) and egg production was $E = 10^{-8.39}L^{3.11}$, nearly proportional to the cube of length.

Fecundity and Survival

After iteratively adjusting survival and the attendant stable age distribution and variability, the final values for age-0 and age-1 survival were 2.4×10^{-5} and 0.63, respectively, leading to an asymptotic population growth rate of 1.0002. Age-specific fecundity ranged from 0.004 at age-9 to 0.375 for the compound age-25+ stage (Figure 2.5). Fecundity increased with age both because of an increasing proportion of reproductively mature individuals and increased expected body size.

Sensitivity

Sensitivity analysis indicated that survival of age-1+ fish, especially reproductive adult classes, had the largest proportional effect on asymptotic population growth rate. In response to a 5% decrease in survival of age-1+ fish, population growth rate decreased from 1.0002 to 0.9525, indicating a sensitivity of 95%. The sensitivity of survival was 39% in immature age classes (1-8) and 57% in reproductive age classes (9-25). The sensitivity of population growth rate to fecundity was 5%.

Age Structure, Population Size, and Relative Fecundity

At the stable age distribution, the transition matrix indicated that age-3+ fish represented 79% of the population, allowing us to extrapolate age-3+ abundance to total abundance. Asymptotic analysis also predicted that more than half of the population, 52.5%, was age-8+. For the low and high population levels, total abundance in the Mississippi River was roughly 5,000 and 25,000 individuals, respectively, half of which we assumed were female. Total and age-8+ abundance in reaches B and CD of the LMR are given in Table 3.5.

The relative fecundity of reach CD differed between the two spatial structures we explored (Table 3.5). Under the assumption of uniform population density among reaches, the LMR population as a whole was expected to include 193 or 961 age-1 pallid sturgeon for the low and high population level, respectively. Given the assumption of no spawning in reach B, reach CD required a relative fecundity of 1.34 to balance births and deaths in the LMR on average. The observed spatial structure, which placed a larger proportion of the population in reach B, required a higher relative fecundity in reach CD, 1.64, to produce the expected total of 165 or 823 age-1 individuals. Relative fecundity calculations rested on the assumption that age structure was the same in both reaches.

Density Dependence Parameters

Cursory exploration of density dependent scenarios illustrated that the observed spatial structure puts a greater strain on reach CD and results in less capacity for compensatory population growth than the uniform spatial structure. A maximum population growth rate, R_{max}, of 1.05 in reach CD was high enough to allow persistence under both spatial structures, representing a maximum 2.68-fold increase in fecundity (i.e., through higher first-year survival or mass-specific egg production) over the baseline rate. For the uniform spatial structure, the 26% emigration rate of larvae to reach B reduced the maximum contribution to local recruitment to 2 times the baseline level, resulting in a local maximum population growth rate, R_{loc}, of 1.035 (Table 3.5). For the observed spatial structure, emigration of 39% of larvae to reach B reduced maximum relative local fecundity in population CD to 1.64 times the baseline level, yielding R_{loc} = 1.025 (Table 3.5). For both spatial structures and population levels, the carrying capacity (of age-8+ adults) in reach CD required to maintain target equilibrium population sizes was higher than the target adult abundance (Table 3.5), a result that stems from the need to maintain elevated fecundity in reach CD.

Impact of Episodic Entrainment

Due to the stochasticity of vital rates, baseline models without entrainment exhibited some probability for increase or decrease over time (Figure 3.5), including a 1% to 2% chance of declining by 30% after 60 years (Table 4.5). With episodic entrainment, the projected median final number of age-3+ fish across all scenarios with entrainment ranged approximately seven-fold, from 1,290 to 8,362, representing a reduction of 0% to 20% from baseline abundance (Table 4.5). The five-fold difference in abundance between population levels was reflected by a roughly 5-fold difference in entrainment impact on median abundance (Table 4.5). For the high abundance estimate, even the highest entrainment level only led to a doubling in the probability of 30% decline for either spatial structure (Table 4.5). However, for the low abundance estimate, the probability of a 30% decline rose from 2% in the baseline model to as much as 26% with entrainment (Table 4.5). Unlike median declines, 30% decline risk did not echo the 5-fold difference in abundance between high and low population levels, becoming 6-fold for the uniform spatial structure and 8-fold in the observed spatial structure with high episodic entrainment. As illustrated by Figure 4.5, the observed spatial structure was generally more robust to entrainment, exhibiting smaller probabilities than the uniform spatial structure for any level of decline. Figure 4.5 also demonstrates that uncertainty in projected decline risk was driven primarily by current uncertainty about abundance; uncertainty about the entrainment rate only had an appreciable effect if abundance was low.

Impact of Chronic Entrainment

Figure 5.5 provides the risk curves for all density independent chronic scenarios. As with episodic entrainment, abundance estimate had the largest absolute effect on risk, followed by entrainment rate and spatial structure. Compared with episodic entrainment (Figure 4.5), the risk curves associated with chronic entrainment (Figure 5.5) were steeper due less variance in outcome and indicated greater risk of decline. Mean final age-3+ abundance in the LMR ranged approximately an order of magnitude, from 813 to 8,232, across all scenarios with entrainment (Table 5.5). As compared with baseline projections, median abundance with entrainment was between 2% and 50% lower after 60 years (Table 5.5). Despite the five-fold difference in abundance between high and low population estimates, the impact of chronic entrainment generally differed by less than a factor of five between corresponding scenarios at high and low abundance (Table 5.5). At the highest chronic entrainment rate, 56 age-3+ females per year, spatial structure made a nearly two-fold difference in the risk of a 30% decline at the high abundance estimate (Table 5.5). In contrast, spatial structure had little effect on the probability of a 30% decline at the low abundance estimate (Table 5.5). As can be seen from the vertical distance between curves in Figure 5.5d, spatial structure had larger effects on risk at higher decline thresholds.

Combined Entrainment Effects

The impacts of chronic and episodic entrainment were multiplicative, as would be expected in the absence of nonlinearities such as a strong impact of demographic stochasticity at small population size. Figure 6.5 depicts the decline risk of best- and worst-case scenarios. If purely multiplicative, the best case scenarios (high abundance estimate and lowest entrainment rates) should have exhibited 4% and 2% declines from baseline median abundance for the uniform and observed spatial structures, respectively. In line with these expectations, the best-case scenarios showed 3% and 2% declines for the uniform and observed spatial structures, respectively. Worst-case scenarios (low abundance estimate and highest entrainment rates) displayed a similar multiplicative response. We expected declines from median abundance of 60% and 55% and recorded 57% and 52% for the uniform and observed spatial structures, respectively.

Age-1+ Dispersal

Changes to the dispersal rate of age-1+ individuals affected a large and qualitatively important change in population dynamics (Figure 7.5). In the absence of age-1+ dispersal, the population in reach B declined to a lower but stable median abundance supported by larval drift from reach CD. The degree of decline from initial abundance depended on the type and magnitude of entrainment. While the impacted median abundance of reach B was stable, it was not an actual equilibrium; the trajectories of individual replicates of the simulations were random walks above and below the median. The absence of age-1+ dispersal prevented any upstream impact of entrainment in reach B, preserving the reproductive capacity of the population in reach CD. As illustrated by the lowermost curves in Figure 7.5, the risk of decline for the LMR as a whole was substantially lower in the absence of age-1+ dispersal than at our baseline dispersal rates. For the low-abundance, uniform spatial structure scenario with intermediate entrainment and no dispersal, the impact on median final abundance was 3% and 8% for episodic and chronic entrainment, respectively, as compared with 11% and 31% at baseline dispersal rates. The probability of 30% decline was 0.04 and 0.07 for episodic and chronic entrainment, respectively, as compared with 0.10 and 0.54 at baseline dispersal rates.

Higher dispersal rates led to increased impacts on the LMR (Figure 7.5). Setting age-1+ dispersal from reach CD to equal larval drift and increasing reach B dispersal to balance the exchange individuals between reaches, an approximately five-fold increase in movement. Under the high dispersal scenario, reach CD was un-buffered from impacts of entrainment in reach B, the opposite of the case of no dispersal. As a result, reach CD declined more quickly, on average, than in simulations with baseline dispersal. In the intermediate-entrainment scenarios we explored, the impact on median final abundance in the LMR as a whole was 14% and 39% for episodic and chronic entrainment, respectively, with 30% decline probabilities of 0.13 and 0.79.

Density Dependence

The capacity for compensatory population growth reduced the impact of entrainment on final median abundance relative to density-independent scenarios. Decline in risk was slightly higher for the observed spatial structure than for the uniform, a reversal of the outcome in density-independent scenarios.

With the uniform spatial structure, median final abundance in the absence of entrainment was 1,621 or 8,135 for the low and high abundance level, respectively, with a 30% decline probability of 0.00. Episodic entrainment of 130 individuals age-3+ decreased median final abundance by 10% or 2% and resulted in a 30% decline probability of 0.01 or 0.00. Chronic entrainment of 56 age-3+ individuals decreased median final abundance by 21% or 6% and resulted in a 30% decline probability of 0.44 or 0.00.

With the observed spatial structure, median final abundance in the absence of entrainment was 1,668 or 8,370 for the low and high abundance level, respectively, with a 30% decline probability of 0.00. Episodic entrainment of 130 age-3+ individuals decreased median final abundance by 11% or 3% and resulted in a 30% decline probability of 0.02 or 0.00. Chronic entrainment of 56 age-3+ individuals decreased median final abundance by 31% or 8% and resulted in a 30% decline probability of 0.57 or 0.00.

Discussion

Population Model

The demographic model we developed for this study is, to our knowledge, the first to focus on the LMR population of pallid sturgeon. The model accounted for the reduced size and accelerated life history that appears typical of LMR individuals as compared with more northern populations (Killgore et al. 2007b; Murphy et al. 2007; George et al. 2012). Growth differs between Mississippi River pallid sturgeon and those in the Missouri River. Bertalanffy growth models for pallid sturgeon in the lower Missouri River (Bajer and Wildhaber 2007) and the LMR (Killgore et al. 2007b) suggest that southern fish reach the mass of northern age-15 fish by age nine, but achieve an asymptotic maximum fork length that is less than 60% of that found in the north. Latitudinal gradients in growth and life history are common to ectothermic species and can be explained in large part by variation in temperature (Munch and Salina 2009).

Despite our use of a decelerating mass-fecundity relationship, mass-specific egg production was higher than previously estimated based on a pallid sturgeon from North Dakota (Keenlyne et al. 1992), again illustrating the dramatic differences between southern and northern populations. Studies commonly assume that fecundity scales linearly with mass (Keenlyne et al. 1992; Bajer and Wildhaber 2007; Doukakis et al. 2010). Accelerating mass-fecundity relationships have been found in other species, such as Gulf sturgeon (Pine et al. 2001) and shovelnose sturgeon (Bajer and Wildhaber 2007). Our choice of a less-than-linear function to extrapolate fecundity across age classes therefore appears conservative.

The estimate of survival from egg to age one, on the order of 10^{-5}, is comparable to young-of-year survival estimated for shortnose and white sturgeon using similar methods (Gross et al. 2002), and two orders of magnitude higher than that of Atlantic sturgeon (Gross et al. 2002) and beluga sturgeon (Doukakis et al. 2010). In practice, we implied a higher age-0 survival rate when we increased the relative fecundity of reach CD.

Our final fecundity estimates for reach CD rested heavily on the assumptions that there is no reproduction in reach B and age structure is the same in all reaches of the LMR. Adults in reach B may make upstream movements to spawn. Large seasonal movements have been observed in other parts of the range (Bramblett and White 2001) and there is indirect evidence consistent with upstream spawning migrations in the LMR (Hoover et al. 2007). It is also possible that individuals in reach B have a propensity to relocate permanently to upstream reaches upon maturation, which would result in a difference in age structure among reaches.

Sensitivity analysis indicated that management actions affecting the survival had the greatest effect on expected population growth rate. In contrast, changes in fecundity, which includes age-0 survival, had little influence on population growth rate. Previous studies have found age-0 survival to be a relatively sensitive parameter, supporting conservation methods that improve fecundity and early survival (e.g., Bajer and Wildhaber 2007). The difference in our analysis is that we assumed a management action, like entrainment through water diversions, was likely to affect multiple age classes. The general rule that long-lived species with delayed maturation are most sensitive to changes in adult survival is, not surprisingly, built upon stage-based models in which demographic rates apply to a range of age classes (Lande 1988; Heppell 2007). Sensitivity analysis should always be interpreted with caution

(Bakker and Doak 2009). For instance, though fecundity was less sensitive than survival to a comparable proportional change, management may be able to increase age-0 survival by a much larger margin than is possible for the survival of older age classes.

The population model is useful for making inferences about population size from information on a subset of age classes. We demonstrated the use of projected age structure when extrapolating total abundance from the abundance of age-3+ fish. A similar approach can be applied to other sources of data that exclude some age classes. For instance, in a study of commercial bycatch of sturgeon in the Mississippi River (Bettoli et al. 2009), the smallest pallid sturgeon measured was 683 mm in fork length, equivalent in size to an age-9 fish. The study reported three pallid sturgeon deaths out of 114 sturgeon harvested, a mortality rate of 0.026. Over two seasons, 9,371 sturgeon were collected by commercial fishers between rkm 1240 and 1422 (Bettoli et al. 2009), suggesting that 123 pallid sturgeon, or 0.67 fish rkm^{-1}, were killed per year. Annual survival in the MMR, measured when commercial take was still allowed, was 70% compared with 89-93% survival in the LMR, where commercial take was not allowed in most reaches (Killgore et al. 2007b). If we attribute this difference entirely to commercial take in the MMR and assume the difference applies only to age-8+ fish, then we can infer that 123 is 21-25% of the adult population in the study reach, leading to an adult population density estimate on the order of 3.0-3.4 age-8+ pallid sturgeon rkm^{-1}. Finally, incorporating the age structure predicted by our demographic model for the LMR, in which 48% of the population is younger than age-8 and 79% is age-3+, the estimated total population density is 4.4-5.1 age-3+ pallid sturgeon rkm^{-1}. This value falls near the 95% lower bound on river-wide age-3+ abundance reported by Friedenberg et al. (2013) and is intermediate between the low and high abundance levels investigated in the current study. This example suggests that the results of our risk analyses bracket a reality that lies between the extremes.

The Impact of Entrainment

Quantification of entrainment and its relevance to population viability are necessary to inform efforts surrounding the recovery of pallid sturgeon in the LMR (U.S. Fish and Wildlife Service 2013). Our modeling indicated that both episodic and chronic causes of entrainment mortality had the potential to contribute to meaningful declines in the abundance of pallid sturgeon in the LMR, though no level of entrainment we explored led to an elevated risk of extinction over three generations. Our volumetric estimates of entrainment could be extended to other diversion structures. For instance, the Old River Control Complex handles a maximum of roughly 20,000 cubic meters per second and diverts 30% of the flow of the Mississippi and Red Rivers into the Atchafalaya River. Our results suggest that a full accounting of entrainment through diversion structures in the LMR, including both the Old River Control Complex and the Morganza spillway, could indicate biologically significant impacts to abundance.

The draft revised recovery plan calls for population size of 5,000 adults in the LMR and Atchafalaya River (coastal plain management unit) based on rules of thumb for minimum viable population size (U.S. Fish and Wildlife Service 2013). Given the suspected lack of reproduction in the Atchafalaya River (Keenlyne and Jenkins 1993), this criterion should apply to the LMR alone. The abundance levels examined in this study included approximately 1,000 – 5,000 adults (age-8+). If the true abundance is near 1,000, then entrainment can be seen as a significant factor challenging recovery and a valid focus of management and mitigation. If the true abundance of pallid sturgeon adults in the LMR is near 5,000 or more, entrainment is not a central factor in the recovery and maintenance of the population.

Rates of episodic entrainment through the Bonnet Carré Spillway were developed from three distinct scenarios. We do not know which scenario is most likely. Episodic entrainment, in isolation, presented small risks to population viability. Only the worst-case scenario of low abundance and high entrainment presented an appreciable risk to the population, a 20% decline in median abundance. It is interesting to consider this impact retrospectively. In the worst case, abundance may have been 20% higher 60 years ago based on episodic entrainment alone. The range of uncertainty around episodic impacts is larger than the range we explored. Only the 2008 diversion event was used to establish possible entrainment rates. The magnitude and duration of diversion has varied over the spillway's historical use such that average entrainment may be higher than we estimated.

Surprisingly, the small chronic diversions posed a more substantial threat than the Bonnet Carré. Unlike our episodic entrainment estimates, entrainment levels for the chronic diversions were probabilistic with 98% coverage. It is therefore possible to assert that the intermediate entrainment rate is more likely than the high or low rates. As such, the most likely impact of chronic diversion was a 6-31% decline in median abundance. However, we included the White Ditch diversion in our study even though it is south of New Orleans, LA, in a reach of the Mississippi River where pallid sturgeon have not been found (Killgore et al. 2007a). Hence, our estimates of risk are conservative. At the low abundance level, our estimate of chronic diversion was sufficient to induce an IUCN rating of vulnerable (IUCN Standards and Petitions Subcommittee 2010) if the LMR pallid population was otherwise stable.

It is possible that mitigation efforts, such as monitoring and rescue below small diversion structures could reduce risks posed by the wetlands restoration project planned in reach B of the LMR. For instance, stranding behind diversion structures has been found to imperil the endangered green sturgeon population in the Sacramento River (Thomas et al. 2013). However, monitoring and rescue efforts focused on water impounded by diversion structures greatly reduced projected risks to the population (Thomas et al. 2013).

The envelope of median decline for combined episodic and chronic entrainment was 2-57% over 60 years, highlighting the large uncertainty associated with impacts. The effects of episodic and chronic entrainment combined multiplicatively. This result was expected given that we modeled entrainment as age-independent and population growth as density-independent. Age specificity or bias could lead to changes in age structure and reproductive potential. Density dependence could also lead to more complicated cumulative effects; chronic entrainment could reduce the population's capacity for compensatory growth following episodic events.

The effect of spatial structure on the risk of population decline was relatively small in this study. Among models utilizing the baseline dispersal rates and density-independent growth, median declines in final abundance differed by 5% or less between the uniform and observed patterns of population density. However, the difference between the spatial structures themselves was also small. We only explored minor differences in population density rather than possible variation in age structure. This choice allowed us to parameterize the model in the absence of key data on reach-specific and age-specific rates of survival and movement. Even with the similarity of the two spatial structures and their median responses to entrainment, the probability of a 30% decline was meaningfully higher for the uniform pattern in some cases.

Density dependence reduced the impact of both episodic and cumulative entrainment. However, the particular magnitude of this reduction was based on an arbitrary assumption of 5% maximum population increase per year. Our density-independent simulations are a more conservative approach to the assessment of risk in populations where the strength and form of density independence are unknown (Ferson et al. 2003). By assuming long-term stasis in abundance, our density-independent models captured the essential feature of density-dependent models while permitting maximum sensitivity to perturbations. One useful result of the density-dependent simulations, however, was their illustration of the effect of spatial structure when maximum fecundity is constrained. The higher fecundity required for maintenance of equilibrium with the observed spatial structure reduced the degree to which fecundity could further increase to compensate for entrainment.

Counterintuitively, reproduction by reach B residents would increase the projected impact of entrainment in our model. This is because entrainment would directly affect individuals with high reproductive value. If residents of reach B do not spawn, then reproductive value is only realized upon dispersal to reach CD. The resulting link between movement and reproductive value also explains the sensitivity of decline risk to age-1+ dispersal. In turn, if reach B supports spawning directly or upstream spawning migrations occur, dispersal rate will have less effect on the population-level response to entrainment.

It may be possible that the high population density in reach B associated with the observed spatial structure of the LMR population could be reduced by habitat modification upstream. Though the LMR still features a large amount of floodplain habitat (Schramm et al. 2000), flood control structures and engineering of the river bank modified flows, sedimentation patterns, and channel complexity (Baker et al. 1991) in such a way that fewer larvae may be retained in reach CD. As parameterization of our demographic model demonstrated, the drift of larvae to reach B from upstream locations is a tax on the productive capacity of the LMR population. Retention of larvae in reach CD would not only keep a larger fraction of the population associated with reproductive habitat but would also reduce the fraction of the population subject to entrainment by the high concentration of diversion structures in reach B.

Data Priorities

Demographic models are essential tools for guiding research priorities and modifying adaptive management plans (Bakker and Doak 2009). The uncertainty in our estimates of risk posed by entrainment is currently too large to support management decisions directly. While some of the uncertainty in our analysis of the impact of entrainment is attributable to intrinsic environmental variation and is therefore not reducible by further study, the majority is attributable to a lack of knowledge that could be addressed by continued research in the LMR. Estimates of abundance ranged five-fold and entrainment rates for both episodic and chronic diversions spanned more than an order of magnitude. In both cases, the true range of uncertainty is actually larger but can be reduced through continued monitoring of the population. Finally, the large sensitivity of projected risk to dispersal rate strongly suggests that the collection and synthesis of large-scale adult movement data would provide a better understanding of the relationship between management actions and recovery goals.

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Table 1.5. Derivation of age-specific fecundity, Ft, and survival St, to generate the baseline population models, in which median abundance is not expected to change through time.

Characteristic	Predictor	Expression	Parameter values	Source
L_t, fork length (mm)	Age, t (y)	$L_t = L_\infty\left[1 - e^{-k(t-t_0)}\right]$	L_∞ = 849.6 mm k = 0.16 y^{-1} t_0 = -1.3 y	Killgore, et al. (2007b)
M_t, mass (kg)	L (mm)	$M_t = \alpha {L_t}^\beta$	$\alpha = 10^{-9.22}$ kg/mm β = 3.42	Analysis of updated survey dataset following Killgore et al. (2007b).
E_t, eggs	M (kg)	$E_t = a{M_t}^b$	a = 18,780 eggs/kg b = 0.91	Fit of a to two Atchafalaya females (George et al. 2012) given the value of b for white sturgeon (DeVore 1995).
p, proportion female		p = 0.5		Wildhaber et al. (2007)
m_t, proportion mature	t (y)	$m_t = \Pr\left[\frac{1}{\mathrm{N}(\mu,\sigma)} < t\right]$	μ = 0.091 y^{-1} σ = 0.01	Consistent with varied observations (Keenlyne 1992; George et al. 2012)
I, reproductive interval (y)		I = 3		Lower limit observed by Keenlyne (1992)
F_t, fecundity	t (y)	$F_t = \frac{pm_t}{I}a\left(\alpha {L_t}^\beta\right)^b S_0$		
S_0, first-year survival			$S_0 = 2.4 \times 10^{-5}$	Balances births and deaths in baseline model
S_1, survival of age-1 fish			S_1 = 0.63	Steffenson, et al. (2010), then adjusted to balance model
S_2, survival of age-2 fish			S_2 = 0.75	Hadley and Rotella (2009)
$S_3 \ldots S_{24}$, survival of fish age-3 to age-24			$S_3 .. S_{24}$ = 0.93	Killgore, et al. (2007b)
S_{25}, survival of age-25+ fish			S_{25} = 0.86	Twice the mortality of younger adults

Table 2.5. Scenarios of pallid sturgeon entrainment explored in this study. Episodic entrainment occurred at random time intervals with a given annual probability, whereas chronic entrainment occurred every year. Per capita probabilities of entrainment in reach B depended on total take, use of the low or high estimate of population size (N), and the assumption that population density was either uniform along the lower Mississippi River's length or followed the observed pattern of catch per unit effort.

			Per Capita Entrainment Probability			
			Uniform		Observed	
Scenario	Annual Probability	Total Take	Low *N*	High *N*	Low *N*	High *N*
Episodic	0.125	18	0.022	0.004	0.014	0.003
		65	0.078	0.016	0.050	0.010
		130	0.157	0.031	0.100	0.020
Chronic	1.0	14	0.010	0.002	0.006	0.001
		28	0.034	0.007	0.021	0.004
		56	0.067	0.013	0.043	0.009

Table 3.5. Initial conditions and model parameters given estimates of female abundance and spatial structure and the assumption of a stable population. Density-dependent models made use of the maximum growth rate and carrying capacity parameters for population CD only. Population B was assumed to be supported by larval drift in the absence of local reproduction.

	Spatial Structure			
	Uniform		CPUE	
	Low *N*	High *N*	Low *N*	High *N*
Population B				
total abundance	525	2,625	825	4,125
adult abundance[a]	275	1,373	431	2,157
age-1+ dispersal[b]	0.135	0.135	0.07	0.07
relative fecundity[c]	0	0	0	0
Population CD				
total abundance	1,525	7,625	1,300	6,500
adult abundance[a]	797	3,987	680	3,399
larval dispersal	0.26	0.26	0.39	0.39
age-1+ dispersal[b]	0.046	0.046	0.044	0.044
relative fecundity[c]	1.34	1.34	1.64	1.64
$R_{max\ local}$[d]	1.035	1.035	1.025	1.025
adult carrying capacity	1,180	5,900	1,420	7,100
carrying capacity SD	118	590	142	710

[a]At the demographic model's stable age distribution, age-8+ females comprise 52.3% of the population

[b]Age-1+ dispersal rates assume an equal number of upstream and downstream migrants consistent with the structure of abundance and emigration as reported by Koch et al. (2012).

[c]There is no reproduction in population B. We assumed age structure is maintained by surplus fecundity and larval drift from population CD.

[d]The effective maximum local population growth rate of population CD is diminished by larval drift. Values given assume a maximum growth rate of 1.05 in the absence of larval drift.

Table 4.5. Median final abundance of pallid sturgeon in the lower Mississippi River under episodic entrainment after 60 years (3 generations).

		Low population estimate				High population estimate			
		Age-3+ fish entrained[a]				Age-3+ fish entrained[a]			
Age-3+ fish[b]	Spatial structure	0	18	65	130	0	18	65	130
median	uniform	1,615	1,580	1,440	1,290	8,086	7,976	7,884	7,709
	observed	1,684	1,649	1,522	1,386	8,365	8,362	8,248	8,119
% reduction from baseline median	uniform		2	11	20		1	2	5
	observed		2	10	18		0	1	3
probability of a 30% decline	uniform	0.02	0.03	0.10	0.26	0.02	0.02	0.03	0.04
	observed	0.02	0.02	0.06	0.17	0.01	0.01	0.01	0.02

[a]Entrainment is both sexes per event. Number of age-3+ fish determines the *per capita* rate of entrainment for all age classes.

[b]Abundance of females after 60 years.

Table 5.5. Median final abundance of pallid sturgeon in the lower Mississippi River under chronic entrainment after 60 years (3 generations)

		Low population estimate				High population estimate			
		Age-3+ fish entrained[a]				Age-3+ fish entrained[a]			
Age-3+ fish[b]	Spatial structure	0	8	28	56	0	8	28	56
median	uniform	1,615	1,436	1,116	813	8,086	7,907	7,452	6,912
	observed	1,684	1,531	1,224	930	8,365	8,232	7,854	7,371
% reduction from baseline median	uniform		11	31	50		2	8	15
	observed		9	27	45		2	6	12
probability of a 30% decline	uniform	0.02	0.09	0.54	0.96	0.02	0.03	0.05	0.13
	observed	0.02	0.05	0.41	0.92	0.01	0.01	0.03	0.07

[a]Entrainment is both sexes per event. Number of age-3+ fish determines the *per capita* rate of entrainment for all age classes.

[b]Abundance of females after 60 years.

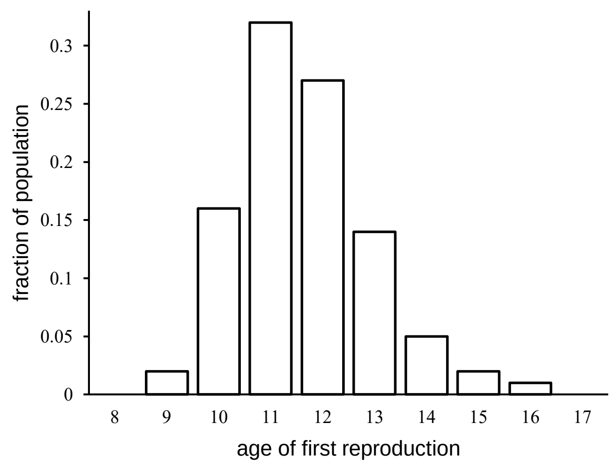

Figure 1.5. The schedule of maturation used in calculating age-specific fecundity. The mean age of first reproduction is age 11. Variance in age of first reproduction arises from the assumption that the rate of maturation has a normal distribution among individuals in the population.

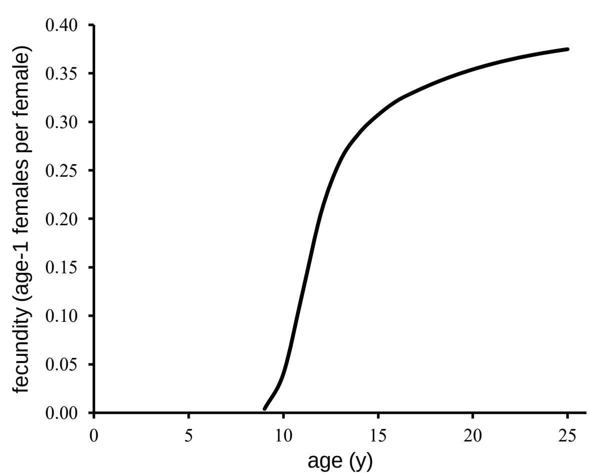

Figure 2.5. Fecundity, the number of age-1females produced per female per year, as a function of age. Values were adjusted to produce no change in median abundance over time. Calculated following the equation for F_t in Table 1.

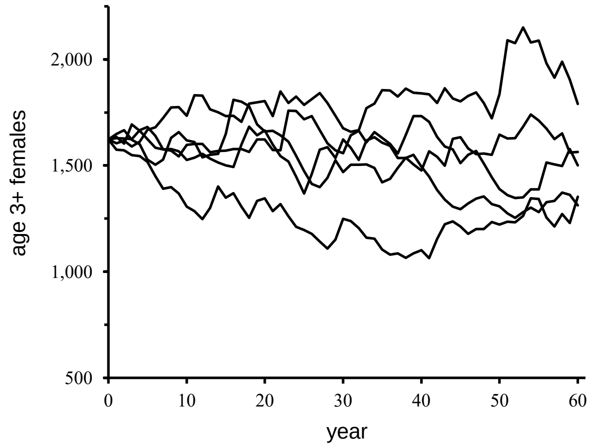

Figure 3.5. Five replicate trajectories of the baseline demographic model, in which births are expected to balance deaths. The trajectories illustrate stochastic changes in abundance of age-3+ fish in the lower Mississippi River over 60 y (~3 generations). Stochasticity includes both yearly environmental variation and demographic stochasticity. Simulations were performed using the low estimate of population density.

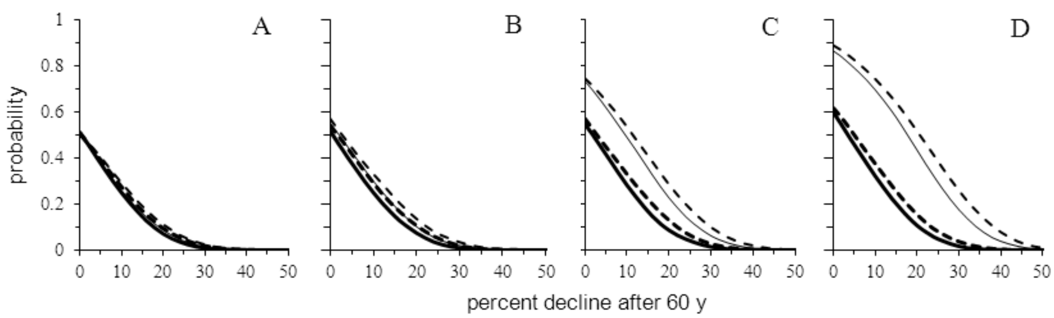

Figure 4.5. A comparison of the probability of decline after 60 y (~3 generations) with the episodic take of 0, 18, 65, or 130 age-3+ fish **(A-D**, respectively) from reach B. Line weight indicates high (heavy) or low (light) population estimate. Line style indicates uniform (dashed) or observed (solid) spatial distribution of the population.

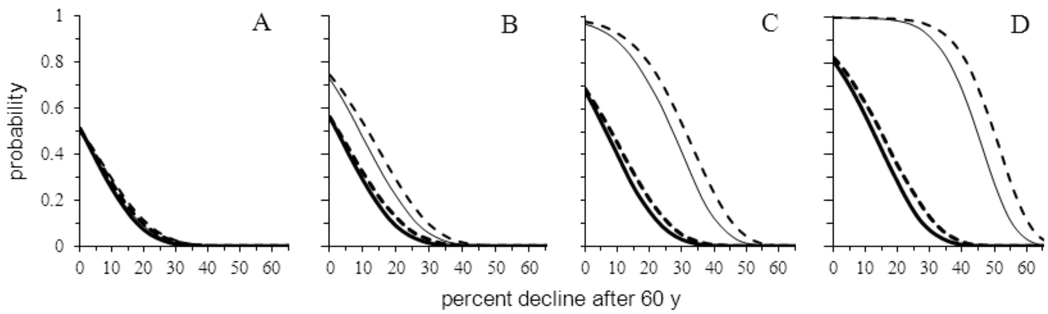

Figure 5.5. A comparison of the probability of decline after 60 y (~3 generations) with the chronic take of 0, 8, 28, or 56 age-3+ fish **(A-D**, respectively) from reach B. Line weight indicates high (heavy) or low (light) population estimate. Line style indicates uniform (dashed) or observed (solid) spatial distribution of the population.

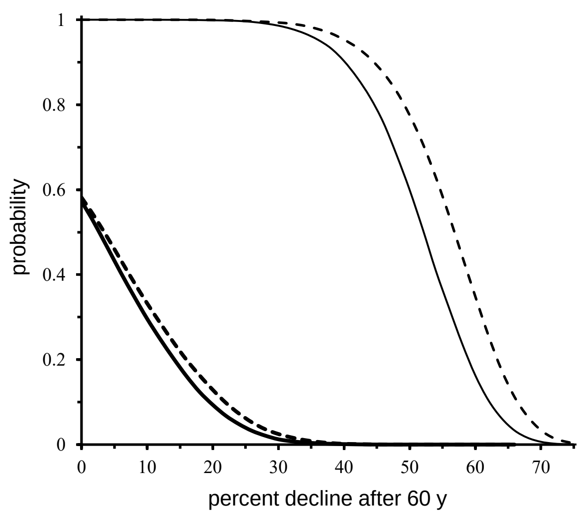

Figure 6.5. Best and worst cases of decline after 60 y given the combination of episodic and chronic take with density-independent population growth. Best case (heavy curves): high abundance estimate, episodic take of 18 and chronic take of 8 age-3+ fish. Worst case (light curves): low abundance estimate, episodic take of 130 and chronic take of 56 age-3+ fish. Line style indicates uniform (dashed) or observed (solid) population distribution.

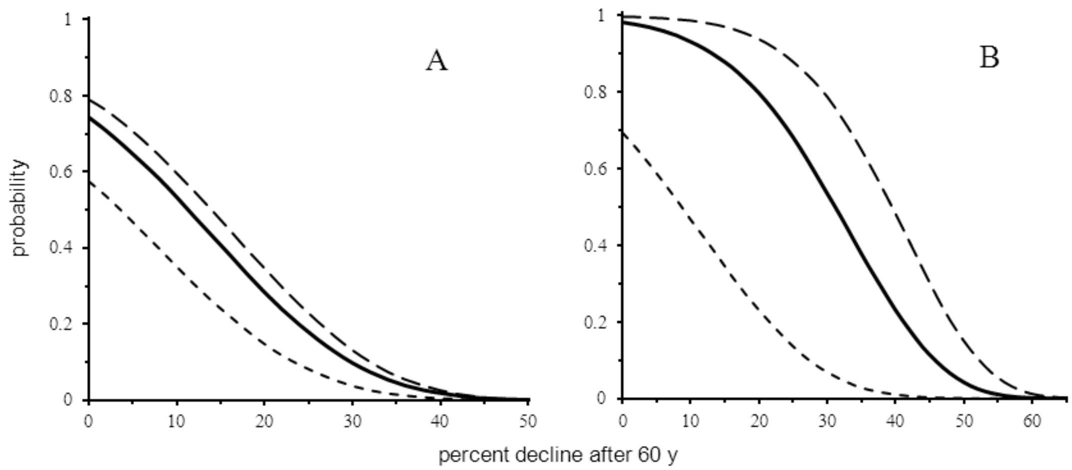

Figure 7.5. The probability of decline after 60 y given **A.** episodic take of 65 or **B.** chronic take of 28 age-3+ pallid sturgeon in reach B with density-independent population growth. All results are for the low abundance estimate and uniform spatial structure. Line style indicates standard (solid), high (long dashes), or no (short dashes) rate of age-1+ dispersal between reaches B and CD.

Manatee and Gulf Sturgeon Avoidance Measures

Manatee

The West Indian manatee may be present in the project vicinity. The Contractor shall instruct all personnel associated with the project of the potential presence of manatees in the area, and the need to avoid collisions with these animals. All construction personnel shall be advised that there are civil and criminal penalties for harming, harassing, or killing manatees, which are protected under the Marine Mammal Protection Act of 1972 (EPA MMPA) and the Endangered Species Act of 1973 (EPA ESA).

The Contractor will be responsible for any manatee harmed, harassed, or killed as a result of construction activities not conducted in accordance with these specifications. All on-site personnel are responsible for observing water-related activities for the presence of manatee(s). Additionally, personnel should be instructed not to attempt to feed or otherwise interact with the animal, although passively taking pictures or video would be acceptable.

Special Operating Conditions If Manatees Are Present in the Project Area

(1) If a manatee(s) is sighted within 100 yards of the project area, all appropriate precautions shall be implemented by the Contractor to ensure protection of the manatee. These precautions shall include the operation of all moving equipment no closer than 50 feet of a manatee. If a manatee is closer than 50 feet to moving equipment or the project area, the equipment shall be shut down and all construction activities shall cease to ensure protection of the manatee. Construction activities shall not resume until the manatee has departed and the 50-foot buffer has been re-established.

(2) If a manatee(s) is sighted in the project area, all vessels associated with the project shall operate at "no wake/idle" speeds at all times and vessels will follow routes of deep water whenever possible, until the manatee has departed the project area. Boats used to transport personnel shall be shallow-draft vessels, preferably of the light-displacement category, where navigational safety permits.

(3) If siltation barriers are used, they shall be made of material in which manatees cannot become entangled, are properly secured, and are regularly monitored to avoid manatee entrapment.

(4) Manatee Signs. Prior to commencement of construction, each vessel involved in construction activities shall display at the vessel control station or in a prominent location, visible to all employees operating the vessel, a temporary sign at least 8-1/2-inch x 11-inch reading, "CAUTION: MANATEE HABITAT/IDLE SPEED IS REQUIRED IN CONSTRUCTION AREA." In the absence of a vessel, a temporary 3-foot x 4-foot sign reading "CAUTION: MANATEE AREA" shall be posted adjacent to the issued construction permit. A second temporary sign measuring 8-1/2-inch x 11-inch reading "CAUTION: MANATEE HABITAT. EQUIPMENT MUST BE SHUTDOWN IMMEDIATELY IF A MANATEE COMES WITHIN 50 FEET OF OPERATION" shall be posted at the dredge operator control station and at a location prominently adjacent to the issued construction permit.The Contractor shall remove the signs upon completion of construction.

Manatee Sighting Reports

Any sightings of manatees, or collisions with a manatee, shall be reported immediately to the Corps of Engineers. The point of contact within the Corps of Engineers will be Edward Creef, (504) 862-2521, FAX (504) 862-2317. In addition, collisions with, injury to, or sightings of manatees should be immediately reported to the U.S. Fish and Wildlife Service's Louisiana Ecological Services Office (337/291-3100) and the Louisiana Department of Wildlife and Fisheries, Natural Heritage Program (225/765-2821). Please provide the nature of the call (i.e., report of an incident, manatee sighting, etc.); time of incident/sighting; and the approximate location, including the latitude and longitude coordinates, if possible.

Gulf Sturgeon

All proposed work is located east of the Causeway Bridge and within the area designated as critical habitat for the Gulf Sturgeon, therefore the potential exists for the Gulf Sturgeon to be found in the project area. In preparation for dredging, the following actions shall be initiated:

Bucket Dredging

If bucket dredging is performed, the Contractor should induce Gulf Sturgeon to leave the immediate work area prior to any bucket dredging work regardless of water depth. The bucket will be dropped into the water and retrieved empty one (1) time. After the bucket has been dropped and retrieved, a one (1)-minute no work period must be observed. During this no dredging period, personnel should carefully observe the work area in an effort to visually detect Gulf Sturgeon. If Gulf Sturgeon are sighted, no work should be initiated until the sturgeon have left the work area. If the water turbidity makes such visual sighting impossible, work may proceed after the one (1)-minute no work period has elapsed. If more than fifteen minutes elapses with no work, then the empty bucket drop/retrieval process shall be performed again prior to re-initiating work efforts. In the event a Gulf Sturgeon is incidentally taken or injured/killed by construction activities, it shall be immediately reported to CEMVN. The point of contact within CEMVN will be Elizabeth Behrens, (504) 862-2025.

Cutterhead Dredging

The Contractor should minimize potential impacts to gulf sturgeon associated with cutterhead dredging by:

(5) The cutterhead should remain completely buried in the bottom material during dredging operations. If pumping water through the cutterhead is necessary to dislodge material or to clean the pumps or cutterhead, etc., the pumping rate should be reduced to the lowest rate possible until the cutterhead is at mid-depth, where the pumping rate can then be increased.

(6) During dredging, the pumping rates should be reduced to the slowest speed feasible while the cutterhead is descending to the channel bottom.

Sea Turtle Avoidance Measures

Sea Turtle(s) and Smalltooth Sawfish

Sea turtle(s) and/or smalltooth sawfish may be present in the project vicinity. The Contractor shall instruct all personnel associated with the project of the potential presence of sea turtle(s) and/or smalltooth sawfish in the area, and the need to avoid collisions with them. All construction personnel shall be advised that there are civil and criminal penalties for harming, harassing, or killing sea turtle(s) or smalltooth sawfish, which are protected under the the Endangered Species Act of 1973. The Contractor will be responsible for any sea turtle(s) and/or smalltooth sawfish harmed, harassed, or killed as a result of construction activities not conducted in accordance with these specifications.

Special Operating Conditions If Sea Turtle(s) and/or Smalltooth Sawfish Are Present in the Project Area

(1) If a sea turtle or smalltooth sawfish is sighted within 100 yards of the active daily construction/dredging operation or vessel movement, all appropriate precautions shall be implemented by the Contractor to ensure protection of the sea turtle(s) and/or smalltooth sawfish. These precautions shall include the operation of all moving equipment no closer than 50 feet of sea turtle(s) or smalltooth sawfish. If a sea turtle(s) or smalltooth sawfish is closer than 50 feet to moving equipment or the project area, the equipment shall be shut down and all construction activities shall cease to ensure protection of the sea turtle(s) or smalltooth sawfish. Construction activities shall not resume until the sea turtle(s) and/or smalltooth sawfish has departed the area of its own volition and the 50-foot buffer has been re-established.

(2) If a sea turtle and/or smalltooth sawfish is sighted in the project area, all vessels associated with the project shall operate at "no wake/idle" speeds, and vessels shall follow routes of deep water whenever possible. Boats used to transport personnel shall be shallow-draft vessels, preferably of the light-displacement category, where navigational safety permits.

(3) If siltation barriers (eg. floating turbidity curtains) are proposed by the Contractor, the design must be approved by the Contracting Officer prior to placement. The barriers shall be made of material in which sea turtle and/or smalltooth sawfish cannot become entangled, shall be properly secured, and shall be regularly monitored to avoid species entrapment. Barriers may not block sea turtle or smalltooth sawfish entry to or exit from designated critical habitat without prior agreement from the National Marine Fisheries Service's Protected Resources Division, St. Petersburg Florida.

Any collisions with and/or injury to a sea turtle and/or smalltooth sawfish, shall be reported immediately to the National Marine Fisheries Service's Protected Resources Division at (727) 824-5312 and the local authorized sea turtle stranding/rescue organization listed below.

Louisiana Department of Wildife and Fisheries, Office of Fisheries

2000 Quail Driver

Baton Rouge, LA 70808

(225) 765-2377

List of Possible Threatened and Endangered Species in the Impact Area

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Louisiana Ecological Services Field Office
200 Dulles Drive
Lafayette, LA 70506
Phone: (337) 291-3100 Fax: (337) 291-3139

In Reply Refer To: November 09, 2021
Consultation Code: 04EL1000-2021-SLI-1446
Event Code: 04EL1000-2022-E-01087
Project Name: West Shore Lake Pontchartrain Environmental Mitigation

Subject: Updated list of threatened and endangered species that may occur in your proposed project location or may be affected by your proposed project

To Whom It May Concern:

***Due to the Louisiana Governor's mandatory quarantine order for the coronavirus (COVID-19), and in order to keep our staff and the public safe, we are unable to accept or respond in a timely manner to consultation request or project review/concurrence that we receive through the U.S. Mail. Please submit your request electronically to lafayette@fws.gov or call 337-291-3100.**

The enclosed species list identifies threatened, endangered and candidate species, as well as designated and proposed critical habitat that may occur within the boundary of your proposed project and may be affected by your proposed project. The Fish and Wildlife Service (Service) is providing this list under section 7 (c) of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 *et seq.*). Changes in this species list may occur due to new information from updated surveys, changes in species habitat, new listed species and other factors. Because of these possible changes, feel free to contact our office (337/291-3126) for more information or assistance regarding impacts to federally listed species. The Service recommends visiting the ECOS-IPaC site or the Louisiana Ecological Services website (www.fws.gov/lafayette) at regular intervals during project planning and implementation for updated species lists and information. An updated list may be requested through the ECOS-IPaC system by completing the same process used to receive the enclosed list.

The purpose of the Act is to provide a means whereby threatened and endangered species and the habitats upon which they depend may be conserved. Under sections 7(a)(1) and 7(a)(2) of the Act and its implementing regulations (50 CFR 402 *et seq.*), Federal agencies are required to utilize their authorities to carry out programs for the conservation of Federal trust resources and to determine whether projects may affect Federally listed species and/or designated critical habitat.

A Biological Assessment is required for construction projects (or other undertakings having similar physical impacts) that are major Federal actions significantly affecting the quality of the human environment as defined in the National Environmental Policy Act (42 U.S.C. 4332(2)(c)). For projects other than major construction activities, the Service suggests that a biological evaluation similar to a Biological Assessment be prepared to determine whether the project may affect listed or proposed species and/or designated or proposed critical habitat. Recommended contents of a Biological Assessment are described at 50 CFR 402.12.

If a Federal agency determines, based on the Biological Assessment or biological evaluation, that listed species and/or designated critical habitat may be affected (e.g. adverse, beneficial, insignificant or discountable) by the proposed project, the agency is required to consult with the Service pursuant to 50 CFR 402. In addition, the Service recommends that candidate species and proposed critical habitat be addressed within the consultation. More information on the regulations and procedures for section 7 consultation, including the role of permit or license applicants, can be found in the "Endangered Species Consultation Handbook" at http://www.fws.gov/endangered/esa-library/pdf/TOC-GLOS.PDF or by contacting our office at the number above.

Bald eagles have recovered and were removed from the List of Endangered and Threatened Species as of August 8, 2007. Although no longer listed, please be aware that bald eagles are protected under the Bald and Golden Eagle Protection Act (BGEPA) (16 U.S.C. 668 *et seq.*). The Service developed the National Bald Eagle Management (NBEM) Guidelines to provide landowners, land managers, and others with information and recommendations to minimize potential project impacts to bald eagles, particularly where such impacts may constitute "disturbance," which is prohibited by the BGEPA. A copy of the NBEM Guidelines is available at: http://www.fws.gov/southeast/es/baldeagle/NationalBaldEagleManagementGuidelines.pdf. Those guidelines recommend: (1) maintaining a specified distance between the activity and the nest (buffer area); (2) maintaining natural areas (preferably forested) between the activity and nest trees (landscape buffers); and (3) avoiding certain activities during the breeding season. On-site personnel should be informed of the possible presence of nesting bald eagles within the project boundary, and should identify, avoid, and immediately report any such nests to this office. If a bald eagle nest occurs or is discovered within or adjacent to the proposed project area, then an evaluation must be performed to determine whether the project is likely to disturb nesting bald eagles. That evaluation may be conducted on-line at: http://www.fws.gov/southeast/es/baldeagle. Following completion of the evaluation, that website will provide a determination of whether additional consultation is necessary. The Division of Migratory Birds for the Southeast Region of the Service (phone: 404/679-7051, e-mail: SEmigratorybirds@fws.gov) has the lead role in conducting any necessary consultation. Should you need further assistance interpreting the guidelines or performing an on-line project evaluation, please contact this office.

Guidance for minimizing impacts to migratory birds for projects including communications towers (e.g. cellular, digital television, radio and emergency broadcast) can be found at: http://www.fws.gov/migratorybirds/CurrentBirdIssues/Hazards/towers/towers.htm ; http://www.towerkill.com; and http://fws.gov/migratorybirds/CurrentBirdIssues/Hazards/towers/comtow.html.

Activities that involve State-designated scenic streams and/or wetlands are regulated by the Louisiana Department of Wildlife and Fisheries and the U.S. Army Corps of Engineers, respectively. We, therefore, recommend that you contact those agencies to determine their interest in proposed projects in these areas.

Activities that would be located within a National Wildlife Refuge are regulated by the refuge staff. We, therefore, recommend that you contact them to determine their interest in proposed projects in these areas.

Additional information on Federal trust species in Louisiana can be obtained from the Louisiana Ecological Services website at: www.fws.gov/lafayette or by calling 337/291-3100.

We appreciate your concern for threatened and endangered species. The Service encourages Federal agencies to include conservation of threatened and endangered species into their project planning to further the purposes of the Act. Please include the Consultation Tracking Number in the header of this letter with any request for consultation or correspondence about your project that you submit to our office.

Attachment(s):

- Official Species List

Official Species List

This list is provided pursuant to Section 7 of the Endangered Species Act, and fulfills the requirement for Federal agencies to "request of the Secretary of the Interior information whether any species which is listed or proposed to be listed may be present in the area of a proposed action".

This species list is provided by:

Louisiana Ecological Services Field Office
200 Dulles Drive
Lafayette, LA 70506
(337) 291-3100

Project Summary

Consultation Code:	04EL1000-2021-SLI-1446
Event Code:	Some(04EL1000-2022-E-01087)
Project Name:	West Shore Lake Pontchartrain Environmental Mitigation
Project Type:	** OTHER **
Project Description:	The Project is proposed as a 2,000 cubic foot per second (cfs) freshwater diversion with the intake of the conveyance channel located on the West Bank of the Mississippi River in St. John the Baptist Parish, immediately west of Garyville, Louisiana, at River Mile 144 Above Head of Passes (AHP). The 300 ft wide construction corridor for the conveyance channel extends from LA 44 (River Road) northward for 5½ miles, terminating approximately 1,000 ft north of Interstate 10 (I-10). The intake channel is roughly 400 ft long by 200 ft wide, with a bottom depth at EL (-) 4 ft NAVD88 excavated into the batture to route flow from the Mississippi River into the diversion headworks. The channel would be lined with riprap to prevent scour. The primary function of the headworks structure is to convey flow from the intake channel underneath the MRL. It would be comprised of a multi-cell box culvert with vertical lift gates (sluice gates). The outlet for the conveyance channel is along the existing centerline of Hope Canal. The diversion flow of 2,000 cfs generally spreads radially outwards as it enters the swamp north of Interstate 10. Approximately, one-third flows westward through the swamp, one-third flows through Dutch Bayou and the remaining third flows eastward through the swamp. The westward flow enters Blind River and largely proceeds to Lake Maurepas. The eastward flow enters the Reserve Relief Canal and mostly proceeds to Lake Maurepas. Mitigation benefits would be captured within primary and secondary benefit areas which total approximately 7,875 acres. Construction Duration of 33 months (start construction in May 2022).

Project Location:

Approximate location of the project can be viewed in Google Maps: https://www.google.com/maps/@30.127271999999998,-90.58691719960248,14z

Counties: Louisiana

Endangered Species Act Species

There is a total of 5 threatened, endangered, or candidate species on this species list.

Species on this list should be considered in an effects analysis for your project and could include species that exist in another geographic area. For example, certain fish may appear on the species list because a project could affect downstream species.

IPaC does not display listed species or critical habitats under the sole jurisdiction of NOAA Fisheries[1], as USFWS does not have the authority to speak on behalf of NOAA and the Department of Commerce.

See the "Critical habitats" section below for those critical habitats that lie wholly or partially within your project area under this office's jurisdiction. Please contact the designated FWS office if you have questions.

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1. NOAA Fisheries, also known as the National Marine Fisheries Service (NMFS), is an office of the National Oceanic and Atmospheric Administration within the Department of Commerce.

Mammals

NAME	STATUS
West Indian Manatee *Trichechus manatus* There is **final** critical habitat for this species. The location of the critical habitat is not available. ***This species is also protected by the Marine Mammal Protection Act, and may have additional consultation requirements.*** Species profile: https://ecos.fws.gov/ecp/species/4469	Threatened

Birds

NAME	STATUS
Red-cockaded Woodpecker *Picoides borealis* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/7614	Endangered

Fishes

NAME	STATUS
Gulf Sturgeon *Acipenser oxyrinchus (=oxyrhynchus) desotoi* There is **final** critical habitat for this species. The location of the critical habitat is not available. Species profile: https://ecos.fws.gov/ecp/species/651	Threatened
Pallid Sturgeon *Scaphirhynchus albus* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/7162	Endangered

Insects

NAME	STATUS
Monarch Butterfly *Danaus plexippus* No critical habitat has been designated for this species. Species profile: https://ecos.fws.gov/ecp/species/9743	Candidate

Critical habitats

THERE ARE NO CRITICAL HABITATS WITHIN YOUR PROJECT AREA UNDER THIS OFFICE'S JURISDICTION.