February 24, 2020

Revised: May 27, 2020

To: Jenny Skufca, IDNR

Subject: Illinois Department of Natural Resources
CONSERVATION PLAN for Lake Leopold Silt Recovery
(Application for an Incidental Take Authorization)
Per 520 ILCS 10/5.5 and 17 Ill. Adm. Code 1080

150-day minimum required for public review, biological and legal analysis, and permitting

PROJECT APPLICANT: *Prairie Crossing Homeowner's Association (PCHOA)*

PROJECT NAME: *Lake Leopold Silt Recovery*

COUNTY: *Lake County*

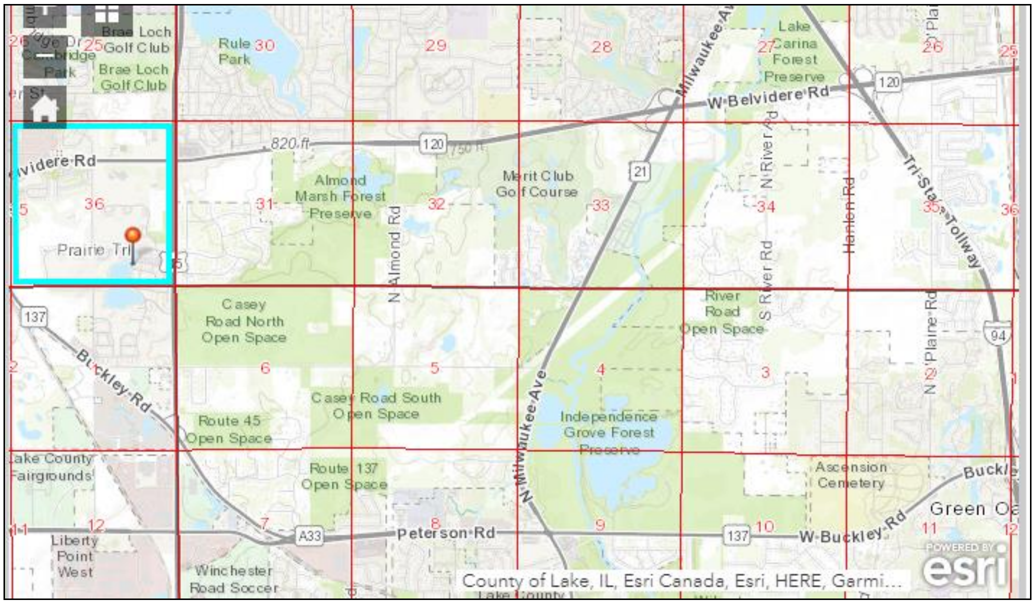
AMOUNT OF IMPACT AREA: *Area of up to, but not to exceed 15.03 acres over a 10-year period*

The incidental taking of endangered and threatened species shall be authorized by the Illinois Department of Natural Resources (IDNR) only if an applicant submits a conservation plan to the IDNR Incidental Take Coordinator that meets the following criteria:

1. A **description of the impact likely to result** from the proposed taking of the species that would be covered by the authorization, including but not limited to -

A) Identification of the **area to be affected** by the proposed action, include a legal description and a detailed description including street address, map(s), and GIS shapefile. Include an indication of ownership or control of affected property. Attached photos of the project area are included at the end of this plan.

Legal Description: SE1/4, Section 36, T45N, R10E, Grayslake Quad, Lake County, IL.



Location is near the intersection of US Highway 45 and Jones Point Road in Grayslake.

Shapefile of the approximate area of disturbance is included.

All areas affected by the proposed work are within tracts of land under the ownership of the project applicant, the PCHOA.

B) **Biological data** on the affected species including life history needs and habitat characteristics. Attach all pre-construction biological survey reports.

Before detailing the specifics of the individual species, it may be important to provide context for which the species identified below have come to exist in Lake Leopold. These fish, while certainly native to the drainageway, are surviving in a manmade impoundment and as such were introduced through a Sanctuary Program initiated in 1998 which transported 546 fish (200 Blackchin Shiner; 150 Iowa Darter; 116 Blacknose Shiner; and 80 Banded Killifish) to "Sanctuary Pond" a nearby stormwater detention facility of the PCHOA subdivision where the species became well established per the 2012 survey and batch weight determinations completed by ILM. The program was initiated with assistance from IDNR and U.S. Fish and Wildlife Service (USFWS). Historical description of the process is included in some of the documentation attached.

Two years later an additional collection of the same four species was translocated to Lake Leopold. The literature provided suggests that Pugnose shiners were also introduced from the transfer of species only originally misidentified as Blacknose shiners upon collection. The Starhead Topminnow has never been identified within the context of a fish survey and its identification within the context of this report is a bit of a mystery.

Nonetheless it is included in this Conservation Plan consistent with the protections the PCHOA intends to extend to all the other identified species.

Pre-construction surveys made available for this report are 2006 & 2012 (ILM) and 2015 (Duechler Environmental, Inc.). All reports are attached.

There are six (6) species identified as State of Illinois threatened status:

- *Banded Killifish (Fundulus diaphanous):* Most often found in shallow and quiet areas of clear lakes, ponds, rivers, and estuaries with abundant aquatic vegetation. Since the fish is relatively small it does not often venture into deeper waters (due to predation potential). Banded Killifish often congregate near aquatic vegetation, as it provides protection and breeding habitat. Spawning commonly occurs in dense vegetation from late spring to early summer in shallow areas (Bland, 2013).

- *Blackchin Shiner (Notropis heterrodon):* The species mostly resides in cool glacial lakes, with a preference for protected weedy areas, near inlets and outlets or large lakes, shallow pools, slow creeks, and small rivers. Typically prefer clear water with sandy bottoms. Spawning begins as early as May running through early August over vegetation (Bland, 2013)

- *Blacknose Shiner (Notropis heterolepis):* Typically living in cool weedy creeks, small rivers, and lakes over sand. In lakes it typically inhabits bays and marsh areas. Spawns in April through July scattering eggs over vegetation (Bland, 2013).

- *Iowa Darter (Etheostoma exile):* Found in natural lakes and very sluggish streams or marshes with dense to moderate aquatic vegetation and clear waters often over a sandy substrate. Breeding takes place in early spring over shallow water. Eggs are laid near the roots of vegetation near the waters edge where they are guarded until they hatch (ODNR, 2012).

- *Pugnose Shiner (Notropis anogenus):* Found typically in shallow waters during warm water month and found inhabiting weedy, clear lakes and slow-moving streams. Spawning and fertilization occur in summer between May and July, with eggs distributed in shallow water in areas of dense vegetation (Bland, 2013).

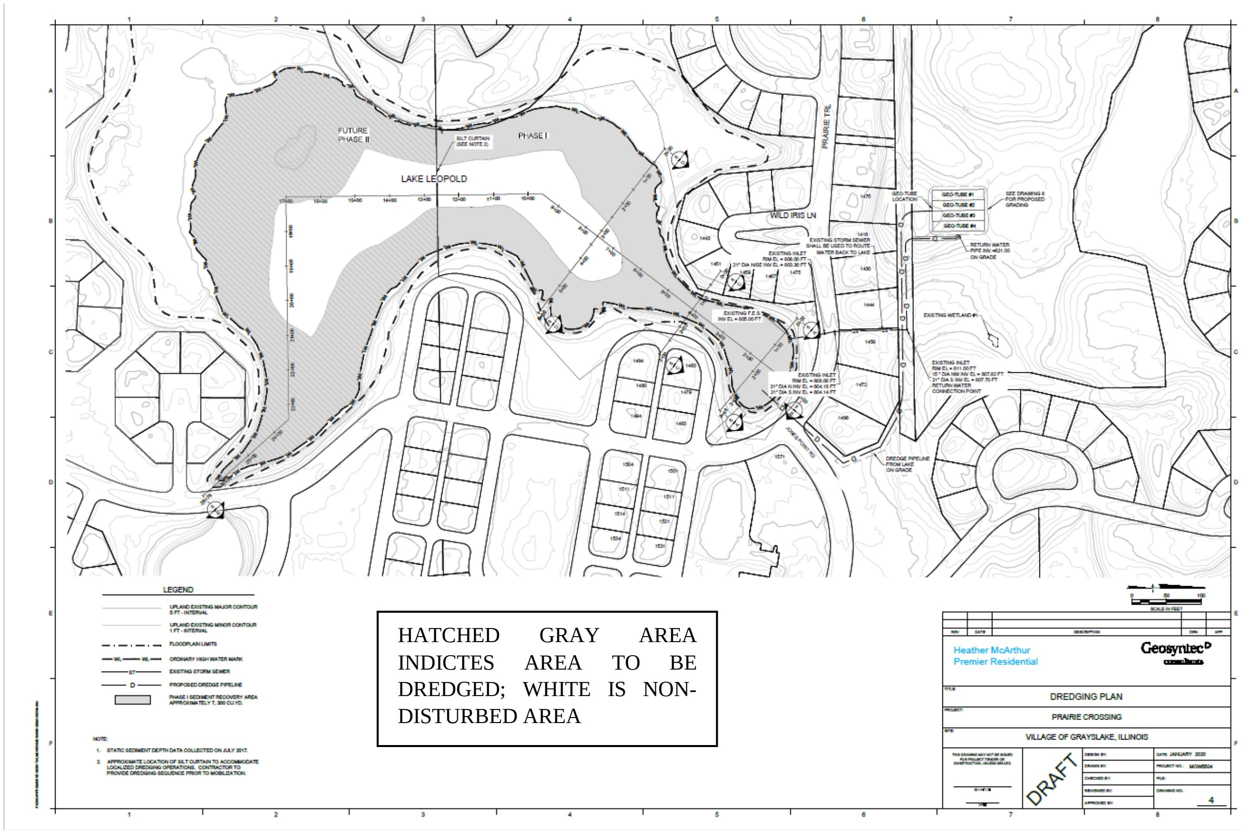
- *Starhead Topminnow (Fundulus dispar):* Habitat is typically glacial lakes and clear, well vegetated floodplain lakes, swamps, and marshes. Prefer quiet, clear to slightly turbid, shallow backwaters with an abundance of submergent vegetation. Spawning occurs from June through July (WDNR, 2019).

C) **Description of project activities** that will result in taking of an endangered or threatened species, including practices and equipment to be used, a timeline of proposed activities, and any permitting reviews, such as a USFWS biological opinion or U.S. Army Corps of Engineers (USACE) wetland review. Please consider all potential impacts such as noise, vibration, light, predator/prey alterations, habitat alterations, increased traffic, etc.

The PCHOA intends to recover enriched lake sediments by selectively dredging portions of Lake Leopold. The work will be spread over ten (10) years and performed with a hydraulic dredge specification focused on low turbidity. The specification could include, but not be limited to: a 6-inch horizontal auger type dredge that distributes the suction across a 6 ft. wide horizontal intake auger with a low turbidity shroud, producing a less concentrated suction zone than a rotating basket type cutterhead dredge. A diver operated approach may also be warranted using a 4-inch intake, or similar. The 6-inch dredge would pump about 1,000 gpm whereas the diver dredge is going to run about 400 to 500 gpm. An 8-inch horizontal auger may be considered also, assuming the contractor can demonstrate the higher gpm pumping will not result in unwarranted suspension of material.

All phased work is proposed for September through November.

- *Phase 1: Lake area: 8.52 acres; area to be dredged: 6.05 acres*
- *Phase 2: Lake area: 11.93 acres; area to be dredged: 8.98 acres*



Based on the sediment samples provided from the onset of the project, the material to be dredged is extremely light and should be retrievable without the need of heavy cutterhead style dredges. There is no intention of going below the hard bottom of the lake, nor an intention to dredge within the littoral zone of the lake, as there is no significant buildup of sediment to retrieve in these locations. Since the lake is proposed to be dredged in phases, fish (prey) typically associated with mid to deep lake water levels will have ample space to temporarily relocate to the remainder of the lake. The speed of the dredge is anticipated to be less than one foot per second allow ample opportunity for fish to relocate if needed. For the species specifically identified within this report, the impact of dredging should minimally interface with suggested habitat and life cycle which have been deliberately avoided. It is possible that fish will choose to mix habitats during the operation; however, it would be the exception and not the rule.

The material will be pumped offsite for dewatering within placed geotubes. Return water will be delivered via an existing storm drain. The return water effect should be consistent with traditional stormwater flow and should not be an issue as it cannot exceed the water quality parameters or turbidity of the existing water source.

The following potential impacts were reviewed as suggested above:

Noise: Most focused, low suction silt recovery dredges produce less noise pollution than standard cutter-head dredges. Because the material to be removed is believed to be mostly an organic based sediment-biomass matrix of decaying vegetation, the need to apply large boat traditional dredges should be unnecessary. Any mechanical motors or engines used in the removal will be kept away from direct habitat, centered more towards the deep waters (4 feet or greater) to accommodate distance from habitat.

Vibration: Much in the fashion of noise, the vibration is typically tied to the horsepower of the device needed to pull materials from the bottom. Since any machinery used will be positioned during the work as described above, we feel the impact of vibration will be minimized in that same extent. Furthermore, to benefit the species this work will not chase sediments in the deepest parts of the lake (>10 feet), so equipment will not need to run at maximum RPM to achieve the needed suction to deliver sediment to the dewatering area.

Light: With the proposed partitioning of the work area from the habitat of the focus, light related impact should be minimal. The sediment curtain partition should greatly minimize if not eliminate horizontal movement of turbid water into the habitat. It is possible some slight initial disturbance could occur during installation.

Predator/prey alterations: It is possible that the daily interaction with some typical predator species could be altered by the partition, as non-target predator species may no longer be able migrate into and out of these habitat zones to feed with ease during the term of the project.

Habitat alterations: The largest impact to the species of concern and their associated habitats will be the installation and likely removal of the silt curtain partition. No additional disturbance is anticipated and would furthermore not be consistent with the scope of work being suggested as part of this project. The habitat zone is therefore proposed to remain undisturbed.

Traffic: Other than the light boat traffic traditionally emphasized on the lake, the means to remove the soft sediments would require placement of on-water barge with motor and cutterhead or feed line to a diver assisted removal process. Again, the use of the partition should greatly reduce or remove altogether any traffic related impacts to the species or their habitat of concern.

D) Explanation of the anticipated **adverse effects on listed species**;

- How will the proposed actions impact each of the species' life cycle stages?

- Describe potential impacts to individuals and the population. Include information on the species life history strategy (life span, age at first reproduction, fecundity, recruitment, survival) to indicate the most sensitive life history stages.

- Identify where there is uncertainty, place reasonable bounds around the uncertainty, and describe how the bounds were determined. For example, indicate if it is uncertain how many individuals will be taken, make a reasonable estimate with high and low bounds, and describe how those estimates were made.

  All the representative documentation received and researched along with verbal communication with ILM and Duechler has resulted in a common theme; these identified fish species inhabit a common foraging area, the littoral zone of the lake and shallow waters of Lake Leopold. While we understand each fish may work within niche habitats within the littoral zone, the proposed work is focused on complete avoidance of that area and working outside critical life cycle timeframes. The dredging equipment proposed will be specified as low impact and. low suction which typically also results in low vibration when compared to typical hydraulic cutterhead style augers. Partitioning of the work area also ensures little interaction with fish species.

- *Banded Killifish (Fundulus diaphanous):*

  The project proposes to minimize interaction with the species, specifically during crucial life stages. With work scheduled from September through November, the general reproductive cycle will be avoided, and fry will have several weeks to develop. Based on survey results and typical area within the representative collection area, we do not anticipate more than 5 fish would be taken and would typically assume one. These are representative populations that we believe might exist outside of the species' typical forage zones. We cannot accurately determine if fish would travel outside of its typical forage area either due to sickness or age in which the typical travel area is uncharacteristic.

- *Blackchin Shiner (Notropis heterrodon):*

  The project proposes to minimize species interaction, specifically during crucial life stages. With work scheduled from September through November, the general reproductive cycle will be avoided, and fry will have several weeks to develop. Based on survey results and typical area within the representative collection area we do not anticipate more than 5 fish would be taken and would typically assume one. These are representative populations that we believe might exist outside of the species' typical forage zones. We cannot accurately determine if fish would *travel outside of its typical forage area either due to sickness or age in which the typical travel area is uncharacteristic.*

- *Blacknose Shiner (Notropis heterolepis):*

  The project proposes to minimize species interaction, specifically during crucial life stages. With work scheduled from September through November, the general reproductive cycle will be avoided, and fry will have several weeks to develop. Based on survey results and typical area within the representative collection area we do not anticipate more than 5 fish would be taken and would typically assume one. These are representative populations that we believe might exist outside of the species' typical forage zones. We cannot accurately determine if fish would travel outside of its typical forage area either due to sickness or age in which the typical travel area is uncharacteristic.

- *Iowa Darter (Etheostoma exile):*

  The project proposes to minimize species interaction, specifically during crucial life stages. With work scheduled from September through November, the general reproductive cycle will be avoided, and fry will have several weeks to develop. Based on survey results and typical area within the representative collection area we do not anticipate more than 5 fish would be taken and would typically assume zero. These are representative populations that we believe might exist outside of the species' typical forage zones. We cannot accurately determine if fish would travel outside of its typical forage area either due to sickness or age in which the typical travel area is uncharacteristic. The Iowa Darter is even less prone to travel into deep water, rather driving further into shallower water and heavier cover.

- *Pugnose Shiner (Notropis anogenus):*

  The project proposes to minimize species interaction, specifically during crucial life stages. With work scheduled from September through November, the general reproductive cycle will be avoided, and fry will have several weeks to develop. Based on survey results and typical area within the representative collection area we do not anticipate more than 5 fish would be taken and would typically assume one. These are representative populations that we believe might exist outside of the species' typical forage zones. We cannot accurately determine if fish would travel outside of its typical forage area either due to sickness or age in which the typical travel area is uncharacteristic.

- *Starhead Topminnow (Fundulus dispar):*

Of all the threatened species listed within this document, the Starhead Topminnow is the most puzzling. No referenced material from fish surveys have identified the fish within the lake and no provided documentation has suggested its presence. Additionally, since the lake was manmade, records of the transplantation should be known. The outfall configuration in relation to the downstream area would make it near impossible for the fish to migrate into the lake from a downstream source. For this reason, it can only be assumed that the species is being considered because of proximity to another nearby observation and for that reason we have included it as a take consideration. The project proposes to minimize species interaction, specifically during crucial life stages. With work scheduled from September through November, the general reproductive cycle will be avoided, and fry will have several weeks to develop. Based on survey results and typical area within the representative collection area we do not anticipate more than 5 fish would be taken and would typically assume zero. These are representative populations that we believe might exist outside of the species' typical forage zones. We cannot accurately determine if fish would travel outside of its typical forage area either due to sickness or age in which the typical travel area is uncharacteristic.

2) Measures the applicant will take to **minimize and mitigate** that impact <u>and</u> the **funding** that will be available to undertake those measures, including, but not limited to -

A) Plans to **minimize the area affected** by the proposed action, the estimated **number of individuals** of each endangered or threatened species that will be taken, and the **amount of habitat** affected (please provide an estimate of area by habitat type for each species).

Lake Leopold is a man-made lake impoundment; however remarkably high in water quality and as a result has served as an unexpected nursery for the listed State threatened and endangered species. The lake is managed through the efforts of PCHOA. Prairie Crossing is a uniquely created conservation-design based community which monitors the lake and the housed species on a regular basis. Every effort has been put in place to ensure minimal accidental takes occur. PCHOA includes monies in its annual budget to maintain the native shorelines, upland prairie site, and stormwater management basins in a manner conducive to the reputation of the development.

The act of hydraulic dredging in itself has not been known to significantly impact populations (Schwerdtfeger, 2016). The typical process of dredging is done with a slow-moving suction head which creates a disturbance easily avoided by most species. Since the project is proposed to be phased, the material damage to the ecology of the lake will be limited to area of each individual phase with proper area controls in place such as turbidity curtains.

- *Banded Killifish (Fundulus diaphanous):*

  The work itself is scheduled (each independent phase) to be coordinated outside the critical reproductive cycle of the Killifish. The work is also scheduled to avoid the littoral zone of the lake and the typical foraging area of this species. Work is phased to allow for minimal total lake and ecosystem impact, allow for ample recovery time in between work phases, and using low suction, low impact equipment needed to address the specific sediment material to be recovered. It is not anticipated that the Banded Killifish will be subject to mortality through suction capture since the head of the dredge will typically be submersed in 4+ feet of water and a turbidity curtain will limit horizontal movement of suspended material from transitioning into typical habitat. The most likely immediate impact could be the displacement of typical predators into the littoral zone due to the proposed work; however, we are uncertain as to how displaced predators may alter their typical dietary schedule. Based on the information above and the populations as identified in the lake, we feel each phase will take three (3) fish.

- *Blackchin Shiner (Notropis heterrodon):*

  The work itself is scheduled (each independent phase) to be coordinated outside the critical reproductive cycle of the Blackchin Shiner. The work is also scheduled to avoid the littoral zone of the lake and the typical foraging area of the species. Work is phased to allow for minimal total lake and ecosystem impact, allow for ample recovery time in between work phases, and using low suction, low impact equipment needed to address the specific sediment material to be recovered. It is not anticipated that the Blackchin Shiner will be subject to mortality through suction capture since the head of the dredge will typically be submersed in over four feet of water and a turbidity curtain will limit horizontal movement of suspended material from transitioning into their typical habitat. The most likely immediate impact could be the displacement of typical predators into the littoral zone due to the proposed work; however, we are uncertain as to how displaced predators may alter their typical dietary schedule. Based on the information above and the populations as identified in the lake, we feel each phase will take three (3) fish.

- *Blacknose Shiner (Notropis heterolepis):*

  The work itself is scheduled (each independent phase) to be coordinated outside the critical reproductive cycle of the Blacknose Shiner. The work is also scheduled to avoid the littoral zone of the lake and the typical foraging area of the species. Work is phased to allow for minimal total lake and ecosystem impact, allow for ample recovery time in between work phases, and using low suction, *low impact equipment needed to address the specific sediment material to be recovered. It is not anticipated that the Blacknose Shiner will be subject to mortality through suction capture since the head of the dredge will typically be submersed in over four feet of water and a turbidity curtain will limit horizontal movement of suspended material from transitioning into their typical habitat. The most likely immediate impact could be the displacement of typical predators into the littoral zone due to the proposed work; however, we are uncertain as to how displaced predators may alter their typical dietary schedule. Based on the information above and the populations as identified in the lake, we feel each phase will take three (3) fish.*

- *Iowa Darter (Etheostoma exile):*

  The work itself is scheduled (each independent phase) to be coordinated outside the critical reproductive cycle of the Darter. The work is also scheduled to avoid the littoral zone of the lake and the typical foraging area of the species. Work is phased to allow for minimal total lake and ecosystem impact, allow for ample recovery time in between work phases, and using low suction, low impact equipment needed to address the specific sediment material to be recovered. It is not anticipated that the Darter will be subject to mortality through suction capture since the head of the dredge will typically be submersed in over four feet of water and a turbidity curtain will limit horizontal movement of suspended material from transitioning into their typical habitat. The most likely immediate impact could be the displacement of typical predators into the littoral zone due to the proposed work; however, we are uncertain as to how displaced predators may alter their typical dietary schedule. Based on the information above and the populations as identified in the lake, we feel each phase will take two (2) fish.

- *Pugnose Shiner (Notropis anogenus):*

  The work itself is scheduled (each independent phase) to be coordinated outside the critical reproductive cycle of the Pugnose Shiner. The work is also scheduled to avoid the littoral zone of the lake and the typical foraging area of the species. Work is phased to allow for minimal total lake and ecosystem impact, allow for ample recovery time in between work phases, and using low suction, low impact equipment needed to address the specific sediment material to be recovered. It is not anticipated that the Pugnose Shiner will be subject to mortality through suction capture since the head of the dredge will typically be submersed in over feet of water and a turbidity curtain will limit horizontal movement of suspended material from transitioning into their typical habitat. The most likely immediate impact could be the displacement of typical predators into the littoral zone due to the proposed work; however, we are uncertain as to how displaced predators may *alter their typical dietary schedule. Based on the information above and the populations as identified in the lake, we feel each phase will take three (3) fish.*

- *<u>Starhead Topminnow (Fundulus dispar):</u>*

  The work itself is scheduled (each independent phase) to be coordinated outside the critical reproductive cycle of the Topminnow. The work is also scheduled to avoid the littoral zone of the lake and the typical foraging area of the species. Work is phased to allow for minimal total lake and ecosystem impact, allow for ample recovery time in between work phases, and using low suction, low impact equipment needed to address the specific sediment material to be recovered. It is not anticipated that the Topminnow will be subject to mortality through suction capture since the head of the dredge will typically be submersed in over four feet of water and a turbidity curtain will limit horizontal movement of suspended material from transitioning into their typical habitat. The most likely immediate impact could be the displacement of typical predators into the littoral zone due to the proposed work; however, we are uncertain as to how displaced predators may alter their typical dietary schedule. Based on the information above and the fact that there has not been a known captured fish of this specie, we feel each phase will take no more than one (1) fish.

B) **Plans for management of the area** affected by the proposed action that will **enable continued use** of the area by endangered or threatened species by maintaining/re-establishing suitable habitat (for example, native species planting, invasive species control, use of other best management practices, restored hydrology, etc.).

As touched on above, the project will be parsed to enable ample space for species inhabiting the lake to move freely during the project. The PCHOA maintains the lake and surrounding natural areas on an annual basis. When minor erosion was noticed in the northeast bay 4 years ago the PCHOA at its own expense made the repairs and fully restored the area at its own expense. The areas proposed for dredge are expected to have minimal permanent habitat issues.

Rotational maintenance dredging is part of the PCHOA's management needs to maintain the lake in its desired condition. Iowa Darters for example are sensitive to minor siltation as it it impacts their reprodcutive habitat. All the fish species identified are further akin to clear, non-turbid environments. The management as such in an urban environment entails maintenance dredging. Due to the cost of dredging (hydrualic or otherwise), HOA's (or any entity with lake management responsibilities) are often handcuffed with a responsibility of occassional investment in significant projects or delaying the event until it is unavoidable and extremely cost prohibitive in which case said project is ultimately shevled. The PCHOA has to balance the cost of rotational *maintenance dredging on a 20 year basis to maintain the Lake at it's expected water quality level or delay the event while putting their unique fishery and high-quality resource at risk and ultimately facilitating a bigger project at a higher cost.*

C) Description of **all measures to be implemented to avoid, minimize, and mitigate** the effects of the proposed action on endangered or threatened species.

- Avoidance measures include working outside the species' habitat.

- Minimization measures include timing work when species is less sensitive, reducing the project footprint, or relocating species out of the impact area.

- Mitigation is additional beneficial actions that will be taken for the species such as needed research, conservation easements, propagation, habitat work, or recovery planning.

- It is the **applicant's responsibility to propose mitigation measures.** IDNR expects applicants to provide species conservation benefits 5.5 times larger than their adverse impact.

Based on the document research (attached) and personal discussion with Duechler Fisheries Biologist Leonard Dane who performed the majority of the fish identification during the last fish survey, the preferred method of collection and identification for all species is typically seining due to the similarities in species habitat and life cycle. While some species were captured and identified while electrofishing, it was more of a function of proximity of those fish to other larger fish such as bluegill, for example. Therefore, as a basis of this discussion the measures described for this component of the ITA request will be lumped as it appropriate due to the commonalities of all species involved. Below is a summary of project oriented best practices that have been instituted to make for a functional project with minimal impact to the identified species within this report, as well as all species in the lake and the overall aquatic ecosystem of Lake Leopold:

i. *The project will utilize a turbidity curtain as a standard practice in dividing the work area from areas of the lake outside of the work footprint. This will minimize horizonal movement of suspended material from traveling laterally into traditional habitat areas as well as creating a physical barrier for fish passage into the work zone.*

ii. *The work is being initiated within a time period most conducive to minimize conflicts with species reproductive cycles as well as minimizing impacts to typical growth patterns of the native plant ecology of Lake Leopold (submersed, emergent, and terrestrial). The project will be initiated as late as practical*

(September or later) to minimize ecological impact while still allowing for enough time to complete any of the three phases to be completed prior to the onset of cold weather conditions which make for poor hydraulic performance of the equipment used in the proposed dredging operation.

iii. *We are coordinating this project through a phased approach and a 10-year permit process through the USACE. This provides multiple benefits to the PCHOA and the lake. Environmental impact can be minimized in size and scope with the consideration of allowing one phase appropriate recovery time before undertaking a second or third phase. The PCHAO will have time to assess any lessons learned from the first phase to subsequent phases; this includes in-water work as well as the dewatering site. Any monitoring post phase one can be assessed and considered by the PCHOA and regulatory agencies as necessary.*

iv. *All areas which are in dedicated natural resources easement areas can be assessed as part of the PCHOA's ongoing management protocols.*

v. *Mitigation: The PCHOA is proposing that the project serves as its own mitigation through proper execution. Periodic removal of sediment is an anticipated action in an urban environment to improve habitat for more sensitive species, providing indirect benefits for feeding, spawning productivity, respiration, etc. The anticipated value associated with the complete maintenance dredging of Lake Leopold is $800K; the ongoing maintenance for Lake Leopold since its creation has exceeded $1.1M through invasive species control, shoreline restoration, and species monitoring. The proposed project will be further continue to provide a conservation benefit to the lake and local ecosystem by maintaining the high level of habitat in Prairie Crossing.*

D) Plans for **<u>monitoring</u>** the effects of the proposed actions on endangered or threatened species, such as monitoring the species' survival rates, reproductive rates, and habitat before and after construction, include a plan for follow-up **reporting to IDNR**. Monitoring surveys should be targeted at reducing the uncertainty identified in Section 1.d.

The PCHOA monitors the lake as part of their normal routine. We have included the three latest fish surveys with this plan. The lake is planned to be surveyed again in 2021. As part of this permit, the survey result will be forwarded to IDNR. The survey is scheduled to taked place after the dredging in phase 1 and the purpose is to reevaluate fishery population. The goal of that survey could be expanded or targeted to address specifically the species identified within this conservation plan.

To date the all surveys for Lake Leopold have been in held in-house. As part of the project the results will be provided directly to the IDNR staff and will include an assessment of the vegetative community associated with the species habitat. The PCHOA has an ongoing assessments for all shoreline and native areas within the subdivision and can added as a component to the fish survey along with an assessment to determined species population estimates taken from trends established in previous surveys.

E) **<u>Adaptive management practices</u>** that will be used to deal with changed or unforeseen circumstances that may affect the endangered or threatened species.

- Adaptive management is a way to make decisions in the face of uncertainty by monitoring the uncertain element over time and adjusting to the new information. Adaptive management requires identifying objectives and uncertainties, thinking through a range of potential outcomes, developing triggers that will lead to different actions being taken, and monitoring to detect those triggers.

- Consider environmental variables such as flooding, drought, and species dynamics as well as other catastrophes. Management practices should include contingencies and specific triggers. Note: Not foreseeing any changes does not quality as an adaptive management plan.

<u>Pre-Project Implementation</u>

The PCHOA has documentation history and tracking surveys of all the species in question other than the Starhead Topminnow. This documentation has been provided as a means to assess populations dynamics of the species in question and furthermore provides a means of which to assess conditions post project. These surveys provide the basis of the current populations.

<u>During Project Implementation</u>

Hydraulic dredging is typically monitored at the return water line. This is a pump return line that runs excess water back to the water body from which the dredging originates (typically). The contractor per Section 401 requirements is required to sample the return water daily to ensure that the return water is meeting specific state water quality requirements and goals per the Section 401 permit (IEPA). If takes are occurring this is the place that it would be first noticed. To ensure takes are limited the PCHOA can stipulate that the return line be monitored more frequently for loss. Additionally, the project will implement a "pilot" dredge using a small (30 CY +/-) geotube, fill the tube, temporarily dewater and open and examine the materials for takes.

In the event that takes are noticed additional protection measures can be put in place to further reduce the possibility of loss. Such protection measures could include:

- *Stop operation and pre-seine the area in an attempt to relocate fish outside the zone of work.*

- *Stop operation, electroshock, capture, and relocate species out of proposed project area.*

- *The work will not be performed if a flooding condition exists or other abnormal physical conditions exist which may change lake dynamics. These changes put equipment as well as operators at risk.*

<u>*Post-Project Evaluation*</u>

The geotubes will be evaluated at the end of Phase one upon dewatering and respread of material. Should takes be identified, the processes not above can be reevaluated for subsequent phases. Additionally, the conditions of the shoreline will be assessed in conjunction with the fish survey to determine if there have been any occurrences of fish mortality, noticeable sediment buildup or displacement onto littoral zone vegetation, or even vegetative mortality or displacement. Fisheries biologists can further assess the littoral zone for appropriate reproductive preparedness and post dredging restoration, if necessary.

F) **Verification that adequate funding exists** to support and implement all minimization and mitigation activities described in the conservation plan. This may be in the form of bonds, certificates of insurance, escrow accounts, or other financial instruments adequate to carry out all aspects of the conservation plan.

The PCHOA has a dedicated HOA and funding mechanism of dues collection that supports yearly maintenance activities along with special projects including shoreline protection restorations and dredging. Unlike many HOAs which require the need to hold special assessments, the PCHOA has budgeted for such maintenance activities which includes restoration and dredging. Should money need to be allocated from the other phases of dredging to restore unforeseen issues, this can be accomplished by adjusting the annual budget. The PCHOA has money budgeted for needs such as rotational fish surveys and can add components to the survey including suggestive restoration with board approval. The contingency and minimization measures proposed within this plan are work items that the PCHOA planned for in the cost of the project and are not considered special cost items but included in the project cost for dredging. Monitoring components will be added to the originally scheduled fish survey.

3) A description of **alternative actions** the applicant considered that would reduce take, and the reasons that each of those alternatives was not selected. A **"no-action" alternative** shall be included in this description of alternatives. Please describe the economic, social, and ecological tradeoffs of each action.

- Consideration of **alternative actions** is an important tool in conservation planning as it allows for thinking of other options and evaluating the potential outcomes in terms of all relevant objectives. However, to be useful it requires creativity in developing alternatives and systematic analysis in evaluating the alternatives.

- In evaluating alternatives, describe the economic, social, and ecological tradeoffs of each.

  A. *It is plausible for the PCHOA to employ a smaller footprint to dredge (additional phases), but in the end, this minimizes the footprint and need to dredge more frequently, which we feel is better in the long run. The cost re-mobilize and subsequently enter the water should be minimized and makes the project more cost-prohibitive and difficult to permit with other agencies. 10-year dredge approvals are the maximum recurring dredge permit approved by the USACE.*

  B. *The PCHOA can opt to slow drain the area of phase to be dredged. This would require the placement of a physical barrier between each phase slow draining the lake and continually pumping dry removing any remaining fish via electo-fishing and/or seining. While this may sound like a viable option it may be the most destructive to habitat for all species within the lake and certainly more costly. The PCHOA expect the project to be as non-invasive as possible and for that reason we feel the actions as proposed will be the least destructive and allow for the fastest recovery of the lake.*

  C. *No Action: This alternative, while a plausible action is ultimately counterintuitive to the act in which it is meant to accomplish. The lake is not imposing the action of dredging for navigability, aesthetic concern, or resident complaints. It is being enacting on a rotational need to maintain the vary water quality and species protection that this ITA seeks to protect, therefore no action will lead to a buildup of sediments in which the PCHOA will be further encumbered with cost restriction and be less willing to undertake. Maintenance dredging is essential for all lakes and impoundments regardless of water quality and habitat concerns to ensure those very variables are protected.*

4) Data and information to indicate that the proposed taking **will not reduce the likelihood of the survival** of the endangered or threatened species in the wild within the State of Illinois, the biotic community of which the species is a part, or the habitat essential to the species existence in Illinois.

The PCHOA is providing previously available surveys and the history of the sanctuary program under which these species have been identified and proliferated. Several of these surveys were undertaken by the PCHOA on their own behalf which are not subject to delivery to any specific agency under the existing sanctuary program. As documented in the attached American Currents document (Bland, 2013), this is not native habitat for the species, but a manmade impoundment created circa 1995 with artificial fish introduction from 1998 and 2000 in Sanctuary Pond and Lake Leopold, respectively. While documentation reflects that the introduction of these species at these two locations has likely spurred reintroduction of various species to downstream drainageways and hence in possible past habitats. The work in no way impacts the original nursery located in Sanctuary Pond and as structured with the appropriate protections will minimize the number of potential takes.

No work is being proposed within the area that has been identified to the PCHOA through document research and correspondence with various staff involved in the fish surveys. While resuspension of materials is a possibility, the methods of containment, properly installed and monitored throughout the life of the project should ensure minimal escape of unwanted sediments and organic constituents. The timing of the project as discusses will also minimize exposure of the biotic community to the project and have minimal direct contact with the habitat identified for the species. The work itself is not located within the environment under which they traditionally range and the measure employed should further limit exposure to indirect effects of the work.

Information from associated research is attached regarding the likelihood of a take under the proposed practice.

Based on review of INHS databases, the result of any taking from this project either unanticipated or as a result of negligence should not result in reduced likelihood of the survival of any of these listed species in the wild.

5) An **implementing agreement,** which shall include, but not be limited to (on a separate piece of paper containing signatures):

A) <u>Names and signatures</u> of all participants in the execution of the conservation plan;

B) The <u>obligations and responsibilities</u> of each of the identified participants with schedules and deadlines for completion of activities included in the conservation plan and <u>a schedule for preparation of progress reports</u> to be provided to the IDNR;

C) Certification that each participant in the execution of the conservation plan has the <u>legal authority</u> to carry out their respective obligations and responsibilities under the conservation plan;

D) Assurance of compliance with all other federal, State and local regulations pertinent to the proposed action and to execution of the conservation plan;

E) **Copies of any final federal authorizations for a taking already issued to the applicant**, if any.

ATTACHMENTS

1. Field Notes for Fish Collection in September 2006 from Lake Leopold at Prairie Crossing. ILM, 2006, 6 pages.

2. 2012 Fish Survey Report Sanctuary Pond at Prairie Crossing. ILM, 2012, 17 pages.

3. Lake Leopold Fish Survey. Duechler Environmental, Inc., 2015, 25 pages.

4. Sediment Recovery Engineering Drawings for Prairie Crossing. Manhard Consulting, Ltd., 7 pages.

5. Use of Urban Detention Pond as Refuge for Endangered and Threatened Fish Species. ILM Presentation, undated, 28 pages.

6. Field Notes, Chicago Wilderness. Undated, 1 page.

7. How Do You Spell Success? The Rare Fish Variety, That Is. American Currents, Vol. 38, No.4. Bland, Jim, 2013. 9 pages.

8. Genetic Evaluation of Remnant and translocated shiners, *Notropis heterodon* and *Notropis heterolepis*. Journal of Fish Biology, Vol 82, Ozer, F., and Ashley M.V., 2013, 16 pages.

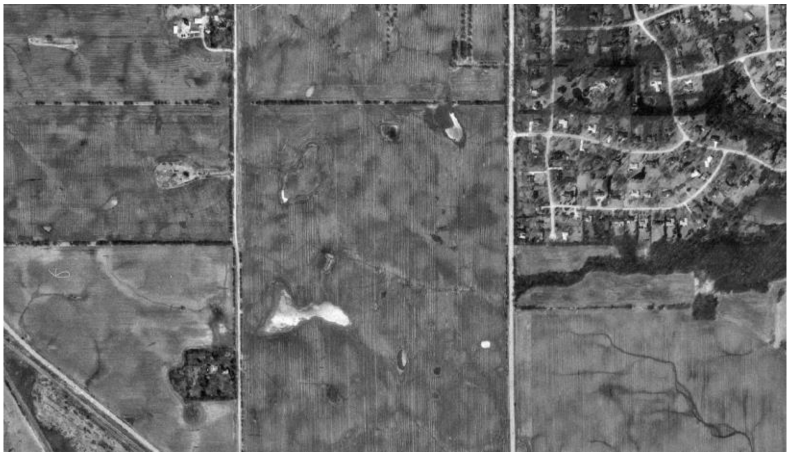
9. Ohio Department of Natural Resources, copyrighted 2012. http://wildlife.ohiodnr.gov/species-and-habitats/species-guide-index/fish/iowa-darter.

10. Wisconsin Department of Natural Resources, latest revision 11/18/209. https://dnr.wi.gov/topic/EndangeredResources/Animals.asp?mode=detail&SpecCode=AFCNB04250

11. Does lake dredging affect biodiversity? Evaluating biodiversity levels of fish at various stages of the dredging process in freshwater lakes. An Undergraduate Thesis submitted in Partial Fulfillment for the Requirements of Bachelor of Arts in Environmental Science: Conservation and Ecology, Carthage College, 2016. Schwerdtfeger Jr., Robert. 22 pages.

12. A critical analysis of the direct effects of dredging on fish. Fish and Fisheries, Vol. 18. Wenger et al, 2017, 18 pages.

PROJECT AREA PHOTOS



Prior to construction – 1993

During subdivision construction – 1997

Present Day ~ 2018

GROUND LEVEL PHOTOS


Lake from a distance

Near shore habitat zone

Near shore habitat zone

Geosyntec consultants

1420 Kensington Road, Suite 103
Oak Brook, Illinois 60523
PH 630.203.3340
FAX 630.203.3341
www.geosyntec.com

February 24, 2020

Subject: PRAIRIE CROSSING SILT RECOVERY PROJECT INCIDENTAL TAKE AUTHORIZATION IMPLEMENTATION PLAN

A. Introduction: The purpose of this document is to serve as an instrument to identify the key components of the Conservation Plan, the necessary steps needed to carry out the implementation measures identified within the plan, and those parties (or individuals) responsible for carrying out the necessary actions identified herein.

B. Obligations and Responsibilities: The following list of obligations and responsibilities shall be undertaken by the Prairie Crossing Homeowner's Association (PCHOA) or their assigns as part of this agreement which is contingent upon approval of the Project Conservation Plan entitled "Conservation Plan for Lake Leopold Silt Recovery".

- Obtain approval of Incidental Take Authorization (ITA) Project Conservation Plan and Implementation Plan from the State of Illinois Department of Natural Resources (IDNR). *Timeline: August 2020.*

- Obtain all necessary approvals from various federal, state, and local agencies needed to carry out permitting components for the project. *Timeline: July 2020*

- Identify qualified contractors capable of implementing the project in a phased manner as proposed within the Conservation Plan and approved Engineering plans for Phase 1 of the silt recovery project. *Timeline: July 2020*

- Select qualified contractor capable of performing project specifications per the Conservation Plan. *Timeline: August 2020*
    - Low suction design and dredging equipment
    - Understands and agrees to follow conservation plan variables

- Execute Conservation Plan components as necessary to be completed as part of the silt recovery project. *Timeline: September 2020*
    - Install turbidity curtain for project isolation.
    - Run test dredge using small geotube: approximate 30 CY
    - Dewater and review for takes
    - Determine if contingencies are necessary

- Comply with post-project Conservation Plan components to identify any loss of species, habitats, etc. *Timeline: Submit August 2021*
    - Review vegetation and habitat growth, April- May
    - Re-survey fish population with focus on identified threatened species
    - Report findings to IDNR
    - Determine if contingencies are necessary

C. Certification: By way of approval from the PCHOA, the PCHOA or its assigns have full operational authority to undertake the work associated under this approved plan.

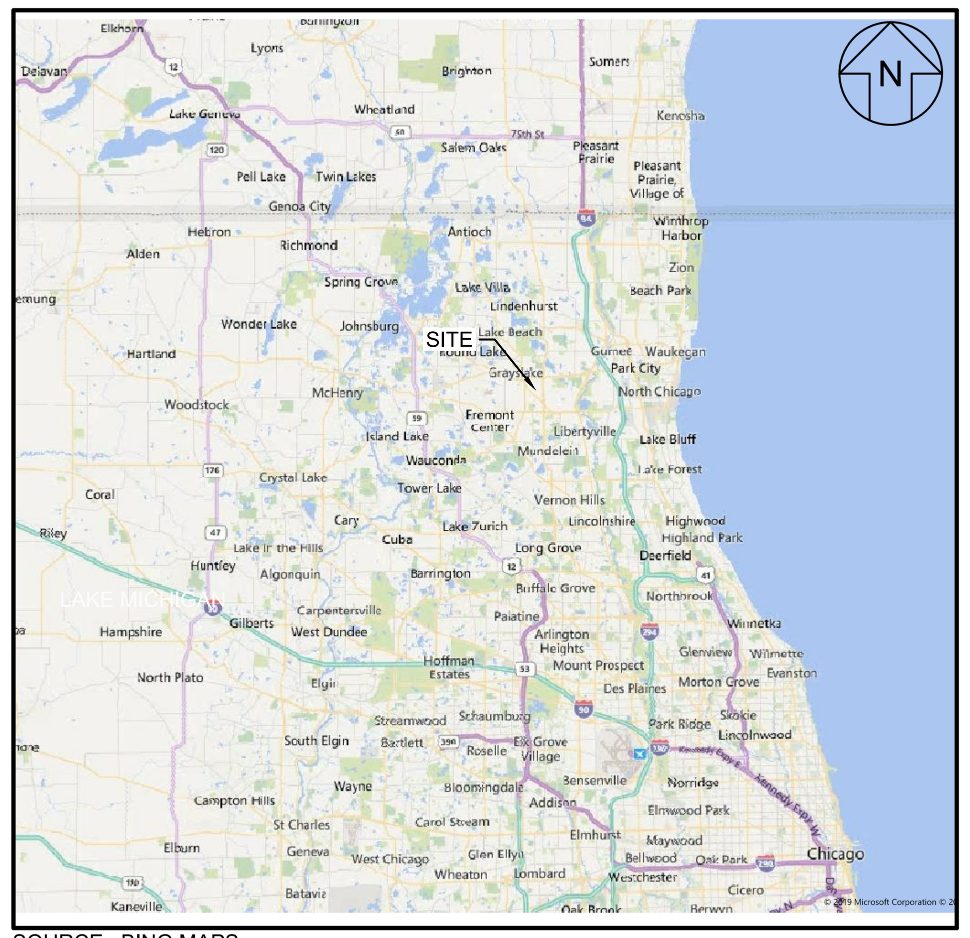
D. Assurance of Compliance: by approval of this Conservation Plan the PCHOA acknowledges to obtain and comply with the conditions of all permits and regulatory requirements of the project both written and unwritten.

E. Names and Signatures:

The following individual is responsible for the proper execution of this Conservation Plan and approved Implementation Plan on behalf of the Prairie Crossing Homeowner's Association (PCHOA):

Signature: ______________________________

SEDIMENT RECOVERY
FOR PRAIRIE CROSSING
VILLAGE OF GRAYSLAKE, ILLINOIS
JANUARY 2020

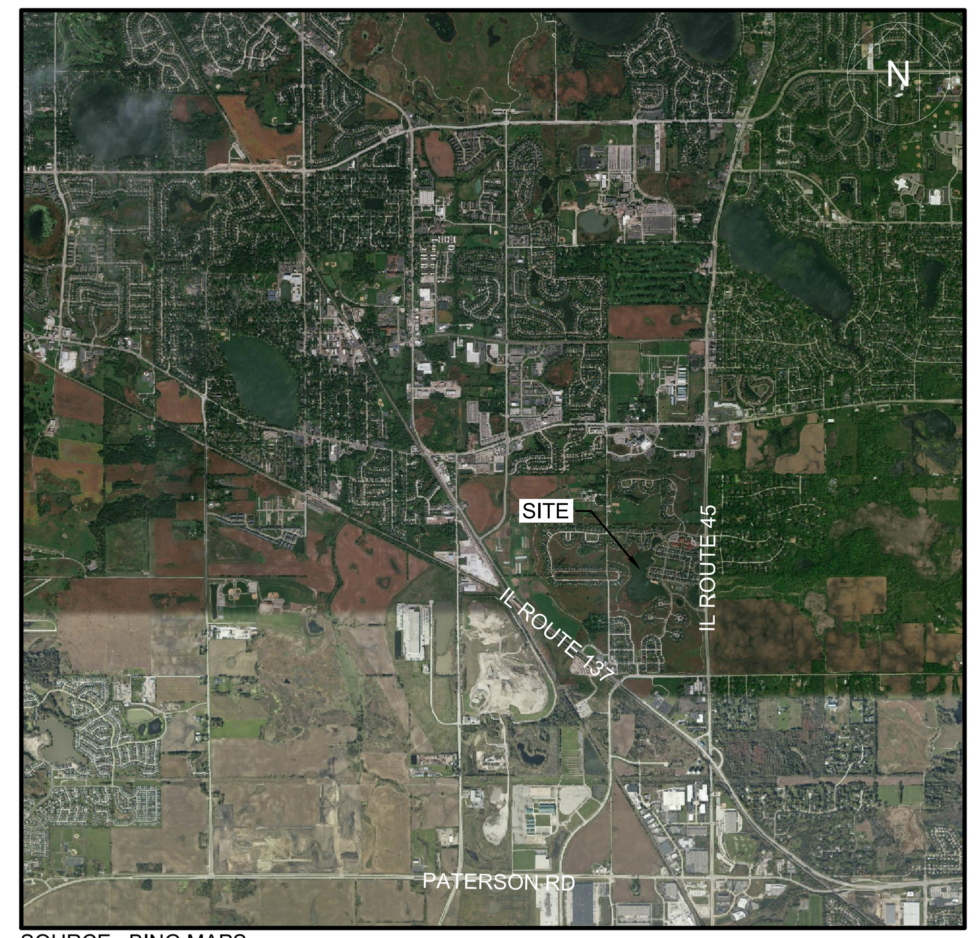


SOURCE: BING MAPS

VICINITY MAP

0 10 20

SCALE IN MILES



SOURCE: BING MAPS

LOCATION MAP

0 4000 8000

SCALE IN FEET

SOURCE: BING MAPS

SITE MAP

0 500 1000

SCALE IN FEET

INDEX OF SHEETS	
SHEET NO.	TITLE
1	COVER SHEET
2	GENERAL SITE PLAN
3	EXISTING CONDITIONS PLAN
4	DREDGING PLAN
5	CROSS – SECTIONS
6	PROPOSED GRADING PLAN
7	SOIL EROSION AND SEDIMENT CONTROL
8	CONSTRUCTION SPECIFICATIONS

REFERENCE BENCHMARK:

NGS MONUMENT (AJ2870)
FLANGE ENCASED STAINLESS STEEL ROD LOCATED APPROXIMATELY 39 FEET NORTHEAST OF THE CENTERLINE OF ILLINOIS ROUTE 60 (TOWNLINE ROAD), APPROXIMATELY 89 FEET NORTWEST OF THE ENTRANCE TO IVANHOE ESTATES.

ELEVATION = 822.33 DATUM: NAVD 88

4/6 – DETAIL NUMBER

DRAWING ON WHICH ABOVE DETAIL IS PRESENTED

DETAIL NUMBER 4

DRAWING ON WHICH ABOVE DETAIL WAS FIRST REFERENCED 3

XXXXXXXXXX

TITLE2

SCALE:

XREF:

EXAMPLE: DETAIL NUMBER 4 PRESENTED ON DRAWING NO. 6 WAS REFERENCED FOR THE FIRST TIME ON DRAWING NO. 3.

ABOVE SYSTEM ALSO APPLIES TO SECTION IDENTIFICATIONS.

DETAIL IDENTIFICATION LEGEND

PREPARED FOR:

HEATHER MCARTHUR
PREMIER RESIDENTIAL
4180 ROUTE 83, SUITE 14
LONG GROVE, ILLINOIS 60047

PREPARED BY:

Geosyntec consultants

1420 KENSINGTON RD, SUITE 103
OAK BROOK, ILLINOIS 60523
TELEPHONE: 630.203.3340

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec consultants

TITLE: COVER SHEET

PROJECT: PRAIRIE CROSSING

SITE: VILLAGE OF GRAYSLAKE, ILLINOIS

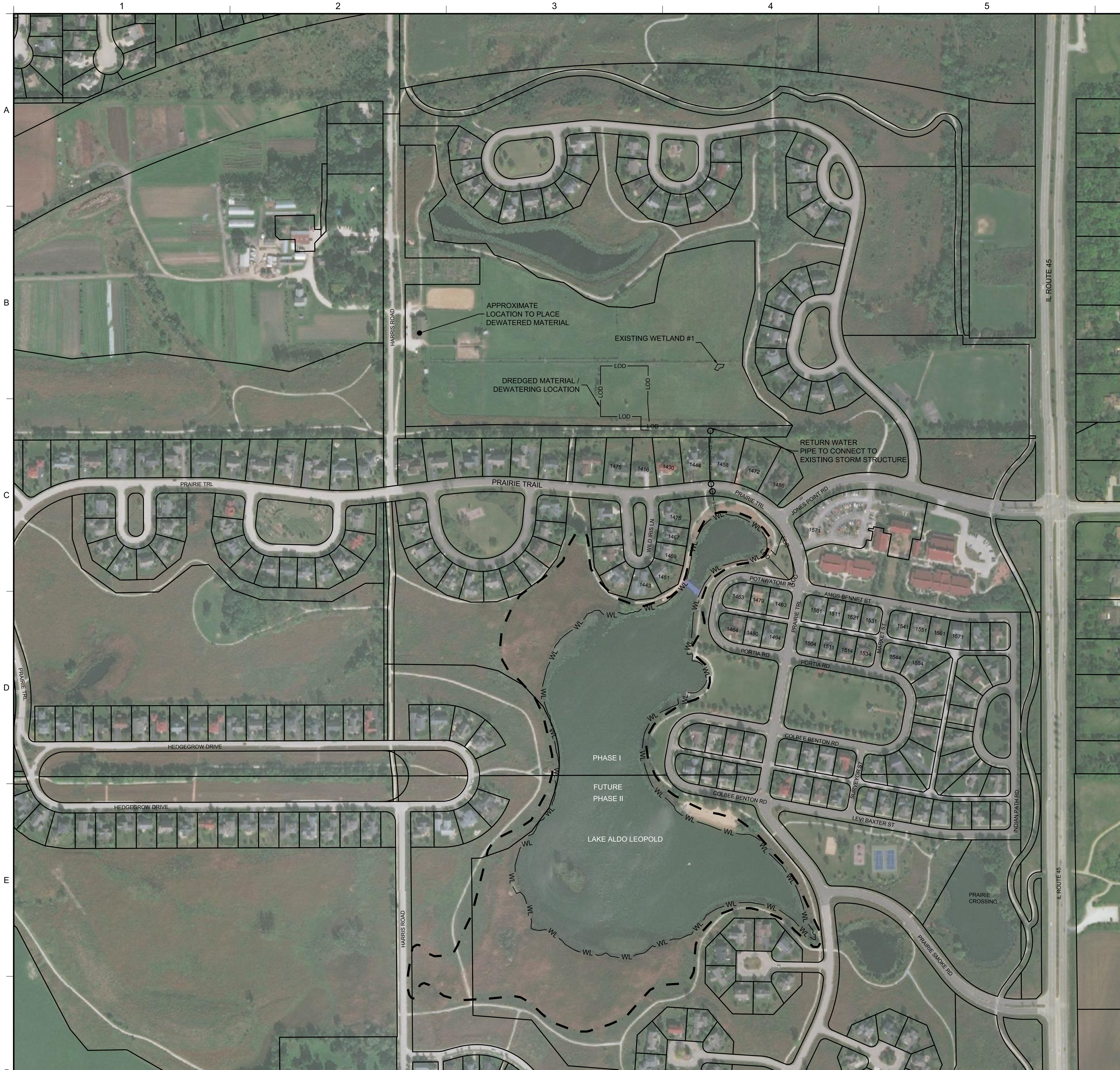
THIS DRAWING MAY NOT BE ISSUED FOR PROJECT TENDER OR CONSTRUCTION, UNLESS SEALED.

SIGNATURE

DATE

DRAFT

DESIGN BY:	DATE: JANUARY 2020
DRAWN BY:	PROJECT NO.: MOW5504
CHECKED BY:	FILE:
REVIEWED BY:	DRAWING NO.: 1
APPROVED BY:	



LEGEND

- PROPERTY LINE
- FLOODPLAIN LINE
- WL —— WL ORDINARY HIGH WATER MARK
- —— LOD —— LIMITS OF DISTURBANCE

NOTE:

1. PHASE I SEDIMENT RECOVERY IS PROPOSED WITH THESE IMPROVEMENT PLANS. PHASE II WILL BE COMPLETED IN THE FUTURE.

0 200 400
SCALE IN FEET

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec consultants

TITLE: GENERAL SITE PLAN

PROJECT: PRAIRIE CROSSING

SITE: VILLAGE OF GRAYSLAKE, ILLINOIS

THIS DRAWING MAY NOT BE ISSUED FOR PROJECT TENDER OR CONSTRUCTION, UNLESS SEALED.

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DESIGN BY:	DATE: JANUARY 2020
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CHECKED BY:	FILE:
REVIEWED BY:	DRAWING NO.: 2
APPROVED BY:	

LEGEND

UPLAND EXISTING MAJOR CONTOUR 5 FT - INTERVAL

UPLAND EXISTING MINOR CONTOUR 1 FT - INTERVAL

PROPERTY LINE

FLOODPLAIN LIMITS

WL —— WL ORDINARY HIGH WATER MARK

—— ST —— EXISTING STORM SEWER

EXISTING WETLAND

SITE BENCHMARK:

INVERT OF THE 27" FLARED END SECTION LOCATED IN THE NORTHEAST QUADRANT OF THE POND.

ELEVATION = 799.74

DATUM: NAVD 88

0 150 300

SCALE IN FEET

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec consultants

TITLE: EXISTING CONDITIONS PLAN

PROJECT: PRAIRIE CROSSING

SITE: VILLAGE OF GRAYSLAKE, ILLINOIS

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SIGNATURE

DATE

DRAFT

DESIGN BY:	DATE: JANUARY 2020
DRAWN BY:	PROJECT NO.: MOW5504
CHECKED BY:	FILE:
REVIEWED BY:	DRAWING NO.:
APPROVED BY:	3

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LEGEND

	UPLAND EXISTING MAJOR CONTOUR 5 FT - INTERVAL
	UPLAND EXISTING MINOR CONTOUR 1 FT - INTERVAL
	FLOODPLAIN LIMITS
WL —— WL	ORDINARY HIGH WATER MARK
ST	EXISTING STORM SEWER
D	PROPOSED DREDGE PIPELINE
	PHASE I SEDIMENT RECOVERY AREA APPROXIMATELY 7, 300 CU.YD.

NOTE:

1. STATIC SEDIMENT DEPTH DATA COLLECTED ON JULY 2017.
2. APPROXIMATE LOCATION OF SILT CURTAIN TO ACCOMMODATE LOCALIZED DREDGING OPERATIONS. CONTRACTOR TO PROVIDE DREDGING SEQUENCE PRIOR TO MOBILIZATION.

0 50 100
SCALE IN FEET

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec consultants

TITLE: DREDGING PLAN

PROJECT: PRAIRIE CROSSING

SITE: VILLAGE OF GRAYSLAKE, ILLINOIS

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SIGNATURE

DATE

DRAFT

DESIGN BY:	DATE: JANUARY 2020
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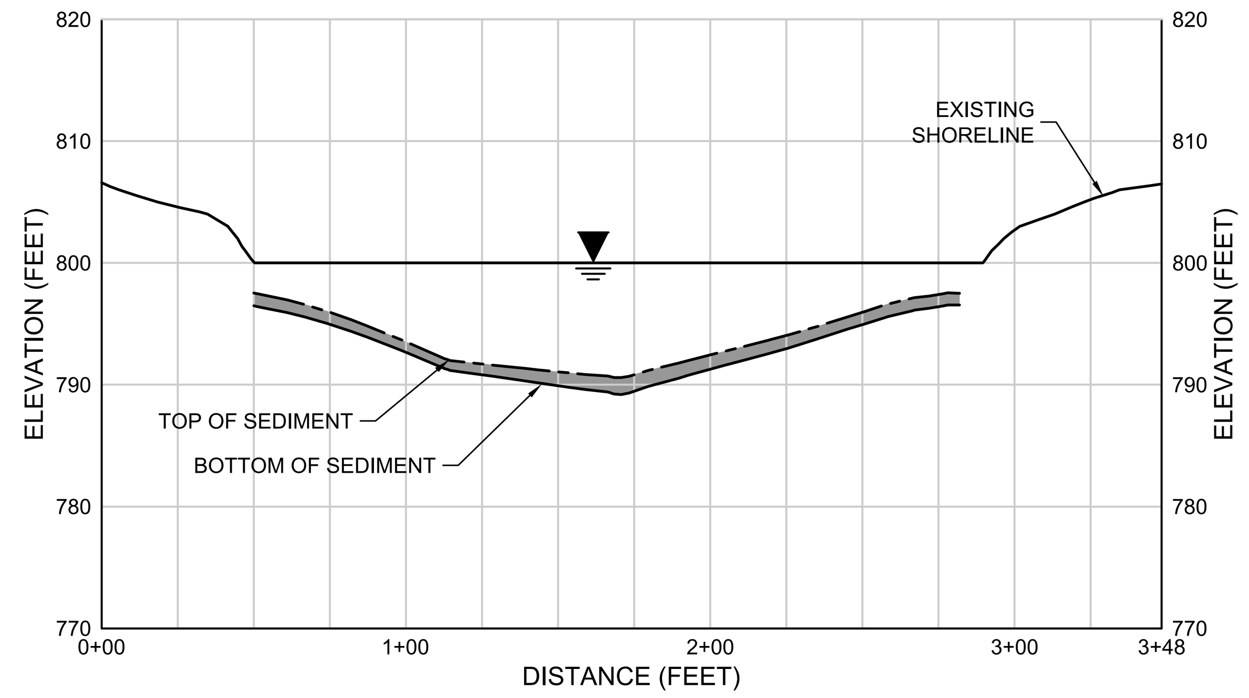
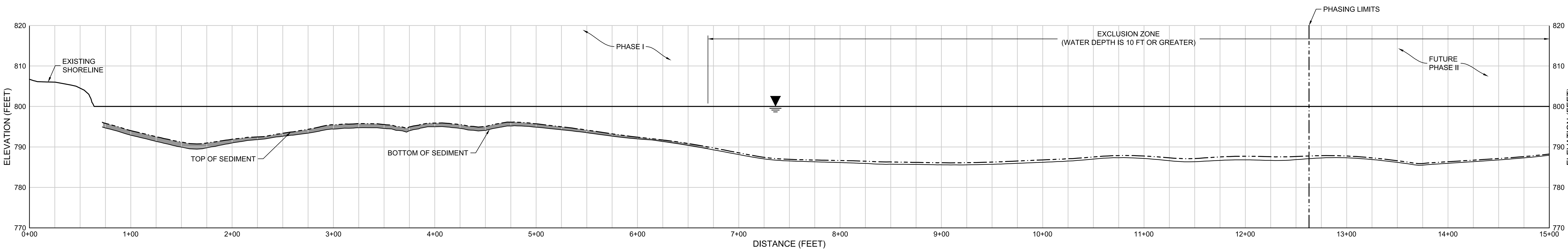
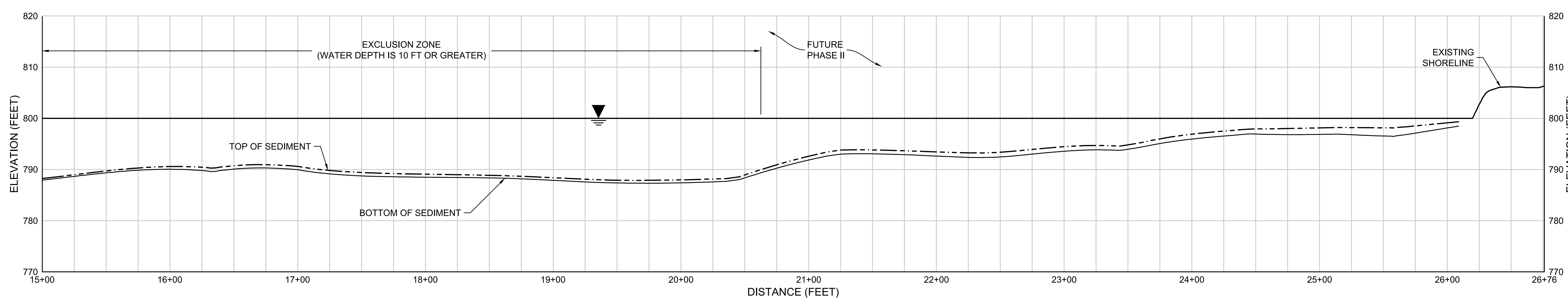
CHECKED BY:	FILE:
REVIEWED BY:	DRAWING NO.:
APPROVED BY:	4



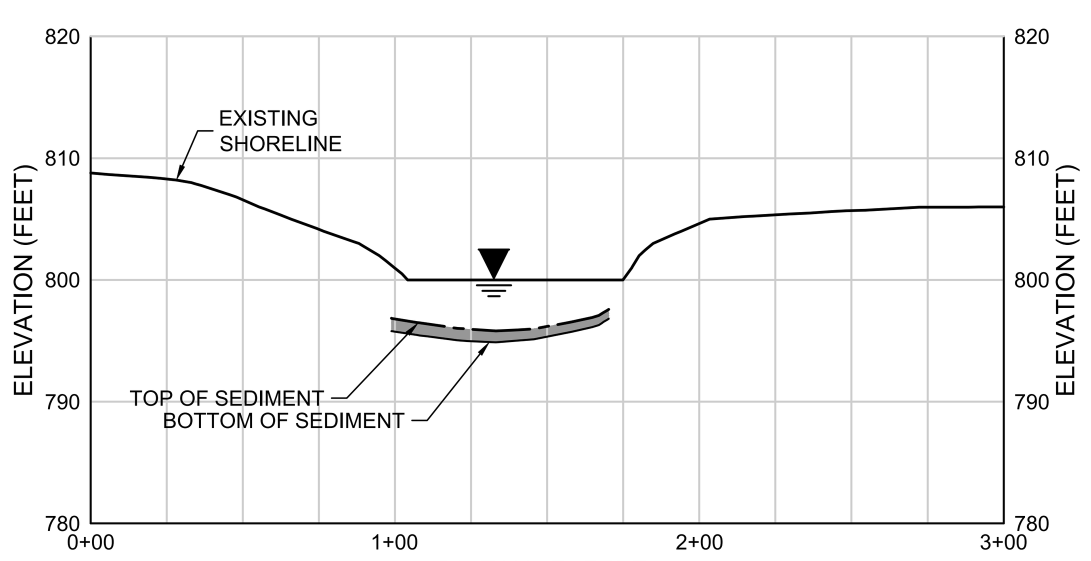
A PROFILE
HORIZONTAL: 1" =50'
VERTICAL: 1" =12'



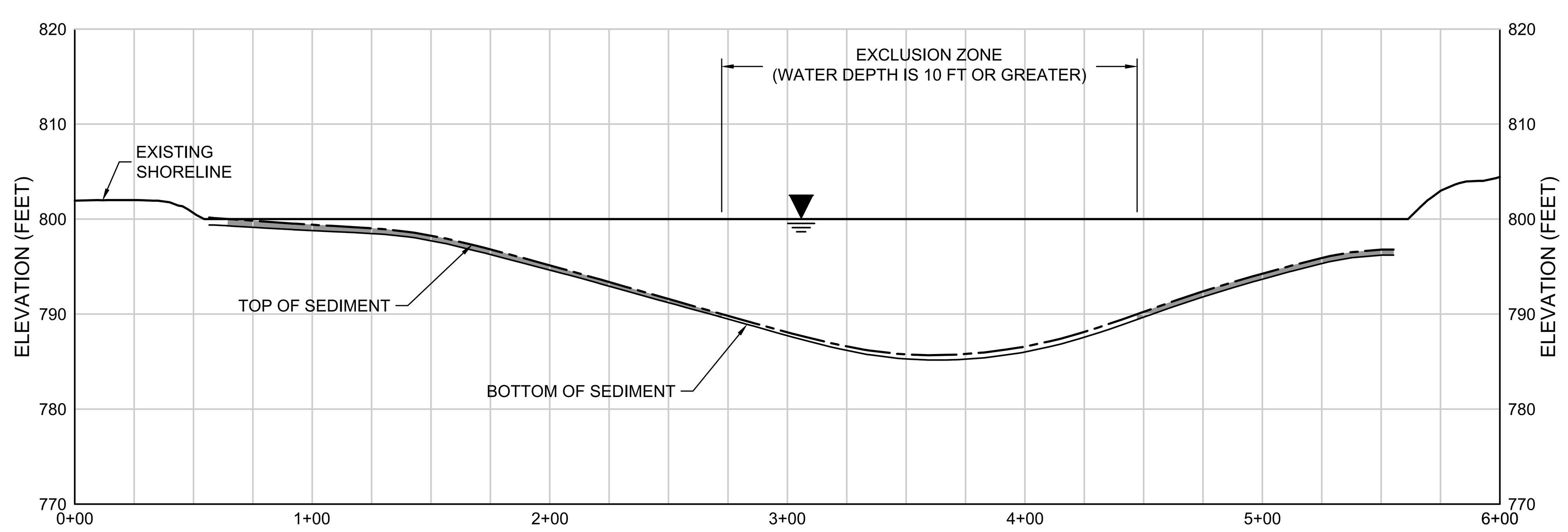
B PROFILE
HORIZONTAL: 1" =50'
VERTICAL: 1" =12'



B PROFILE
HORIZONTAL: 1" =50'
VERTICAL: 1" =12'



C PROFILE
HORIZONTAL: 1" =50'
VERTICAL: 1" =12'



D PROFILE
HORIZONTAL: 1" =50'
VERTICAL: 1" =12'

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec consultants

TITLE: CROSS - SECTIONS

PROJECT: PRAIRIE CROSSING

SITE: VILLAGE OF GRAYSLAKE, ILLINOIS

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DATE

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DESIGN BY:	DATE: JANUARY 2020
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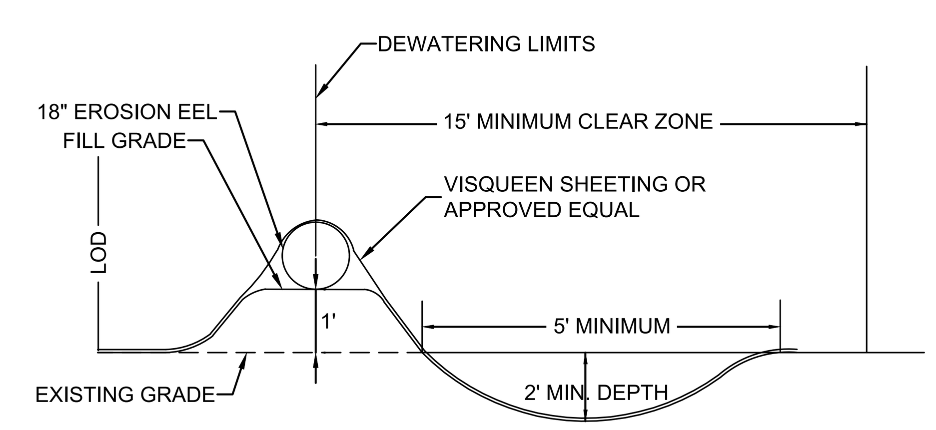
CHECKED BY:	FILE:
REVIEWED BY:	DRAWING NO.: 5
APPROVED BY:	

SEE SHEET 4
FOR CONTINUATION

0 30 60
SCALE IN FEET

LEGEND

- UPLAND EXISTING MAJOR CONTOUR 5 FT - INTERVAL
- UPLAND EXISTING MINOR CONTOUR 1 FT - INTERVAL
- PROPOSED GRADE
- FLOODPLAIN LINE
- WL — WL: ORDINARY HIGH WATER LINE
- ST: EXISTING STORM SEWER
- D: PROPOSED DREDGE PIPELINE
- LOD: LIMITS OF DISTURBANCE



NOTE: RETURN WATER CHANNEL LINED WITH NAG DS 75 EROSION CONTROL BLANKET

CROSS SECTION A-A

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec
consultants

TITLE: PROPOSED GRADING PLAN

PROJECT: PRAIRIE CROSSING

SITE: VILLAGE OF GRAYSLAKE, ILLINOIS

THIS DRAWING MAY NOT BE ISSUED FOR PROJECT TENDER OR CONSTRUCTION, UNLESS SEALED.

SIGNATURE

DATE

DRAFT

DESIGN BY:
DRAWN BY:
CHECKED BY:
REVIEWED BY:
APPROVED BY:

DATE: JANUARY 2020
PROJECT NO.: MOW5504
FILE:
DRAWING NO.: 6

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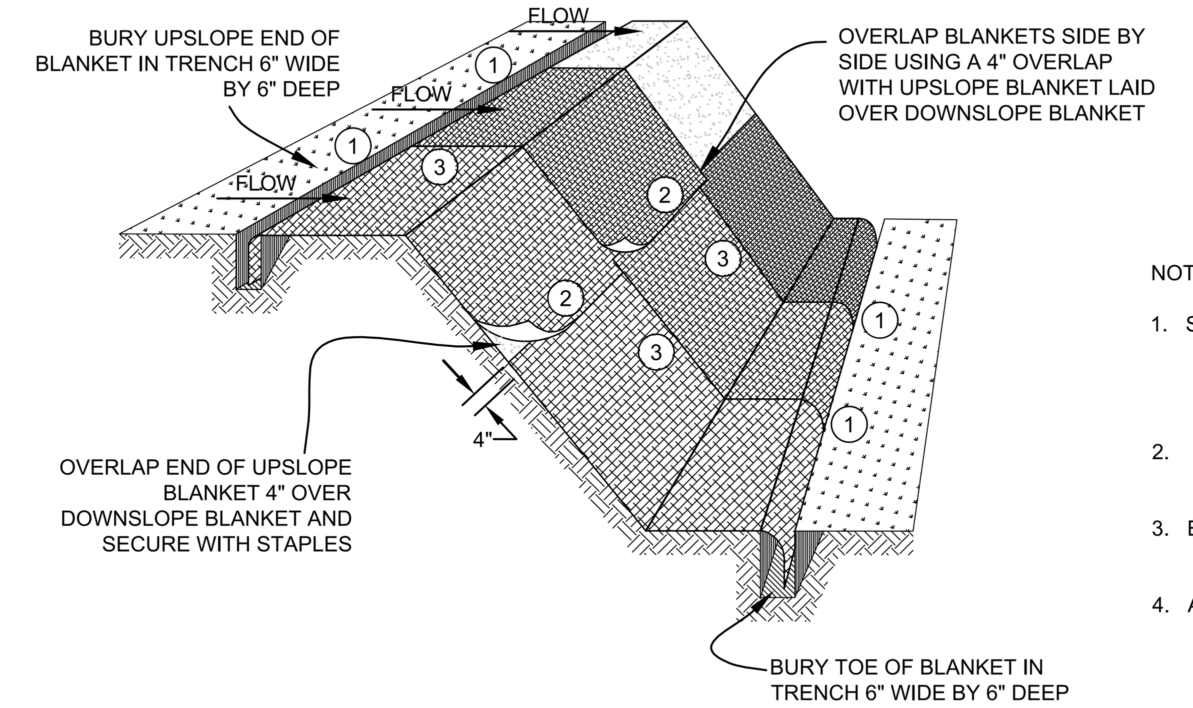
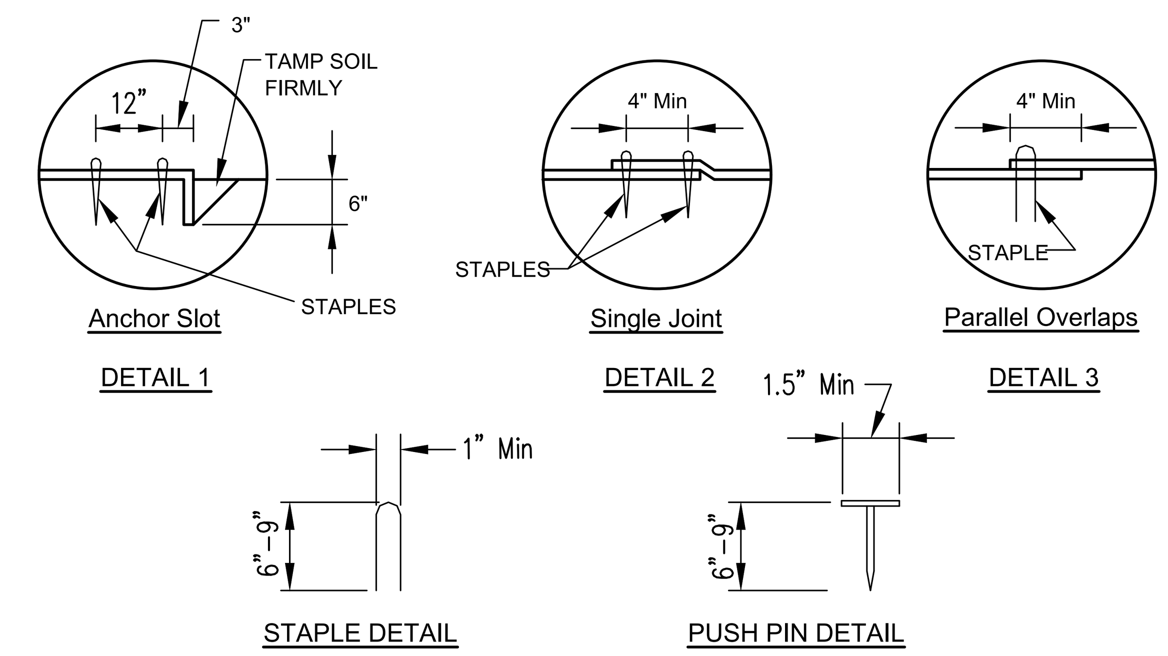


NOTES:

1. STAPLES SHALL BE PLACED IN A DIAMOND PATTERN AT 2 PER S.Y. FOR STICHED BLANKETS. NON-STICHED SHALL USE 4 STAPLES PER S.Y. OF MATERIAL. THIS EQUATES TO 200 STAPLES WITH STICHED BLANKET AND 400 STAPELS WITH NON-STICHED BLANKET PER 100 S.Y. OF MATERIAL.
2. STAPLE OR PUSH PIN LENGTHS SHALL BE SELECTED BASED ON SOIL TYPE AND CONDITIONS. (MINIMUM STAPLE LENGTH IS 6")
3. EROSION CONTROL MATERIAL SHALL BE PLACED IN CONTACT WITH THE SOIL OVER A PREPARED SEEDBED.
4. ALL ANCHOR SLOTS SHALL BE STAPLED AT APPROXIMATELY 12" INTERVALS.

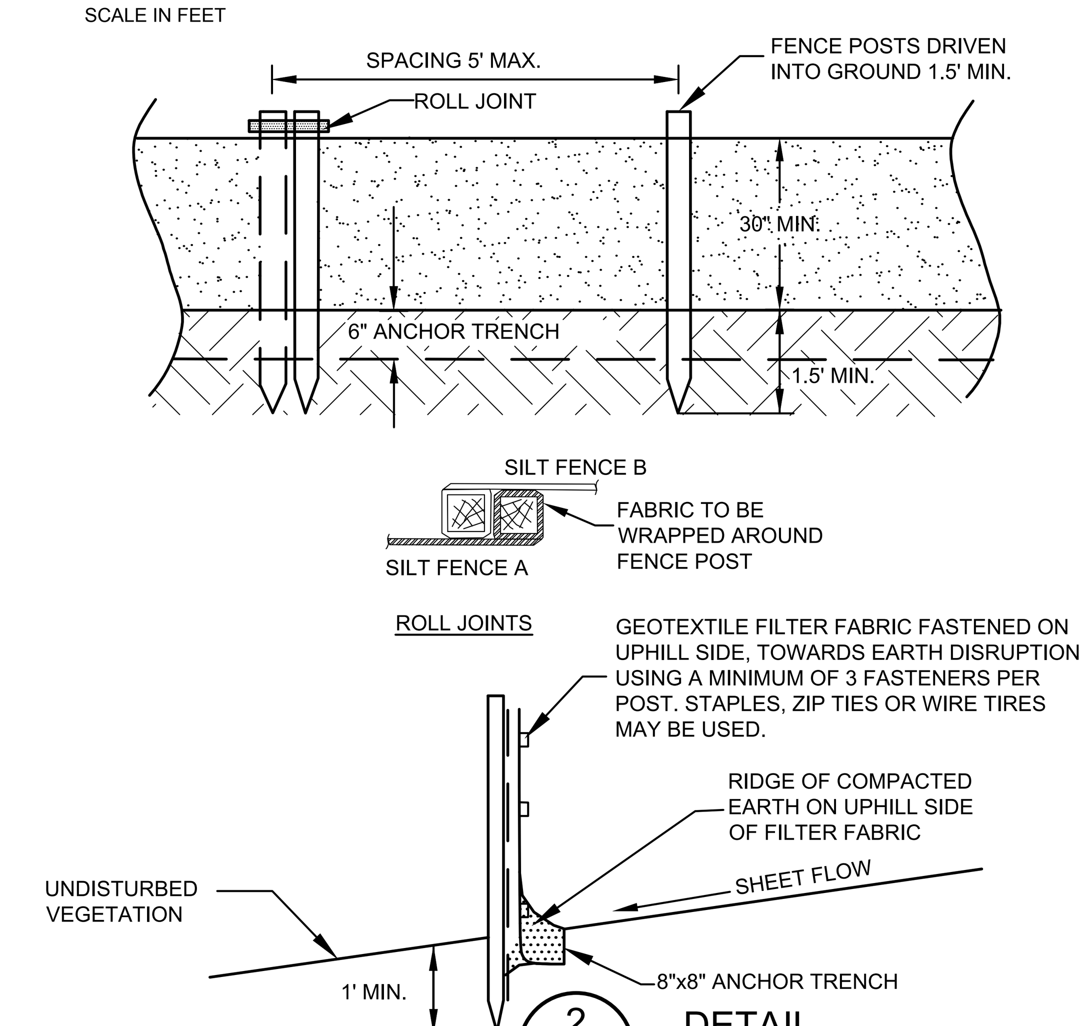


3 - DETAIL
EROSION CONTROL BLANKET
SCALE: N.T.S.

CONSTRUCTION SEQUENCE

1. STAKE THE LIMITS OF DISTURBANCE AS SHOWN ON THE SESC DRAWINGS.
2. INSTALLATION OF SESC MEASURES.
   a. SELECTIVE VEGETATION REMOVAL FOR SILT FENCE INSTALLATION ;
   b. SILT FENCE INSTALLATION;
   c. CONSTRUCTION FENCING AROUND AREAS NOT TO BE DISTURBED;
   d. STABILIZED CONSTRUCTION ENTRANCE;
3. CONSTRUCT SEDIMENT TRAPPING DEVICES WHERE REQUIRED (SEDIMENT TRAPS, BASINS) .
4. STRIP TOPSOIL, STOCKPILE TOPSOIL AND BEGIN GRADING WORK IN DEWATERING AREA.
5. TEMPORARILY STABILIZE TOPSOIL STOCKPILES WHERE REQUIRED (SEED AND SILT FENCE AROUND TOE OF SLOPE) .
6. LAY DREDGING PIPES AS SHOWN IN THE SESC PLAN.
7. INSTALL HYDRAULIC DREDGING SYSTEM FOR PHASE I DREDGING WORK.
8. INSTALL STORM SEWER, SANITARY SEWER, WATER AND ASSOCIATED INLET & OUTLET PROTECTION WHERE REQUIRED .
9. PERMANENTLY STABILIZE SLOPES STEEPER THAN 3H:1V WITH SEED AND EROSION CONTROL BLANKET. DEWATERING AREA TO BE STABILIZED AFTER COMPLETION OF PHASE I DREDGING AND DEWATERING WORK.
10. RESTORE DISTURBED AREA TO ORIGINAL CONDITION.
11. REMOVE ALL TEMPORARY SESC MEASURES AFTER THE SITE IS STABILIZED WITH VEGETATION.
12. PERMANENTLY STABILIZE ANY AREAS DISTURBED BY THE REMOVAL OF TEMPORARY BMPS.

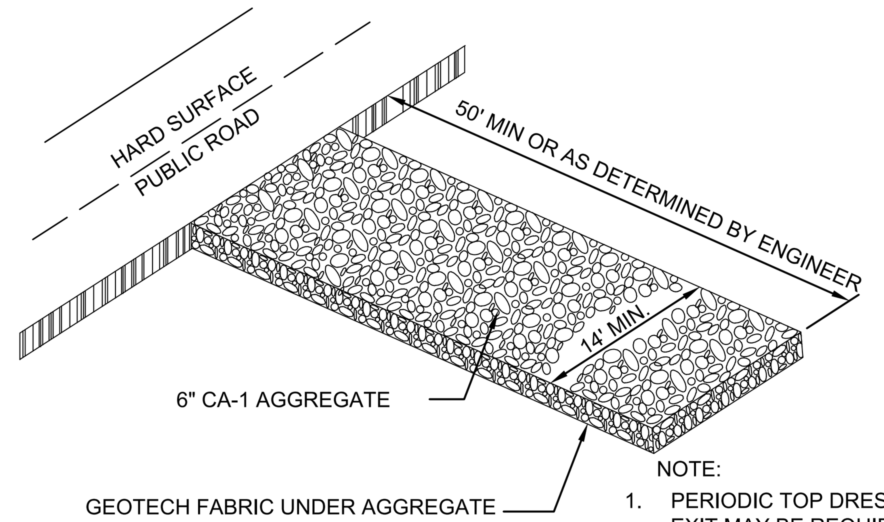
NOTE: CONTRACTOR IS RESPONSIBLE TO MEET SESC REQUIREMENTS.



2 - DETAIL
SILT FENCE
SCALE: NTS

LEGEND

	UPLAND EXISTING MAJOR CONTOUR 5 FT - INTERVAL
	UPLAND EXISTING MINOR CONTOUR 1 FT - INTERVAL
	PROPOSED CONTOURS 1 FT - INTERVAL
	FLOODPLAIN LIMITS
— WL — WL —	ORDINARY HIGH WATER MARK
— ST —	EXISTING STORM SEWER
— D —	PROPOSED DREDGE PIPELINE
— SF —	SILT FENCE
— LOD —	LIMITS OF DISTURBANCE TOTAL = 1.18 AC
	EROSION CONTROL BLANKET
	TEMPORARY PORTABLE CONSTRUCTION MAT



NOTE:
1. PERIODIC TOP DRESSING OF THE CONSTRUCTION EXIT MAY BE REQUIRED TO PREVENT TRACK OUT.

1 - DETAIL
TEMPORARY STABILIZED CONSTRUCTION ACCESS
SCALE: N.T.S.

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec consultants

TITLE: SOIL EROSION AND SEDIMENT CONTROL

PROJECT: PRAIRIE CROSSING

SITE: VILLAGE OF GRAYSLAKE, ILLINOIS

THIS DRAWING MAY NOT BE ISSUED FOR PROJECT TENDER OR CONSTRUCTION, UNLESS SEALED.

SIGNATURE

DATE

DRAFT

DESIGN BY:	DATE: JANUARY 2020
DRAWN BY:	PROJECT NO.: MOW5504
CHECKED BY:	FILE:
REVIEWED BY:	DRAWING NO.:
APPROVED BY:	7

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SOIL EROSION AND SEDIMENTATION CONTROL GENERAL NOTES:

1. ALL VEGETATIVE AND STRUCTURAL EROSION CONTROL PRACTICES SHALL BE CONSTRUCTED AND MAINTAINED IN ACCORDANCE WITH THE MINIMUM STANDARDS AND SPECIFICATIONS OF THE "ILLINOIS URBAN MANUAL".

2. MAINTENANCE AND REPLACEMENT OF EROSION CONTROL ITEMS, WHEN DIRECTED BY THE OWNER, SHALL BE CONSIDERED AS INCIDENTAL TO THE CONTRACT.

3. INSTALL ALL PERIMETER SILT FENCING PRIOR TO ANY CLEARING OR GRADING. ONSITE SEDIMENT CONTROL MEASURES AS SHOWN AND SPECIFIED BY THIS EROSION AND SEDIMENTATION CONTROL PLAN SHALL BE CONSTRUCTED AND FUNCTIONAL PRIOR TO INITIATING CLEARING, GRADING, STRIPPING, EXCAVATION OR FILLING ACTIVITIES ON THE SITE.

4. DISTURBED AREA SHALL BE STABILIZED BY SEEDING AT A MINIMUM, WITHIN SEVEN (7) DAYS OF COMPLETION OF DISTURBANCE UNLESS THE AREA WILL BE DISTURBED WITHIN FOURTEEN (14) DAYS AND GRASS SOWN AS NECESSARY TO RE- ESTABLISH VEGETATION FOR CONTROL OF SILTATION AND SOIL EROSION.

5. TEMPORARY SEED MIXTURE SHALL BE APPLIED AT 64 LBS/ACRE.

6. TOPSOIL STOCKPILES SHALL BE SEEDED WITHIN SEVEN (7) CALENDAR DAYS OF COMPLETION FOR EROSION CONTROL UNLESS THEY WILL BE DISTURBED WITHIN FOURTEEN (14) CALENDAR DAYS. ALL SOIL STORAGE PILES SHALL BE PROTECTED FROM EROSION WITH SILT FENCE ON THE DOWN SLOPE SIDE OF THE PILES.

7. DUST CONTROL SHALL BE PERFORMED ON A DAILY BASIS USING WATER DISPERSED FROM A TRUCK MOUNTED TANK WITH STANDARD DISCHARGE HEADER TO PROVIDE A UNIFORM RATE OF APPLICATION.

8. TEMPORARY GRAVEL CONSTRUCTION ENTRANCES SHALL BE MAINTAINED, ADJUSTED OR RELOCATED AS NECESSARY TO PREVENT SEDIMENT FROM BEING TRACKED ONTO PUBLIC ROADWAYS. ANY SEDIMENT REACHING A PUBLIC ROAD SHALL BE REMOVED BY SHOVELING OR STREET CLEANING BEFORE THE END OF EACH WORKING DAY.

9. ANY LOOSE MATERIAL THAT IS DEPOSITED IN THE FLOW LINE OF ANY GUTTER OR DRAINAGE STRUCTURE DURING CONSTRUCTION OPERATIONS SHALL BE REMOVED AT THE CLOSE OF EACH WORKING DAY.

LAKE COUNTY STORMWATER MANAGEMENT COMMISSION
SOIL EROSION AND SEDIMENT CONTROL CONSTRUCTION NOTES

A. SEDIMENT CONTROL MEASURES SHALL BE INSTALLED PRIOR TO THE COMMENCEMENT OF HYDROLOGIC DISTURBANCE OF UPLAND AREAS.

B. FOR THOSE DEVELOPMENTS THAT REQUIRE A DESIGNATED EROSION CONTROL INSPECTOR (DECI), INSPECTIONS AND DOCUMENTATION SHALL BE PERFORMED, AT A MINIMUM:

- UPON COMPLETION OF SEDIMENT AND RUNOFF CONTROL MEASURES (INCLUDING PERIMETER CONTROLS AND DIVERSIONS), PRIOR TO PROCEEDING WITH ANY OTHER EARTH DISTURBANCE OR GRADING.
- AFTER EVERY SEVEN (7) CALENDAR DAYS OR STORM EVENT WITH GREATER THAN 0.5 INCH OF RAINFALL OR LIQUID EQUIVALENT PRECIPITATION.

C. SOIL DISTURBANCE SHALL BE CONDUCTED IN SUCH A MANNER AS TO MINIMIZE EROSION. IF STRIPPING, CLEARING, GRADING, OR LANDSCAPING ARE TO BE DONE IN PHASES, THE PERMITTEE SHALL PLAN FOR APPROPRIATE SOIL EROSION AND SEDIMENT CONTROL MEASURES.

D. A STABILIZED MAT OF CRUSHED STONE MEETING IDOT GRADATION CA 1 UNDERLAIN WITH FILTER FABRIC AND IN ACCORDANCE WITH THE ILLINOIS URBAN MANUAL, OR OTHER APPROPRIATE MEASURE(S) AS APPROVED BY THE ENFORCEMENT OFFICER, SHALL BE INSTALLED AT ANY POINT WHERE TRAFFIC WILL BE ENTERING OR LEAVING A CONSTRUCTION SITE. SEDIMENT OR SOIL REACHING AN IMPROVED PUBLIC RIGHT OF WAY, STREET, ALLEY OR PARKING AREA SHALL BE REMOVED BY SCRAPING OR STREET CLEANING AS ACCUMULATIONS WARRANT AND TRANSPORTED TO A CONTROLLED SEDIMENT DISPOSAL AREA.

E. TEMPORARY DIVERSIONS SHALL BE CONSTRUCTED AS NECESSARY TO DIRECT ALL RUNOFF FROM HYDROLOGICALLY DISTURBED AREAS TO AN APPROPRIATE SEDIMENT TRAP OR BASIN.

F. DISTURBED AREAS SHALL BE STABILIZED WITH TEMPORARY OR PERMANENT MEASURES WITHIN SEVEN (7) CALENDAR DAYS FOLLOWING THE END OF ACTIVE HYDROLOGIC DISTURBANCE OR REDISTURBANCE.

G. ALL STOCKPILES SHALL HAVE APPROPRIATE MEASURES TO PREVENT EROSION. STOCKPILES SHALL NOT BE PLACED IN FLOOD PRONE AREAS OR WETLANDS AND DESIGNATED BUFFERS.

H. SLOPES STEEPER THAN 3H:1V SHALL BE STABILIZED WITH APPROPRIATE MEASURES AS APPROVED BY THE ENFORCEMENT OFFICER. EROSION CONTROL BLANKET MEETING THE REQUIREMENTS OF ARTICLE 1081.10 OF THE IDOT STANDARD SPECIFICATIONS SHALL BE INSTALLED ON THE AREAS SHOWN IN THE SESC PLAN DRAWING.

I. APPROPRIATE EROSION CONTROL BLANKET SHALL BE INSTALLED ON ALL INTERIOR DETENTION BASIN SIDE SLOPES BETWEEN THE NORMAL WATER LEVEL AND HIGH WATER LEVEL.

J. STORM SEWERS THAT ARE OR WILL BE FUNCTIONING DURING CONSTRUCTION SHALL BE PROTECTED BY AN APPROPRIATE SEDIMENT CONTROL MEASURE.

K. IF DEWATERING SERVICES ARE USED, ADJOINING PROPERTIES AND DISCHARGE LOCATIONS SHALL BE PROTECTED FROM EROSION AND SEDIMENTATION. DISCHARGES SHALL BE ROUTED THROUGH AN APPROVED ANIONIC POLYMER DEWATERING SYSTEM OR A SIMILAR MEASURE AS APPROVED BY THE ENFORCEMENT OFFICER. DEWATERING SYSTEMS SHOULD BE INSPECTED DAILY DURING OPERATIONAL PERIODS. THE ENFORCEMENT OFFICER, OR APPROVED REPRESENTATIVE, MUST BE PRESENT AT THE COMMENCEMENT OF DEWATERING ACTIVITIES.

L. IF INSTALLED SOIL EROSION AND SEDIMENT CONTROL MEASURES DO NOT MINIMIZE SEDIMENT LEAVING THE DEVELOPMENT SITE, ADDITIONAL MEASURES SUCH AS ANIONIC POLYMERS OR FILTRATION SYSTEMS MAY BE REQUIRED BY THE ENFORCEMENT OFFICER.

M. ALL TEMPORARY AND PERMANENT EROSION CONTROL MEASURES MUST BE MAINTAINED AND REPAIRED AS NEEDED. THE PROPERTY OWNER SHALL BE ULTIMATELY RESPONSIBLE FOR MAINTENANCE AND REPAIR.

N. ALL TEMPORARY SEDIMENT CONTROL MEASURES SHALL BE REMOVED WITHIN 30 DAYS AFTER FINAL SITE STABILIZATION IS ACHIEVED OR AFTER THE TEMPORARY MEASURES ARE NO LONGER NEEDED.

O. THE EROSION CONTROL MEASURES INDICATED ON THE PLANS ARE THE MINIMUM REQUIREMENTS. ADDITIONAL MEASURES MAY BE REQUIRED, AS DIRECTED BY THE ENGINEER, ENFORCEMENT OFFICER, OR OTHER GOVERNING AGENCY.

STANDARD SPECIFICATIONS

GENERAL CONDITIONS
CONTRACTOR ACKNOWLEDGES AND AGREES THAT THE USE AND RELIANCE OF THESE PLANS AND SPECIFICATIONS IS SUFFICIENT CONSIDERATION FOR
CONTRACTOR'S COVENANTS STATED HEREIN.

DEFINITION OF TERMS
a. "CLIENT" SHALL MEAN PRAIRIE CROSSING HOME OWNERS ASSOCIATION, WHICH IS THE PERSON OR ENTITY WITH WHOM GEOSYNTEC CONSULTANTS HAS CONTRACTED WITH TO PREPARE CIVIL ENGINEERING PLANS AND SPECIFICATIONS.
b. "ENGINEER" SHALL MEAN GEOSYNTEC CONSULTANTS, A CIVIL ENGINEERING CONSULTANT ON THE SUBJECT PROJECT.
c. "PLANS AND SPECIFICATIONS" SHALL MEAN THE CIVIL ENGINEERING PLANS AND SPECIFICATIONS PREPARED BY THE ENGINEER, WHICH MAY BE A PART OF THE CONTRACT DOCUMENTS FOR THE SUBJECT PROJECT.
d. "CONTRACTOR" SHALL MEAN ANY PERSON OR ENTITY PERFORMING ANY WORK DESCRIBED IN THE PLANS AND SPECIFICATIONS.
e. "JURISDICTIONAL GOVERNMENTAL ENTITY" SHALL MEAN ANY MUNICIPAL, COUNTY, STATE OR FEDERAL UNIT OF GOVERNMENT FROM WHOM AN APPROVAL, PERMIT AND/OR REVIEW IS REQUIRED FOR ANY ASPECT OF THE SUBJECT PROJECT.

INTENT OF THE PLANS AND SPECIFICATIONS
THE INTENT OF THE PLANS AND SPECIFICATIONS IS TO SET FORTH CERTAIN REQUIREMENTS OF PERFORMANCE, TYPE OF EQUIPMENT AND STRUCTURES, AND STANDARDS OF MATERIALS AND CONSTRUCTION. THEY MAY ALSO IDENTIFY LABOR AND MATERIALS, EQUIPMENT AND TRANSPORTATION NECESSARY FOR THE PROPER EXECUTION OF THE WORK BUT ARE NOT INTENDED TO BE INFINITELY DETERMINED SO AS TO INCLUDE MINOR ITEMS OBVIOUSLY REQUIRED AS PART OF THE WORK. THE PLANS AND SPECIFICATIONS REQUIRE NEW MATERIAL AND EQUIPMENT UNLESS OTHERWISE INDICATED, AND TO REQUIRE COMPLETE PERFORMANCE OF THE WORK IN SPITE OF OMISSIONS OF SPECIFIC REFERENCES TO ANY MINOR COMPONENT PART. IT IS NOT INTENDED, HOWEVER, THAT MATERIALS OR WORK NOT COVERED BY OR PROPERLY INFERRED FROM ANY HEADING, BRANCH, CLASS OR TRADE OF THE SPECIFICATIONS SHALL BE SUPPLIED UNLESS DISTINCTLY SO NOTED. MATERIALS OR WORK DESCRIBED IN WORDS, WHICH SO APPLIED HAVE A WELL-KNOWN TECHNICAL OR TRADE MEANING, SHALL BE HELD TO REFER TO SUCH RECOGNIZED STANDARDS.

INTERPRETATION OF PLANS AND SPECIFICATIONS
a. THE CLIENT AND/OR CONTRACTOR SHALL PROMPTLY REPORT ANY ERRORS OR AMBIGUITIES IN THE PLANS AND SPECIFICATIONS TO THE ENGINEER. QUESTIONS AS TO MEANING OF PLANS AND SPECIFICATIONS SHALL BE INTERPRETED BY THE ENGINEER, WHOSE DECISION SHALL BE FINAL AND BINDING ON ALL PARTIES CONCERNED.
b. THE ENGINEER WILL PROVIDE THE CLIENT WITH SUCH INFORMATION AS MAY BE REQUIRED TO SHOW REVISED OR ADDITIONAL DETAILS OF CONSTRUCTION.
c. SHOULD ANY DISCREPANCIES OR CONFLICTS ON THE PLANS OR SPECIFICATIONS BE DISCOVERED EITHER PRIOR TO OR AFTER AWARD OF THE CONTRACT, THE ENGINEER'S ATTENTION SHALL BE CALLED TO THE SAME BEFORE THE WORK IS BEGUN THEREON AND THE PROPER CORRECTIONS MADE. NEITHER THE CLIENT NOR THE CONTRACTOR MAY TAKE ADVANTAGE OF ANY ERROR OR OMISSIONS IN THE PLANS AND SPECIFICATIONS. THE ENGINEER WILL PROVIDE INFORMATION WHEN ERRORS OR OMISSIONS ARE DISCOVERED.

GOVERNING BODIES
ALL WORKS HEREIN PROPOSED SHALL BE COMPLETED IN ACCORDANCE WITH ALL REQUIREMENTS OF ANY JURISDICTIONAL GOVERNMENTAL ENTITY, AND ALL SUCH PERTINENT LAWS, DIRECTIVES, ORDINANCES AND THE LIKE SHALL BE CONSIDERED TO BE A PART OF THESE SPECIFICATIONS. IF A DISCREPANCY IS NOTED BETWEEN THE PLANS AND SPECIFICATIONS AND REQUIREMENTS OF ANY JURISDICTIONAL GOVERNMENTAL ENTITY, THE CLIENT AND/OR THE CONTRACTOR SHALL IMMEDIATELY NOTIFY THE ENGINEER IN WRITING.

LOCATION OF UNDERGROUND FACILITIES AND UTILITIES
WHEN THE PLANS AND SPECIFICATIONS INCLUDE INFORMATION PERTAINING TO THE LOCATION OF EXISTING UNDERGROUND FACILITIES AND UTILITIES (INCLUDING BUT NOT LIMITED TO WATER MAINS, SANITARY SEWERS, STORM SEWERS, ELECTRIC, TELEPHONE, GAS AND CABLE TV LINES), SUCH INFORMATION REPRESENTS ONLY THE OPINION OF THE ENGINEER AS TO THE APPROXIMATE LOCATION AND ELEVATION OF SUCH FACILITIES AND UTILITIES. AT THE LOCATIONS WHEREIN DETAILED POSITIONS OF THESE FACILITIES AND UTILITIES BECOME NECESSARY TO THE NEW CONSTRUCTION, INCLUDING ALL POINTS OF CONNECTION, THE CONTRACTOR SHALL FURNISH ALL LABOR AND TOOLS TO VERIFY OR DEFINITELY ESTABLISH THE HORIZONTAL LOCATION, ELEVATION, SIZE AND MATERIAL (IF APPROPRIATE) OF THE FACILITIES AND UTILITIES. THE CONTRACTOR SHALL NOTIFY THE ENGINEER AT LEAST 48 HOURS PRIOR TO CONSTRUCTION IF ANY DISCREPANCIES IN EXISTING UTILITY INFORMATION OR CONFLICTS WITH EXISTING UTILITIES EXIST. THE ENGINEER ASSUMES NO RESPONSIBILITY WHATEVER WITH RESPECT TO THE SUFFICIENCY OR ACCURACY OF THE INFORMATION SHOWN ON THE PLANS AND SPECIFICATIONS RELATIVE TO THE LOCATION OF UNDERGROUND FACILITIES AND UTILITIES, NOR THE MANNER IN WHICH THEY ARE REMOVED OR ADJUSTED.
IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY PRIOR TO CONSTRUCTION, TO NOTIFY ALL UTILITY COMPANIES OF THE INTENT TO BEGIN CONSTRUCTION AND TO VERIFY THE ACTUAL LOCATION OF ALL SUCH FACILITIES AND UTILITIES. THE CONTRACTOR SHALL ALSO OBTAIN FROM THE RESPECTIVE UTILITY COMPANIES THE WORKING SCHEDULES FOR REMOVING OR ADJUSTING THESE FACILITIES.

PROTECTION OF TREES
ALL TREES THAT ARE NOT TO BE REMOVED SHALL BE PROTECTED FROM DAMAGE. TREES SHALL NOT BE REMOVED UNLESS REQUESTED TO DO SO IN WRITING BY THE CLIENT.

NOTIFICATION OF OWNERS OF FACILITIES AND UTILITIES
THE CONTRACTOR SHALL NOTIFY ALL APPLICABLE JURISDICTIONAL GOVERNMENTAL ENTITIES OR UTILITY COMPANIES, I.E., WATER, SEWER, ELECTRIC, TELEPHONE, GAS AND CABLE TV PRIOR TO BEGINNING ANY CONSTRUCTION SO THAT SAID ENTITY OR COMPANY CAN ESTABLISH THE LOCATION AND ELEVATION OF UNDERGROUND PIPES, CONDUITS OR CABLES ADJOINING OR CROSSING PROPOSED CONSTRUCTION.

TRAFFIC CONTROL
THE CONTRACTOR SHALL PROVIDE WHEN REQUIRED BY ANY JURISDICTIONAL GOVERNMENTAL ENTITY, ALL SIGNS, EQUIPMENT, AND PERSONNEL NECESSARY TO PROVIDE FOR SAFE AND EFFICIENT TRAFFIC FLOW IN ALL AREAS WHERE THE WORK WILL INTERRUPT, INTERFERE OR CAUSE TO CHANGE IN ANY FORM, THE CONDITIONS OF TRAFFIC FLOW THAT EXISTED PRIOR TO THE COMMENCEMENT OF ANY PORTIONS OF THE WORK. THE CLIENT MAY, AT HIS DISCRETION, REQUIRE THE CONTRACTOR TO FURNISH TRAFFIC CONTROL UNDER THESE OR OTHER CIRCUMSTANCES WHERE IN HIS OPINION IT IS NECESSARY FOR THE PROTECTION OF LIFE AND PROPERTY. EMERGENCY VEHICLE ACCESS SHALL BE MAINTAINED AT ALL TIMES. UNLESS AUTHORIZED BY THE CLIENT OR CLIENT'S CONSTRUCTION REPRESENTATIVE, ALL EXISTING ACCESS POINTS SHALL BE MAINTAINED AT ALL TIMES BY THE CONTRACTOR. THE NEED FOR TRAFFIC CONTROL SHALL BE ANTICIPATED BY THE CLIENT.

WORK AREA
THE CONTRACTOR, HIS AGENTS AND EMPLOYEES AND THEIR EMPLOYEES AND ALL EQUIPMENT, MACHINERY AND VEHICLES SHALL CONFINE THEIR WORK WITHIN THE BOUNDARIES OF THE PROJECT OR WORK AREA SPECIFIED BY THE CLIENT. THE CONTRACTOR SHALL BE SOLELY LIABLE FOR DAMAGE CAUSED BY HIM OR HIS AGENTS AND EMPLOYEES AND THEIR EQUIPMENT, MACHINERY AND VEHICLES ON ADJACENT PROPERTY OR AREAS OUTSIDE DESIGNATED WORK AREAS.

UTILITY POLES
IT SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR TO ARRANGE FOR THE RELOCATION OR BRACING OF EXISTING UTILITY POLES THAT MAY BE WITHIN THE WORKING LIMITS OF THIS CONTRACT. IT IS EXPRESSLY UNDERSTOOD THAT ALL WORK AND COSTS CONNECTED WITH THE MAINTENANCE OF THESE UTILITY POLES, THEIR TEMPORARY RELOCATIONS, ETC., SHALL BE THE RESPONSIBILITY OF THE CLIENT OR THE CONTRACTOR.

RESTORATION
IT IS THE INTENT OF THESE SPECIFICATIONS THAT CLEAN-UP AND FINAL RESTORATION SHALL BE PERFORMED IMMEDIATELY UPON COMPLETION OF EACH PHASE OF THE WORK, BOTH INSIDE AND OUTSIDE THE PROJECT, OR WHEN SO DIRECTED BY THE CLIENT SO THAT THESE AREAS WILL BE RESTORED AS NEARLY AS POSSIBLE TO THEIR ORIGINAL CONDITION OR BETTER, AND SHALL INCLUDE BUT NOT BE LIMITED TO, RESTORATION OF MAINTAINED LAWNS AND RIGHTS-OF-WAY, ROADWAYS, DRIVEWAYS, SIDEWALKS, DITCHES, BUSHES, HEDGES, TREES, SHRUBS, FENCES, MAILBOXES, SEWERS, DRAIN TILES, WATER MAINS, ETC.

CLEANING UP
THE CONTRACTOR SHALL AT ALL TIMES KEEP THE PREMISES FREE FROM ACCUMULATIONS OF WASTE MATERIAL OR RUBBISH CAUSED BY HIS EMPLOYEES OR WORK, AND AT THE COMPLETION OF THE WORK HE SHALL REMOVE ALL HIS RUBBISH, TOOLS, SCAFFOLDING AND SURPLUS MATERIALS AND SHALL LEAVE HIS WORK "BROOM CLEAN" OR ITS EQUIVALENT, UNLESS MORE EXACTLY SPECIFIED.

ROAD CLEANING
THE CONTRACTOR SHALL MAINTAIN ROADWAYS ADJOINING THE PROJECT SITE FREE FROM MUD AND DEBRIS AT ALL TIMES. IF MUD AND/OR DEBRIS IS CARRIED ONTO THE ROADWAYS FROM VEHICLES ENTERING ONTO THE HIGHWAY FROM EITHER THE CONTRACTOR'S TRUCKS, HIS EMPLOYEES' VEHICLES, OR HIS MATERIAL SUPPLIERS, THE CONTRACTOR SHALL IMMEDIATELY REMOVE SAID MUD AND/OR DEBRIS.

SAFETY AND PROTECTION
THE CONTRACTOR SHALL BE SOLELY AND COMPLETELY RESPONSIBLE FOR THE CONDITIONS OF THE JOB SITE, INCLUDING SAFETY OF ALL PERSONS AND PROPERTY DURING PERFORMANCE OF THE WORK. THIS REQUIREMENT SHALL APPLY CONTINUOUSLY AND NOT BE LIMITED TO NORMAL WORKING HOURS. THE CONTRACTOR SHALL COMPLY WITH ALL APPLICABLE LAWS AND REGULATIONS RELATING TO THE SAFETY OF PERSONS OR PROPERTY, OR TO THE PROTECTION OF PERSONS OR PROPERTY FROM DAMAGE, INJURY, OR LOSS; AND SHALL ERECT AND MAINTAIN ALL NECESSARY SAFEGUARDS FOR SUCH SAFETY AND PROTECTION. CONTRACTOR'S DUTIES AND RESPONSIBILITIES FOR SAFETY AND FOR PROTECTION OF THE WORK SHALL CONTINUE UNTIL SUCH TIME AS ALL WORK IS COMPLETED AND THE ENGINEER HAS NOTIFIED CONTRACTOR THAT THE WORK IS ACCEPTABLE. THE DUTIES OF THE ENGINEER DO NOT INCLUDE REVIEW OF THE ADEQUACY OF EITHER THE CONTRACTOR'S OR THE GENERAL PUBLIC'S SAFETY IN, ON, OR NEAR THE CONSTRUCTION SITE.

HOLD HARMLESS
TO THE FULLEST EXTENT PERMITTED BY LAW, ANY CONTRACTOR; MATERIAL SUPPLIER OR OTHER ENTITY BY USE OF THESE PLANS AND SPECIFICATIONS HEREBY WAIVES ANY RIGHT OF CONTRIBUTION AND AGREES TO INDEMNIFY, DEFEND, SAVE AND HOLD HARMLESS THE CLIENT AND ENGINEER AND ITS AGENTS, EMPLOYEES AND CONSULTANTS FROM AND AGAINST ALL MANNER OF CLAIMS, CAUSES OF ACTION, DAMAGES, LOSSES AND EXPENSES, INCLUDING BUT NOT LIMITED TO, ATTORNEYS' FEES ARISING OUT OF, RESULTING FROM OR IN CONNECTION WITH THE PERFORMANCE OF ANY WORK, PURSUANT TO OR WITH RESPECT TO THESE PLANS AND SPECIFICATIONS. HOWEVER, THIS INDEMNITY SHALL NOT BE CONSTRUED TO INDEMNIFY ENGINEER, ITS CONSULTANTS, AGENTS OR EMPLOYEES AGAINST ITS OWN NEGLIGENCE.
CLAIMS, DAMAGES, LOSSES AND EXPENSES AS THESE WORDS ARE USED IN THE AGREEMENT SHALL MEAN AND INCLUDE, BUT NOT BE LIMITED TO (1) INJURY OR DAMAGE OCCURRING BY REASON OF THE FAILURE OF OR USE OR MISUSE OF ANY HOIST, RIGGINGS, BLOCKING, SCAFFOLDING OR ANY AND ALL OTHER KINDS OF ITEMS OF EQUIPMENT, WHETHER OR NOT THE SAME BE OWNED, FURNISHED OR LOANED BY ANY PART OR ENTITY, INCLUDING ANY CONTRACTOR; (2) ALL ATTORNEYS' FEES AND COSTS INCURRED IN BRINGING AN ACTION TO ENFORCE THE PROVISIONS OF THIS INDEMNITY; (3) COSTS FOR TIME EXPENDED BY THE INDEMNIFIED PARTY AND ITS EMPLOYEES, AT ITS USUAL RATES PLUS COSTS OR TRAVEL, LONG DISTANCE TELEPHONE AND REPRODUCTION OF DOCUMENTS AND (4) CONSEQUENTIAL DAMAGES.
IN ANY AND ALL CLAIMS AGAINST THE CLIENT OR ENGINEER OR ANY OF THEIR AGENTS OR EMPLOYEES AND CONSULTANTS BY ANY PARTY, INCLUDING ANY EMPLOYEE OF THE CONTRACTOR OR ANY SUBCONTRACTOR, ANYONE DIRECTLY OR INDIRECTLY EMPLOYED BY ANY OF THEM OR ANYONE FOR WHOSE ACTS ANY OF THEM MAY BE LIABLE, THE INDEMNIFICATION OBLIGATION SHALL NOT BE LIMITED IN ANY WAY BY ANY LIMITATION ON THE AMOUNT OF TYPE OF DAMAGES, COMPENSATION OR BENEFITS PAYABLE BY OR FOR THE CONTRACTOR OR ANY SUBCONTRACTOR UNDER WORKERS' OR WORKMEN'S COMPENSATION ACTS, DISABILITY BENEFIT ACTS OR OTHER EMPLOYEE BENEFIT ACTS OR ANY INSURANCE MAINTAINED BY CONTRACTOR OR ANY SUBCONTRACTOR OR ANY OTHER PARTY.

INSURANCE
ANY PARTY USING OR RELYING ON THESE PLANS, INCLUDING ANY CONTRACTOR, MATERIAL SUPPLIER, OR OTHER ENTITY SHALL OBTAIN, (PRIOR TO COMMENCING ANY WORK) GENERAL PUBLIC LIABILITY INSURANCE INSURING AGAINST ALL DAMAGES AND CLAIMS FOR ANY BODILY INJURIES, DEATH OR PROPERTY DAMAGE ARISING OUT OF ANY WORK, INCLUDING THE CONSTRUCTION WORK PROVIDED FOR IN THESE PLANS, AND SHALL NAME THE CLIENT AND ENGINEER AND ITS CONSULTANTS, AGENTS AND REPRESENTATIVES AS ADDITIONAL INSUREDS UNDER SUCH INSURANCE POLICY; PROVIDED THAT ANY PARTY USING OR RELYING ON THESE PLANS HAVING OBLIGATIONS TO MAINTAIN SPECIFIC INSURANCE BY REASON OF ANY AGREEMENT WITH CLIENT OR ANY CONTRACTOR OR ENGINEER SHALL PROVIDE EVIDENCE AND CERTIFICATES OF INSURANCE AS REQUIRED BY SUCH CONTRACT OR AGREEMENT. SUCH INSURANCE MUST CONTAIN A CLAUSE STATING THAT THE INSURANCE IS PRIMARY COVERAGE FOR ENGINEER AND ENGINEER'S OTHER APPLICABLE COVERAGE IS CONSIDERED SECONDARY. SUCH INSURANCE SHALL NOT LIMIT ANY LIABILITY OF ANY PARTY PROVIDING WORK OR SERVICES OR PROVIDING MATERIALS.

DETAILED SPECIFICATIONS

I. DEMOLITION
THE CONTRACTOR SHALL COORDINATE WITH RESPECTIVE UTILITY COMPANIES PRIOR TO THE REMOVAL AND/OR RELOCATION OF UTILITIES. THE CONTRACTOR SHALL COORDINATE WITH THE UTILITY COMPANY CONCERNING PORTIONS OF WORK WHICH MAY BE PERFORMED BY THE UTILITY COMPANY'S FORCES AND ANY FEES WHICH ARE TO BE PAID TO THE UTILITY COMPANY FOR THEIR SERVICES. THE CONTRACTOR IS RESPONSIBLE FOR PAYING FOR ALL FEES AND CHARGES. SHOULD REMOVAL AND/OR RELOCATION ACTIVITIES DAMAGE FEATURES INDICATED TO REMAIN, THE CONTRACTOR SHALL PROVIDE NEW MATERIALS/STRUCTURES IN ACCORDANCE WITH THE CONTRACT DOCUMENTS. EXCEPT FOR MATERIALS DESIGNED TO BE RELOCATED ON THIS PLAN, ALL OTHER CONSTRUCTION MATERIALS SHALL BE NEW. PRIOR TO DEMOLITION OCCURRING, ALL EROSION CONTROL DEVICES ARE TO BE INSTALLED. ALL EXISTING UTILITY LINES AND CONDUITS LOCATED UNDER PROPOSED BUILDINGS SHALL BE REMOVED AND PROPERLY BACKFILLED. ALL UTILITY LINES AND CONDUITS LOCATED UNDER DRIVES, ON-SITE ROADS, PARKING LOTS OR SIDEWALKS SHALL BE FILLED WITH A FLOWABLE BACKFILL AND END PLUGGED. ALL EXISTING STRUCTURES SHALL BE REMOVED. ALL EXISTING UTILITY LINES LOCATED UNDER LANDSCAPE AREAS SHALL BE LEFT IN PLACE AND PLUGGED AT ALL STRUCTURES. THE CONTRACTOR IS RESPONSIBLE FOR DEMOLITION, REMOVAL AND DISPOSAL (IN A LOCATION APPROVED BY ALL JURISDICTIONAL GOVERNING ENTITIES) OF ALL STRUCTURES, PADS, WALLS, FLUMES, FOUNDATIONS, ROAD, PARKING LOTS, DRIVES, DRAINAGE STRUCTURES, UTILITIES, ETC., SUCH THAT THE IMPROVEMENTS SHOWN ON THESE PLANS CAN BE CONSTRUCTED. ALL DEMOLITION WORK SHALL BE IN ACCORDANCE WITH ALL APPLICABLE FEDERAL, STATE AND LOCAL REQUIREMENTS. ALL FACILITIES TO BE REMOVED SHALL BE UNDERCUT TO SUITABLE MATERIAL AND BROUGHT TO GRADE WITH SUITABLE COMPACTED FILL MATERIAL PER THE SPECIFICATIONS. THE CONTRACTOR IS RESPONSIBLE FOR OBTAINING ALL PERMITS REQUIRED FOR DEMOLITION AND DISPOSAL.ND BROUGHT TO GRADE WITH SUITABLE COMPACTED FILL MATERIAL PER THE SPECIFICATIONS. THE CONTRACTOR IS RESPONSIBLE FOR OBTAINING ALL PERMITS REQUIRED FOR DEMOLITION AND DISPOSAL. ELECTRICAL, TELEPHONE, CABLE, WATER, FIBER OPTIC CABLE AND/OR GAS LINES NEEDING TO BE REMOVED SHALL BE COORDINATED BY THE CONTRACTOR WITH THE AFFECTED UTILITY COMPANY. CONTRACTOR MUST PROTECT THE PUBLIC AT ALL TIMES WITH FENCING, BARRICADES, ENCLOSURES, AND OTHER APPROPRIATE BEST MANAGEMENT PRACTICES. CONTINUOUS ACCESS SHALL BE MAINTAINED FOR SURROUNDING PROPERTIES AT ALL TIMES DURING DEMOLITION. ALL FIRE ACCESS LANES WITHIN THE PROJECT AREA SHALL REMAIN IN SERVICE, CLEAN OF DEBRIS, AND ACCESSIBLE FOR USE BY EMERGENCY VEHICLES. CONTRACTOR SHALL MAINTAIN ALL EXISTING PARKING AREAS, SIDEWALKS, DRIVES, ETC. CLEAR AND FREE FROM ANY CONSTRUCTION ACTIVITY AND/OR MATERIAL TO ENSURE EASY AND SAFE PEDESTRIAN AND VEHICULAR TRAFFIC TO AND FROM THE SITE. CONTRACTOR SHALL COORDINATE/PHASE ALL CONSTRUCTION ACTIVITY WITHIN PROXIMITY OF THE BUILDING AND UTILITY INTERRUPTIONS WITH THE FACILITY MANAGER TO MINIMIZE DISTURBANCE AND INCONVENIENCE TO FACILITY OPERATIONS. CONTRACTOR SHALL DEVELOP AND IMPLEMENT A DAILY PROGRAM OF DUST CONTROL AND SHALL SUBMIT AND OBTAIN JURISDICTIONAL GOVERNING ENTITY APPROVAL OF DUST CONTROL PROCEDURES PRIOR TO DEMOLITION OF ANY STRUCTURES. MODIFICATION OF DUST CONTROL PROCEDURES SHALL BE PERFORMED BY THE CONTRACTOR TO THE SATISFACTION OF THE JURISDICTIONAL GOVERNING ENTITY AS REQUESTED. THE CONTRACTOR SHALL COORDINATE ALL DEMOLITION WITH THE JURISDICTIONAL GOVERNING ENTITY AND CLIENT TO ENSURE PROTECTION AND MAINTENANCE OF SANITARY SEWER AND WATER UTILITIES AS NECESSARY AND TO PROVIDE STORMWATER CONVEYANCE UNTIL NEW FACILITIES ARE CONSTRUCTED, TESTED AND PLACED INTO OPERATION. THE LOCATIONS OF ALL EXISTING UTILITIES SHOWN ON THIS PLAN HAVE BEEN DETERMINED FROM THE BEST INFORMATION AVAILABLE AND ARE GIVEN FOR THE CONVENIENCE OF THE CONTRACTOR AND ARE NOT TO BE INTERPRETED AS THE EXACT LOCATION, OR AS THE ONLY OBSTACLES THAT MAY OCCUR ON THE SITE. THE ENGINEER ASSUMES NO RESPONSIBILITY FOR THEIR ACCURACY. PRIOR TO THE START OF ANY DEMOLITION ACTIVITY, THE CONTRACTOR SHALL NOTIFY THE UTILITY COMPANIES FOR LOCATION OF EXISTING UTILITIES AND SHALL VERIFY EXISTING CONDITIONS AND PROCEED WITH CAUTION AROUND ANY ANTICIPATED FEATURES.

II.SITE WORK
STANDARDS
THIS WORK SHALL BE COMPLETED IN CONFORMANCE WITH THE APPLICABLE SECTIONS OF THE STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION, DEPARTMENT OF TRANSPORTATION, STATE OF ILLINOIS, LATEST EDITION EXCEPT AS MODIFIED BELOW.

MATERIAL VOLUME CALCULATIONS AND CROSS SECTIONS
THE CONTRACTOR UNDERSTANDS THAT ANY VOLUME CALCULATIONS, QUANTITIES OR CROSS SECTIONS THAT HAVE BEEN FURNISHED BY THE ENGINEER ARE FOR INFORMATION ONLY AND ARE PROVIDED WITHOUT ANY GUARANTEE BY THE CLIENT OR ENGINEER WHATSOEVER AS TO THEIR SUFFICIENCY OR ACCURACY. CONTRACTOR WARRANTS THAT HE HAS PERFORMED HIS OWN SUBSURFACE INVESTIGATIONS AS NECESSARY AND HIS OWN CALCULATIONS AND CROSS SECTIONS TO DETERMINE SITE SOIL CONDITIONS AND MATERIAL VOLUMES.

CLEARING, GRUBBING AND TREE REMOVAL
THE SITE SHALL BE CLEARED, GRUBBED, AND TREES AND STUMPS REMOVED WHERE DESIGNATED ON THE PLANS. TREES DESIGNATED TO REMAIN SHALL BE PROTECTED FROM DAMAGE.

TOPSOIL STRIPPING
UPON COMPLETION OF DEMOLITION, CLEARING, GRUBBING AND TREE REMOVAL, ALL TOPSOIL SHALL BE STRIPPED FROM UNDER ALL BUILDINGS AND PAVEMENTS AREAS, AND OTHER AREAS NECESSARY TO COMPLETE THE WORK. TOPSOIL STRIPPED SHALL BE PLACED IN STOCKPILES IN LOCATIONS AS DESIGNATED BY THE CLIENT.

TOPSOIL RESPREAD
UPON COMPLETION OF ROADWAY AND/OR PARKING LOT IMPROVEMENTS AND INSTALLATION OF UNDERGROUND UTILITIES A MINIMUM OF SIX INCHES (6") OF TOPSOIL SHALL BE RESPREAD OVER ALL UNPAVED AREAS WHICH HAVE BEEN DISTURBED BY EARTHWORK CONSTRUCTION, EXCEPT BUILDING PADS AND OTHER DESIGNATED AREAS, WHICH SHALL BE KEPT FREE FROM TOPSOIL.

SEEDING
UPON COMPLETION OF TOPSOIL RESPREAD, THE CONTRACTOR SHALL APPLY SEED AND FERTILIZER TO ALL RESPREAD AREAS IN ACCORDANCE WITH IDOT STANDARDS OR AS DESIGNATED ON LANDSCAPE DRAWINGS AND SPECIFICATIONS PROVIDED BY THE CLIENT.

SODDING
UPON COMPLETION OF TOPSOIL RESPREAD, THE CONTRACTOR SHALL INSTALL SOD TO ALL AREAS DESIGNATED ON THE PLANS OR AS DESIGNATED ON THE LANDSCAPE DRAWINGS AND SPECIFICATIONS PROVIDED BY THE CLIENT.

DEWATERING AREA
UPON INSTALLATION OF THE SILT FENCE, THE CONTRACTOR SHALL PREPARE THE GROUND SURFACE TO HAVE POSITIVE DRAINAGE PRIOR TO INSTALLATION OF THE GEOTUBES. TEMPORARY DRAINAGE DITCHES ARE THE RESPONSIBILITY OF THE CONTRACTOR TO PROVIDE A POSITIVE OUTLET FOR THE DEWATERING DISCHARGE LINE TO THE EXISTING PUBLIC STORM SEWER. A SOILS TESTING FIRM EMPLOYED BY THE CLIENT SHALL DETERMINE WHICH SOILS ARE UNSUITABLE. MATERIALS IN THEIR NATURAL STATE BEING DEFINED AS UNSUITABLE THAT WOULD BE SUITABLE MATERIAL IF MOISTURE CONDITIONED, SHALL BE CONDITIONED BY THE CONTRACTOR AND USED AS SUITABLE EMBANKMENT MATERIAL OR HAULED FROM THE SITE.
FOR PURPOSES OF DEFINITION, UNSUITABLE MATERIAL SHALL BE AS FOLLOWS UNLESS DETERMINED OTHERWISE BY THE SOILS ENGINEER:

1. ANY SOIL WHOSE OPTIMUM MOISTURE CONTENT EXCEEDS 25%.
2. ANY COHESIVE SOIL WITH AN UNCONFINED COMPRESSIVE STRENGTH OF 1.5 TONS PER SQUARE FOOT OR LESS.
3. ANY SOIL WHOSE SILT CONTENT EXCEEDS 60% BY WEIGHT.
4. ANY SOIL WHOSE MAXIMUM DENSITY IS LESS THAN 100 POUNDS PER CUBIC FOOT.
5. ANY SOIL CONTAINING ORGANIC, DELETERIOUS, OR HAZARDOUS MATERIAL.

THE CONTRACTOR SHALL NOTIFY THE CLIENT IMMEDIATELY UPON ENCOUNTERING GROUNDWATER DURING EXCAVATION. IF IN THE OPINION OF THE CLIENT OR THE JURISDICTIONAL GOVERNING ENTITY THIS CONDITION NECESSITATES THE INSTALLATION OF PERFORATED DRAIN TILE BEDDED IN WASHED GRAVEL OR OPEN STORM SEWER JOINTS WRAPPED WITH FABRIC, THE CONTRACTOR SHALL INSTALL THE SAME.

EROSION CONTROL
SUITABLE EROSION CONTROL PRACTICES SHALL BE MAINTAINED BY THE CONTRACTOR IN ACCORDANCE WITH ILLINOIS URBAN MANUAL AND ALL APPLICABLE SOIL EROSION AND SEDIMENTATION CONTROL ORDINANCES AND THE PLANS.

III.DREDGING
SUMMARY
THE CONTRACTOR SHALL FURNISH ALL LABOR, TOOLS, TRANSPORTATION AND INSTALLATION OF EQUIPMENT NECESSARY TO PERFORM HYDRAULIC DREDGING AND SUBSEQUENT DREDGED MATERIAL DEWATERING WORK AS SPECIFIED AND DEPICTED ON THE PLANS.
DREDGING SHALL EXTEND FROM THE SEDIMENT SURFACE TO THE NATURAL LAKE SURFACE BOTTOM AS DEPICTED ON THE PLANS. THIS WORK INCLUDES BUT NOT NECESSARILY LIMITED TO: REMOVAL OF SEDIMENT, DEWATERING OF DREDGED MATERIAL, TRANSPORTATION AND RELOCATION OF DEWATERED MATERIAL FROM GEOTUBES TO THE ONSITE LOCATION DEPICTED ON THE PLANS. THIS WORK WILL COMPLY WITH APPLICABLE PROJECT PLANS AND PERMITS:

1. UNITED STATES ARMY CORPS OF ENGINEERS (USACE) AND ILLINOIS DNR JOINT PERMIT
2. LAKE COUNTY STORMWATER MANAGEMENT COMMISSION GENERAL PERMIT NUMBER 3

SUBMITTALS
THE CONTRACTOR SHALL SUBMIT THE FOLLOWING FOR APPROVAL BY THE ENGINEER PRIOR TO MOBILIZATION.

1. DREDGING AND DEWATERING PLAN - THE PLAN SHALL INCLUDE A DETAILED NARRATIVE DESCRIPTION, PROPOSED SEQUENCING, DETAILS, AND MEANS AND METHODS OF ALL DREDGING OPERATIONS, SHOP DRAWINGS, MANUFACTURER'S CUT, DATA, AND SPECIFICATION SHEETS, AND ALL OTHER SUPPORTING DATA FOR PROPOSED DREDGING AND DEWATERING EFFORT INCLUDING, BUT NOT LIMITED TO, THE FOLLOWING:
1.1. MOBILIZATION - PROPOSED MEANS AND METHODS FOR MOBILZATION AND DEPLOYMENT OF DREDGING AND SUPPORT EQUIPMENT.
1.2. EQUIPMENT - A LIST OF DREDGE EQUIPMENT TO BE USED, INCLUDING SPECIFICATIONS AND CAPACITIES. DESCRIPTION OF FUEL STORAGE AREAS AND REFUELING PROCEDURES. AN EQUIPMENT LIST INCLUDING ALL EQUIPMENT TO BE USED FOR HANDLING AND TRANSPORT OF DREDGED MATERIAL TO END-PLACEMENT.
1.3. SCHEDULING - PROPOSED SEQUENCING OF DREDGING AND DEWATERING OPERATIONS. ANTICIPATED DREDGE PRODUCTION RATES AND AVERAGE CYCLE TIMES.
1.4. PERSONNEL - THE CONTRACTOR SHALL PROVIDE MOST RECENT CERTIFICATIONS OF ALL EQUIPMENT OPERATORS AND CONTACT INFORMATION FOR THE SUPERINTENDENT.
1.5. DAILY INSPECTIONS - PROCEDURE AND INSPECTION FORMS FOR INSPECTING MAJOR DREDGING EQUIPMENT INCLUDING INSPECTION FREQUENCY AND PROPOSED PLAN FOR ADDRESSING EQUIPMENT MALFUNCTION.
2. DAILY PROGRESS REPORTS - SHALL INCLUDE THE FOLLOWING GENERAL INFORMATION: DATE, WEATHER CONDITIONS, PERSONNEL ON-SITE, BRIEF DESCRIPTION OF THE WORK PERFORMED AND PROGRESS MADE, AND BRIEF DESCRIPTION OF PRODUCTS, MATERIALS, AND EQUIPMENT INSPECTED.
3. CONTRACTOR SHALL PROVIDE A BATHYMETRIC SURVEY FOR PHASE I UPON COMPLETION OF THE DREDGING OPERATIONS

OPERATIONS
THE CONTRACTOR SHALL SEQUENCE THE WORK IN AN ORDERLY AND LOGICAL MANNER, AND ACCOUNT FOR THE STABILITY OF THE SHORELINE/BANK.
THE CONTRACTOR SHALL FURNISH, SET, MAINTAIN RANGES, BUOYS, AND MARKERS TO DEFINE THE WORK AREA. FURNISH, INSTALL, AND MAINTAIN A SILT CURTAIN AS REQUIRED TO LIMIT THE DISTURBANCE OF THE ACTIVE WORK AREA..
IF UNANTICIPATED CONDITIONS ARE ENCOUNTERED, THE CONTRACTOR SHALL IMMEDIATELY STOP AND VERBALLY NOTIFY THE ENGINEER. FOLLOWING RESOLUTION OF THE SITUATION, THE CONTRACTOR WILL PROVIDE WRITTEN NOTIFICATION TO THE ENGINEER DETAILING THE UNANTICIPATED CONDITIONS AND RESULTING RESOLUTION.
THE CONTRACTOR SHALL BE RESPONSIBLE FOR SITE SECURITY AND SHALL COORDINATE VEHICULAR ACCESS AND PARKING ON LOCAL STREETS.

REV	DATE	DESCRIPTION	DRN	APP

Heather McArthur
Premier Residential

Geosyntec consultants

TITLE:
CONSTRUCTION SPECIFICATIONS

PROJECT:
PRAIRIE CROSSING

SITE:
VILLAGE OF GRAYSLAKE, ILLINOIS

THIS DRAWING MAY NOT BE ISSUED FOR PROJECT TENDER OR CONSTRUCTION, UNLESS SEALED.

SIGNATURE

DATE

DRAFT

DESIGN BY:	DATE: JANUARY 2020
DRAWN BY:	PROJECT NO.: MOW5504
CHECKED BY:	FILE:
REVIEWED BY:	DRAWING NO.:
APPROVED BY:	8

P:\DWG\P\PREMIER RESIDENTIAL\MOW5504\DRAWINGS\MOW5504-008

-----Original Message-----
From: Pascus, Kaitlyn A CIV USARMY CELRC (US) <Kaitlyn.A.Pascus@usace.army.mil>
Sent: Wednesday, April 8, 2020 3:55 PM
To: Dawn Brook <DBrook@Geosyntec.com>
Subject: RE: LRC-2018-989 Verification of Regional 4 Permit Status - Lake Aldo Leopold Dredging NWP16 (UNCLASSIFIED)

CLASSIFICATION: UNCLASSIFIED

Hi Dawn,

The dredging would not require a permit since this is just a Section 404 water (if it was a Section 10 water it would require a permit to dredge), but the return flow would require a permit in this case. The reason it was an IP before is because they applied for a 10 year permit to do the work.

So in this case, you would be getting a Nationwide Permit (NWP) 16, information below. NWP 16 does not require a Pre-Construction Notification (PCN), which means as long as you're adhering to all of the general and regional conditions of the NWP, you don't have to notify us that you're doing the work. You do have to submit a compliance certification after the work is complete though.

Note that IEPA has given a conditional 401 provided all of their rules are followed (see attachment 7 specifically) :
https://nam02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.lrc.usace.army.mil%2FPortals%2F36%2Fdocs%2Fregulatory%2Fpdf%2FNWP-IEPA-2017.pdf&data=02%7C01%7CDBrook%40geosyntec.com%7C9f5752f7c76b42725aab08d7dbff386f%7C7125495671b047f48977c4c17bc205cb%7C1%7C1%7C637219761538735641&sdata=%2F9OCQ7oLaLp7gyL9TMPq%2BJBXGznZVPxCZPaPwjjIdWg%3D&reserved=0.

"16. Return Water From Upland Contained Disposal Areas. Return water from an upland contained dredged material disposal area. The return water from a contained disposal area is administratively defined as a discharge of dredged material by 33 CFR 323.2(d), even though the disposal itself occurs in an area that has no waters of the United States and does not require a section 404 permit. This NWP satisfies the technical requirement for a section 404 permit for the return water where the quality of the return water is controlled by the state through the section 401 certification procedures. The dredging activity may require a section 404 permit (33 CFR 323.2(d)), and will require a section 10 permit if located in navigable waters of the United States. (Section 404)"

General conditions found here:
https://nam02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.lrc.usace.army.mil%2FMissions%2FRegulatory%2FIllinois%2FNationwide-Permits%2F&data=02%7C01%7CDBrook%40geosyntec.com%7C9f5752f7c76b42725aab08d7dbff386f%7C7125495671b047f48977c4c17bc205cb%7C1%7C1%7C637219761538735641&sdata=rQNHMFJV6z4bwg2Jf%2BNOUfUNGv2%2BdWwGuQKrVRJVo%2FM%3D&reserved=0

Let me know if you have any questions on this or if you'd like to discuss over the phone, Kaitlyn A. Pascus Regulatory Project Manager
U.S. Army Corps of Engineers - Chicago District Regulatory Branch

231 South LaSalle Street, Suite 1500
Chicago, Illinois 60604
Cell: 312-579-5605

Regulatory Website:
https://nam02.safelinks.protection.outlook.com/?url=http%3A%2F%2Fwww.lrc.usace.army.mil%2FMissions%2FRegulatory.aspx&data=02%7C01%7CDBrook%40geosyntec.com%7C9f5752f7c76b42725aab08d7dbff386f%7C7125495671b047f48977c4c17bc205cb%7C1%7C1%7C637219761538735641&sdata=ZTCiGeih%2FqRIiOMzOWYxKgXypJCaypJdVETKMPx83rM%3D&reserved=0

Field Notes for Fish Collection in September 2006 from Lake Leopold at Prairie Crossing

Prepared By:
Integrated Lakes Management, Inc.
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Gurnee, IL 60031
(847) 244-6662

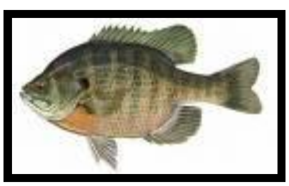
Introduction

Christopher J. Ryan and Christopher C. Rysso of Integrated Lakes Management collected fish from Lake Leopold in Prairie Crossing on September 29, 2006. Collections were conducted using a 20 ft. X 6ft.X 1/8" mesh, common sense seine. Four hauls were conducted using the 20 ft. seine, and active fishing proceeded for 30 min. We collected approximately 170 individuals and measured 140 specimens.

Collection activities were conducted along the northern shoreline in the southeast arm of the lake by the public beach and along the western shoreline around the semi-circular sea wall. The collection was comprised of Bluegills, Blackchin Shiners, Blacknose Shiners, Banded Killifish, Black Crappie, and one unidentifiable *Lepomis* species suspected to be a Warmouth.

Collection activities done in 2004 and 2006 were conducted in an identical manor in roughly the same locations, where as in 2005 activities were more in-depth and encompassed more of the lake. Collection activities in 2005 were conducted in various locations throughout the lake and involved leaving the nets out over night. Sampling equipment and efforts used in 2005 were also geared more towards larger specimens.

Bluegills



Over the past three years Bluegill populations have increased to a healthy diverse collection of various length frequencies and age classes and predator/ prey relations have reached equilibrium with this species within Lake Leopold. Bluegills comprised 83% of the September 2006 catch which is a 6% difference from the June 2005 survey (89%), and 34% difference from May 2004 (49%). While the average minimum length has not changed much (May 2004: 2.8 cm, June 2005: 2.3 cm, and Sept. 2006: 2.0 cm) it has decreased on average .8 cm over the past three years. With minimum lengths decreasing over time, this shows evidence of young of the year (YOY) and continual recruitment of this species within the lake. On average the maximum length has increased (May 2004: 6.3 cm, June 2005: 18.1 cm, and Sept. 2006: 16.7 cm), providing evidence of individual growth and appropriate forage available for species proliferation. Over the past three years length frequencies have increased, and more representatives from each length frequency have been showing up. In 2004 specimens collected represented individuals in the 2.8-6.3 cm length frequencies, with a majority of the collection in the 5 cm range. In 2005 specimens collected represented individuals in the 2.3-18.1 cm length frequencies, with a majority of the collection in the 3.4 cm range. In 2006 specimens collected represented individuals from the 2.0-16.7 cm range, with a majority in the 3.5 range. Initially in 2004 length frequencies and age classes were consolidated to a limited range. Over the preceding two years populations have spread to include specimens in multiple age classes and length frequencies. While collection numbers are greater in the lower length frequencies; this is expected because fish produce large clutch sizes to counter act high mortality rates of YOY. As the 2006 data shows three separate collections of age classes were represented; 2.5-4 cm, 7.5-10 cm, and 13-15.5 cm.

Green Sunfish

Green Sunfish were not represented in the September 2006 survey and may have been out competed by the Bluegill populations. In 2004 they represented 2% of the collection, and in 2005 they represented only 1%. While length frequencies have increased between 2004 (6.1 cm) and 2005 (9.5 cm), the percent representation over the past three years has decreased to no representatives in 2006.

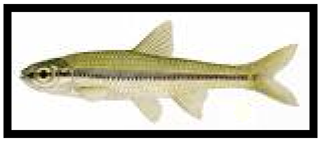
Black Crappie

Over time average sizes have decreased, however there was an increase in the total number of Black Crappie collected from 2004-2006 within Lake Leopold. Black Crappie comprised 2% of the collection in the September 2006 survey. This is a 1% difference from the 2005 survey (1%) and 2% difference from 2004 (0%) where no individuals were represented in the collection. While in 2005 the maximum length was 25.0 cm, this was the only representative specimen of this species. In 2006 three individuals were collected who's lengths ranged from 16-19.5 cm.

Largemouth Bass

Largemouth Bass were not represented in the September 2006 fish survey, or the May 2004 collection. There was one specimen collected in June 2005, whose length was 9.1 cm. Collection activities in 2005 were geared more towards larger specimens and game fish. Collection efforts included sampling different locations within the lake than previously done and involved leaving the nets in over night. In 2004 and 2006 efforts were conducted over a much smaller period of time and in fewer locations than 2005.

Blackchin Shiners

 Data collected from 2004 to 2006 shows that Blackchin Shiner populations have increased in their over all length frequencies, average lengths, and numbers. Data indicates that healthy populations are developing within Lake Leopold. Blackchin Shiners represented 9% of the 2006 collection. This was a 5 % difference from 2005 (4%) and a 2% difference from 2004 (11%). In May 2004 seven specimens ranging from 3.0-5.3 cm were collected with a majority of the collection in the 3.5-4.0 cm range. In June 2005 ten specimens were collected in the 4.3-4.9 range, with a majority of the collection in the 4.7 cm range. In September 2006 fifteen specimens were collected in the 3.7-5.8 range, with a majority of the catch falling in the 5.0 cm range.

Banded Killifish

 Banded Killifish represented 5% of the total collection in 2006, this is a 1% difference from 2005 (6%), and 32% difference from 2004 (37%). Over the past three years of sampling, data indicates a decrease in the numbers of Banded Killifish represented in the surveying activities (2004: 24; 2005: 16; 2006: 9); where as over all average lengths do not vary as much (2004: 4.3 cm; 2005: 4.8cm; 2006: 4.4 cm). Data reflects a decrease in specimens smaller than 4 cm in length. Typically this indicates not only a reduction in the recruitment rate but also an increase in predation upon this species. However, the over all population in Lake Leopold may represent larger specimens per age class than those represented in Sanctuary Pond, due to a reduction in intraspecies specific competition because of predation and food availability.

Blacknose Shiners

 Blacknose Shiners represented only 1% of the September 2006 fish survey which is a 1% difference from 2005 (0%) and identical to 2004 (1%). While there was only one Blacknose Shiner represented in the 2004 collection and one specimen the 2006 fish survey, the average lengths are larger than those present in the Sanctuary Pond. The average length of Blacknose Shiners in Lake Leopold in 2004 was 5.5 cm and in 2006 it was 4.9. In comparison to Sanctuary Pond’s lengths (2004: 3.9 cm; 2006: 3.01 cm), Lake Leopold has less intraspecies specific competition allowing specimens to grow larger than those in the upper pond lacking natural predation.

Iowa Darters

Iowa Darters were not represented in the September 2006 fish survey. Over the course of the past three years of sampling and collection only two specimens were collected. Both of which were captured during the June 2005 sampling activities. One individual was a fry and therefore too small to measure, while the other was 5.4 cm. The presence of Iowa Darter fry indicates recruitment, and a larger average length in comparison to Sanctuary Pond (2004: 3.8 cm) indicates a lack of intraspecies competition.

Summary

From May 2004 to September 2006 there was an over all increase in the percent representation of panfish (Bluegills and Black Crappie). As a result percent representation of prey species (Blackchin Shiners, Blacknose Shiners, and Banded Killifish) have decreased. There was a dramatic decline of shiners and killifish from 2004 to 2005, due to an increase in Bluegill and Black Crappie populations and the respective predation these species offer. However, even though total numbers for shiners and killifish have declined there has been an increase in the length frequencies and a representation of larger individuals from each Endangered/Threatened (E/T) species than occurring in the Sanctuary Pond. While this is an indication of a more balanced ecosystem and a healthy composition of predation and forage, the absence of smaller E/T specimens raises the question whether or not there is adequate recruitment from any of these species to insure proliferation. ILM recommends continued fish transfers from the upper pond to increase fish recruitment as well as increase genetic diversity within the lake. Because of the sensitive nature of the shiners and E/T status of these species assisting the proliferation of these species in a “natural” environment is essential to the success of this program. The ultimate goals of these activities are to create a sustainable population that will inevitably move down stream into the Des Planes River where they have become extirpated by negative environmental influences. While previous years sampling has provided wonderful insight to the dynamics of species interaction there is still room for improvement. Continual fish surveys should be conducted to track the predator/ pry relations over time of the fish species present in Lake Leopold. We recommend a larger budget with more funds allocated to a more in-depth sampling program. Sampling frequencies need to increase to 2-3 times a year, while sampling activities should be spread out over both time and space. Sampling should be conducted throughout the entire lake for longer periods of time. ILM recommends the use of an electrofishing boat in order to obtain a more accurate representation of the fish population diversity among larger specimens, while continuing seine net sampling to track the population diversity among the E/ T species.

Recommendations

- Continued fish transfers from upper pond to lake
- Continued fish surveys including the use of an electrofishing boat 2-3 times a year
- Reduction in aquatic weeds with spot herbicides may help balance the predator/ pray equilibrium between game fish and forage species
- Stocking additional Tiger Muskie will also decrease predation pressure on the E/T species by controlling panfish populations

September 2006 Data

Common Name	Scientific Name	Totals	Percentage
Bluegill	*Lepomis macrochirus*	141	83
Blackchin Shiners	*Notropis heterodon*	15	9
Banded Killifish	*Fundulusd diaphanus*	9	5
Black Crappie	*Pomoxis nigromaculatus*	3	2
Blacknose Shiners	*Fundulus heterolepis*	1	<1
Unidentified *Lepomis*		1	<1
All Fish Collected		170	

Figure 1: Location of fish collection outlined in red

2012 Fish Survey Report
Sanctuary Pond at Prairie Crossing

Prepared By:
Integrated Lakes Management, Inc.
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Waukegan, IL 60085
(847) 244-6662

Introduction

In 1999 Integrated Lakes Management (ILM) introduced four endangered and threatened (E/T) species into Sanctuary Pond in Prairie Crossing. Since then ILM has performed annual fisheries surveys, with the exceptions of 2008 and 2009, to monitor the health of the fish population and to make recommendations for the sustainability of these E/T species. Historically specimens were collected and analyzed using a methodology established in 2001 that focused on relative populations as opposed to total populations. 2011 was the first year additional data was collected (batch weights) to further analyze the population on a whole and extrapolate the suspected total population as well as total biomass (fish) within Sanctuary pond as a whole. In 2012 this data collection trend continued in order to build an archive of valuable data and continue to examine if changes should be made to the fisheries and/ or habitat to ensure the long term survival of these species.

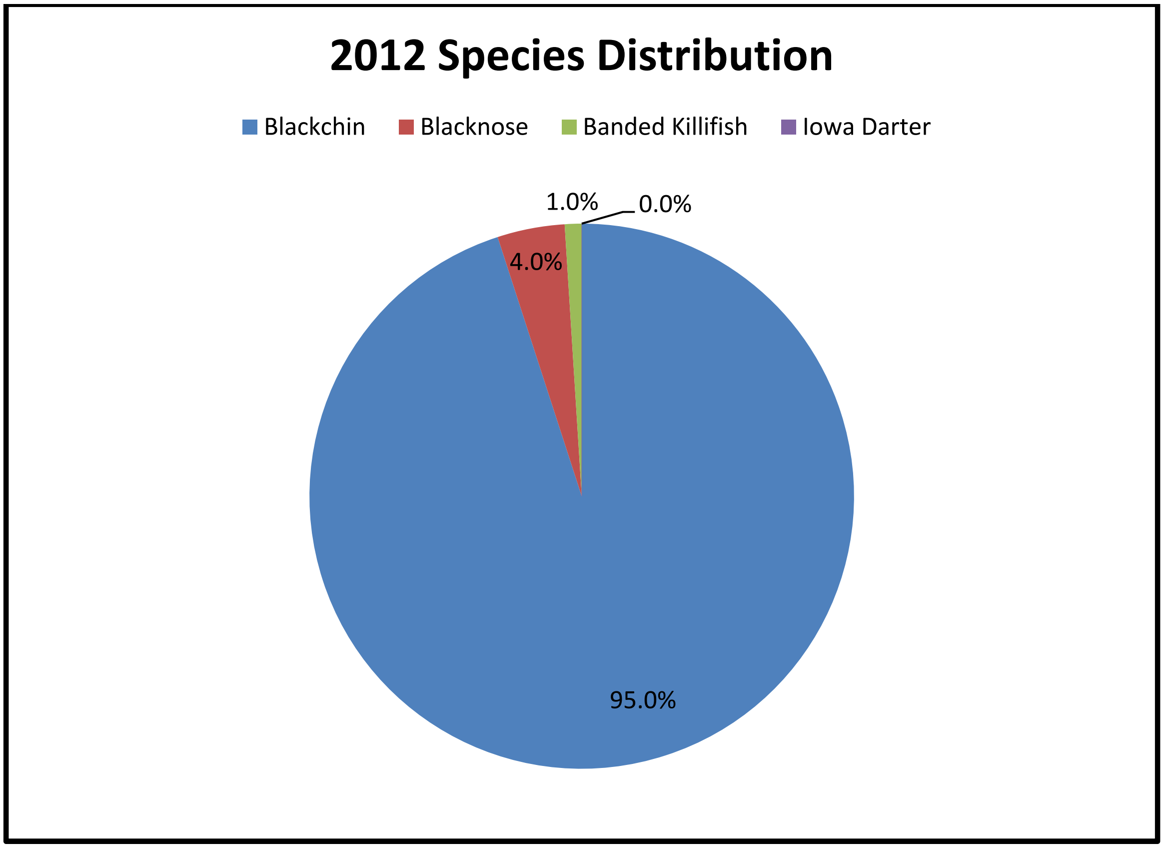
Methods

In previous years granular herbicides were employed to clear excessive coontail growth which had historically made sampling efforts difficult. In 2012 this was not necessary, since coontail growth was minimal. Difficulties encountered during the 2012 survey were limited to extensive water lily growth and low water levels due to the drought. On September 19, 2012 ILM staff members, Chris Ryan and Sandy Kubillus, conducted fisheries surveying activities at Sanctuary Pond. Collections were conducted using a 10 ft. X 5ft.X 1/8" mesh, common sense seine. Two hauls were conducted using the 10 ft. seine, covering a 30 ft. stretch of the littoral zone during each haul. A total of 1,008 individuals were caught and identified. A maximum of 100 individuals (if applicable) from each species were measured, the remaining specimens were counted. With the exception of the Blackchin Shiner, no other species in the sampled population exceeded 100 specimens.

Batch weights were collected for each species, 30 individuals from each species were weighed, except in the case of the Iowa Darter which was not represented in this sample and the Banded Killifish where only 12 specimens were captured. Individuals measured and weighed were randomly chosen to obtain an accurate and non-bias representation of the total population. Data from this survey is compared to previous studies.

Results

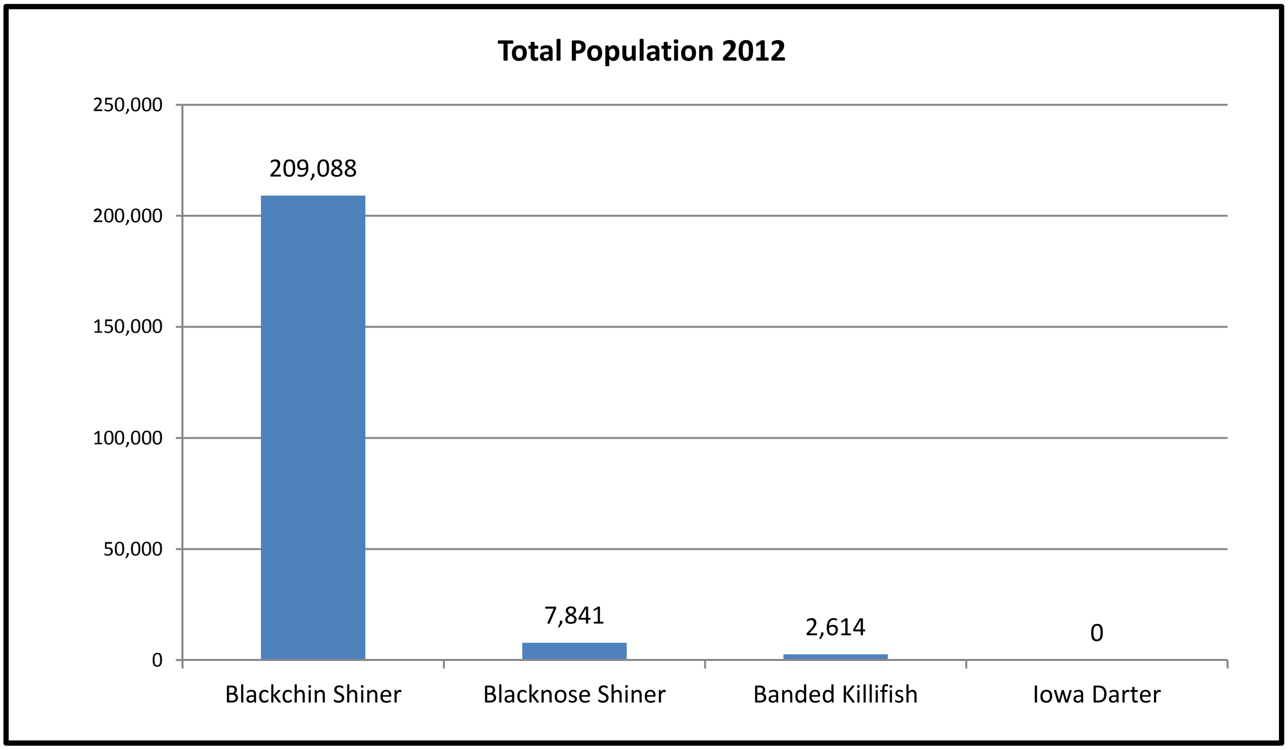
The total collection was comprised of Banded Killifish (*Fundulus diaphanus*), Blackchin Shiners (*Notropis heterodon*), and Blacknose Shiners (*Notropis heterolepis.* The Blackchin Shiner comprised an overwhelming majority of the sampled population, as has been the case since 2004, representing 95% of the collection. The Blacknose Shiner was the second most abundant representing only 4% of the collection. The Banded Killifish Blackchin Shiner comprised 1% of the sampled population, and the Iowa Darter continues to be the least abundant species and was not represented in the sampled population at all this survey.

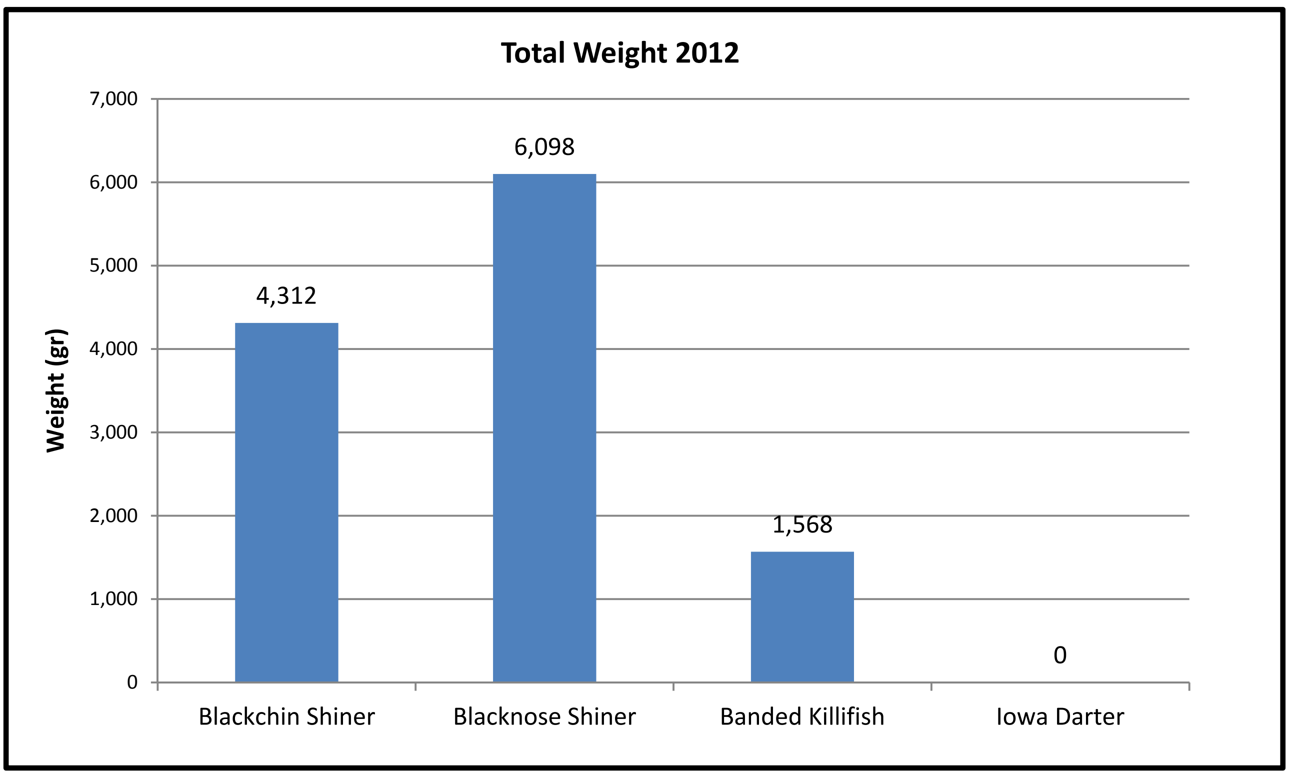


The 2012 data showed a drastic change in abundance and distribution among all four species of E/T stocked at Sanctuary. Blackchin shiners reached a historic high, while Blacknose Shiners and the Banded Killifish dropped to or below historic lows. Despite its absence from this sample the Iowa Darter remains in line with its historic representation within the sampled population. It is suspected that conditions of the lake in terms of aquatic growth and sampling techniques attribute to the low and sporadic representation of this species from year to year.

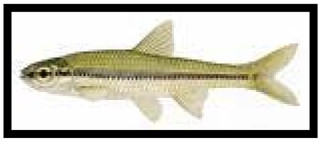
Batch weights were once again gathered this year to generate a total biomass. Total and individual species populations were determined. This is the second year this type of data has been collected and a historic record for future analysis is now established. It was determined that at the time of the survey, Sanctuary Pond was carrying roughly 11, 979 grams (26 lbs.) of fish which was comprised of 209,088 Blackchin Shiners; 7,841 Blacknose Shiners; 2,614 Banded Killifish; and 0 Iowa Darters. Iowa Darters may have been present but were not caught during this survey.

It should be noted these are estimates always subject to biasness and are merely a snapshot in time heavily influenced by many uncontrollable factors (aquatic growth, water temperatures, weather conditions, etc.). A review of the historic sampling dates indicate that sapling typically occurs during the month of September, but during years with multiple sampling sessions the dates have ranged from April 20th to October 22nd.

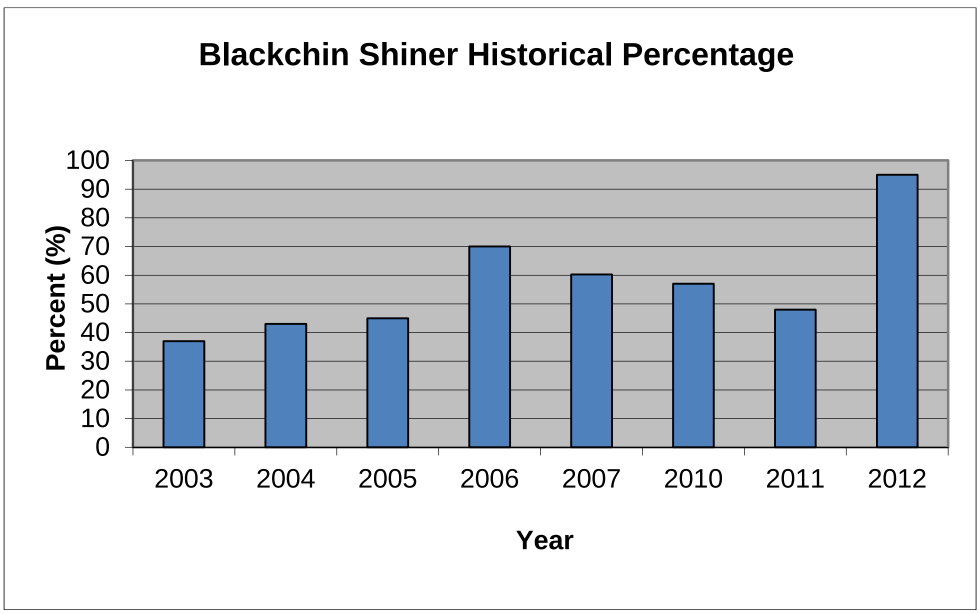

Total Population 2012
250,000
200,000
150,000
100,000
50,000
0
209,088
7,841
2,614
0
Blackchin Shiner
Blacknose Shiner
Banded Killifish
Iowa Darter


Total Weight 2012
Weight (gr)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
4,312
6,098
1,568
0
Blackchin Shiner
Blacknose Shiner
Banded Killifish
Iowa Darter

Blackchin Shiner



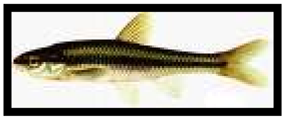
Blackchin Shiners continued to be the most abundant species in 2012, this trend has held true since 2004. There was a dramatic increase in their representation reaching a historic high. Ninety-five percent of the collection was comprised of Blackchin Shiners. Batch weight data shows that this species, while being the overwhelming numeric majority, represents only 36% of the total fisheries biomass. This was also the case in 2011. Length frequency data places a majority of the sampled Blackchin population within the 3.0-5.5 cm range. The species average total length is indicated as being 5.6 cm by the Fishes of Wisconsin (George C. Becker, 1983). Batch weight and length frequency data indicate that the current population continues to invested energy into generating greater numbers rather than individual growth.



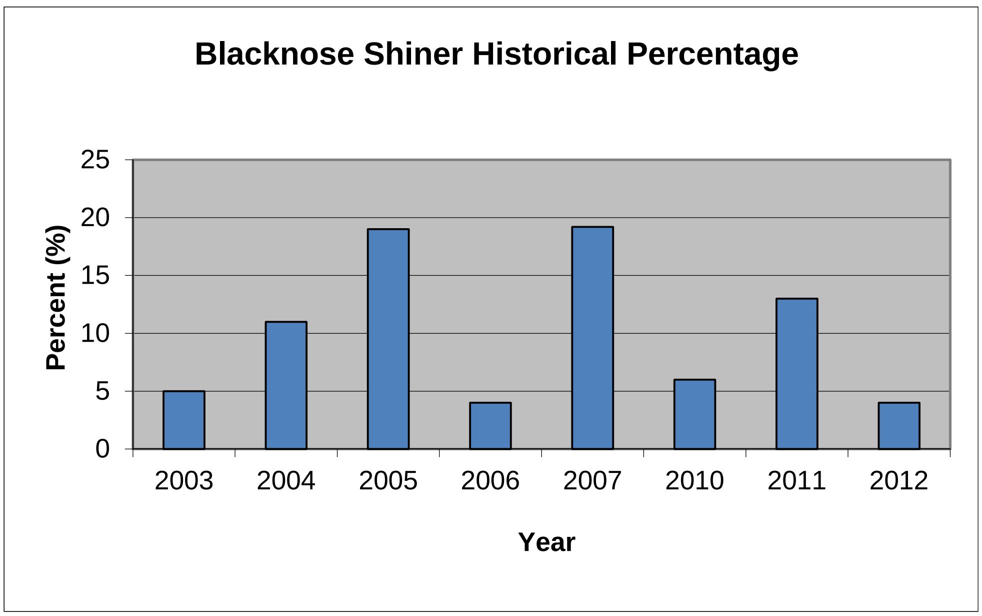
*2008 and 2009 no surveys performed

Date	Percent Of Total Catch
2003	37
2004	43
2005	45
2006	70
2007	60
2010	57
2011	48
2012	95

Blacknose Shiner



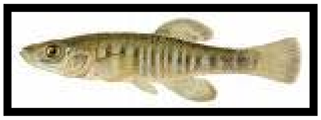
The 2012 survey shows a decline in the percent representation in comparison to 2011 dropping from 13% of the sampled population to only 4%. This is in line with the historic low last seen in 2006. Historic data has indicated that the Blacknose Shiner in this pond experiences cyclical "boom and bust" in its population throughout the years. It is suspected that the population is currently in the valley of its cycle and that we can expect an increase in 2013. Despite the low representation of 4%, batch weight data indicates that the current Blacknose population represents 51% of the total fisheries biomass which makes this species the most abundant species by weight. Length frequency data places a majority of the sampled population between 5.0 and 6.5 cm which is consistent with the average total length of 5.1 cm as indicated by the Fishes of Wisconsin (George C. Becker, 1983). Current length frequency data is consistent with that of previous surveys.



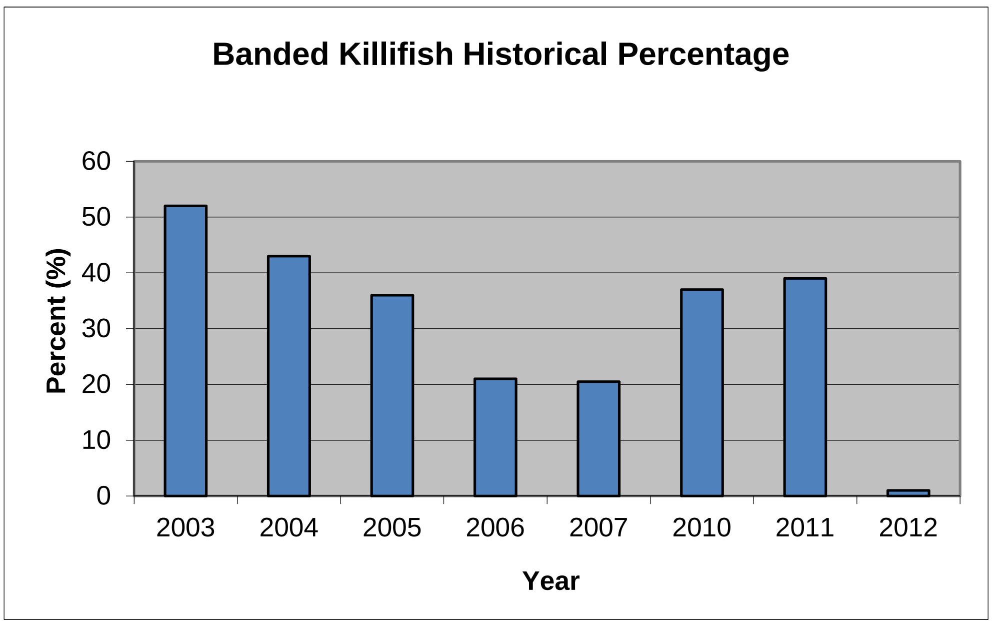
*2008 and 2009 no surveys performed

Date	Percent of Total Catch
2003	5
2004	11
2005	19
2006	4
2007	19
2010	6
2011	13
2012	4

Banded Killifish



In 2012 the Banded Killifish represented only 1% of the total catch; this is an unprecedented historic low. Batch weight data shows this species represents 13% of the total fisheries biomass, the least abundant represented species by weight. Length frequency data puts a majority of the specimens within 4.0-5.0 cm; the Fishes of Wisconsin (George C. Becker, 1983) indicates this species has an average total length of 5.1-6.4 cm. The 2012 survey places this species below average. It is suspected that sampling conditions were most likely the attributing factor to this species low representation, future surveys will be required to confirms or deny this theory.

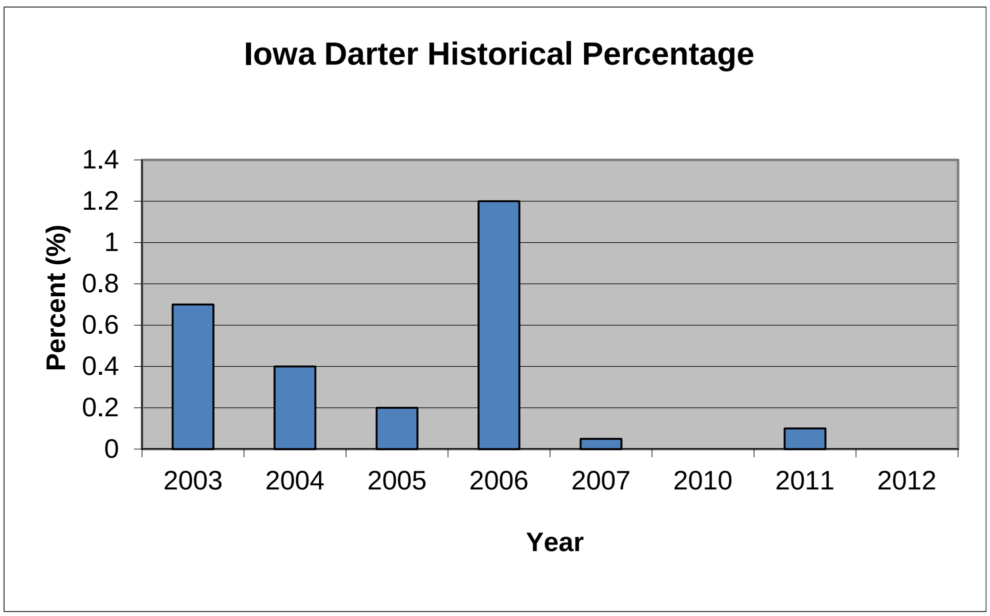


*2008 and 2009 no surveys performed

Date	Percent of Total Catch
2003	52
2004	43
2005	36
2006	21
2007	20
2010	37
2011	39
2012	1

Iowa Darter

 The Iowa Darter continues to be the least abundant species represented in the 2012 survey as has been the case since the establishment of this "refuge pond". This year no specimens were captured. Preferred habitat (sandy substrate) and overall pond conditions (excessive plant growth) are suspected for the lack and/or limited representation of this species within the sampled populations over the years. It is quite possible that an accurate representation of the Iowa Darter population may never be acquired; however, their sporadic presence in the sampled population is a notable occurrence and indicates species proliferation.



*2008 and 2009 no surveys performed

Date	Percent of Total Catch
2003	0.7
2004	0.4
2005	0.2
2006	1.2
2007	0.05
2010	0
2011	0.1
2012	0

Recommendations

Since the introduction of these four E/T species ILM has been monitoring the fisheries at Sanctuary Pond for evidence of population stabilization and sustainability. Data gathered over the past 13 years has proven that these species have the ability to survive and reproduce. This is the second year that batch weights were collected and the snapshot populations were estimated. A historic data log is now established and data collection of this nature should be continued in future surveys to observe changes over time. In order to maintain consistency the preceding surveys should continue to utilize the same collection areas, depths, and vegetation density (if possible), and time of year.

The removal of sediment accumulation and the addition of sand and gravel in certain shallow areas will create a more preferred habitat for Iowa Darters and increase recruitment rates of this species.

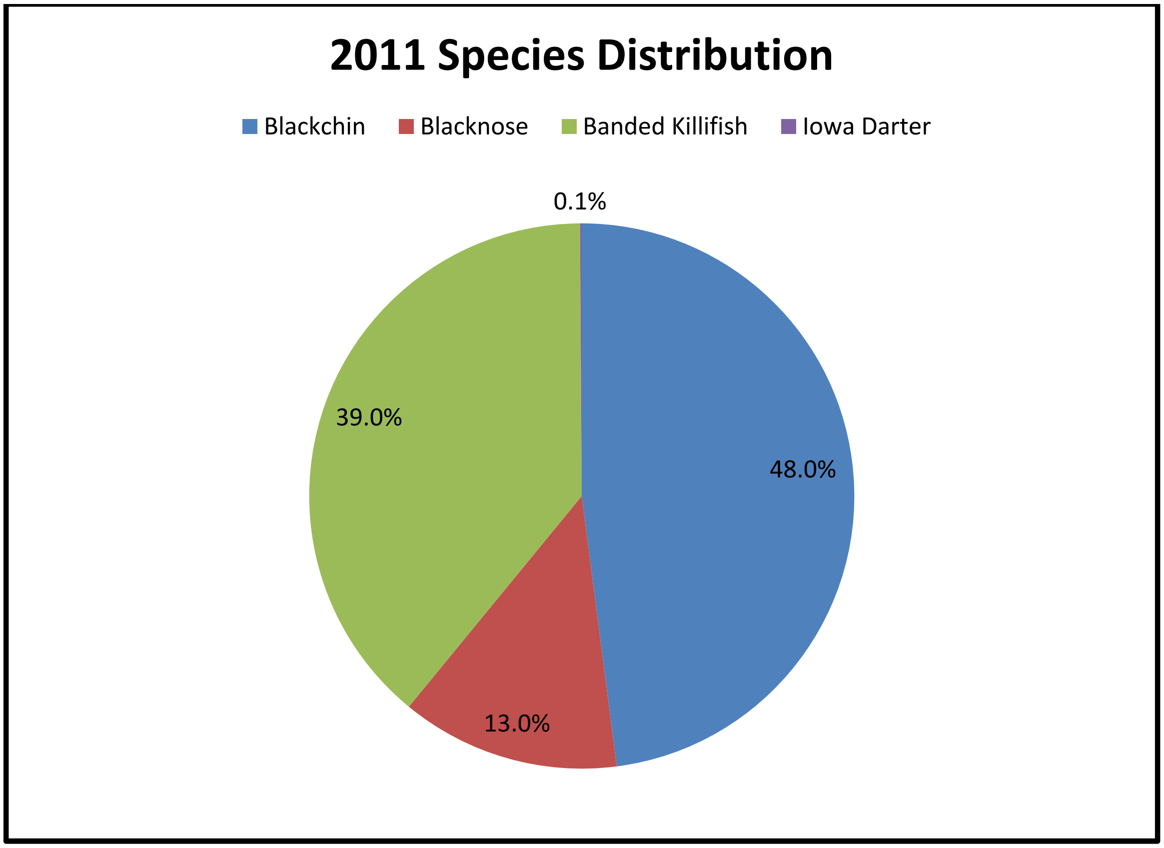
In previous reports it was recommended that a top predator be introduced into Sanctuary Pond to help maintain a more balanced ecosystem and prevent population crashes of one or more of the introduced E/T species. After 13 years of monitoring and evaluating the population dynamics of this refuge pond the necessity for a top predator is still questionable. While a drastic dip in the representation of the Banded Killifish and the Blacknose Shiner was observed, a similar trend over time would be required to deem it necessary for the introduction of a top predator into this ecosystem.

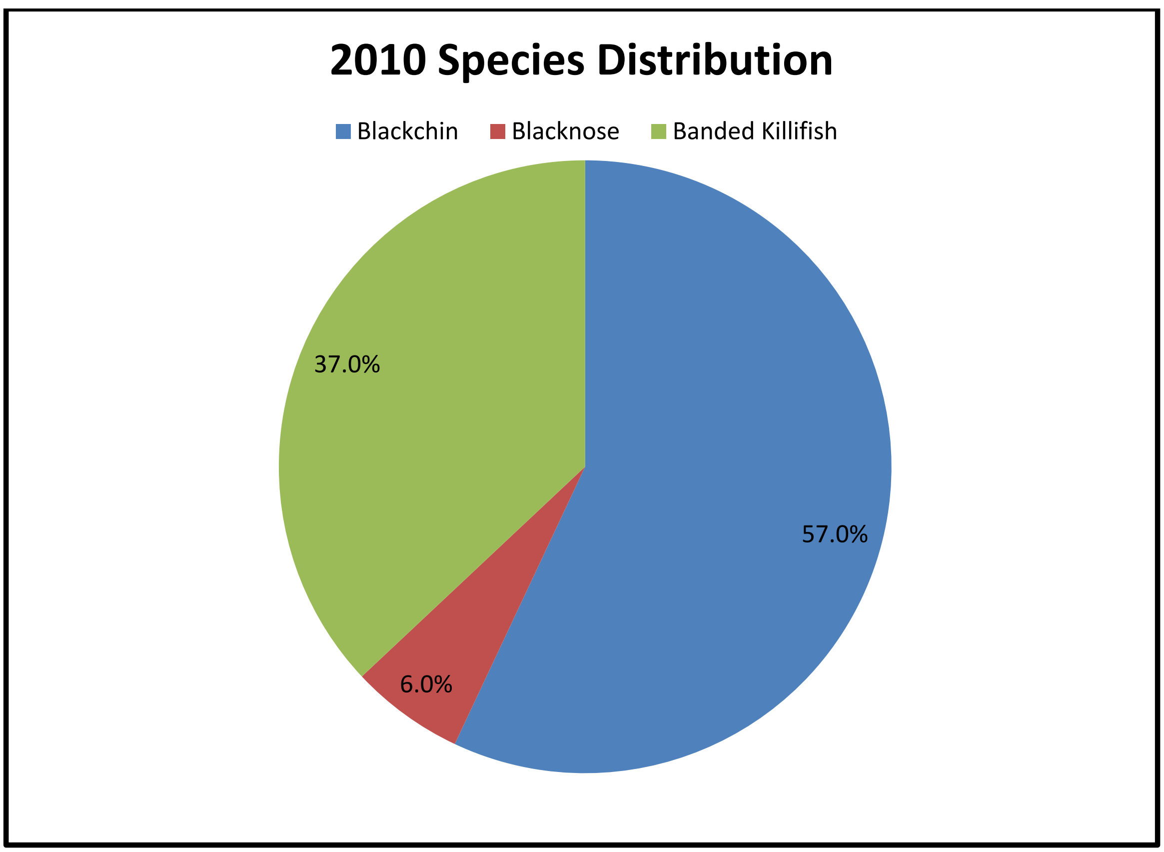
If future surveys and data analysis suggests that a top predator is necessary to maintain the viability of these E/T populations, it is recommended that a species incapable of reproducing in this environment such as Rainbow Trout stocked at a rate of 1-2 per acre be introduced. This particular species will keep the target species populations in check and not survive the summer. These two characteristics make this species perfect for population control in this particular situation if warranted.

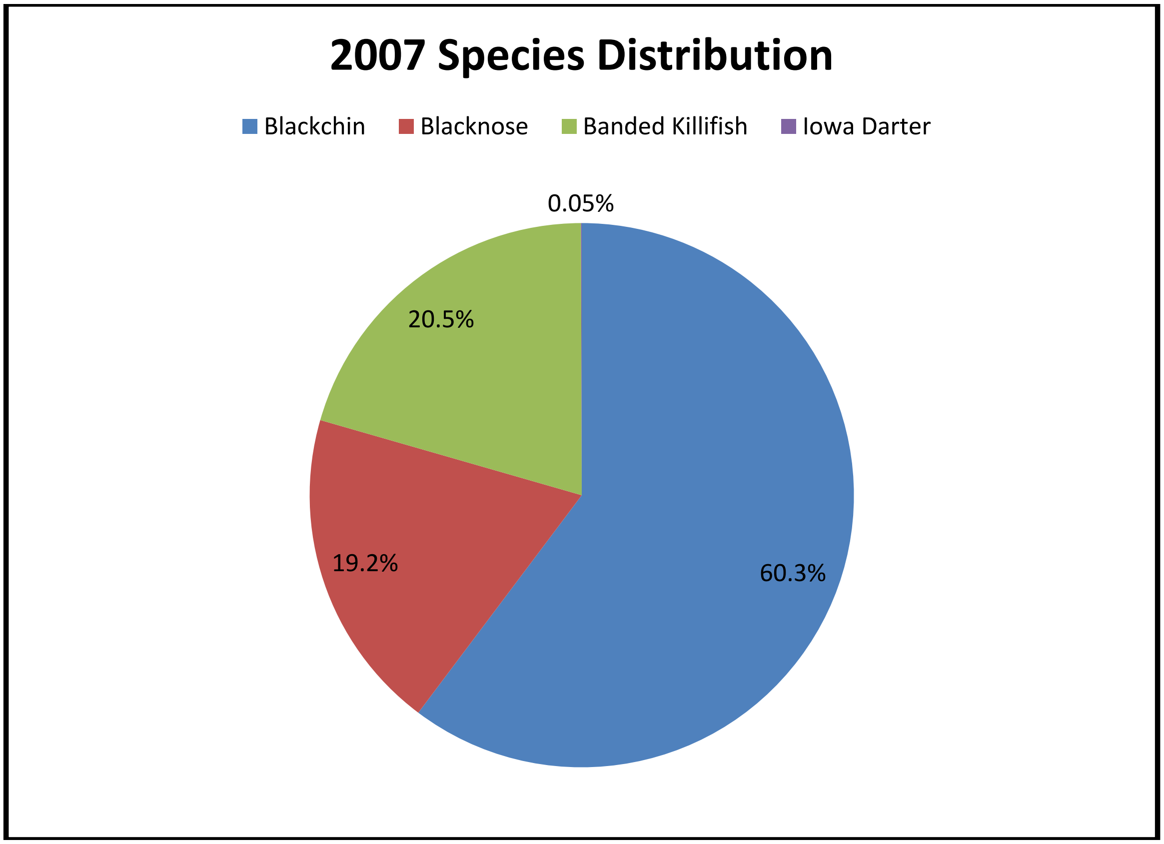
The translocation of large numbers of the E/T species from Sanctuary Pond to Lake Leopold and other lakes should not be overlooked as an effective means of reducing population densities. The overall purpose of this established refuge was to assist in E/T recruitment and re-introduction to extirpated regions of the DesPlaines River basin. It is recommended that due to the sensitive nature of the shiner populations and their susceptibility to mortality during handling, that that any population transfers be conducted solely for the purpose of species relocation and that numerating and length frequency data be forgone to ensure the survival of the individuals being relocated.

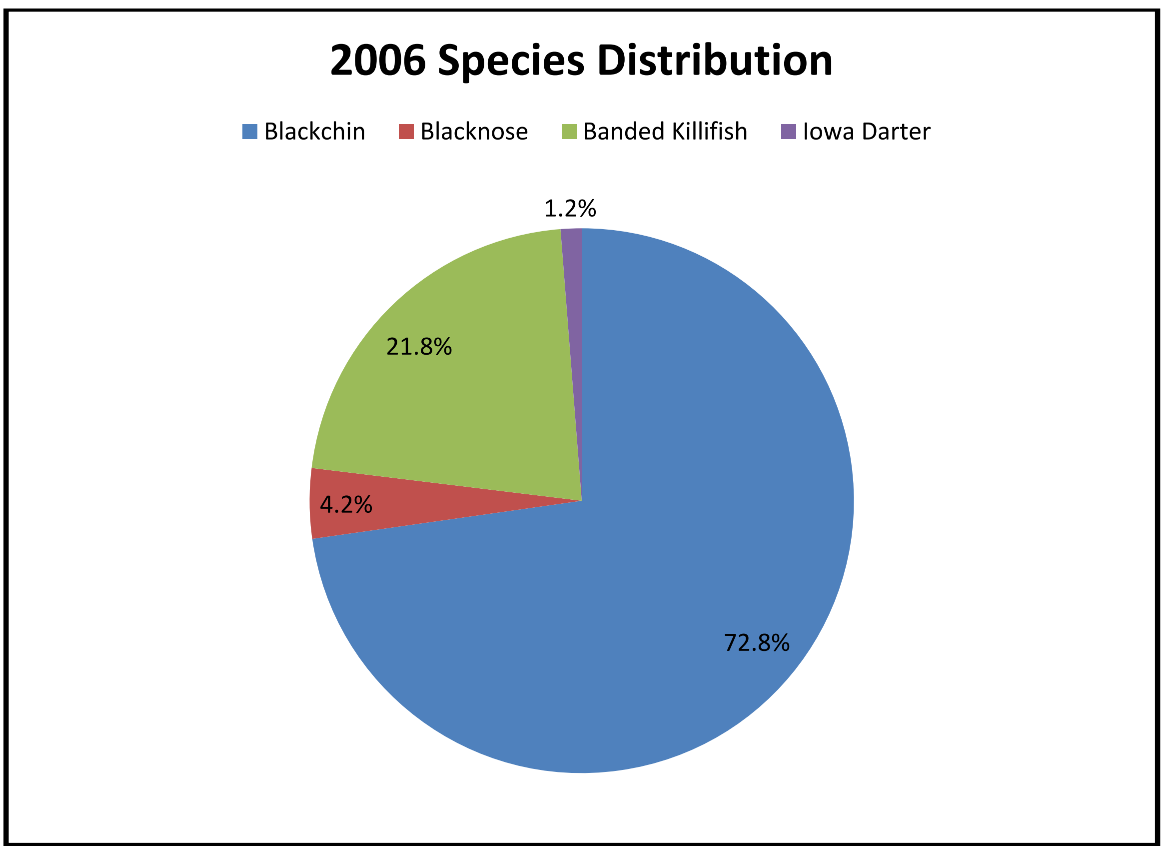
Figure 1: Location of fish collection outlined in red

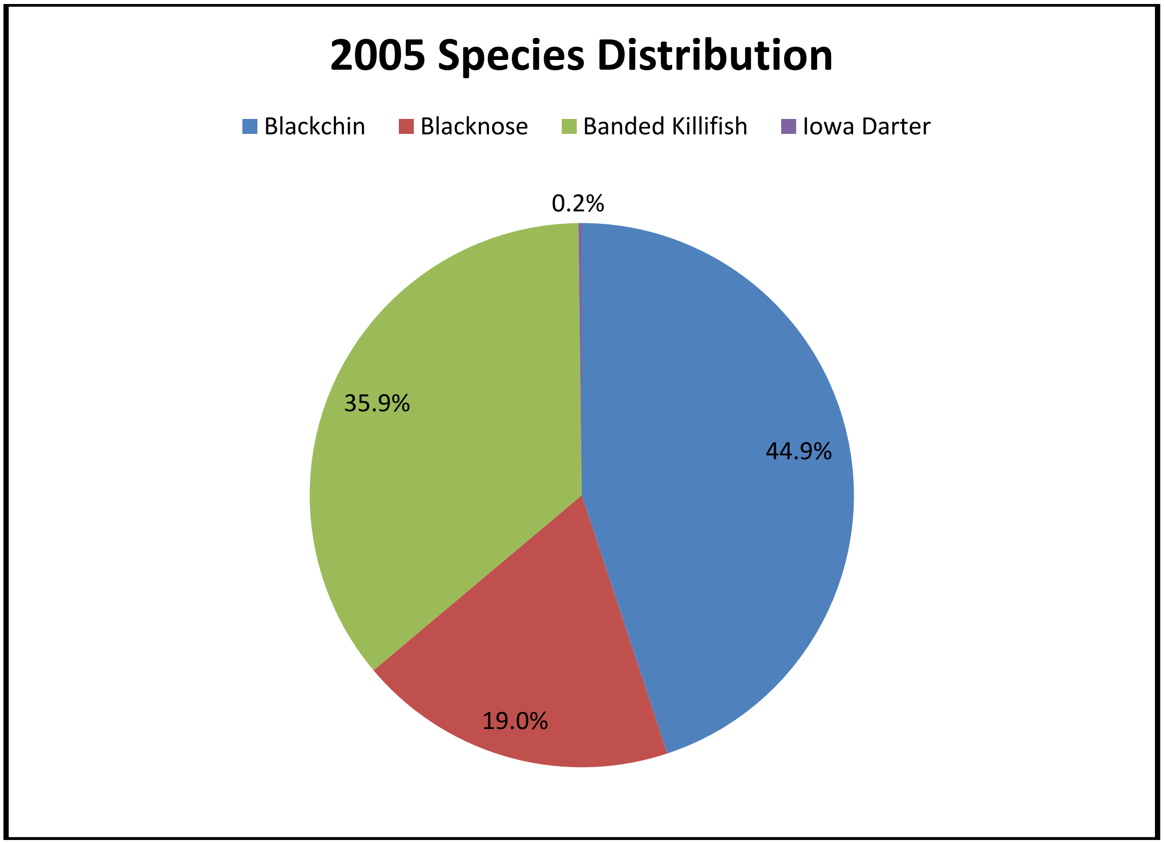
Appendix

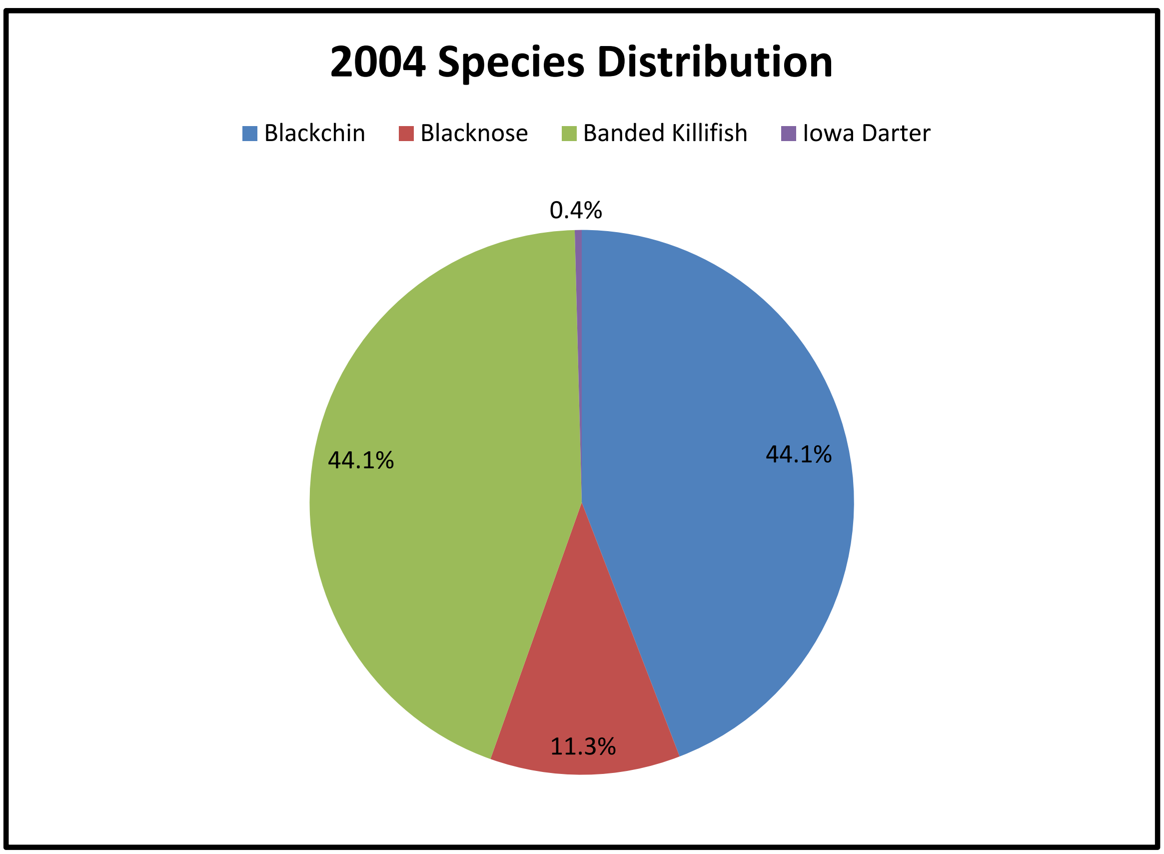

2011 Species Distribution
Blackchin
Blacknose
Banded Killifish
Iowa Darter
0.1%
39.0%
48.0%
13.0%

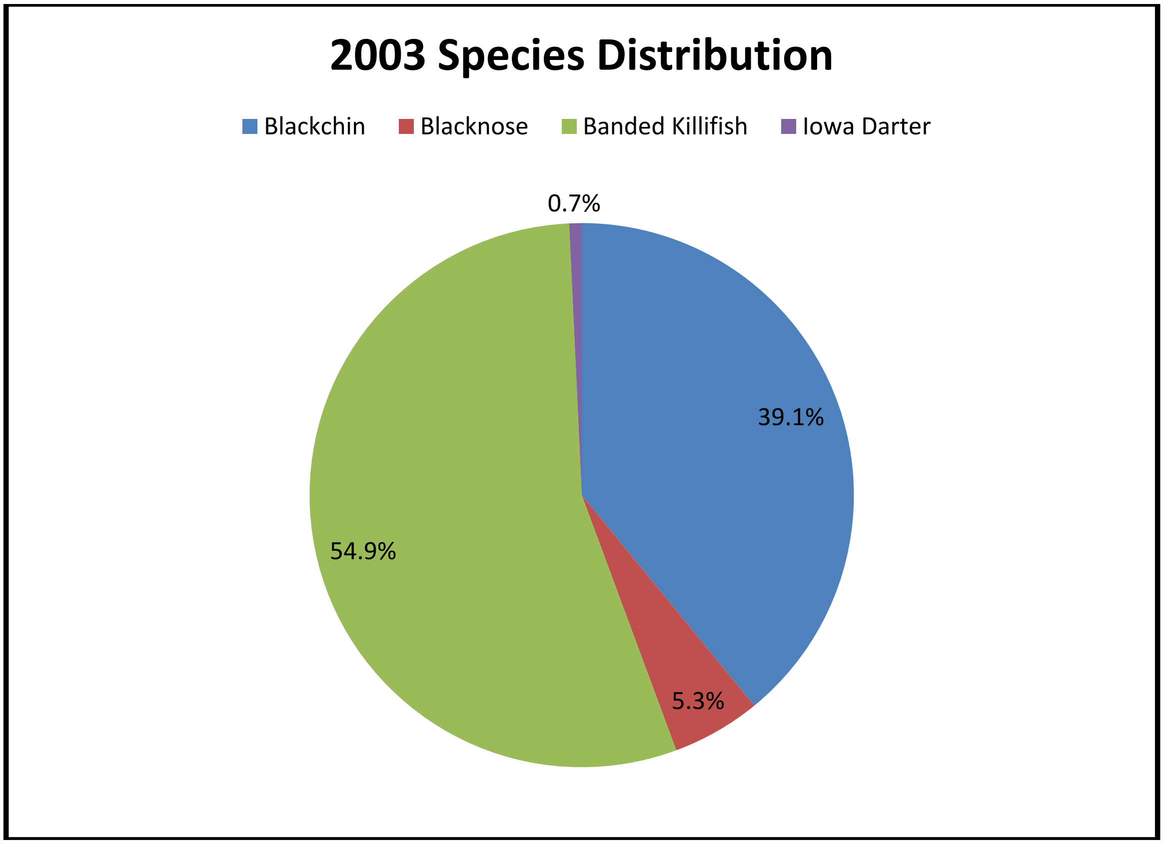

2010 Species Distribution
Blackchin
Blacknose
Banded Killifish
37.0%
57.0%
6.0%

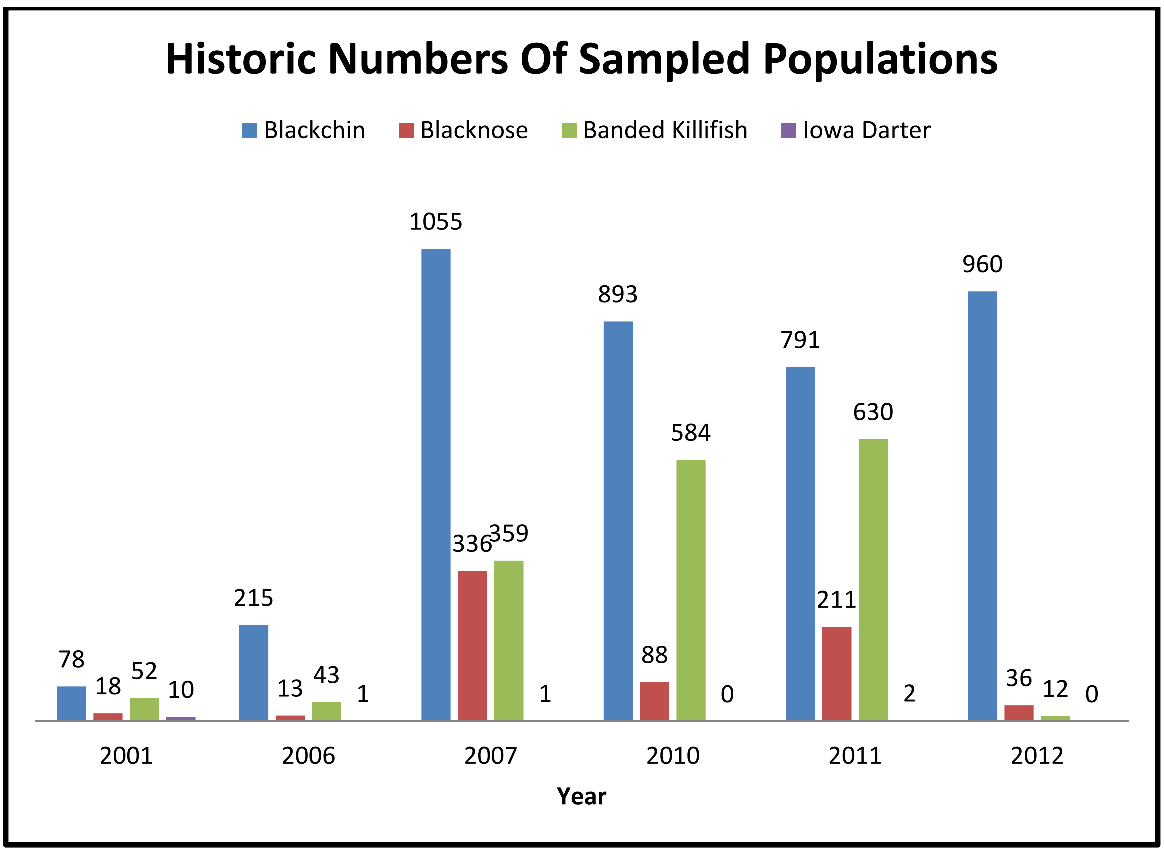

2007 Species Distribution
Blackchin
Blacknose
Banded Killifish
Iowa Darter
0.05%
20.5%
19.2%
60.3%

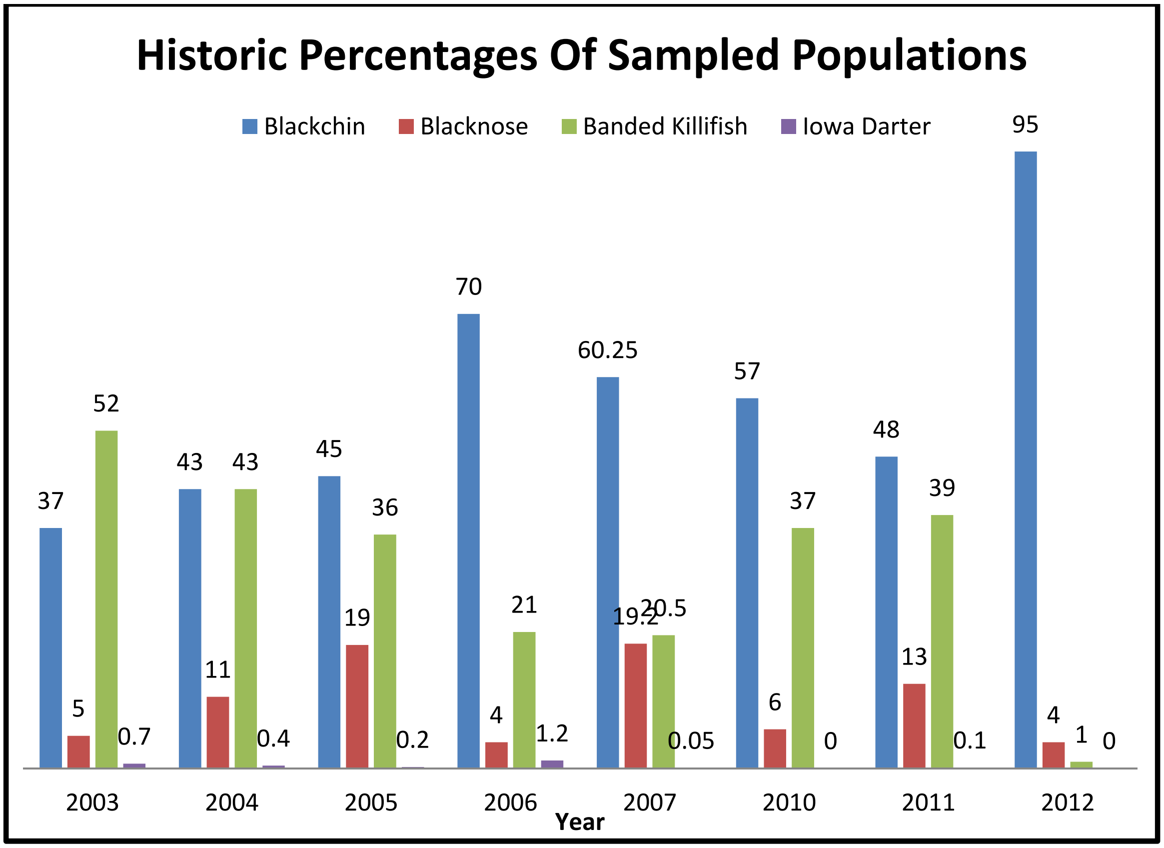

2006 Species Distribution
Blackchin
Blacknose
Banded Killifish
Iowa Darter
1.2%
21.8%
4.2%
72.8%


2005 Species Distribution
Blackchin
Blacknose
Banded Killifish
Iowa Darter
0.2%
35.9%
44.9%
19.0%

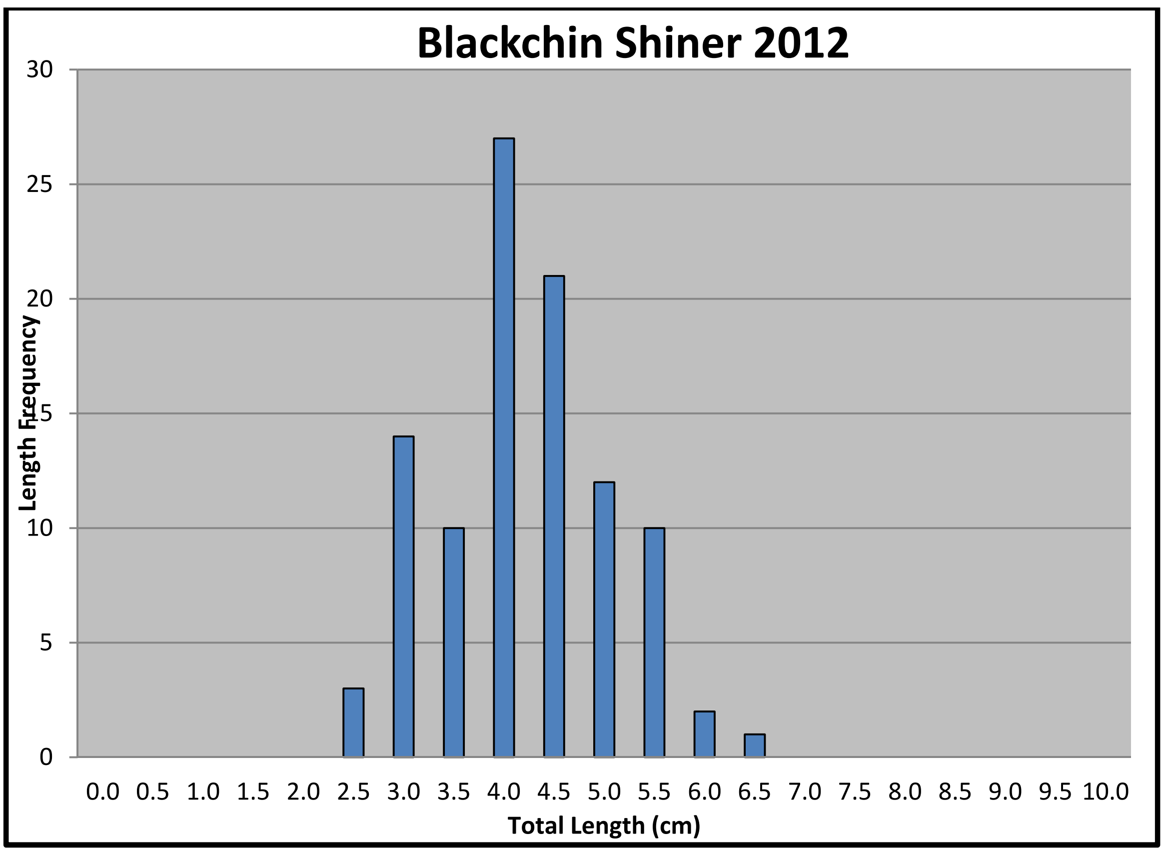

2004 Species Distribution
Blackchin
Blacknose
Banded Killifish
Iowa Darter
0.4%
44.1%
44.1%
11.3%


2003 Species Distribution
Blackchin
Blacknose
Banded Killifish
Iowa Darter
0.7%
39.1%
54.9%
5.3%

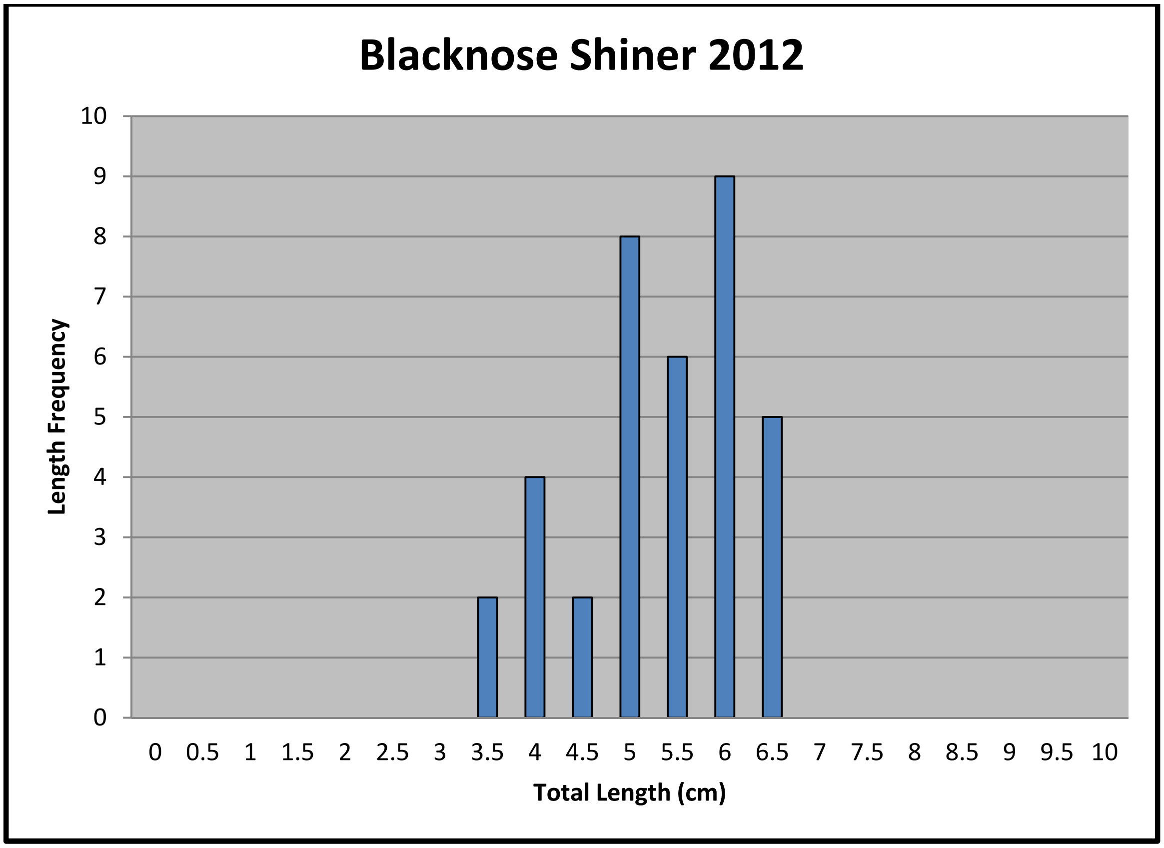

Historic Numbers Of Sampled Populations
Blackchin
Blacknose
Banded Killifish
Iowa Darter
78
18
52
10
215
13
43
1
1055
336
359
1
893
88
584
0
791
211
630
2
960
36
12
0
2001
2006
2007
2010
2011
2012
Year

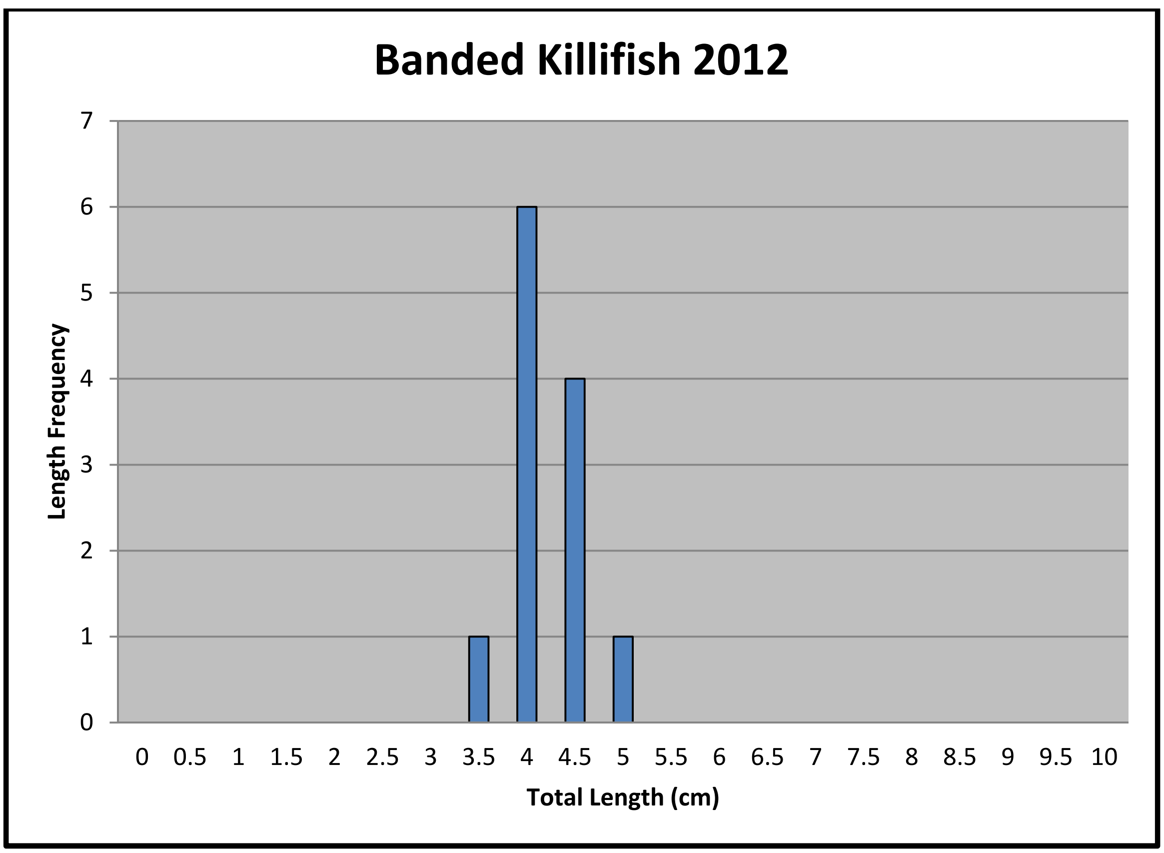


Historic Percentages Of Sampled Populations
Blackchin
Blacknose
Banded Killifish
Iowa Darter
37
5
52
0.7
43
11
43
0.4
45
19
36
0.2
70
4
21
1.2
60.25
19.2
20.5
0.05
57
6
37
0
48
13
39
0.1
95
4
1
0
2003
2004
2005
2006
2007
2010
2011
2012
Year



Blackchin Shiner 2012
30
25
20
15
10
5
0
Length Frequency
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0
Total Length (cm)


Blacknose Shiner 2012
Length Frequency
Total Length (cm)
0 1 2 3 4 5 6 7 8 9 10
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10


Banded Killifish 2012
Length Frequency
Total Length (cm)
0 1 2 3 4 5 6 7
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10

Lake Leopold Fish Survey

Submitted to:

Prairie Crossing Homeowners Association
City of Graylake, Illinois

June 2015

Deuchler Environmental, Inc.
CONSULTING ENGINEERS

Prairie Crossing

Deuchler Environmental, Inc.
CONSULTING ENGINEERS

230 Woodlawn Avenue • Aurora, IL 60506 • Phone: (630) 897-8380 • Fax: (630) 897-5696

Project Number:
15007-00

Lake Leopold
Fish Community Assessment
2015

Prepared For:

Prairie Crossing Homeowners Association
Board of Directors
4180 Route 83, Suite 14
Long Grove, IL 60047

Prepared By:

Leonard Dane, Fisheries Biologist
Karen K. Clementi, Senior Biologist

June 2015

EXECUTIVE SUMMARY

This study was conducted for the Prairie Crossing Homeowners Association to provide current biological data of fish composition in Lake Leopold in Grayslake, Illinois. The entire shoreline was electrofished and three locations were seined. The electrofishing was conducted in a counter-clockwise direction around the perimeter of the lake for a total of 79 minutes. There was a total of 192 fish collected during electrofishing effort. The catch was dominated by Largemouth Bass (79%) and Bluegill (18%). The Largemouth Bass catch was comprised of mainly immature fish. The fish were healthy, in good condition and in a few years should reach mature age and increase the reproduction of Largemouth Bass in Lake Leopold. The median length of the Bluegill collected was 6.6 inches. Smaller Bluegills could have been seeking cover in the deeper aquatic plants and may have been present in larger numbers than were collected during the survey. With the mature size fish present, the Bluegill population appears to be in good condition. The Illinois State listed threatened fish known to inhabit Lake Leopold were all collected. Banded Killifish and Blackchin Shiner were collected by both seining and electrofishing and Iowa Darter was collected by seining only. Overall, Lake Leopold has a good population of Largemouth Bass and Bluegill. The presence of the threatened fish species also indicate the lake has good water quality and healthy aquatic plants.

Recommendations to improve the fishing at the lake and to maintain the water quality include:

- Stocking predator species such as Channel Catfish to increase species diversity and provide opportunities for anglers.

- Harvesting some of the Largemouth Bass under 12 inches to avoid possible disease or stunting
- Conducting a fish survey every three to five years to ensure the fishery is meeting expectations.
- Reducing stormwater inputs with the use of buffer strips, limiting lawn fertilizers, and using alternatives to winter de-icing.
- Maintain native aquatic plants for fish cover and habitat.

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1.0 INTRODUCTION

1.1 Purpose

Deuchler Environmental (DEI) was contracted by the Prairie Crossing Homeowners Association to provide current biological data of fish composition in Lake Leopold. No previous fish sampling had been conducted on Lake Leopold and the Prairie Crossing Homeowners Association was looking for management recommendations.

1.2 Sample Location Description

Lake Leopold is a 22 acre lake located in the Village of Grayslake, Illinois. It has a maximum depth of 15 feet with an average depth of 6.5 feet. The lake was constructed to receive stormwater when the Prairie Crossing Development was created. A map depicting the three seine locations is included as **Figure 1**. The objective of the seining was to confirm the presence of the Illinois State listed threatened fish that have been known to exist in Lake Leopold. The fish are the state threatened include the Banded Killifish, Blackchin Shiner, and Iowa Darter. In addition to the seining, the entire shoreline of Lake Leopold, including the perimeter of the island, was electrofished (**Figure 2**).

2.0 MATERIALS AND METHODS

2.1 Sampling Plan

DEI boat electrofished the shoreline of Lake Leopold as well as sampled three locations using a seine to emphasize the collection of small fish and the threatened and endangered fish species present in Lake Leopold. All game fish collected during the electrofishing were identified, measured, and weighed. All nongame species collected during electrofishing and all fish collected during seining were identified and counted. All fish were released back into Lake Leopold. Sampling was conducted on May 20, 2015.

2.2 Gear Types

The fish sampling was conducted using two standard sampling gears: electrofishing and shoreline seining. In an attempt to minimize the bias created from electrofishing, increase species diversity, and sample for the state listed fishes, shoreline seining was also conducted.

2.2.1 Electrofishing

Electrofishing is a standard gear type for sampling lakes and rivers used by various government research agencies, including the Illinois Department of Natural Resources and Illinois Natural History Survey. Electrofishing is a shallow water gear that targets all sizes and species of fish, though it is somewhat biased towards collecting larger individuals.

A 16’ Alumacraft boat equipped with a Smith-Root 5.0 Generator Powered Pulsator (GPP) electrofisher system was used to sample the perimeter of Lake Leopold including the perimeter of the island. The electrode array consisted of the aluminum boat hull as the cathode and 6 droppers suspended from two retractable booms as the anode. Each anode dropper is 3/8” woven steel cable that has a length of three feet. The booms extend eight feet in front of the bow of the boat. The electrofishing sampling crew consisted of a boat operator and a crew member responsible for netting the stunned fish (**Photo 1**). Electrofishing was conducted in a clockwise direction around the lake with a total pedal time of 159 minutes. A concerted effort was made to net every stunned fish. The electrofishing boat maneuvered along the shoreline out to the aquatic plant edge. The catch was placed into a 75 gallon stock tank that was aerated with oxygen. After 20 to 50 minutes of electrofishing, the fish were measured to the nearest millimeter, weighed to the nearest gram, and analyzed for anomalies before being released back into Lake Leopold.

Photo 1. Boat Electrofishing

2.2.2 Seining

A straight seine was used to conduct the shoreline seining. The seine was 25 feet in length and four feet tall with 3/16 inch mesh. The seine was attached to two wooden handles. Two seine hauls were conducted at each site comprising a total distance of approximately 75 feet (**Photo 2**). All fish collected were identified, counted, and released back into Lake Leopold. While approaching these sites, small fish were observed in the deeper water where some aquatic plants were present. These areas were too deep to be sampled by seining.

Photo 2. Shoreline Seining

3.0 RESULTS

Abundance of fish species provides an overview of the total number of each species present in the survey area. The study yielded a total of 202 individual fish representing five families and seven species (**Table 1**).

Seining sampled three areas around the lake. Location 1 was along the west side of the lake and north of the island, near the fishing pier (**Photo 3**). The bottom substrate was a mix of sand and muck. White Water Lily, cattails, filamentous algae and green algae (*Chara* sp.) were present. This site yielded two Bluegill, two Banded Killifish, and one Iowa Darter. Location 2 was along the east shoreline near a park area. Sampling occurred just south of the seawall area (**Photo 4**). The bottom substrate consisted of muck and there was filamentous algae, green algae (*Chara* sp.), white water lily, and cattails present. This location produced two Bluegills. Location 3 was along the southeast shoreline just south of the beach area (**Photo 5**). The bottom consisted of a mix of sand and muck with cattails and White Water Lily present. This area produced one Largemouth Bass and two Blackchin Shiners. The Blackchin Shiner, Banded Killifish, and Iowa Darter are listed as threatened in Illinois. Schools of shiners were observed among the aquatic plants in areas too deep to seine. It is likely that these were Blackchin Shiners.

Photo 3. Seine Location 1.

Photo 4. Seine Location 2.

Photo 5. Seine Location 3.

There was a total of 192 fish collected during the 79 minute electrofishing effort. The catch was dominated by Largemouth Bass (79%) and Bluegill (18%). A proportional stock density (PSD) is used to evaluate the condition of the fishery. The index compares the number of fish longer than a species specific quality size to the number of fish longer than a species specific stock size. This produces a value that can be used to compare samples among different years and different lakes. The PSD value represents the percent of sexually mature fish in the sample and the sample is assumed to be representative of the population. A balanced population has a PSD value between 40% and 60%. A relative stock density (RSD) was used for larger fish to show the proportion of mature fish.

The PSD for Largemouth Bass uses a stock size of eight inches and a quality size of 12 inches. A PSD was calculated to be eight, well below the management goal indicating more immature fish than mature fish. A RSD for fish greater than 13 inches was three, for fish greater than 14 inches was two and for fish greater than 15 inches was two. There were three fish collected over 17 inches with the largest being 20.3 inches (**Photo 6**). **Figure 3** shows the length distribution of Largemouth Bass collected in 2015. A 93% of the catch was between nine inches and 11 inches. These year classes of fish will grow to maturity within the next few years and increase the natural reproduction of Lake Leopold. With such a large number of fish just below the 12 inch size, a relative weight (Wr) was calculated to assess the condition of the fish and to see if there was indication of stunting of the Largemouth Bass. Relative weights should be between 85 and 104 for fish in good condition (Murphy and Willis 1996). The median Wr for fish in the six to eleven inch size range was 86 indicating the fish are in good condition and stunting doesn't appear to be a problem. The Largemouth Bass were collected at a rate of 1.92 fish per minute. The Illinois Department of Natural Resources (IDNR) recommends a management goal for Largemouth Bass of 1.0 fish per minute. With a 79% of the catch consisting of Largemouth Bass, they could be having an impact on the forage and juvenile fish.

Photo 6. Largemouth Bass

The PSD for Bluegill uses a stock size of three inches and a quality size of six inches. The PSD was calculated to be 76, above the management goal of 40 to 60. This indicates the Bluegill population is dominated by mature size fish (**Photo 7)**. The median size of the Bluegills collected was 6.6 inches and ranged in size from 2.2 inches to 7.9 inches (**Figure 4**). There were areas of abundant vegetation around Lake Leopold which provide refuge sites for the smaller fish to escape predators. Smaller Bluegills could have been seeking cover in the deeper aquatic plants and may have been present in larger numbers than were collected during the survey. Generally lakes with few predator species have an abundance of small size Bluegills. With the mature size fish present, the Bluegill population is sustaining and natural reproduction should enhance the current population.

Photo 7. Bluegill

There were two Black Crappie collected during the survey (**Photo 8)**. They ranged in size from 8.3 up to 9.0 inches. Both fish collected were of mature size. No juvenile Black Crappie were collected or observed. A dead Crappie was noted during DEI's survey. This is not unusual as Crappie tend to get bacterial infections that cause die-offs as a result of stress incurred from spawning.

Photo 8. Black Crappie

Other non-game species collected include Central Mudminnow, Blackchin Shiner, Banded Killifish, and Iowa Darter. None of these species were collected in large numbers but were present in the lake and add to the diversity. The Blackchin Shiner are known to persist in well vegetated lakes (Becker 1983). It is believed that the range is limited to Lake or Cook Counties in Illinois (Smith 1979). The Iowa Darter and Banded Killifish also prefer clear, well vegetated lakes (Smith 1979).

There were no Common Carp or Yellow Bass collected during the survey. Common Carp disrupt the bottom sediments creating turbid water and re-suspending nutrients that can lead to algae blooms. Yellow Bass have the capacity to impact nesting species like Largemouth Bass, Bluegill, and Crappie by preying on eggs, fry and small fingerlings.

4.0 DISCUSSION

Largemouth Bass was the most commonly collected fish species. The Largemouth Bass catch was comprised of mainly immature fish. The fish were healthy, in good condition, and in a few years should reach mature age and increase the natural reproduction of Largemouth Bass in Lake Leopold. It is recommended to harvest some of the Largemouth Bass that are under 12 inches in length to prevent any possible problems of disease and possible stunting. Harvesting some of the Largemouth Bass will also reduce the predation on the smaller young of year and juvenile fish.

A majority of the Bluegill collected were above six inches, which is generally a size when anglers tend to start keeping them, indicating that angler harvest was low. Black Crappie generally have a minimum size limit of eight inches. Both Black Crappie collected were above eight inches. Although in low numbers, Black Crappie was another fish present for anglers to pursue. It was likely that more Black Crappie were present in Lake Leopold as they tend to inhabit deeper water once spawning is completed in lake systems.

The Illinois State listed threatened fish known to inhabit Lake Leopold were all collected. Banded Killifish and Blackchin Shiner were collected by both seining and electrofishing and Iowa Darter was collected by seining only. These species require clear, well vegetated lakes with good water quality. Their presence indicates that Lake Leopold was maintaining good lake health.

The fish population in Lake Leopold was dominated by Largemouth Bass and not diverse. If the goal is to make this lake more attractive to anglers, it is recommended to harvest some of the Largemouth Bass and stock another top predator such as Channel Catfish to increase the species diversity and offer anglers more options.

It is also recommended to maintain a quality native aquatic plant population within the lake and control any exotic plants, such as Eurasian Watermilfoil and Curlyleaf Pondweed, if they make their way into the lake. Signs should be posted to discourage residents from releasing any fish or plants into the lake. Lake Leopold is a clear, well-vegetated lake. The current aquatic plant coverage seemed adequate and there appeared to be good species diversity, although no formal aquatic plant sampling was conducted.

The threatened fish species prefer lakes such as Lake Leopold. To maintain the quality of the lake it is recommended to control the stormwater run-off. There were several stormwater inlets empting directly into the lake. Stormwater brings detrimental nutrients such as phosphorus and chloride into the lake. Creating buffer strips, limiting lawn fertilizer containing phosphorus, and using chloride alternatives for winter de-icing will help maintain the quality of Lake Leopold.

Finally, it is recommended to have a fish survey completed every three to five years to ensure that the fish population is continuing to meet the expectations of the Prairie Crossing Homeowners Association.

5.0 REFERENCES

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison.

Murphy, B. R., and D. W. Willis, editors. 1996. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Smith, P. W. 1979. The Fishes of Illinois. University of Illinois Press, Urbana, IL.

FIGURES

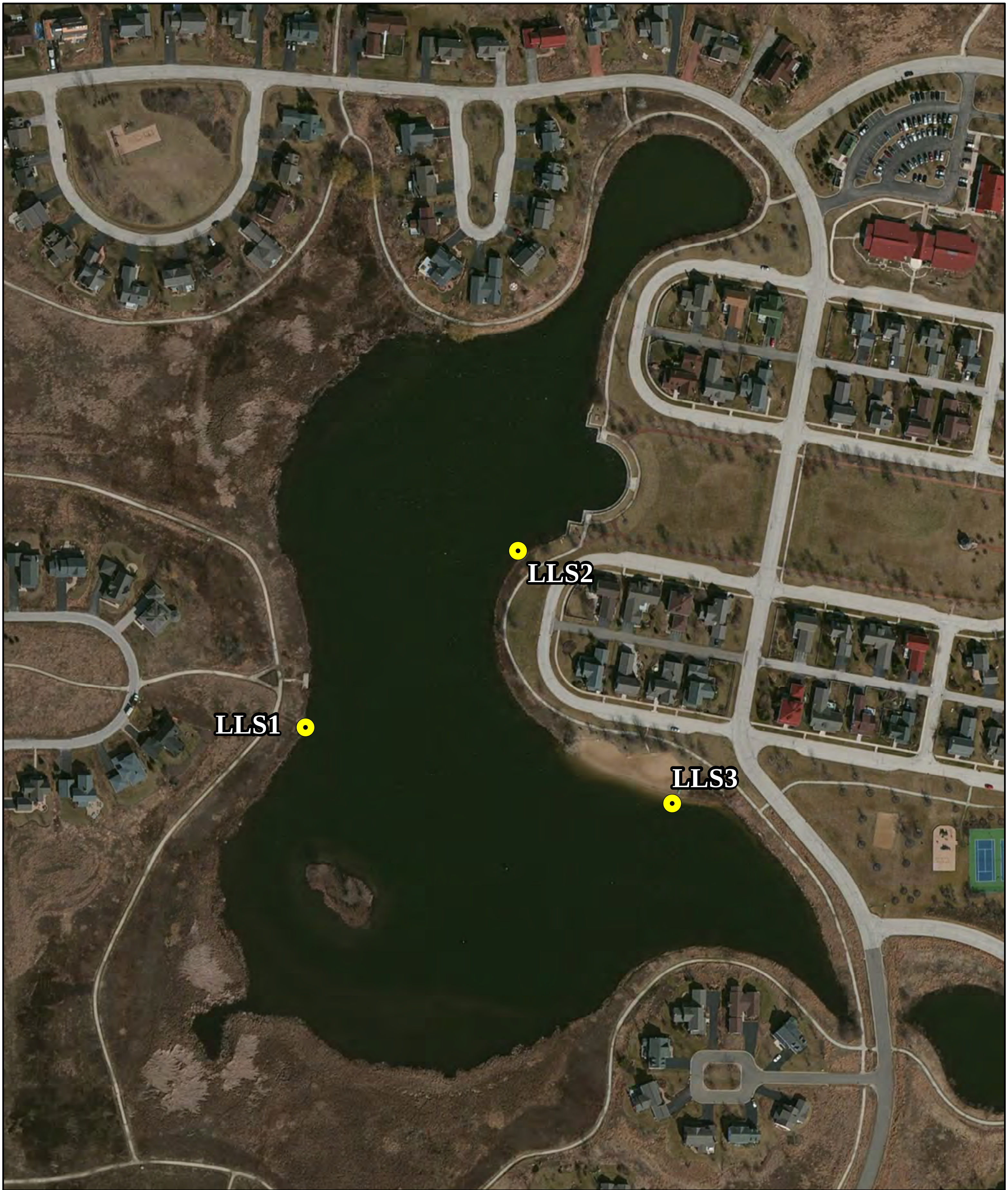

Figure 1
Lake Leopold - Grayslake, IL
Seine Sampling Locations

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CONSULTING ENGINEERS

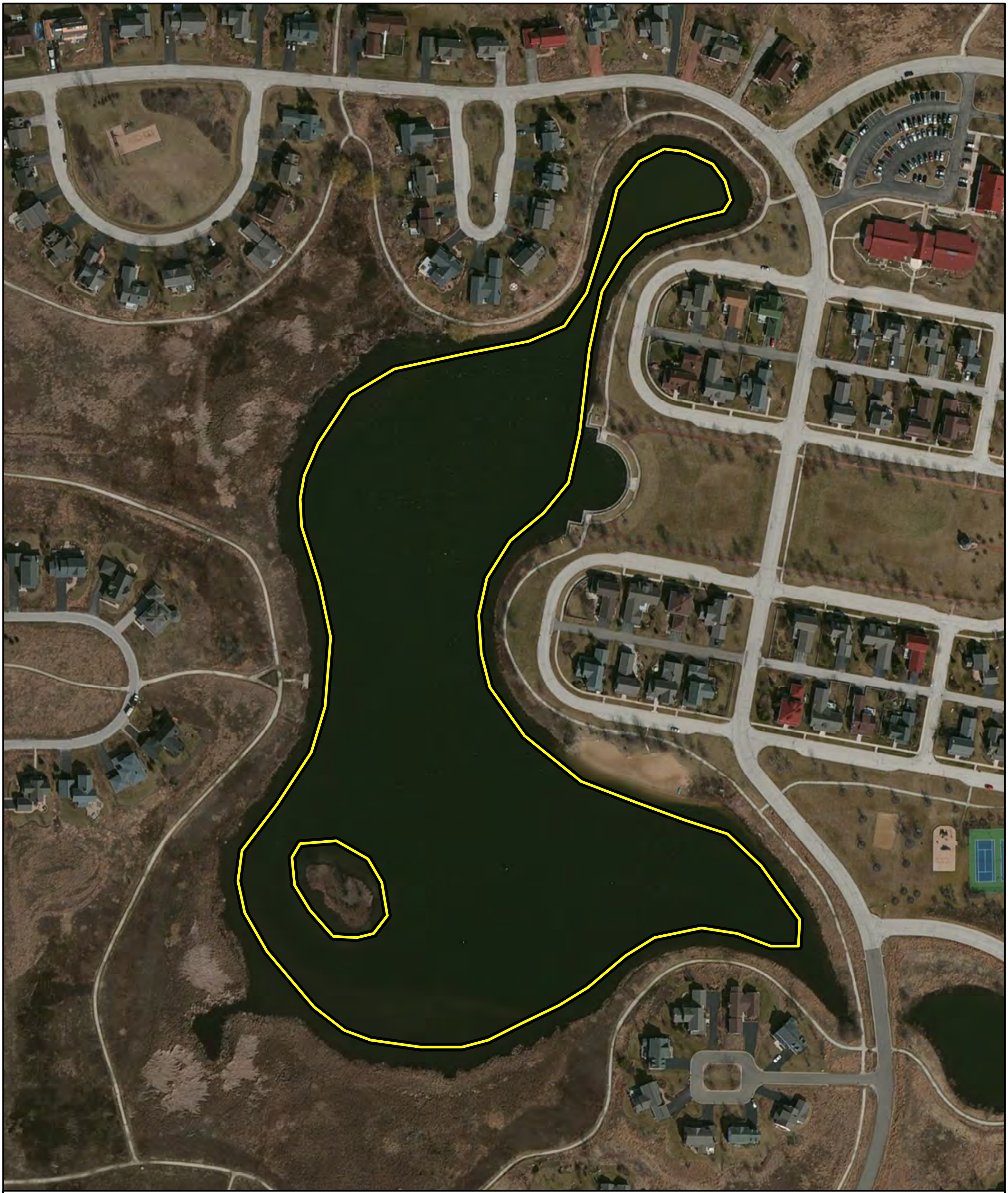

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Figure 2
Lake Leopold - Grayslake, IL
Electrofishing Sampling Area

Figure 3. Length Distribution of Largemouth Bass Collected in 2015.

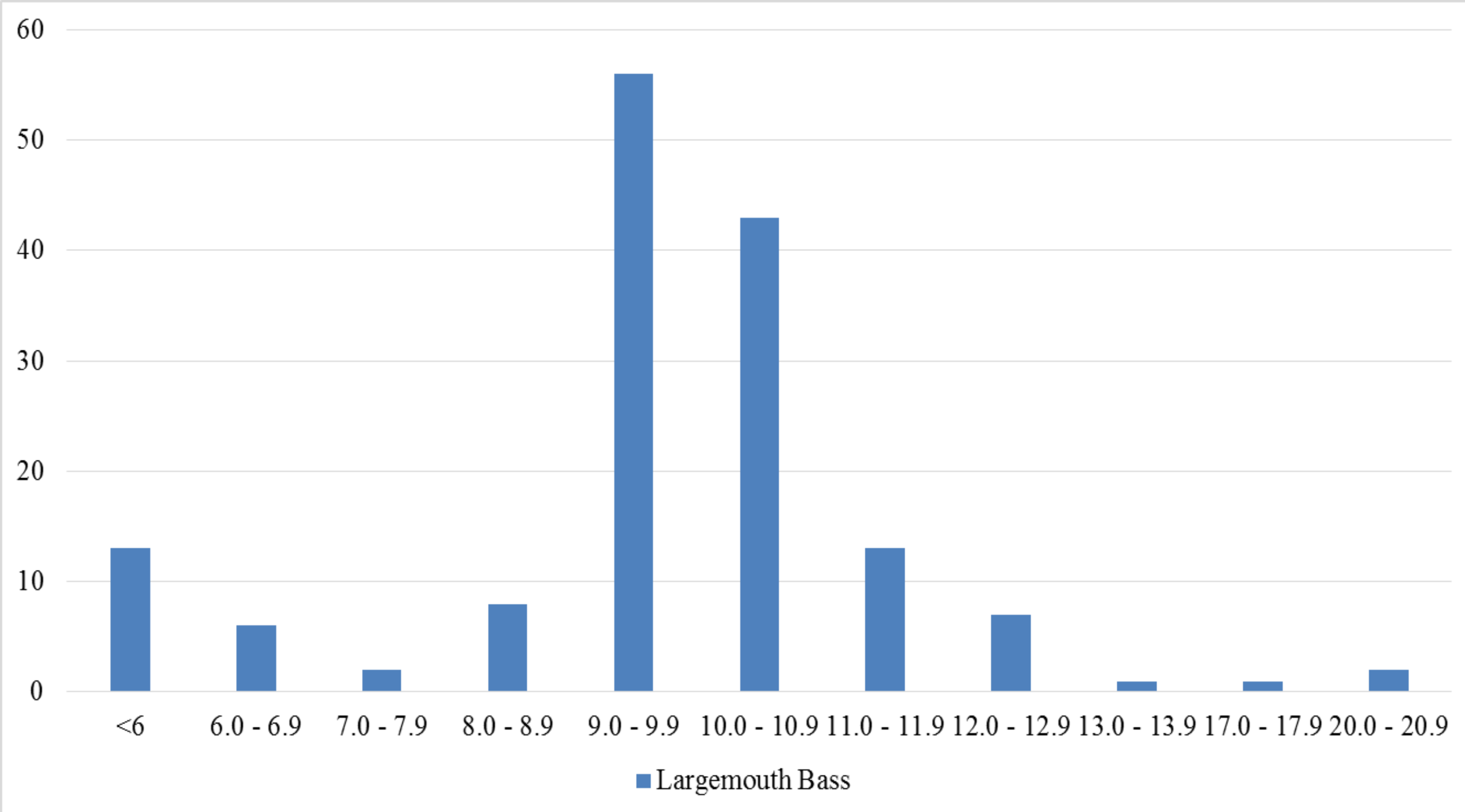
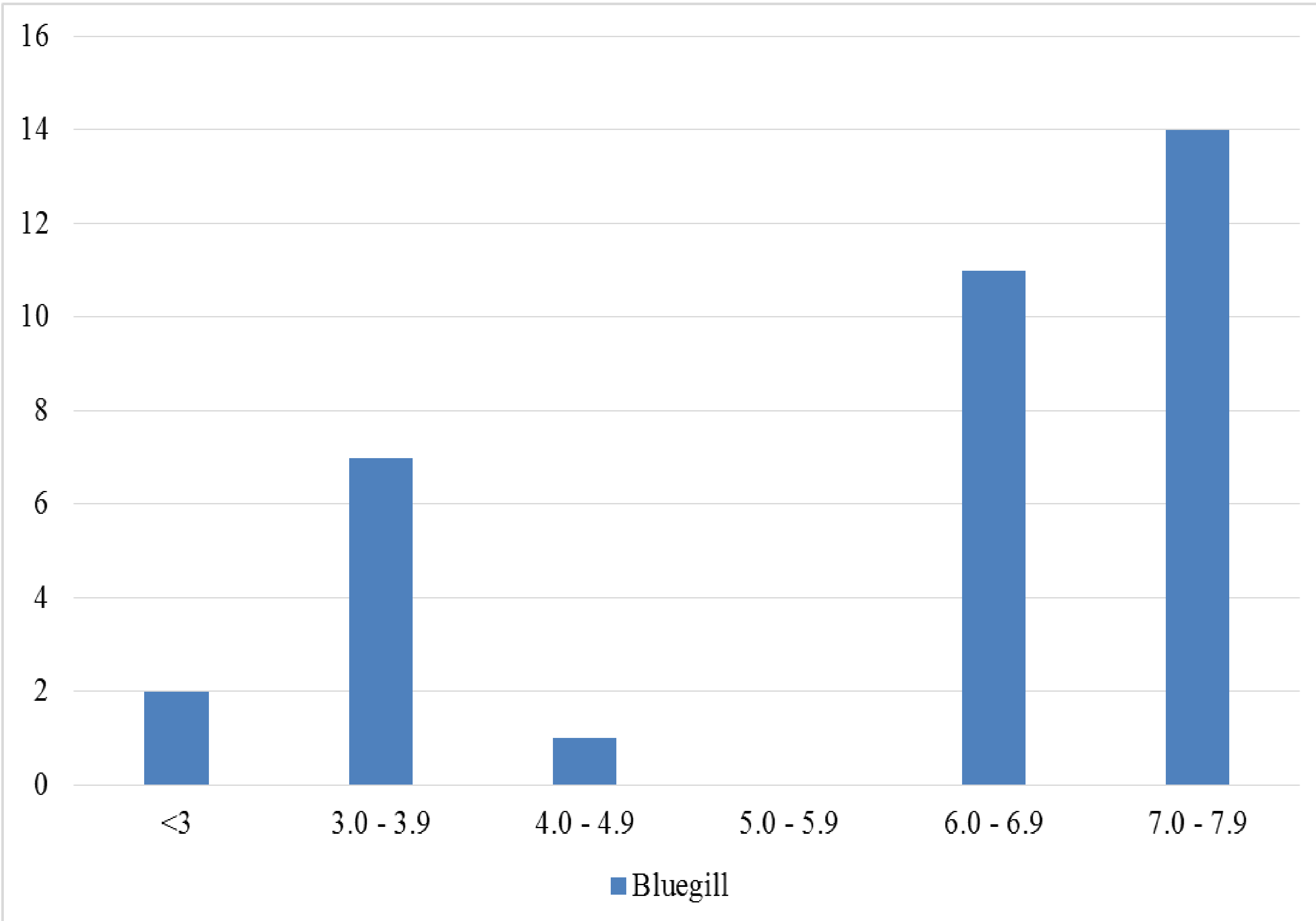


Figure 4. Length Distribution of Bluegill Collected in 2015.



TABLES

Table 1. Total Number of Fish Species Collected.

Family	Common Name	Scientific Name	Total	%
Centrarchidae	Black Crappie	*Pomoxis nigromaculatus*	2	1.0%
	Bluegill	*Lepomis macrochirus*	39	19.3%
	Largemouth Bass	*Micropterus salmoides*	153	75.7%
Cyprinidae	Blackchin Shiner+	*Notropis heterodon*	3	1.5%
Fundulidae	Banded Killifish+	*Fundulus diaphanus*	3	1.5%
Percidae	Iowa Darter+^	*Etheostoma nigrum*	1	0.5%
Umbridae	Central Mudminnow	*Umbra limi*	1	0.5%
		Total	**202**	**100.0%**

+ State Threatened

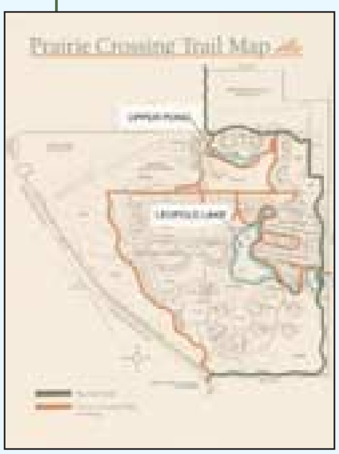
^ collected seining only

Field Notes

The Fish at Prairie Crossing

The most diverse assemblage of freshwater fishes is not in Africa, Southeast Asia, or South America; it is here in North America. About eight hundred freshwater fishes are native to Canada and the United States. Presettlement Illinois was home to close to 185 total native fish species. Of these, 12 have been extirpated from the state, and 31 are listed as endangered or threatened. While native game fish such as bass and trout get a great deal of attention, our native non-game fish species are little appreciated. Several years ago, Integrated Lakes Management (ILM) created the first Illinois refuge for state endangered and threatened non-game fish species in a 2.8-acre residential detention pond at Prairie Crossing in Grayslake, Illinois. (CW, Fall '99).

The project focused on four fish species found in Chicago Wilderness: blackchin shiners (*Notropis heterodon*), blacknose shiners (*Notropis heterolepis*), banded killifish (*Fundulus diaphanus*), and the Iowa darter (*Etheostoma exile*). Biologists captured from one hundred to two hundred individuals of each species from two source lakes in Lake County and transplanted them to the 2.8-acre pond. In the fall of 2000, they transferred the four species from the pond to the 28-acre Lake Leopold, also at the Prairie Crossing site. Since the larger lake had tiger muskies and largemouth bass – both predators for the native fish – researchers were not certain how each species would fare. They needn't have worried.



Informal seining studies conducted in the fall of 2001 suggest that they have not only survived but are thriving. The research team found thousands to hundreds of thousands of individuals of each of these four species in the Prairie Crossing lake and pond. An added bonus was the recent discovery of the presence of the pugnose shiner (*Notropis anogenus*) among the other species.

As a consequence of this success, the project has entered a new phase. The Illinois Department of Natural Resources has prepared four recovery outlines, the first of their kind for endangered and threatened fish species in Illinois. Matthew Roberts and Adrienne Davis, graduate students from Southern Illinois University, will be working under the tutelage of Dr. Brooks Burr to study and characterize the life histories and ecology of the four target species. Dr. Burr is a nationally recognized expert on native non-game fish and co-author of the Peterson Field Guide to Freshwater Fishes of North America. Dr. Mary Ashley of the University of Illinois at Chicago and her graduate student, Fusun Ozer, will be studying the genetics of the shiner species. This is particularly critical since the initial fish transfer involved a relatively small number of individuals, and genetic bottlenecks (loss of viability in future generations) are a possibility. Vic Santucci of Max McGraw Wildlife Foundation will provide oversight of the overall research project and aid in the continued sampling of the Prairie Crossing Pond and Lake Leopold. The research team will also look at the status of these species both regionally and nationally and try to determine factors responsible for their population declines.

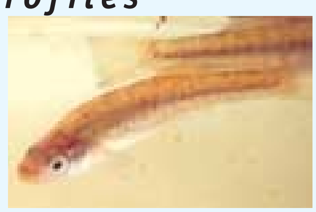
Future phases will include additional fish transfers to other northeastern Illinois lakes and ponds, as well as the publication of information on the genetics and life histories of these four species. If things continue to progress well, these species will become the first Illinois endangered and threatened species to be relieved of that unfortunate distinction.

– Jim Bland is the director of ILM, based in Gurnee. To learn more, go to www.prairiecrossing.com, or visit the North American Native Fishes Association Web site at www.nanfa.org.

Fish Profiles

*The blackchin shiner (*Notropis heterodon*) was once found in both the Fox and DesPlaines River drainages, but disappeared from rivers and lakes of the DesPlaines drainage in the 1980s. Black coloring on its jaw distinguishes it from the blacknose shiner.*

*The blacknose shiner (*Notropis heterolepis*) lives for only two years, and only becomes sexually mature after one year. With such a brief window for reproduction, the blacknose is vulnerable to fluctuating environmental conditions.*



*Known as "timid and secretive," the pugnose shiner (*Notropis anogenus*) lives in clear, weedy shoals of streams and glacial lakes. It is highly intolerant of turbidity, which may account for its diminishing range.*

*The male Iowa darter (*Etheostoma exile*) turns brilliant colors during the breeding season. Lacking a swim bladder, this fish is a bottom feeder that depends on clear water for mating.*

The gypsy moth came by its name because it continuously moves from one place to another. Certain bacteria and fungi populations build up when the moths colonize a new area, eventually killing off most of the gypsy moth population for a few years.

Iowa Darter - *Etheostoma exile*

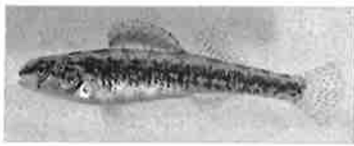


Photo courtesy of Brian Zimmerman

Overview:

The Iowa darter is found in natural lakes in Ohio that were formed by glacial activity. These lakes are often referred to as pothole or kettle lakes.

Ohio Status: Endangered

Description

The Iowa darter has a long, slender body shape and a very short, blunt snout. They have 9-12 dark, squarish blotches along their side. These are blue on breeding males and often less distinct or absent on females. Iowa darters have a light brown back and a white or cream colored belly and throat. They also have a distinct tear drop under the eye and a very short lateral line which ends beneath the first dorsal fin. The second dorsal, tail, and pectoral fins have many small, dark spots that tend to form wavy rows. Breeding males have a blue base to the dorsal fin, followed by a narrower red-orange band, and a thin blue band on the outer edge. Males also have some blue on the anal and pelvic fins. The dark blotches along their sides can have some blue as well with the spaces between the blotches along their side flushed with red. Females typically lack most of the colors but can have a very thin and faint red band in the dorsal fin and occasionally some faint blue in the blotches along their side or fins but it is far less prominent than on males. Members of the Percidae (perches and darters) family, Iowa darters are typically 1.5-2.5 inches long, but can reach 3 inches.

Reproduction

Habitat & Behavior

Research & Surveys

Photos and Media

Iowa Darter - *Etheostoma exile*

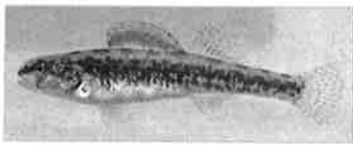


Photo courtesy of Brian Zimmerman

Overview:

The Iowa darter is found in natural lakes in Ohio that were formed by glacial activity. These lakes are often referred to as pothole or kettle lakes.

Ohio Status: Endangered

Description

Reproduction

Iowa darters breed in early spring in shallow water. The females deposit their eggs on roots or vegetation near the waters edge and the male guards a loose territory near the eggs until they hatch.

Habitat & Behavior

Research & Surveys

Photos and Media

CONTACT US

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2045 Morse Road, Building G
Columbus, Ohio 43229-6693

Questions: 1-800-WILDLIFE (945-3543)

Email Us

More Contact Information ›

Iowa Darter - *Etheostoma exile*

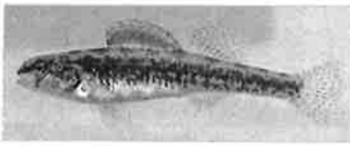

Photo courtesy of Brian Zimmerman

Overview:

The Iowa darter is found in natural lakes in Ohio that were formed by glacial activity. These lakes are often referred to as pothole or kettle lakes.

Ohio Status: Endangered

Description

Reproduction

Habitat & Behavior

Iowa darters are found in natural lakes and very sluggish streams or marshes with dense to moderate aquatic vegetation and clear waters often over a sandy substrate. In Ohio they are primarily found in glacially formed natural lakes, often referred to as pothole or kettle lakes. Historically they were found in Nettle Lake of extreme NW Ohio, a group of small pothole lakes between Bellefontaine and Urbana Ohio, and in many small pothole lakes in NE Ohio including the Portage Lakes. Additionally, they were found in Buckeye Lake which is a man-made lake where one or several of these small natural lakes were flooded to form a larger reservoir. Today they are still present in a few of these natural lakes including the Portage Lakes and a few other smaller natural lakes in both west central and northeast Ohio. They feed on insect larvae, crustaceans, and other aquatic invertebrates.

Research & Surveys

Photos and Media

CONTACT US

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Questions: 1-800-WILDLIFE (945-3543)

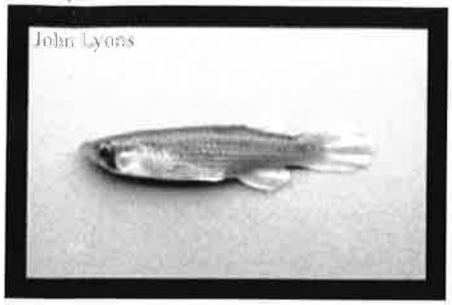

Photo by John Lyons, WDNR

- Overview
- State status
- Species guidance
- Other resources
- Photos/Video
- Wildlife Action Plan

Overview

Overview

Starhead Topminnow (*Fundulus dispar*), a fish listed as Endangered in Wisconsin, prefers quiet, clear-slightly turbid, shallow backwaters with an abundance of submerged aquatic plants. Spawning occurs from June through July.

State status

Status and Natural Heritage Inventory documented occurrences in Wisconsin

The table below provides information about the protected status - both state and federal - and the rank (S and G Ranks) for Starhead Topminnow (*Fundulus dispar*). See the Working List Key for more information about abbreviations. Counties shaded blue have documented occurrences for this species in the Wisconsin Natural Heritage Inventory database. The map is provided as a general reference of where occurrences of this species meet NHI data standards and is not meant as a comprehensive map of all observations.

Note: Species recently added to the NHI Working List may temporarily have blank occurrence maps.

Summary Information

State Status	END
Federal Status in Wisconsin	none
State Rank	S2
Global Rank	G4
Tracked by NHI	Y
WWAP	SGCN

Species guidance

Note: a species guidance document is not available at this time. Information below was compiled from publication ER-091.

Identification: Back and upper sides light olive tan, lower sides and belly lighter to yellowish. Series of red to brown dots arranged horizontally along sides. Dorsal fin is mounted far down the posterior end on the back, prominent dark blotch ("teardrop") beneath eye. Adult length: 1.8-2.2 inches (47-55mm).

Habitat: Glacial lakes and clear, well-vegetated floodplain lakes, swamps and marshes. Prefer quiet, clear to slightly turbid (cloudy), shallow backwaters with an abundance of submergent vegetation.

State Distribution: Wisconsin River between Spring Green and Sauk City, lower Sugar River and Coon Creek of the Rock River Drainage, Mukwonago River in Fox River basin, and Black River near LaCrosse. A map outlining Pre-1977 and 1997 to Present Distribution is available.

Phenology: Occur singly or in pairs just beneath the water's surface, seldom diving deeper even to avoid predators. Spawn in dense beds of aquatic vegetation during late spring to early summer. When placed in unfamiliar locations, starheads have the ability to orient themselves with respect to the sun and attempt to return to familiar waters.

Diet: Starheads feed on terrestrial and aquatic insects, crustaceans, mollusks and delicate aquatic vegetation.

Management Guidelines: Watershed management to improve water clarity and reduce sedimentation, or conducting plantings to reestablish necessary vegetation beds for cover and spawning may benefit this species.

Other resources

Links to additional Starhead Topminnow information

Other links related to fishes

- NatureServe Explorer
- Non-game Fish Habitat Information
- Fish Identification Database [exit DNR]
- USGS Great Lakes Gap And WI-DNR Fish Mapping Application [exit DNR]

Photos/Video

Photos

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ORIGINAL ARTICLE

WILEY FISH and FISHERIES

A critical analysis of the direct effects of dredging on fish

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Abstract

Dredging can have significant impacts on aquatic environments, but the direct effects on fish have not been critically evaluated. Here, a meta-analysis following a conservative approach is used to understand how dredging-related stressors, including suspended sediment, contaminated sediment, hydraulic entrainment and underwater noise, directly influence the effect size and the response elicited in fish across all aquatic ecosystems and all life-history stages. This is followed by an in-depth review summarizing the effects of each dredging-related stressor on fish. Across all dredging-related stressors, studies that reported fish mortality had significantly higher effect sizes than those that describe physiological responses, although indicators of dredge impacts should endeavour to detect effects before excessive mortality occurs. Studies examining the effects of contaminated sediment also had significantly higher effect sizes than studies on clean sediment alone or noise, suggesting additive or synergistic impacts from dredging-related stressors. The early life stages such as eggs and larvae were most likely to suffer lethal impacts, while behavioural effects were more likely to occur in adult catadromous fishes. Both suspended sediment concentration and duration of exposure greatly influenced the type of fish response observed, with both higher concentrations and longer exposure durations associated with fish mortality. The review highlights the need for *in situ* studies on the effects of dredging on fish which consider the interactive effects of multiple dredging-related stressors and their impact on sensitive species of ecological and fisheries value. This information will improve the management of dredging projects and ultimately minimize their impacts on fish.

KEYWORDS

contaminated sediment, dredging impacts, fisheries, meta-analysis, noise pollution, suspended sediment

1 | INTRODUCTION

Dredging involves the excavation and relocation of sediment from lakes, rivers, estuaries or sea beds and is a critical component of most major marine infrastructure developments along the coast (dredging, the fishing technique commonly associated with the catch of bivalves, is not discussed in this review; but see Reine, Dickerson, & Clarke, 1998; Watson, Revenga, & Kura, 2006). The removal of seabed sediments is commonly used to create or maintain navigable depths for shipping channels and harbours and provide material for land reclamation and coastal development projects. Material may also be dredged for the purpose of beach replenishment and mineral and/or gas extraction from underwater deposits (USACE 1983). The expansion of port facilities to accommodate the new generation of large-capacity vessels, and continued development of offshore energy resources will also require an increase in dredging services.

Globally, dredging methods include both mechanical (e.g. grab and excavator dredges) and hydraulic (e.g. trailer suction hopper and pipeline cutterhead dredges) processes (USACE 1983; VBKO 2003). Dredging in coastal marine waters generally requires hydraulic dredges to obtain economic efficiencies for sustaining high production rates. Dredging often has two main sites of operations, the dredge site and the dredged material disposal site. In addition to direct impacts at these sites, sediment plumes can extend several kilometres from the dredging operations, depending on the quantities and grain-size composition of the dredged material and local hydrodynamic conditions (Evans *et al.*, 2012; Fisher, Stark, Ridd, & Jones, 2015). Local physical and environmental conditions, as well as the scale and method of dredging, determine the spatial and temporal scale of the exposure that aquatic organisms experience during dredging-induced perturbations (Bridges *et al.*, 2008; PIANC 2009; Wilber & Clarke, 2001). Scales and modes of impact are also dependent on whether the project involves capital dredging (excavation of previously undisturbed sediment) or maintenance dredging (periodic removal of accumulated sediments following construction) and the history of the site that is to be dredged. A distinction must also be made between scales of impact associated with excavation vs. placement processes. A detailed characterization of diverse dredging methods and their sediment release mechanisms is beyond the scope of this study, but it is recognized that knowledge of dredging processes is a prerequisite for an accurate risk assessment of a dredging project.

Despite the necessity of dredging for industrial development, its potential impacts on the environment are of particular concern as multiple potential stressors associated with dredging activities have been well documented. Chief among these are sediment stress (suspended and deposited), release of toxic contaminants, hydraulic entrainment and noise pollution (Figure 1; McCook *et al.*, 2015; Reine & Clarke, 1998; Reine, Clarke, & Dickerson, 2014; Reine, Clarke, Dickerson, & Wikel, 2014; Wilber & Clarke, 2001). Although there are significant dredging operations undertaken across a range of aquatic environments, and an increasing body of literature documenting dredging-related effects on fish is available (e.g. Wenger *et al.* 2015), our knowledge of the relationships between multiple dredging-related pressures and of their cumulative or interactive effects on fish is still poor. Fish are ecologically, economically and culturally important components of all aquatic environments, with millions of people relying on fish for food or income, thus warranting further investigation into how they are impacted by dredging. Reviews on the effects of dredging-related stressors on fish have previously focused on solitary stressors, such as exposure to elevated suspended sediment concentrations (e.g. Kerr, 1995; Newcombe & Jensen, 1996; Wilber & Clarke, 2001). Effects from multiple dredging components on fish, however, have yet to be synthesized. Such knowledge is critical for predicting potential impacts and designing appropriate, fish-focused management

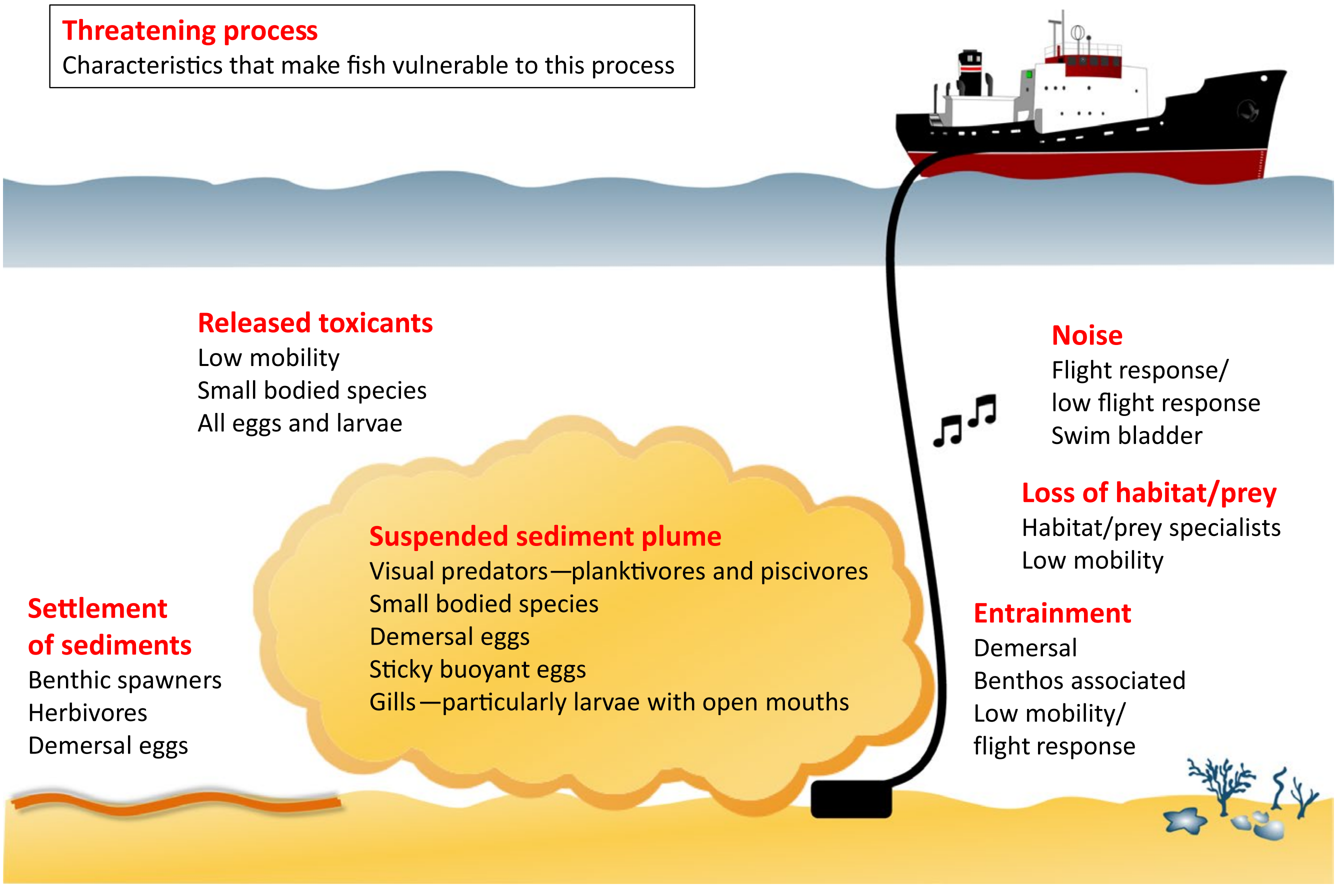

FIGURE 1 A schematic diagram of categories of potential effects of dredging on fish. [Colour figure can be viewed at wileyonlinelibrary.com]

strategies, which avoid or minimize potential impacts, but do not unnecessarily constrain dredging activities (Kemp, Sear, Collins, Naden, & Jones, 2011; NAS, 2001; PIANC 2009). Consequently, reviews of the state of knowledge of dredging-induced impacts and identification of knowledge gaps are an essential first step in determining effective risk reduction measures, and developing best management practices (NAS, 2001; PIANC 2009).

Ultimately, the risk of detrimental impacts depends on exposure characteristics, in particular intensity and duration, and on the tolerance thresholds to the various stressors for the fish species of concern (ANZECC and ARMCANZ 2000; Browne, Tay, & Todd, 2015; Erftemeijer & Lewis, 2006; Wilber & Clarke, 2001). If both the exposures and responses are accurately assessed, appropriate risk management measures can be identified to balance the need to construct and maintain coastal infrastructure with adequate protection of vulnerable species and valuable finfish fishery resources. This review and meta-analysis synthesizes and characterizes the known direct effects on fish from exposures to the most commonly cited potential stressors associated with dredging: sediment, release of toxic contaminants, hydraulic entrainment and noise (McCook *et al.*, 2015; Reine & Clarke, 1998; Reine, Clarke, & Dickerson, 2014; Reine, Clarke, & Dickerson, 2014; Reine, Clarke, Dickerson, & Wikel, 2014; Wilber & Clarke, 2001), with an emphasis on exposures relevant to dredging processes.

2 | METHODS

2.1 | Development of framework for the review

The development of this review was undertaken at a workshop in October 2013 by stakeholders from state and federal government agencies, including the Environment Protection Authority (Western Australia), Western Australia Department of Fisheries and Department of Parks and Wildlife, and the Australian Institute of Marine Science; experts from multiple universities; and representatives from private industry. The overall objective of the workshop and the assessment was to synthesize and quantify the effects of dredging-related pressures on critical ecological and physiological processes for finfish and critically evaluate the factors that influence the effects of dredging on fish. To identify what the potential impacts of dredging could be, previous studies and reviews on the effects of dredging on aquatic organisms were assessed as a group. Literature on impacts of dredging was found through Google Scholar, Scopus and the ISI Web of Knowledge, using the search terms "dredg*," "impact*," "effect*" and "environment*." Results that did not pertain to dredging as defined in our review were filtered out. Results that did not mention particular impacts or environmental responses associated with dredging were also excluded. For the purposes of creating an initial list of impacts, all potential impacts were recorded, regardless of the aquatic organism it was shown to affect. Articles were also provided by stakeholders with particular dredging expertise. In the end, 33 sources of information were used to compile a list of environmental impacts associated with dredging (Table S1).

There were six main potential impacts identified as associated with dredging: habitat loss, hydraulic entrainment, release of contaminants, sedimentation, suspended sediment and underwater noise (Figure 1). The strong relationship between fish and habitat means that any direct impact on habitat will affect most fish species (e.g. Jones, McCormick, Srinivasan, & Eagle, 2004). Habitat loss and degradation can be a major aspect of the impact of dredging on fish communities (Amesbury, 1981; Galzin, 1981; Lindeman & Snyder, 1999). Dredging-induced habitat loss was considered to have an indirect effect on fish, and as this has been reviewed previously (e.g. Erftemeijer & Lewis, 2006; Erftemeijer, Riegl, Hoeksema, & Todd, 2012) and is generally already considered during the approval process for proposed dredging works (Erftemeijer *et al.*, 2013; PIANC 2009), it was not considered in this review. Ultimately, the overarching objective for this review was to characterize the direct effects of dredging impacts on fish. The protocol used to search the literature is described below.

2.2 | Review protocol

Literature was sourced from Google Scholar, Scopus and the ISI Web of Knowledge using search terms relevant to each potential impact. The following search terms were used: ["suspended sediment*" OR "sedimentation" OR "turbid*" OR "dredg*"] AND "fish*"; "suspended sediment*"AND ["contam*" OR "metal*" OR "PAH*" OR "PCB*" OR "OCP*" OR "organochlor*"] AND "fish*"; "dredg*" AND "entrain*" AND "fish*"; "Dredg*" AND "sound" AND fish"; "Dredg*" AND "noise" AND "fish"; "Contin*" AND "sound" AND "fish"; "Contin*" AND "noise" AND "fish"; "Noise" AND "fish"; "Sound" AND "Fish." Relevant articles from reference lists of papers were used to identify additional sources of literature. In addition, unpublished grey literature, reports and management plans were identified and sourced through consultation with the stakeholders present at the workshop.

Beyond being relevant to each impact, to be included, studies needed to state the fish species and life-history stage being tested, have a clear experimental design (i.e. could be repeated), state concentrations and exposure times used (when experimental), have a clear experimental endpoint and present data in units that could be compared to other studies. To be conservative, the data that were extracted from each study were the lowest concentration where a specific effect was observed. If no effect was observed, the highest concentration that did not elicit an effect was extracted.

2.3 | Meta-analysis

Once the results of each study were extracted, they were ranked by type of response, which facilitated comparison across stressors (Table 1; see ranks of each study in Tables S2–S5). Where possible, the Hedges' *g* effect size (absolute value) of each study was calculated (Equation 1; Tables S2–S5).

$$g = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}}} \tag{1}$$

TABLE 1 The types of effect ranked to facilitate comparison

Rank	Type of effect
0	No effect
1	Minor behavioural changes—avoidance of a stressor
2	Minor physical damage—gill damage, skin abrasions and changes to development times, OR Moderate behavioural changes—reduced foraging rate or changes to habitat association, but did not record any physiological changes
3	Physiological changes—changes in hormone levels, reduced growth rate, organ function or developmental abnormalities
4	Increase in mortality or reduced hatching success

where $\overline{X_1}$ equals the mean of the treatment group response, $\overline{X_2}$ equals the mean of the control group response, n_1 is the sample size of the treatment group, n_2 is the sample size of the control group, and S_1 and S_2 are the standard deviations of the treatment and control groups, respectively. We chose Hedges' *g*, as it is more robust for studies with small sample sizes (Hedges, 1981). To examine potential drivers of variability in effect sizes across all stressors, we generated a generalized mixed-effects model with the package lme4 in the R programming language (R Development Core Team 2014) using a Laplace approximation and a log link function to meet the assumptions of the model (Bates *et al.* 2014). We evaluated the appropriateness of the model by examining Q–Q normality plots of effect sizes using the package car (Fox & Weisberg, 2011; Figure S1). The models included response type (as described above), habitat (freshwater, estuarine, marine, anadromous, catadromous), stressor type (contaminated sediment, suspended sediment, sound), life-history stage during exposure (eggs, larvae, juveniles, adults), family and the log of exposure duration as fixed effects, and species as a random effect. We performed a linear correspondence analysis (LCA) and calculated the chi-square statistic to examine the association between habitat, life-history stage, or type of stressor and response type using the package Ca in R (Nenadic & Greenacre, 2007).

For each individual stressor, we conducted generalized linear mixed-effects models fit by restricted maximum likelihood to assess potential drivers of effect size. Individual predictors were mean-centred to facilitate model convergence (Wenger, Whinney, Taylor, & Kroon, 2016). To ensure we were meeting the assumptions of the model, we checked the plotted residuals to assess homoscedasticity prior to utilizing the results of the model. We conducted a Wald's test to establish the significance of predictor variables in each model. We further established the robustness of our results by calculating Rosenthal's fail-safe number, an indicator of the number of studies that would need to exist to overturn a significant result (Rosenthal, 1979). A high fail-safe number relative to the number of experiments included in the meta-analysis indicates that the overall effect size of the meta-analysis is a robust estimate of the true effect size (Gurevitch & Hedges, 1999).

For each individual stressor, we also conducted linear discriminant analyses (LDA) using the package MASS in R (Venables and Ripley 2002) to determine the relative influence that the magnitude of the stressor and the exposure time had on the response type. For each LDA, we performed a MANOVA and a Wilks's lambda test to examine whether the explanatory variables had discriminatory power. For each individual stressor, we also performed a linear correspondence analysis and calculated the chi-square statistic to examine the relationship between life-history stage, habitat, source of stressor and response type.

3 | META-ANALYSIS AND REVIEW

Over 430 papers were fully assessed to understand the effects of suspended sediments on fish. Of those papers, the fish response type elicited by suspended sediment was extracted from 59 studies (Table S2). Of those, it was possible to calculate the effect size for 31 data records (Table 2). In addition, 136 peer-reviewed articles were fully assessed to understand the effects of contaminated sediment on fish, from which data records were extracted from 36 articles that directly reported the response type elicited by exposure of fish to contaminated sediment (Table S3). It was possible to calculate the effect size of 25 studies; however, only 12 of these focused on individual contaminants (Table 2; Table S3). Twenty-four publications on the effects of hydraulic entrainment on fish were assessed. From these studies, it was only possible to extract the fish response elicited by hydraulic entrainment from four studies (Table S4). However, it was not possible to calculate the effect size in any of these studies as they all lacked controls. Thirty-five publications were assessed to understand the effects of dredging-related noise on fish. From those publications, we were able to extract the fish response type elicited by sound from 16 studies (Table S5), from which we could calculate effect sizes for nine data records (Table 2).

3.1 | Overall effects of dredging on fish

The results of the generalized linear mixed-effects model indicated effect size is significantly influenced by the type of response observed in fish, the type of stressor and the life-history stage during exposure (Table 3). Studies that recorded increased mortality (response type 4) had significantly greater effect sizes than studies that recorded physiological impacts (Figure 2a). As the objective of many studies that recorded mortality was to find the LC_{50} concentration (the concentration that causes 50% mortality), it is not surprising those that observed mortality had large effect sizes. Hence, this may be an artefact of the type of experiment that produces mortality results and does not necessarily infer that mortality is a good indicator of impacts from dredging. We argue that indicators should detect early signs of stress and allow management intervention before mortality occurs. Studies examining the effects of contaminated sediment also had significantly higher effect sizes than studies on clean sediment alone or noise, suggesting synergistic impacts from dredging-related stressors (Figure 2b).

The results of the linear correspondence analysis and the calculated chi-square statistic reveal there was a significant association

TABLE 2 Derivation of the effect sizes for each study where it was possible to calculate it. Common names and families are all listed in Tables S2–S5 in the Supporting Information

Dredging stressor	Species name	Source	Response (treatment)	Response (control)	Sample size (treatment)	Sample size (control)	*SD* treatment	*SD* control	Effect size (absolute value Hedges' *g*)
Suspended sediment	*Alosa pseudoharengus*	Auld and Schubel (1978)	78.0	84.0	353	353	8.0	9.0	0.70
Suspended sediment	*Alosa sapidissima*	Auld and Schubel (1978)	82.0	95.0	127	127	9.8	4.7	1.69
Suspended sediment	*Clupea harengus*	Johnston and Wildish (1982)	32.7	49.1	8	8	2.7	1.3	7.70
Suspended sediment	*Chromis atripectoralis*	Wenger *et al.* (2013)	70.8	45.8	200	200	66.5	76.4	0.35
Suspended sediment	*Alosa aestivalis*	Auld and Schubel (1978)	71.0	77.0	243	243	18.2	18.9	0.32
Suspended sediment	*Oncorhynchus kisutch*	Galbraith, MacIsaac, Macdonald, and Farrell (2006)	31.2	61.4	4	3	12.6	19.6	1.92
Suspended sediment	*O. kisutch*	Redding, Schreck, and Everest (1987)	11.0	3.0	11	11	19.9	3.3	0.56
Suspended sediment	*O. kisutch*	Servizi and Martens (1992)	1.5	0.2	93	93	3.5	0.5	0.53
Suspended sediment	*Perca fluviatilis*	Ljunggren and Sandström (2007)	0.1	0.2	36	36	0.1	0.5	0.37
Suspended sediment	*Pomacentrus moluccensis*	Wenger and McCormick (2013)	23.3	61.1	20	20	39.8	44.3	0.90
Suspended sediment	*Amphiprion percula*	Hess *et al.* (2015)	37.6	22.4	174	129	54.1	29.5	0.34
Suspended sediment	*A. percula*	Wenger *et al.* (2014)	12.7	11.1	98	91	2.6	1.0	0.78
Suspended sediment	*Clupea pallasii*	Boehlert (1984)	1.7	1.1	5	9	0.3	0.1	2.72
Suspended sediment	*C. pallasii*	Boehlert (1984)	1.5	1.1	5	9	0.2	0.1	2.11
Suspended sediment	*Sander lucioperca*	Ljunggren and Sandström (2007)	0.1	0.1	36	36	0.1	0.1	0.10
Suspended sediment	*Pagrus major*	Isono, Kita, and Setoguma (1998)	40.0	100.0	60	60	38.7	0.0	2.19
Suspended sediment	*Anoplopoma fimbria*	De Robertis *et al.* (2003)	1.5	4.8	6	6	1.7	2.0	1.79
Suspended sediment	*Oncorhynchus nerka*	Galbraith *et al.* (2006)	17.3	41.9	10	10	13.0	17.4	1.60
Suspended sediment	*Acanthochromis polyacanthus*	Wenger *et al.* (2012)	18.1	27.0	25	27	9.5	9.4	0.94
Suspended sediment	*A. polyacanthus*	Wenger *et al.* (2012)	11.5	20.8	25	27	4.5	3.6	2.28
Suspended sediment	*A. polyacanthus*	Wenger *et al.* (2012)	41.2	0.0	3	3	6.1	0.0	9.55
Suspended sediment	*Salmo gairdneri*	Redding *et al.* (1987)	19.0	2.0	11	6	26.5	4.9	0.78
Suspended sediment	*Morone saxatilis*	Auld and Schubel (1978)	68.0	97.0	135	135	18.1	13.3	1.83
Suspended sediment	*M. saxatilis*	Breitburg (1988)	4.9	7.4	19	24	5.2	5.4	0.47
Suspended sediment	*Oplegnathus fasciatus*	Isono *et al.* (1998)	70.0	97.0	60	60	96.8	0.0	0.39
Suspended sediment	*Parapristipoma trilineatum*	Isono *et al.* (1998)	62.0	100.0	60	60	112.3	0.0	0.48
Suspended sediment	*Morone americana*	Auld and Schubel (1978)	49.0	69.0	270	270	34.7	16.1	0.74
Suspended sediment	*Perca flavescens*	Auld and Schubel (1978)	62.0	93.0	165	165	15.9	6.1	2.58
Suspended sediment	*P. flavescens*	Auld and Schubel (1978)	92.0	91.0	333	333	16.0	10.2	0.07
Suspended sediment	*A. sapidissima*	Auld and Schubel (1978)	73.0	80.0	189	189	14.3	29.1	0.31
Contaminated sediment	*Carassius auratus*	Tao, Liu, Dawson, Long, and Xu (2000)	0.9	0.1	4	4	0.1	0.0	11.19
Contaminated sediment	*Hippoglossoides platessoides*	Marcogliese, Nagler, and Cyr (1998)	254.2	154.6	12	15	226.2	220.0	0.45
Contaminated sediment	*Epinephelus coioides*	Wong *et al.* (2013)	17.0	4.0	10	10	8.0	3.0	2.15

(continues)

TABLE 2 (continued)

Dredging stressor	Species name	Source	Response (treatment)	Response (control)	Sample size (treatment)	Sample size (control)	*SD* treatment	*SD* control	Effect size (absolute value Hedges' *g*)
Contaminated sediment	*Oreochromis niloticus*	Peebua, Kruatrachue, Pokethitiyook, and Kosiyachinda (2006)	50.0	0.0	6	6	26.7	0.0	2.65
Contaminated sediment	*Dicentrarchus labrax*	Martins, Santos, Costa, and Costa (2016)	0.2	0.1	10	10	0.0	0.0	3.94
Contaminated sediment	*P. flavescens*	Seelye, Hesselberg, and Mac (1982)	3.1	1.7	10	10	0.2	0.2	6.41
Contaminated sediment	*P. flavescens*	Seelye *et al.* (1982)	2.0	1.5	3	3	0.1	0.0	8.12
Contaminated sediment	*Pleuronectes yokohamae*	Kobayashi, Sakurai, and Suzuki (2010)	22.0	1.0	3	3	2.0	0.0	14.85
Contaminated sediment	*Pimephales promelas*	Sellin, Snow, and Kolok (2010)	2.0	1.3	7	7	0.3	1.1	0.91
Contaminated sediment	*Limanda limanda*	Livingstone *et al.* (1993)	653.3	245.8	5	5	95.7	91.5	4.35
Contaminated sediment	*Oryzias latipes*	Barjhoux *et al.* (2012)	72.1	20.3	3	3	19.4	4.5	3.68
Contaminated sediment	*Leiostomus xanthurus*	Sved, Roberts, and Van Veld (1997)	30.1	33.4	40	40	4.4	4.7	0.71
Contaminated sediment	*Prochilodus lineatus*	Almeida, Meletti, and Martinez (2005)	45.1	23.0	4	6	14.4	4.2	2.35
Contaminated sediment	*Solea senegalensis*	Costa *et al.* (2011)	3.5	1.0	20	20	0.9	0.6	3.31
Contaminated sediment	*Oncorhynchus mykiss*	Brinkmann *et al.* (2015)	9.9	0.7	6	6	3.4	1.2	3.61
Contaminated sediment	*O. mykiss*	Hudjetz *et al.* (2014)	11.6	0.2	10	10	4.3	0.2	3.78
Contaminated sediment	*Scophthalmus maximus*	Hartl *et al.* (2007)	138.0	25.9	8	8	32.0	15.6	4.45
Contaminated sediment	*S. maximus*	Kilemade *et al.* (2009)	135.0	25.9	8	8	27.0	15.6	4.95
Contaminated sediment	*O. mykiss*	Viganò, Arillo, De Flora, and Lazorchak (1995)	1.4	0.3	3	3	0.1	0.1	21.00
Contaminated sediment	*Liza macrolepis*	Chen and Chen (2001)	18.5	0.0	2	2	5.0	0.0	5.29
Contaminated sediment	*O. latipes*	Cachot *et al.* (2007)	44.9	10.0	3	3	16.0	7.0	2.83
Contaminated sediment	*O. latipes*	Vicquelin *et al.* (2011)	42.0	7.8	3	3	4.0	6.7	6.20
Contaminated sediment	*O. latipes*	Vicquelin *et al.* (2011)	88.0	7.8	3	3	8.0	6.7	10.87
Contaminated sediment	*O. latipes*	Vicquelin *et al.* (2011)	68.0	7.8	3	3	2.0	6.7	12.18
Contaminated sediment	*O. mykiss*	Kemble *et al.* (1994)	59.0	0.0	4	4	7.9	0.0	10.62
Sound	*Anguilla anguilla*	Simpson, Purser, and Radford (2015)	0.5	0.4	9	19	0.1	0.1	0.92
Sound	*Multiple species*	Jung and Swearer (2011)	55.0	18.0	8	8	42.4	22.6	1.09
Sound	*C. auratus*	Smith *et al.* (2006)	12.0	39.0	6	6	12.2	12.2	2.20
Sound	*Myxocyprinus asiaticus*	Liu, Wei, Du, Fu, and Chen (2013)	76.1	69.8	5	5	4.9	5.6	1.20
Sound	*C. auratus*	Smith, Kane, and Popper (2004)	165.0	89.7	6	6	44.3	78.4	1.18
Sound	*Cyprinus carpio*	Wysocki, Dittami, and Ladich (2006)	0.4	0.2	6	6	0.0	0.0	3.06
Sound	*Gobio gobio*	Wysocki *et al.* (2006)	0.8	0.4	7	7	1.0	0.1	0.63
Sound	*P. fluviatilis*	Wysocki *et al.* (2006)	0.3	0.2	7	7	0.0	0.0	5.88
Sound	*Sparus aurata*	Celi *et al.* (2016)	163.4	75.6	10	10	117.0	80.5	0.87

TABLE 3 The results of the Wald's test on the generalized linear mixed-effects model examining drivers of effect size overall and within individual stressors

Explanatory variables	Chisq	*df*	Pr(>Chisq)
All stressors			
Response type	20.89	4	<.001
Habitat	1.14	4	.88
Stressor	54.36	2	<.001
Life-history stage	78.1	3	<.001
Log exposure duration	0.53	1	.47
Suspended sediment			
Suspended sediment concentration	0.93	1	.33
Response type	0.24	4	.63
Habitat	2.99	3	.39
Life-history stage	1.29	3	.52
Exposure duration	0.03	1	.86
Contaminated sediment			
Contaminant concentration	1.89	1	.19
Response type	5.26	2	.07
Habitat	4.51	3	.21
Life-history stage	0.84	2	.36
Exposure duration	0.13	1	.72
Sound			
Decibel level	0.97	1	.32
Response type	4.64	2	.03
Habitat	3.7	2	.16
Life-history stage	0.25	2	.61
Exposure duration	0.01	1	.91

between the predictor variables (habitat, life-history stage and type of stressor; $p < 0.01$) and the response type. Visual inspection of the output show studies on larvae and eggs recorded lethal impacts more frequently than other life-history stages. Studies using adult and juvenile fish observed physical damage and physiological impacts most frequently, respectively, while catadromous fishes were most closely associated with behavioural effects (Figure 3). Additionally, the type of responses recorded for fish from freshwater, estuarine and marine environments were very similar, suggesting that results from dredging stressor studies on a range of species can be combined to develop general management guidelines for both marine and freshwater environments.

3.2 | The effects of suspended sediment on fish

A review of studies that have carried out experiments to examine the effects of suspended sediments on fish found the duration of exposure, concentration of suspended sediment, habitat of origin and life-history stages varied considerably among studies. All studies, however, reported continuous exposure lasting between 1.2 min and 64 days across concentrations ranging from 4 to 87,800 mg/L (Table S2). There were 49 records on the effects of suspended sediment on adult fish, 50 records for juvenile fish, 34 records for larvae and 13 for eggs. Forty-nine of the records were from anadromous species, 33 were from estuarine species, 32 were from freshwater species, and 32 were from marine species (Table S2).

There was a wide range of endpoints measured and responses elicited among the studies. Fourteen studies showed no effect of suspended sediment (although only 11 of these recorded an exposure time), 12 studies observed behavioural changes (response type 1), 34 studies recorded physical damage and substantial behavioural changes (response type 2), 37 studies measured physiological stress and sublethal responses (response type 3), and 49 studies recorded some level of mortality (response type 4). Effect sizes ranged from 0.07 to 9.55, with a mean effect size of 1.53 ± 0.33 (*SE*) (Table 2; Table S2).

None of the predictor variables in the linear mixed-effects model significantly influenced variation in effect size of suspended sediments on fish (Table 3). The predictor variables included were suspended sediment concentration, exposure duration, life-history stage and response type. Rosenthal's fail-safe number was 2,870, suggesting that our results are not an artefact of publication bias (Gurevitch & Hedges, 1999). Furthermore, neither sediment type, habitat, nor life-history stage significantly influenced the response type elicited by suspended sediment exposure ($p = .303$) as revealed by the linear correspondence analysis and chi-square test (Table 4).

However, the linear discriminant analysis indicated that increasing both the concentration and exposure time to suspended sediment increased the severity of fish response (Figure 4a,b). Accordingly, the Wilks's lambda results verified the discriminatory power of the explanatory variables ($p < .0001$; Table 4). While there is a clear trend between response type and increasing concentrations and exposure to suspended sediment, fish have markedly different tolerances to suspended sediment, with some species able to withstand concentrations up to 28,000 mg/L, while others experience mortality starting at 25 mg/L (Figure 4a, Table S2).

3.2.1 | Behavioural changes

One of the most commonly observed behaviours by fish to elevated suspended sediment is the avoidance of turbid water (Collin & Hart, 2015), an effect that has been observed in juvenile Coho salmon (*Oncorhynchus kisutch*, Salmonidae), Arctic grayling (*Thymallus arcticus*, Salmonidae), and Rainbow trout (*Oncorhynchus mykiss*, Salmonidae) (Newcombe & Jensen, 1996), species that have adapted to a range of environments. Avoidance behaviour (response type 1) can be induced at very low levels of suspended sediment (Figure 4a), but ceases once the disturbance is removed, or if the fish becomes acclimated (Berg, 1983; Berg & Northcote, 1985). Increased turbidity has also produced long-term shifts in local abundance and community composition. For example, a switch in dominance occurred between Common dab (*Limanda limanda*, Pleuronectidae) and European plaice (*Pleuronectes platessa*, Pleuronectidae) when turbidity increased as dredging escalated in the Dutch Wadden Sea over several years (De Jonge, Essink,

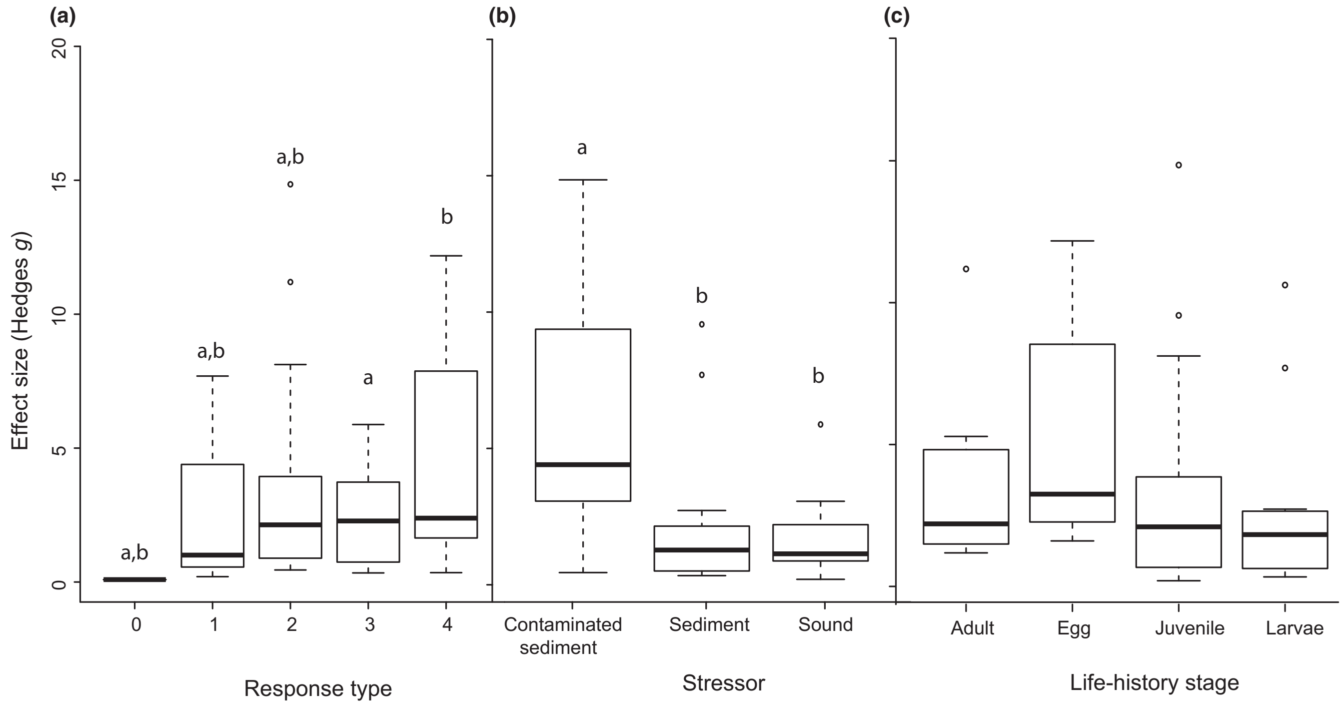

FIGURE 2 The impact of (a) response type, (b) stressor type, (c) life-history stage on effect size across all stressors. A response type of 0 = no effect, 1 = minor behavioural changes, 2 = minor physical damage or moderate behavioural changes, 3 = physiological impacts and 4 = increased mortality. Variables with non-overlapping letters above them are significantly different

& Boddeke, 1993). Additionally, the disappearance of mackerel in the Sea of Marmara, a key spawning ground for this species, was attributed to the presence of dredged material (Appleby & Scarratt, 1989); however it is likely that substantial changes in community composition are a direct result of long or frequent exposure.

Avoidance of dredged areas from dredging-related habitat modifications (e.g. sediment accumulation or loss) by fish can have a negative impact on fisheries at a local scale. For example, large deposits of dredged material in the Gulf of Saint Lawrence, Canada, were linked to a 3–7-fold decrease in catch per unit effort (CPUE) of Atlantic sturgeon (*Acipenser oxyrinchus*, Acipenseridae) (Hatin, Lachance, & Fournier, 2007). A reduced CPUE was related to either or both avoidance and a decreased effectiveness of fishing gear for species that visually locate bait (Utne-Palm, 2002). Conversely, CPUE can increase in turbid water if fish had a decreased ability to avoid fishing gear (Speas *et al.*, 2004). The return of fish to an area after a disturbance is highly dependent on the recovery of the environment to pre-disturbance conditions, the availability of alternative suitable habitat and the ecological plasticity of that species. Trade-offs between the risks associated with the disturbed environment and habitat and food availability will dictate the significance of behavioural changes brought on by dredging (Pirotta *et al.*, 2013).

Because turbidity often impairs visual acuity, activities and processes that require vision can be inhibited, leading to behavioural responses other than avoidance. Coral-associated damselfish were unable to locate live coral in turbid water, a process that relies on both visual acuity and chemoreception (O'Connor *et al.*, 2015; Wenger, Johansen, & Jones, 2011). This is particularly important for species with a pelagic larval phase, whereby the ability to find suitable habitat is crucial for development and survival during the very early life-history stages. If individuals settle into suboptimal habitat, they are more vulnerable to predation and experience slower growth rates (Coker, Pratchett, & Munday, 2009; Feary, McCormick, & Jones, 2009) which may have significant flow-on effects for the adult population (Wilson *et al.*, 2016). Once a fish has settled, however, their home range often expands to include a broader array of habitat patches and exploitable resources, thereby offsetting poor habitat choice at settlement (Wilson *et al.*, 2008). However, for one ubiquitous coral reef fish, the Lemon damselfish (*Pomacentrus moluccensis*, Pomacentridae), usually found in "clear lagoons and seaward reefs" (Syms & Jones, 2000), elevated suspended sediment reduced post-settlement movement by half (Wenger & McCormick, 2013). Fish that are unable to utilize the full extent of their home range due to elevated suspended sediment experience fitness consequences through a reduction in foraging and territorial defence (Lewis, 1997; Lönnstedt & McCormick, 2011). The meta-analysis indicated that many species exhibited moderate behavioural responses at concentrations as low as 20 mg/L, regardless of their habitat of origin, suggesting that dredging is likely to produce significant behavioural modifications.

3.2.2 | Effects on foraging and predation

It is already well established that foraging in both planktivorous and piscivorous fish is negatively affected by suspended sediment and that sedimentation affects herbivory (Utne-Palm, 2002). Foraging by planktivorous and drift feeding species is inhibited by reducing the reactive distance and the visual acuity of individual fish (Asaeda, Park,

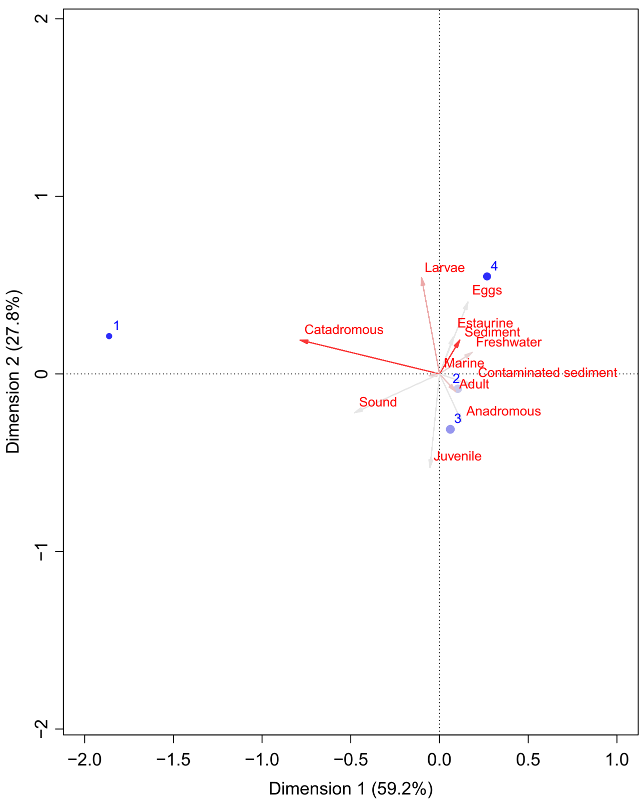

FIGURE 3 An asymmetric graph of the linear correspondence analysis, with the response type in the principal coordinates and the explanatory variables in reconstructions of the standardized residuals (square root of the relative frequency). Response type is represented by points, and the explanatory variables are represented by arrows. Point and vector shading intensity corresponds to the absolute contributions of the data to the display. Point size represents the relative frequency of each response type. The results indicate that across all stressors, larvae and eggs were most closely associated with lethal impacts (noted as 4), while catadromous fishes were most closely associated with behavioural effects (noted as 1). [Colour figure can be viewed at wileyonlinelibrary.com]

& Manatunge, 2002; Barrett, Grossman, & Rosenfeld, 1992; Gardner, 1981; Sweka & Hartman, 2003; Zamor & Grossman, 2007). Foraging success typically declines at higher levels of turbidity (Johansen & Jones, 2013; Utne-Palm, 2002). Berg (1983) documented a 60% reduction in prey consumed by Coho salmon in highly turbid water. Mild levels of turbidity, however, can sometimes enhance the contrast of plankton against its background, making it easier for planktivores to detect their prey (e.g. Utne-Palm, 1999; Wenger *et al.*, 2014). Some freshwater species such as the Rosyside dace (*Clinostomus funduloides*, Cyprinidae), Yellowfin shiner (*Notropis lutipinnis*, Cyprinidae) and Brook trout (*Salvelinus fontinalis*, Salmonidae) have shown an ability to cope with changing levels of turbidity by shifting their foraging strategies under conditions of high turbidity (30-40 NTU; Hazelton & Grossman, 2009; Sweka & Hartman, 2001). The Tenpounder (*Elops machnata*, Elopidae), for example, switches from fast-moving prey, such as fish, to slow-moving zooplankton when in a turbid estuary setting (Hect & Van der Lingen, 1992).

Although the literature has focused on the effects of suspended sediment on foraging, sedimentation can also inhibit foraging ability in benthic feeding species. For example, sediment embedded in algal turfs suppresses herbivory on coral reefs, with sediment removal resulting in a twofold increase in feeding by many herbivorous fish species (Bellwood & Fulton, 2008). Feeding intensity may also be influenced by sediment characteristics, with some parrotfish (*Scarus rivulatus*) displaying lower feeding rates when sediments were coarse and organic content was low (Gordon, Goatley, & Bellwood, 2016). Importantly, reduced feeding due to experimentally elevated sediment loads has been observed across different reef habitats, regardless of the natural sedimentation levels (Goatley & Bellwood, 2012). Ultimately, any reduction in foraging success leads to changes in growth, condition and reproductive output. Sweka and Hartman (2001) showed growth rates of Brook trout (*S. fontinalis*, Salmonidae) declined as turbidity increased (up to 40 NTU), due to an increase in energy used to forage. Similarly, increasing levels of suspended sediment reduced growth and body condition of the Spiny chromis (*Acanthochromis polyacanthus*, Pomacentridae) such that mortality increased by 50% in the highest suspended sediment concentrations (180 mg/L, Wenger, Johansen, & Jones, 2012).

Piscivores are especially sensitive to increasing turbidity because many are visual hunters that detect prey from a distance. An increase in suspended sediment reduces both light and contrast, decreasing encounter distances between predator and prey (Fiksen, Aksnes, Flyum, & Giske, 2002). Accordingly, several studies have shown a linear or exponential decline in piscivore foraging success with increasing turbidity (e.g. De Robertis, Ryer, Veloza, & Brodeur, 2003; Hect & Van der Lingen, 1992; Reid, Fox, & Whillans, 1999). The influence of turbidity on predation is, however, inconsistent among species. Turbidity had no effect on the predation rates of juvenile salmonids by Cutthroat trout (*Oncorhynchus clarkia*, Salmonidae; Gregory and Levings 1996), and Wenger, McCormick, McLeod, and Jones (2013) found a nonlinear

TABLE 4 A summary of the statistical outputs, including Rosenthal's fail-safe number, mean effect size, Wilks's lambda and the results of the linear correspondence analysis

Stressor	Rosenthal's fail-safe number	Mean effect size (Hedges' *g* ± *SE*)	Wilks's lambda (linear discriminant analyses)	Pr(>Chisq) (linear correspondence analysis)
All stressors	NA	NA	NA	.01
Suspended sediment	2,870	1.53 ± 0.33	<.0001	.303
Contaminated sediment (PAHs only)	246	4.24 ± 0.50	.41	.06
Sound	88	1.7 ± 0.5	.67	.23

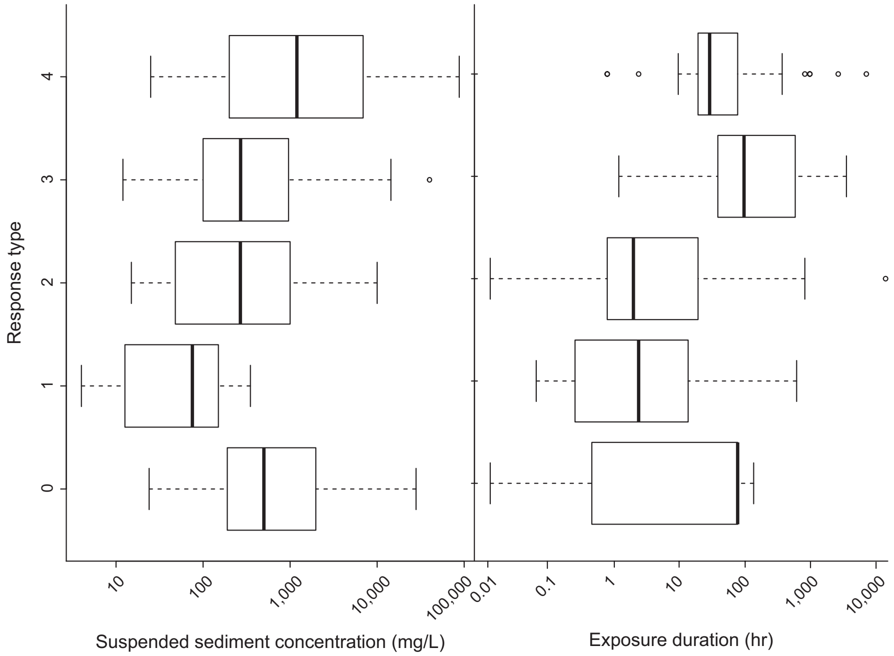

FIGURE 4 The impact of (a) suspended sediment concentration and (b) exposure duration on the type of effect elicited by suspended sediment. A response type of 0 = no effect, 1 = minor behavioural changes, 2 = minor physical damage or moderate behavioural changes, 3 = physiological impacts and 4 = increased mortality

relationship between increasing turbidity and predation success of dottybacks (*Pseudochromis fuscus*, Pseudochromidae), with intermediate levels of turbidity enhancing predation rates and high levels of turbidity reducing predation rates. The variation in species sensitivity to suspended sediment is reflected in the range of suspended sediment concentrations that elicited a reduced foraging and sublethal responses (Figure 4a). These results indicate predation success is partially dependent on factors other than vision and is likely to vary among species depending on the prey type, their natural ambient environment and the senses used to locate prey. However, the meta-analysis found that neither sediment type nor habitat of origin significantly influenced the effect size or response type elicited by suspended sediment exposure, suggesting that there are other factors of influence that have not yet been revealed.

3.2.3 | Light attenuation

Sediment in the water column not only reduces visual acuity due to its physical presence, it can also cause substantial light attenuation that impacts visual acuity (Jones, Fisher, Stark, & Ridd, 2015; Vogel & Beauchamp, 1999). Lower light levels can reduce the reactive distance of fish independent of the presence of sediment in the water column. A drastic change in the reactive distance of Bluegill (*Lepomis macrochirus*, Centrarchidae) from ~26 to 3.5 cm when light was reduced from 10.8 to 0.70 lux (Vinyard & O'Brien, 1976). While the assumption might be that the effects of increased turbidity in combination with low light intensity would be additive, studies that have examined the effects of both light reduction and increased turbidity have found mixed results. Utne (1997) observed a reduced reaction distance for the Two-spotted goby (*Gobiusculus flavescens*, Gobiidae) in both reduced light levels (<5 μmol m^{-2} s^{-1}) and increased turbidity, but there was no additive effect when light and turbidity levels were covaried. In contrast, Vogel and Beauchamp (1999) observed an additive effect of turbidity and light on reactive distance in Lake trout (*Salvelinus namaycush*, Salmonidae). De Robertis *et al.* (2003) found that turbidity decreased prey consumption by juvenile Chum salmon (*Oncorhynchus keta*, Salmonidae) and Walleye pollock (*Theragra chalcogramma*, Gadidae) in high light intensity, but not at low light intensity. Conversely, Miner and Stein (1993) observed that when light intensity was high (>460 lux), food consumption of Bluegill (*L. macrochirus*) larvae increased as turbidity increased, whereas food consumption decreased as turbidity increased in low light conditions (<100–300 lux). Still other studies have found no relationship, positive or negative, between light intensity, turbidity and foraging ability (Granqvist & Mattila, 2004).

3.2.4 | Physiological changes

Suspended sediment from dredging operations can lead to wide-ranging physiological effects in exposed fish. Increasing exposure to suspended sediment causes damage to gill tissue and structure, including epithelium lifting, hyperplasia and increased oxygen diffusion distance in the Orange-spotted grouper (*Epinephelus coioides*, Serranidae) and the Orange clownfish (*Amphiprion percula*, Pomacentridae) (Au, Pollino, Shin, Lau, & Tang, 2004; Hess, Wenger, Ainsworth, & Rummer, 2015). Under these conditions, increased pathogenic bacteria were also observed in Orange clownfish, while Lowe, Morrison, and Taylor (2015) found an increased parasite load on the gills of the Pink snapper (*Chrysophrys auratus*, Sparidae). Any reduction in gill efficiency impairs respiratory ability, nitrogenous excretion and ion exchange (Appleby & Scarratt, 1989; Au *et al.*, 2004; Wong, Pak, & Liu, 2013). The size of the gills is proportional to the size of the fish, meaning that the spaces between lamellae are smaller in larvae. It is therefore likely that sediment can more easily clog the gills and reduce their efficiency in smaller fish and larvae (Appleby & Scarratt, 1989). Larger and more angular sediment particles are also more likely to lodge between the lamellae and cause physical damage to gill tissues and function (Bash, Berman, & Bolton, 2001; Servizi & Martens, 1987); however, this trend was not clear in the meta-analysis, with sediment type not influencing effect size or response type. As larvae have much higher oxygen requirements than other life-history stages, any reduced efficiency in oxygen uptake could increase mortality or sublethal effects (Nilsson, Östlund-Nilsson, Penfold, & Grutter, 2007). This may explain why larvae were highly associated with lethal impacts (Figure 3).

Structural changes in gills elevate haematocrit, plasma cortisol and glucose levels, all of which are consistent with oxygen deprivation (Awata, Tsuruta, Yada, & Iguchi, 2011; Collin & Hart, 2015; Wilber & Clarke, 2001). Increased sedimentation and suspended sediment can also reduce the amount of dissolved oxygen in water, exacerbating the direct physical damage to gills (Henley, Patterson, Neves, & Lemly, 2000). The sublethal effects described here strongly influence growth, development and swimming ability, all of which may inhibit an individual's ability to move away from dredging operations and compound any physiological effects (Collin & Hart, 2015).

3.3 | The effects of released contaminants on fish

The influence of contaminated sediments has a greater impact on fish than either suspended sediments or sounds originating from dredging (Figure 2b). There is substantial evidence that direct exposure to contaminants negatively effects fish (Jezierska, Ługowska, & Witeska, 2009; Nicolas, 1999), so it is not surprising that contaminated sediment has a greater effect on fish than clean sediment (Figure 2b). Studies on the effects of contaminated sediment examined a range of life-history stages (n = 8, 18, 3 and 7 for adults, juveniles, larvae and eggs). Fish species in the studies included five anadromous species, three estuarine species, 16 freshwater species and 12 marine species. The most commonly reported contaminants reported were metals (n = 13), polycyclic aromatic hydrocarbons (PAHs; n = 9) and polychlorinated biphenyls (PCBs; n = 4). There were also multiple studies that examined sediment contaminated from multiple sources (n = 10; Table S3). The effects elicited from contaminated sediment were varied, with two studies showing no effect, one study observing behavioural changes, 11 studies recording physical damage, 15 studies recording physiological and sublethal impacts and seven studies documenting mortality. However, more than half of the studies on contaminated sediment effects on fish used sediment contaminated with multiple contaminants (n = 19/36), making quantitative comparison among studies problematic (Table S3). However, many of the studies collected sediment from polluted aquatic environments, indicating that dredging in polluted environments is likely to expose fish to multiple contaminants. There was only one study on heavy metals (cadmium), two studies on PCBs and six studies on PAHs where an effect size could be calculated that had test contaminants individually and that had units that could be compared. Effect sizes for studies on PAHs ranged from 2.83 to 6.20, with a mean effect size of 4.24 ± 0.50 (SE) (Table S3).

We conducted analysis only on the PAH studies given the low sample sizes of the other contaminant studies. None of the predictor variables (concentration, exposure duration, life-history stage, habitat and response type) in the linear mixed-effects model significantly influenced variation in effect size (Table 3). Rosenthal's fail-safe number for PAH studies was 246, whereas it was 14 for PCB studies (Table 4). Although this number is very low for PCB experiments, it is probably indicative of inadequate studies on the topic, rather than publication bias. Furthermore, the results of the linear correspondence analysis and the calculated chi-square statistic indicated that there was no significant association between the predictor variables (habitat and life-history stage) and response type elicited by exposure to sediment contaminated with PAHs (p = .06; Table 4).

The results of the linear discriminant analysis and the Wilks's lambda results indicated that PAH concentration and exposure times did not explain the response type elicited (p = .41; Table 4).

3.3.1 | Hydrophobic organic contaminants

The studies reviewed and synthesized suggest substantial impacts from exposure to sediment contaminated with hydrophobic organic chemicals (Table S3). Hydrophobic contaminants, such as legacy persistent organic pollutants (POPs; including PCBs, polybrominated diphenyl ethers [PBDEs], organochlorine pesticides OCPs, dioxins PCDDs, furans PCDFs) and high-molecular weight polyaromatic and aliphatic hydrocarbons (PAHs), are closely associated with organic material in sediments (Simpson *et al.*, 2005). Some form naturally and may be present in sites with no human impacts (some PAHs, dioxins and aliphatics; Gaus *et al.*, 2002). Others are only common in sediments exposed to shipping activity and/or industrial development (e.g. PCBs, organotins; Haynes & Johnson, 2000). Anthropogenic compounds with a high bioaccumulation potential (some PCB congeners, PCDDs, PBDEs) may be present in low to moderate concentrations in sediments even at sites well-removed from the source through water and aerial transport and deposition (Evers, Klamer, Laane, & Govers, 1993) or incorporated in the food web (Losada *et al.*, 2009; Ueno *et al.*, 2006). The release of hydrophobic organics requires desorption from particulates which can readily occur under certain environmental conditions (Bridges *et al.*, 2008; Eggleton & Thomas, 2004). The meta-analysis provides further support to the idea that desorption of hydrophobic organics can occur by showing that exposure to contaminated sediment results in a greater effect size than other dredging-related stressors. Further, Steuer (2000) found that around 35% of PCBs downstream of a riverine remedial dredging programme were in the dissolved fraction (i.e. had been released). Thus, exposure to these compounds should therefore not be ignored during the risk assessment process, even at capital dredging sites.

Johnson *et al.* (2014) comprehensively reviewed the direct impacts of POPs on fish and demonstrated the breadth of reproductive impacts on adults (e.g. steroidogenesis, vitellogenesis, gamete production or spawning success) as well as lethal and non-lethal developmental (spinal and organ development, growth) impacts on embryos and larvae. There is also potential for maternal transfer of POPs through accumulation in oocyte lipid stores and the impact of PAHs on steroidogenesis (Monteiro, Reis-Henriques, & Coimbra, 2000) and vitellogenesis (reviewed by Nicolas, 1999). Specific to crude oils, Carls *et al.* (2008)

demonstrated that toxicity to fish embryos was due to the dissolved PAH fraction. This implies that release of sediment-associated PAHs may cause similar deformities as those observed following exposure to oil. Any activity that exposes fish, regardless of its life stage, to POPs or PAHs should be considered high risk to animal health and, in exploited long-lived predators, a potential risk to human consumers. A full understanding of the sediment contaminant profile and release dynamics is required to fully protect fish stocks, particularly where ripening of spawning fish, or their eggs, embryos or larvae is likely to encounter POPs released through the resuspension of contaminated sediment, given the high sensitivity of larvae and eggs to dredging-related stressors (Figure 3).

3.3.2 | Metals

Metals in sediments are generally present as sulphides, a form generally not bioavailable and therefore non-toxic (Rainbow, 2007). Sediments rich in iron sulphides, however, have a large capacity to bind potentially toxic metals (e.g. copper, zinc, nickel, lead, cadmium) by exchanging the bound iron with the competitor metal (Rainbow, 1995). When iron sulphides are resuspended, they are readily oxidized, causing localized acidification, and release of bioavailable and toxic ionic metal (Petersen, Willer, & Willamowski, 1997). Some metals are released more readily than others (Maddock, Carvalho, Santelli, & Machado, 2007), so the duration for which the contaminated sediment is exposed to the seawater is a critical variable. Fine sediments (silts and clays) remain in suspension longer and will therefore release more metals.

It is clear that there is a gap in the understanding of the potential for metals adsorbed to sediment to be taken up by fishes. Despite the well-understood desorption of metals from sediment (reviewed by Eggleton & Thomas, 2004), only 12 studies have examined the effects of metal-contaminated suspended sediment on fish, with five of them focusing on single metals and only one where the effect size was able to be calculated. However, the limited laboratory studies that have investigated uptake have demonstrated that it can and does occur (Table S3). Further, the studies that examined sediment contaminated with multiple heavy metals highlight that exposure to metal-contaminated sediment can elicit large effects, regardless of the response type (Table S3).

Although not widely studied, it is possible to infer the likely impacts of the uptake of metals from contaminated suspended sediment based on a large body of empirical studies examining direct effects of metal exposure on fish. Metals impact reproductive output and early development in fish via a range of entry routes and mechanisms (reviewed by Jezierska *et al.*, 2009). Metals accumulate in gonad tissue (Alquezar, Markich, & Booth, 2006; Chi,, Zhu, & Langdon, 2007) and in the egg shell and chorion causing developmental delays, changes in time to hatch and larval deformities (Chow and Chang 2003; Witeska, Jezierska, & Chaber, 1995). Heavy metals such as mercury, zinc and cadmium are also known to reduce sperm motility (Abascal, Cosson, & Fauvel, 2007; Kime *et al.*, 1996). At higher but still within concentrations recorded in the environment (0.1 and 10 mg/L), ionic metals can be lethal to larvae (*Cyprinodon variegatus*, Cyprinidae; Hutchinson, Williams, & Eales, 1994). Jezierska *et al.* (2009) reviewed the physiological stress responses in adult fish exposed to ionic metals as osmoregulatory disturbance (copper), antioxidant inhibition (cadmium), interference with the citric acid cycle (cadmium), oxidative stress, disruption of thyroid hormones (lead) and antagonistic binding to oestrogen receptors (cadmium). With the wide range of known impacts of exposure to metals, full characterization of metals in sediment and release kinetics is required on a case-by-case basis to assess any exposure and impacts to fish.

3.4 | The effects of hydraulic entrainment on fish

Hydraulic entrainment, through the direct uptake of aquatic organisms by the suction field generated at the draghead or cutterhead during dredging operations (Reine *et al.*, 1998), results in the localized by-catch of fish eggs, larvae and even mobile juveniles and adults. A review of entrainment rates of fishes, fish eggs and fish larvae has been previously undertaken by Reine *et al.* (1998). However, as studies only record rates of entrainment, without controls for comparison, it was not possible to calculate effect sizes or conduct quantitative analyses. The studies did, however, record a variation in the mortality or damage that occurred and suggest that eggs are more vulnerable to entrainment than adults, with observed damage/mortality of 62.8 ± 13.6 (mean ± *SE*) for eggs compared to 38.4 ± 13.2 for adults (Table S4). This result, in combination with the results from the meta-analysis that demonstrate eggs and larvae are most likely to experience lethal impacts (Figure 3), underscores the vulnerability of early life-history stages to dredging.

3.4.1 | Entrainment of eggs and larvae

Most published research into the effects of dredging entrainment on fish eggs and larvae has been carried out in riverine or estuarine river systems (Griffith & Andrews, 1981; Harvey, 1986; Harvey & Lisle, 1998; Wyss, Aylin, Burks, Renner, & Harmon, 1999). Whereas extensive attention has been placed on the consequences of entrainment by hydropower facilities or power plant cooling water intakes, less research has been devoted to entrainment by hydraulic dredges. Because volumes of water entrained by dredges are small in comparison with these other sources, the entrainment rates of eggs and larval fish are generally thought to represent a minor proportion of the total fish production (Reine & Clarke, 1998; Reine *et al.*, 1998). Hydraulic dredging is not directly comparable to hydropower or cooling water sources in other ways. For example, trailer suction hopper dredges are mobile, generally advancing at speeds under several metres per second. Depending on the capabilities of a given dredge, pumping capacities span a very wide range. When entrainment occurs in close proximity to large spawning aggregations, however, replenishment of fish populations could theoretically be suppressed via the removal of reproductive adults. Where sufficient ecological information exists, the risk of entraining larval fish and eggs can be minimized by restricting dredging during key reproductive and recruitment time periods (Suedel, Kim, Clarke, & Linkov, 2008) and avoiding nurseries and spawning aggregations. While the entrainment rates are likely to represent a small proportion of total larval production, fish entrained at the egg, embryo and larval stages will experience extremely high mortality rates (Harvey & Lisle, 1998; Table S4), although mortality rates will vary among fish species and development stages (Griffith & Andrews, 1981; Wyss *et al.*, 1999).

3.4.2 | Entrainment of mobile juvenile and adult fish

Documented entrainment rates of mobile fish species are low, but are highest for benthic species or those in high densities (Drabble, 2012; Reine *et al.*, 1998). While the potential for entrainment of abundant demersal species can be relatively high, the overall mortality rates of entrained fish may be low. Mortality rates vary depending on the type and scale of dredging operation, with the longer term survival of fish after entrainment reliant on the method of separation of the dredged sediment from the fluid, and on how the dredged sediment is disposed (Armstrong, Stevens, & Hoeman, 1982). For example, mortality rate of estuarine fish in Washington immediately after hydraulic entrainment and deposition into the hopper was 38%, but was 60% for pipeline dredges with a cutter head (Armstrong *et al.*, 1982). In the English Channel, only six of the 23 adult fish entrained by a suction trailer dredger were damaged (Lees, Kenny, & Pearson, 1992; Table S4). Furthermore, as fish may avoid areas that are repeatedly dredged (Appleby & Scarratt, 1989), hydraulic entrainment may be more pronounced during capital dredging, when fish densities have not yet been altered by coastal development.

3.5 | Effects of dredging sounds on fish

Sound levels recorded from dredge operations ranged from 111 to 170 dB re 1 μPa rms, with exposure lasting from 2 min to 10 days (Table S5). There were seven records each on the effects of sound on both juvenile and adult fish, one record for larvae and one unknown. There were two studies on catadromous fish, one on an estuarine fish, eleven records from freshwater species and two from the marine environment (Table S5).

There was a range of endpoints measured and responses elicited from dredge sound, although none of these were lethal. Five studies observed behavioural changes (response type 1), six studies recorded physical damage and substantial behavioural changes (response type 2), and five studies measured physiological stress (response type 3). Effect sizes ranged from 0.2 to 5.9, with a mean effect size of 1.7 ± 0.5 (*SE*) (Figure 2b; Table 2).

According to the results of the generalized linear mixed-effects model, only response type had any significant influence on the effect size from dredge sound ($p = .03$; Table 3), with effect size generally increasing as the severity in response increased (Table S5). However, there was no lethal response recorded in any of the studies we reviewed. The other predictor variables tested were decibel level, exposure duration, life-history stage and habitat. Rosenthal's fail-safe number was 88, indicating that our results are not an artefact of publication bias (Table 4).

The results of the linear correspondence analysis and the calculated chi-square statistic indicated that there was no association between the predictor variables (habitat, life-history stage and species) and response type elicited by exposure to continuous sound ($p = .23$). Similarly, according to the linear discriminant analysis, neither decibel level or exposure duration drove variations in response type ($p = .67$; Table 4).

While the effects of anthropogenic sound on fish have been thoroughly reviewed by Hawkins, Pembroke, and Popper (2015) and Popper and Hastings (2009) and synthesized into guidelines by Popper *et al.* (2014), they do not specifically include dredging as a sound source. Moreover, there is a paucity of information on the impacts of anthropogenic sound on fish in terms of their physiology and hearing. Data exist for only ~100 of the more than 32,000 recorded fish species (Popper & Hastings, 2009). Based on the existing information, underwater noise can affect fish in a number of ways, including (i) behavioural responses, (ii) masking, (iii) stress and physiological responses, (iv) hearing loss and damage to auditory tissues, (v) structural and cellular damage of non-auditory tissues and total mortality, (vi) impairment of lateral line functions and (vii) particle motion-based effects on eggs and larvae (Popper & Hastings, 2009; Popper *et al.*, 2014; Table S4).

Effects of dredging noise vary among fish species with one of the most important determinants being the presence or absence of a swim bladder (Popper *et al.*, 2014), which we did not account for in the meta-analysis. Fish species that have a swim bladder used for hearing are more likely affected by continuous noise than those without a swim bladder (Popper *et al.*, 2014). For example, after exposure to white noise at 170 dB re 1 μPa rms for 48 hr, goldfish (*C. auratus*, Cyprinidae) developed temporary loss of sensory hair bundles and experienced a temporary threshold shift (TTS, i.e. temporary hearing loss) of 13–20 dB (Smith, Coffin, Miller, & Popper, 2006; Table S5), enough to change their ability to interpret the auditory scene. After 7 days, TTS had recovered, and after 8 days, hair bundle density had recovered (Smith *et al.*, 2006). In another study, exposure to 158 dB re 1 μPa rms for 12 and 24 hr resulted in TTS of 26 dB in goldfish and 32 dB in catfish (*Pimelodus pictus*, Pimelodidae) (Amoser & Ladich, 2003; Table S5). Hearing thresholds recovered within 3 days for the goldfish, and after 14 days for catfish, and the duration of exposure had no influence on long-term hearing loss (Amoser & Ladich, 2003). The results of the meta-analysis support this observation, with exposure duration having no impact on the response type elicited by sound.

Several published studies exist that have quantified dredging sounds from hydraulic and mechanical dredging (e.g. Reine, Clarke, & Dickerson, 2014; Reine, Clarke, Dickerson, & Wikel, 2014; Thomsen, McCully, Wood, White, & Page, 2009). The available evidence indicates that dredging scenarios do not produce intense sounds comparable to pile driving and other in-water construction activities, but rather lower levels of continuous sound at frequencies generally below 1 kHz. However, when dredging includes the removal or breaking of rocks, the sound generated is likely to exceed the sound of soft sediment dredging. The exposure to dredging sounds does depend on site-specific factors, including bathymetry and density stratification of the water column (Reine, Clarke, & Dickerson, 2014). Exposures to a given sound in relatively deep coastal oceanic waters will be different to those experienced in shallow estuaries with complex bathymetries. While sound levels produced by dredging can approach, or exceed, the levels tested in the aforementioned studies, received sound levels will be lower than source levels (Reine, Clarke, & Dickerson, 2014). As sound pressure is significantly lower from natural sources compared to that produced by anthropogenic impacts such as dredging, most fish species do not have the physiology to detect sound pressure (Hawkins *et al.*, 2015; Popper *et al.*, 2014) and therefore show no TTS in response to long-term noise exposure (Popper *et al.*, 2014). Impacts on fish from dredging-generated noise are therefore likely to be TTSs (temporary hearing loss) in some species, behavioural effects and increased stress-related cortisol levels (Table S4). Finally, although dredging may not cause levels of sound that can be physiologically damaging to fish, dredging noise may mask natural sounds used by larvae to locate suitable habitat (Simpson *et al.*, 2005).

4 | SUMMARY AND RECOMMENDATIONS

Increased waterborne trade and the expansion of port facilities infer that dredging operations will continue to intensify over the next few decades (PIANC 2009). The development of meaningful management guidelines to mitigate the effects of dredging on fish requires a thorough understanding of how dredging can impact fish. This review represents a substantive descriptive and quantitative assessment of the literature to characterize the direct effects of dredging-related stressors on different life-history stages of fish. Across all dredging-related stressors, studies that reported fish mortality had significantly higher effect sizes than those that describe physiological responses, although indicators of dredge impacts should endeavour to detect effects before excessive mortality occurs. Our results demonstrate that contaminated sediment led to greater effect sizes than either clean sediment or sound, suggesting additive or synergistic impacts from dredging-related stressors. Importantly, we have explicitly demonstrated that early life stages such as eggs and larvae are most likely to suffer lethal impacts, which can be used to improve the management of dredging projects and ultimately minimize the impacts to fish. Although information on drivers of effect sizes provides insight into the factors contributing to impacts, an examination of the drivers that influence the elicited response type is more informative to management, because it allows for early detection of stress, which can trigger management intervention before sublethal and lethal impacts occur. As such, this review provides critical information necessary for dredging management plans to minimize impacts from dredging operations on fish. Furthermore, it highlights the need for *in situ* studies on the effects of dredging on fish which consider the interactive effects of multiple dredge stressors and their impact on sensitive species of ecological and fisheries value.

Currently, the literature on dredging-related stressors is biased towards examining the effects of suspended sediment, as is evidenced by the large number of studies that exist on the topic compared to other stressors. While suspended sediment is a ubiquitous stressor in any dredging project, our review highlights the need for further research on how contaminants released during dredging, noise associated with dredging and hydraulic entrainment can impact fish. There is also a paucity of direct field measurements of the effects of dredging on fish, which needs to be addressed. The characterization of multiple, long-term impacts from stressors associated with dredging needs to consider all combinations of acute toxicity, chronic stress, loss of habitat and the frequency and duration of repeated exposures. This is particularly important in the light of the results that contaminated sediment caused significantly higher effect sizes than sediment alone, which suggests there are additive or synergistic impacts occurring. An increased understanding of how each stressor acts alone or in combination will improve our ability to effectively manage potential impacts from dredging.

In many developed countries, the disposal of contaminated sediments is well regulated and includes strict requirements to avoid contamination of the environment, as the release of contaminants into the water column can cause environmental damage (Batley and Simpson 2009). The release of contaminants from sediments resuspended during dredging and their impact on fish depend on the characteristics of the sediment, water chemistry, suspension time and the compound itself (reviewed by Eggleton & Thomas, 2004). Because seldom is only one contaminant found in contaminated sediment, systematic studies on the effects of combined contaminants should be carried out to better assess the potential impact to fish of dredging-induced exposure to contaminated sediments. Where the contaminant load is significant and results in the slow leaching of toxins, the re-establishment of habitat and appropriate larval settlement sites could be significantly prolonged. Repeat maintenance dredging of contaminated sediments will expose resident fish populations to multiple pulses of SS and released toxicants. While the impact of a single exposure may have little or no effect, repeated exposures or the effects of exposure of fishes to multiple contaminants can cause contaminant accumulation to levels that are toxic (Maceda-Veiga *et al.* 2010).

Although the effects of suspended sediment, noise, hydraulic entrainment and contaminant release have been considered separately here, there are likely to be interactions among dredging-related stressors that could reduce or magnify the intensity of a response or raise or lower the threshold of response. Interactive effects of multiple stressors on fish are poorly represented in the literature. Crain, Kroeker, and Halpern (2008) performed an analysis of 171 fully factorial studies using two stressors on marine organisms or communities finding that the overall impact of two stressors tends to be synergistic in heterotrophs, which the results of this meta-analysis support. However, the interactions may present themselves differently. For instance, where high-molecular weight hydrophobic contaminants and metals co-occur in sediments and resuspension, the combination of the particular compounds needs to be considered in determining risk, because of potential toxicity across all life-history stages. In this case, reducing the concentration or exposure to contaminated sediment is likely to be the best management option. Conversely, the identification of larvae and eggs as being more vulnerable to dredging-related stressors, as demonstrated by the meta-analysis, suggests that dredging management aimed at minimizing dredging activities during certain times of year when eggs and larvae would be abundant would be warranted. Given the complexities of different dredging-related stressors and their influence on the response type and size of effect elicited, it is likely that more than one management intervention would be necessary. This review provides critical information about factors influencing how fish would respond to dredging.

This review has assessed the weight of evidence that exists for direct effects of dredging on fish. However, indirect effects on fish through loss of prey, changes to biochemical processes and habitat loss may also occur. In particular, changes to habitat may be substantial and could exceed the impacts caused by direct effects of dredging-related stressors on fish (Barbier *et al.*, 2011). Consequently, benthic habitats have been explicitly accounted for in management recommendations and plans (Erftemeijer *et al.*, 2013; PIANC 2009). When fish are considered in dredging management plans, there is often limited scientific evidence used to support the recommended management interventions (Dickerson, Reine, & Clarke, 1998; Suedel *et al.*, 2008). The information generated in this meta-analysis demonstrates that there can also be significant direct effects of dredging on fish, which can compound the indirect effects of habitat loss, leading to further impacts. Therefore, management plans should consider both indirect and direct impacts to fish, in line with the precautionary principle.

The knowledge generated here represents a rigorous assessment of the available information, especially in relation to suspended sediment. However, it highlights the current lack of *in situ* data that are critical to the decision-making process for environmental impact assessments. There is a great need for more applied research to provide the necessary information to management agencies so that they can make educated decisions on the impacts of future dredging developments to fish and fishery resources in freshwater, estuarine and coastal ecosystems. In particular, targeted Before, After, Control, Impact ("beyond" BACI) designed *in situ* field studies focused on assessing multiple responses of key and representative species (across all life-history stages) to multiple stressors over time are needed. Such studies would be challenging both financially and logistically, but if conducted in collaboration with dredging companies, they could provide a realistic experiment of dredging impacts and ultimately reduce costs of dredging operations and environmental impacts. We recommend that managers use the information generated here in tandem with any information on the effects of dredging on critical fish habitat, in order to develop comprehensive practices to target direct and indirect impacts.

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AUTHOR CONTRIBUTIONS

All authors presented at or contributed to a workshop on effects of sediment on fish held at the University of Western Australia, led by EH. AW conducted all of the analyses, and AW, EH, CR, SW, SN, DC, BS, NB, PE and DM wrote the review. SW, JM, JH, MD and RE edited the final document.

REFERENCES

Abascal, F. J., Cosson, J., & Fauvel, C. (2007). Characterization of sperm motility in sea bass: The effect of heavy metals and physicochemical variables on sperm motility. *Journal of Fish Biology*, *70*, 509–522.

Almeida, J. S., Meletti, P. C., & Martinez, C. B. R. (2005). Acute effects of sediments taken from an urban stream on physiological and biochemical parameters of the neotropical fish *Prochilodus lineatus*. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, *140*, 356–363.

Alquezar, R., Markich, S. J., & Booth, D. J. (2006). Metal accumulation in the smooth toadfish, *Tetractenos glaber*, in estuaries around Sydney, Australia. *Environmental Pollution*, *142*, 123–131.

Amesbury, S. S. (1981, 18–22 May). *Effect of turbidity on shallow water reef fish assemblages in Truk, Eastern Caroline Islands*. Proceedings of the 4th International Coral Reef Symposium, Manila (Philippines), 18–22 May.

Amoser, S., & Ladich, F. (2003). Diversity in noise-induced temporary hearing loss in otophysine fishes. *The Journal of the Acoustical Society of America*, *113*, 2170–2179.

ANZECC and ARMCANZ (2000). *Australian and New Zealand guidelines for fresh and marine water quality* (pp. 1–103). Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT, Australia.

Appleby, J., & Scarratt, D. J. (1989). *Physical effects of suspended solids on marine and estuarine fish and shellfish with special reference to ocean dumping: A literature review* (pp. 33). Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1681, Department of Fisheries and Oceans, Halifax, Nova Scotia.

Armstrong, D. A., Stevens, B. G., & Hoeman, J. C. (1982). *Distribution and abundance of Dungeness crab and crangon shrimp and dredging-related mortality of invertebrates and fish in Grays Harbor, Washington* (pp. 349). U.S. Army Corps of Engineers Technical report No. N-NACW67-80-C0086, Seattle. Department of Fisheries, Olympia.

Asaeda, T., Park, B. K., & Manatunge, J. (2002). Characteristics of reaction field and the reactive distance of a planktivore, *Pseudorasbora parva* (Cyprinidae), in various environmental conditions. *Hydrobiologia*, *489*, 29–43.

Au, D., Pollino, C., Shin, P., Lau, S., & Tang, J. (2004). Chronic effects of suspended solids on gill structure, osmoregulation, growth, and triiodothyronine in juvenile green grouper *Epinephelus coioides*. *Marine Ecology Progress Series*, *266*, 255–264.

Auld, A., & Schubel, J. (1978). Effects of suspended sediment on fish eggs and larvae: A laboratory assessment. *Estuarine and Coastal Marine Science*, *6*, 153–164.

Awata, S., Tsuruta, T., Yada, T., & Iguchi, K. I. (2011). Effects of suspended sediment on cortisol levels in wild and cultured strains of ayu *Plecoglossus altivelis*. *Aquaculture*, *314*, 115–121.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*, 169–193.

Barjhoux, I., Baudrimont, M., Morin, B., Landi, L., Gonzalez, P., & Cachot, J. (2012). Effects of copper and cadmium spiked-sediments on embryonic development of Japanese medaka (*Oryzias latipes*). *Ecotoxicology and Environmental Safety*, *79*, 272–282.

Barrett, J. C., Grossman, G. D., & Rosenfeld, J. (1992). Turbidity-induced changes in reactive distance of rainbow trout. *Transactions of the American Fisheries Society*, *121*, 437–443.

Bash, J., Berman, C. H., & Bolton, S. (2001). *Effects of turbidity and suspended solids on salmonids*. Seattle: University of Washington Water Center.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1–48.

Batley, G. E., & Simpson, S. L. (2009). Development of guidelines for ammonia in estuarine and marine water systems. *Marine Pollution Bulletin*, *58*, 1472–1476.

Bellwood, D. R., & Fulton, C. J. (2008). Sediment-mediated suppression of herbivory on coral reefs: Decreasing resilience to rising sea-levels and climate change? *Limnology and Oceanography*, *53*, 2695–2701.

Berg, L. (1983). *Effects of short term exposure to suspended sediment on the behavior of juvenile Coho salmon* (pp. 117). Master's thesis, University of British Columbia, Vancouver.

Berg, L., & Northcote, T. (1985). Changes in territorial, gill-flaring, and feeding behaviour in juvenile Coho salmon (*Oncorhynchus kisutch*) following short-term pulses of suspended sediment. *Canadian Journal of Fisheries and Aquatic Sciences*, *42*, 1410–1417.

Boehlert, G. W. (1984). Abrasive effects of Mount Saint Helens ash upon epidermis of yolk sac larvae of Pacific herring *Clupea harengus* pallasi. *Marine Environmental Research*, *12*, 113–126.

Breitburg, D. L. (1988). Effects of Turbidity on Prey Consumption by Striped Bass Larvae. *Transactions of the American Fisheries Society*, *117*, 72–77.

Bridges, T. S., Ells, S., & Hayes, D. *et al.* (2008). *The four R's of environmental dredging: resuspension, release, residual, and risk*. (pp. 64). Dredging Operations and Environmental Research Program (ERDC/EL TR-08-4). U.S. Army Corps of Engineers, Washington, DC.

Brinkmann, M., Eichbaum, K., Reininghaus, M., *et al.* (2015). Towards science-based sediment quality standards—effects of field-collected sediments in rainbow trout (*Oncorhynchus mykiss*). *Aquatic Toxicology*, *166*, 50–62.

Browne, N. K., Tay, J., & Todd, P. A. (2015). Recreating pulsed turbidity events to determine coral–sediment thresholds for active management. *Journal of Experimental Marine Biology and Ecology*, *466*, 98–109.

Cachot, J., Law, M., Pottier, D., *et al.* (2007). Characterization of toxic effects of sediment-associated organic pollutants using the λ transgenic medaka. *Environmental Science & Technology*, *41*, 7830–7836.

Carls, M. G., Holland, L., Larsen, M., Collier, T. K., Scholz, N. L., & Incardona, J. P. (2008). Fish embryos are damaged by dissolved PAHs, not oil particles. *Aquatic Toxicology*, *88*, 121–127.

Celi, M., Filiciotto, F., Maricchiolo, G., *et al.* (2016). Vessel noise pollution as a human threat to fish: Assessment of the stress response in gilthead sea bream (*Sparus aurata*, Linnaeus 1758). *Fish Physiology and Biochemistry*, *42*, 631–641.

Chen, M.-H., & Chen, C.-Y. (2001). Toxicity of contaminated harbour sediment to grey mullet, *Liza macrolepis*. *WIT Transactions on Ecology and the Environment*, *49*, 279–288.

Chi, Q.Q., Zhu, G.W., & Langdon, A. (2007). Bioaccumulation of heavy metals in fishes from Taihu Lake, China. *Journal of Environmental Sciences*, *19*, 1500–1504.

Chow, E. S. H., & Cheng, S. H. (2003). Cadmium affects muscle type development and axon growth in zebrafish embryonic somitogenesis. *Toxicological Sciences*, *73*, 149–159.

Coker, D. J., Pratchett, M. S., & Munday, P. L. (2009). Coral bleaching and habitat degradation increase susceptibility to predation for coral-dwelling fishes. *Behavioural Ecology*, *113*, 1–7.

Collin, S. P., & Hart, N. S. (2015). Vision and photoentrainment in fishes: The effects of natural and anthropogenic perturbation. *Integrative Zoology*, *10*, 15–28.

Costa, P. M., Neuparth, T. S., Caeiro, S., *et al.* (2011). Assessment of the genotoxic potential of contaminated estuarine sediments in fish peripheral blood: Laboratory versus in situ studies. *Environmental Research*, *111*, 25–36.

Crain, C. M., Kroeker, K., & Halpern, B. S. (2008). Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters*, *11*, 1304–1315.

De Jonge, V., Essink, K., & Boddeke, R. (1993). The Wadden Sea: A changed ecosystem. In E. P. H. Best & J. P. Bakker (Eds.), *Netherlands-Wetland. Developments in Hydrobiology 88* (pp. 45–71). Dordrecht, the Netherlands: Kluwer Academic Publishers.

De Robertis, A., Ryer, C. H., Veloza, A., & Brodeur, R. D. (2003). Differential effects of turbidity on prey consumption of piscivorous and planktivorous fish. *Canadian Journal of Fisheries and Aquatic Sciences*, *60*, 1517–1526.

Dickerson, D. D., Reine, K. J., & Clarke, D. G. (1998). *Economic impacts of environmental windows associated with dredging operations* (pp. 18). DOER Technical Notes Collection (TN DOER E-3), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Drabble, R. (2012). Projected entrainment of fish resulting from aggregate dredging. *Marine Pollution Bulletin*, *64*, 373–381.

Eggleton, J., & Thomas, K. V. (2004). A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. *Environment International*, *30*, 973–980.

Erftemeijer, P. L. A., Jury, M. J., & Gabe, B., *et al.* (2013, 11–13 September). *Dredging, port-and waterway construction near coastal plant habitats*. Coasts and Ports 2013: 21st Australasian Coastal and Ocean Engineering Conference and the 14th Australasian Port and Harbour Conference, Sydney, NSW, Australia.

Erftemeijer, P. L. A., & Lewis, R. I. I. I. (2006). Environmental impacts of dredging on seagrasses: A review. *Marine Pollution Bulletin*, *52*, 1553–1572.

Erftemeijer, P. L. A., Riegl, B., Hoeksema, B. W., & Todd, P. A. (2012). Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin*, *64*, 1737–1765.

Evans, R. D., Murray, K. L., Field, S. N., *et al.* (2012). Digitise This! A Quick and Easy Remote Sensing Method to Monitor the Daily Extent of Dredge Plumes. *PLoS One*, *7*, e51668.

Evers, E. H. G., Klamer, H. J. C., Laane, R. W. P. M., & Govers, H. A. J. (1993). Polychlorinated dibenzo-P-dioxin and dibenzofuran residues in estuarine and coastal North Sea sediments: Sources and distribution. *Environmental Toxicology and Chemistry*, *12*, 1583–1598.

Feary, D. A., McCormick, M. I., & Jones, G. P. (2009). Growth of reef fishes in response to live coral cover. *Journal of Experimental Marine Biology and Ecology*, *373*, 45–49.

Fiksen, Ø., Aksnes, D. L., Flyum, M. H., & Giske, J. (2002). The influence of turbidity on growth and survival of fish larvae: A numerical analysis. *Hydrobiologia*, *484*, 49–59.

Fisher, R., Stark, C., Ridd, P., & Jones, R. (2015). Spatial patterns in water quality changes during dredging in tropical environments. *PLoS One*, *10*, e0143309.

Fox, J., & Weisberg, S. (2011). *An R companion to applied regression* (2nd ed.). Thousand Oaks, CA: Sage.

Galbraith, R. V., MacIsaac, E. A., Macdonald, J. S., & Farrell, A. P. (2006). The effect of suspended sediment on fertilization success in sockeye (*Oncorhynchus nerka*) and coho (*Oncorhynchus kisutch*) salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, *63*, 2487–2494.

Galzin, R. (1981, 18–22 May). *Effects of coral sand dredging on fish fauna in the lagoon of the grand cul de sac marin Guadeloupe-French West Indies*. Proceedings of the 4th International Coral Reef Symposium, Manila (Philippines).

Gardner, M. B. (1981). Mechanisms of size selectivity by planktivorous fish: A test of hypotheses. *Ecology*, *62*, 571–578.

Gaus, C., Brunskill, G. J., Connell, D. W., *et al.* (2002). Transformation processes, pathways, and possible sources of distinctive polychlorinated dibenzo-p-dioxin signatures in sink environments. *Environmental Science & Technology*, *36*, 3542–3549.

Goatley, C. H. R., & Bellwood, D. R. (2012). Sediment suppresses herbivory across a coral reef depth gradient. *Biology Letters*, *8*, 1016–1018.

Gordon, S. E., Goatley, C. H. R., & Bellwood, D. R. (2016). Low-quality sediments deter grazing by the parrotfish *Scarus rivulatus* on inner-shelf reefs. *Coral Reefs*, *35*, 285–291.

Granqvist, M., & Mattila, J. (2004). The effects of turbidity and light intensity on the consumption of mysids by juvenile perch (*Perca fluviatilis* L.). *Hydrobiologia*, *514*, 93–101.

Gregory, R. S., & Levings, C. D. (1996). The effects of turbidity and vegetation on the risk of juvenile salmonids, *Oncorhynchus* spp., to predation by adult cutthroat trout, *O. clarkii*. *Environmental Biology of Fishes*, *47*, 279–288.

Griffith, J. S., & Andrews, D. A. (1981). Effects of a small suction dredge on fishes and aquatic invertebrates in Idaho streams. *North American Journal of Fisheries Management*, *1*, 21–28.

Gurevitch, J., & Hedges, L. V. (1999). Statistical issues in ecological meta-analyses. *Ecology*, *80*, 1142–1149.

Hartl, M. G. J., Kilemade, M., Sheehan, D., *et al.* (2007). Hepatic biomarkers of sediment-associated pollution in juvenile turbot, *Scophthalmus maximus* L. *Marine Environmental Research*, *64*, 191–208.

Harvey, B. C. (1986). Effects of suction gold dredging on fish and invertebrates in two California streams. *North American Journal of Fisheries Management*, *6*, 401–409.

Harvey, B. C., & Lisle, T. E. (1998). Effects of suction dredging on streams: A review and an evaluation strategy. *Fisheries*, *23*, 8–17.

Hatin, D., Lachance, S., & Fournier, D. (2007). *Effect of dredged sediment deposition on use by Atlantic sturgeon and lake sturgeon at an open-water disposal site in the St. Lawrence estuarine transition zone*. In Proceedings of the American Fisheries Society Symposium 56 (pp. 235–255). Bethesda, MD: American Fisheries Society.

Hawkins, A., Pembroke, A., & Popper, A. (2015). Information gaps in understanding the effects of noise on fishes and invertebrates. *Reviews in Fish Biology and Fisheries*, *25*, 39–64.

Haynes, D., & Johnson, J. E. (2000). Organochlorine, heavy metal and polyaromatic hydrocarbon pollutant concentrations in the Great Barrier Reef (Australia) environment: A review. *Marine Pollution Bulletin*, *41*, 267–278.

Hazelton, P., & Grossman, G. (2009). Turbidity, velocity and interspecific interactions affect foraging behaviour of rosyside dace (*Clinostomus funduloides*) and yellowfin shiners (*Notropis lutippinis*). *Ecology of Freshwater Fish*, *18*, 427–436.

Hect, T., & Van der Lingen, C. D. (1992). Turbidity-induced changes in feeding strategies of fish in estuaries. *South African Journal of Zoology*, *27*, 95–107.

Hedges, L. V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational and Behavioral Statistics*, *6*, 107–128.

Henley, W., Patterson, M., Neves, R., & Lemly, A. D. (2000). Effects of sedimentation and turbidity on lotic food webs: A concise review for natural resource managers. *Reviews in Fisheries Science*, *8*, 125–139.

Hess, S., Wenger, A. S., Ainsworth, T. D., & Rummer, J. L. (2015). Exposure of clownfish larvae to suspended sediment levels found on the Great Barrier Reef: Impacts on gill structure and microbiome. *Scientific Reports*, *5*, 1–8.

Hudjetz, S., Herrmann, H., Cofalla, C., *et al.* (2014). An attempt to assess the relevance of flood events—biomarker response of rainbow trout exposed to resuspended natural sediments in an annular flume. *Environmental Science and Pollution Research*, *21*, 13744–13757.

Hutchinson, T. H., Williams, T. D., & Eales, G. J. (1994). Toxicity of cadmium, hexavalent chromium and copper to marine fish larvae (*Cyprinodon variegatus*) and copepods (*Tisbe battagliai*). *Marine Environmental Research*, *38*, 275–290.

Isono, R., Kita, J., & Setoguma, T. (1998). Acute effects of kaolinite suspension on eggs and larvae of some marine teleosts. *Comparative Biochemistry and Physiology Part C*, *120*, 449–455.

Jezierska, B., Ługowska, K., & Witeska, M. (2009). The effects of heavy metals on embryonic development of fish (a review). *Fish Physiology and Biochemistry*, *35*, 625–640.

Johansen, J., & Jones, G. (2013). Sediment-induced turbidity impairs foraging performance and prey choice of planktivorous coral reef fishes. *Ecological Applications*, *23*, 1504–1517.

Johnson, L. L., Anulacion, B. F., & Arkoosh, M. R., *et al.* (2014). Effects of legacy persistent organic pollutants (POPs) in fish – current and future challenges. In K. B. Tierney, A. P. Farrell & C. J. Brauner (Eds.), *Organic chemical toxicology of fishes, fish physiology vol. 33* (pp. 53–140). London, UK: Academic Press.

Johnston, D. D., & Wildish, D. J. (1982). Effect of suspended sediment on feeding by larval herring (*Clupea harengus harengus* L.). *Bulletin of Environmental Contamination and Toxicology*, *29*, 261–267.

Jones, R., Fisher, R., Stark, C., & Ridd, P. (2015). Temporal patterns in seawater quality from dredging in tropical environments. *PLoS One*, *10*, e0137112.

Jones, G., McCormick, M., Srinivasan, M., & Eagle, J. V. (2004). Coral Decline Threatens Fish Biodiversity in Marine Reserves. *Proceedings of the National Academy of Sciences*, *101*, 8251–8253.

Jung, C. A., & Swearer, S. E. (2011). Reactions of temperate reef fish larvae to boat sound. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *21*, 389–396.

Kemble, N. E., Brumbaugh, W. G., Brunson, E. L., *et al.* (1994). Toxicity of metal-contaminated sediments from the upper clark fork river, montana, to aquatic invertebrates and fish in laboratory exposures. *Environmental Toxicology and Chemistry*, *13*, 1985–1997.

Kemp, P., Sear, D., Collins, A., Naden, P., & Jones, I. (2011). The impacts of fine sediment on riverine fish. *Hydrological Processes*, *25*, 1800–1821.

Kerr, S. J. (1995). *Silt, turbidity and suspended sediments in the aquatic environment: an annotated bibliography and literature review* (pp. 1–277). Ontario Ministry of Natural Resources Technical Report TR-008, Southern Region Science and Technology Transfer Unit, Ontario, Canada.

Kilemade, M., Hartl, M. G. J., O'Halloran, J., *et al.* (2009). Effects of contaminated sediment from Cork Harbour, Ireland on the cytochrome P450 system of turbot. *Ecotoxicology and Environmental Safety*, *72*, 747–755.

Kime, D. E., Ebrahimi, M., Nysten, K., *et al.* (1996). Use of computer assisted sperm analysis (CASA) for monitoring the effects of pollution on sperm quality of fish; application to the effects of heavy metals. *Aquatic Toxicology*, *36*, 223–237.

Kobayashi, J., Sakurai, T., & Suzuki, N. (2010). Transfer of polychlorinated biphenyls from marine sediment to a benthic fish (*Pleuronectes yokohamae*). *Journal of Environmental Monitoring*, *12*, 647–653.

Lees, P., Kenny, A., & Pearson, R. (1992). *The condition of benthic fauna in suction dredger outwash: initial findings. Annex II*. In Report of the working group on the effects of extraction of marine sediments on fisheries. International Council for the Exploration of the Sea (ICES), 22–28.

Lewis, A. R. (1997). Recruitment and post-recruitment immigration affect the local population size of coral reef fishes. *Coral Reefs*, *16*, 139–149.

Lindeman, K. C., & Snyder, D. B. (1999). Nearshore hardbottom fishes of southeast Florida and effects of habitat burial caused by dredging. *Fishery Bulletin*, *97*, 508–525.

Liu, M., Wei, Q., Du, H., Fu, Z., & Chen, Q. (2013). Ship noise-induced temporary hearing threshold shift in the Chinese sucker *Myxocyprinus asiaticus* (Bleeker, 1864). *Journal of Applied Ichthyology*, *29*, 1416–1422.

Livingstone, D. R., Lemaire, P., Matthews, A., Peters, L., Bucke, D., & Law, R. J. (1993). Pro-oxidant, antioxidant and 7-ethoxyresorufin O-deethylase (EROD) activity responses in liver of Dab (*Limanda limanda*) exposed to sediment contaminated with hydrocarbons and other chemicals. *Marine Pollution Bulletin*, *26*, 602–606.

Ljunggren, L., & Sandström, A. (2007). Influence of visual conditions on foraging and growth of juvenile fishes with dissimilar sensory physiology. *Journal of Fish Biology*, *70*, 1319–1334.

Lönnstedt, O. M., & McCormick, M. I. (2011). Growth history and intrinsic factors influence risk assessment at a critical life transition for a fish. *Coral Reefs*, *30*, 805–812.

Losada, S., Roach, A., Roosens, L., *et al.* (2009). Biomagnification of anthropogenic and naturally-produced organobrominated compounds in a marine food web from Sydney Harbour, Australia. *Environment International*, *35*, 1142–1149.

Lowe, M. L., Morrison, M. A., & Taylor, R. B. (2015). Harmful effects of sediment-induced turbidity on juvenile fish in estuaries. *Marine Ecology Progress Series*, *539*, 241–251.

Maceda-Veiga, A., Monroy, M., Viscor, G., & De Sostoa, A. (2010). Changes in non-specific biomarkers in the Mediterranean barbel (*Barbus meridionalis*) exposed to sewage effluents in a Mediterranean stream (Catalonia, NE Spain). *Aquatic Toxicology*, *100*, 229–237.

Maddock, J. E. L., Carvalho, M. F., Santelli, R. E., & Machado, W. (2007). Contaminant metal behaviour during re-suspension of sulphidic estuarine sediments. *Water, Air, and Soil Pollution*, *181*, 193–200.

Marcogliese, J. D., Nagler, J. J., & Cyr, G. D. (1998). Effects of Exposure to Contaminated Sediments on the Parasite Fauna of American Plaice (*Hippoglossoides platessoides*). *Bulletin of Environmental Contamination and Toxicology*, *61*, 88–95.

Martins, M., Santos, J. M., Costa, M. H., & Costa, P. M. (2016). Applying quantitative and semi-quantitative histopathology to address the interaction between sediment-bound polycyclic aromatic hydrocarbons in fish gills. *Ecotoxicology and Environmental Safety*, *131*, 164–171.

McCook, L. J., Schaffelke, B., Apte, S. C., Brinkman, R., Brodie, J., Erftemeijer, P., … Warne, M. St. J. (2015). *Synthesis of current knowledge of the biophysical impacts of dredging and disposal on the Great Barrier Reef: Report of an independent panel of experts*. Great Barrier Reef Marine Park Authority, Townsville, Qld.

Miner, G. J., & Stein, R. A. (1993). Interactive influence of turbidity and light on larval bluegill (*Lepomis macrochirus*) foraging. *Canadian Journal of Fisheries and Aquatic Sciences*, *50*, 781–788.

Monteiro, P., Reis-Henriques, M., & Coimbra, J. (2000). Plasma steroid levels in female flounder (*Platichthys flesus*) after chronic dietary exposure to single polycyclic aromatic hydrocarbons. *Marine Environmental Research*, *49*, 453–467.

National Academies of Science Marine Board (NAS) (2001). *A process for setting, managing, and monitoring environmental windows for dredging projects* (pp. 1–83). National Research Council Special Report 262, National Academy Press, Washington, DC.

Nenadic, O., & Greenacre, M. (2007). Correspondence Analysis in R, with two- and three-dimensional graphics: The ca package. *Journal of Statistical Software*, *20*, 1–13.

Newcombe, C. P., & Jensen, J. O. T. (1996). Channel suspended sediment and fisheries: A synthesis for quantitative assessment of risk and impact. *North American Journal of Fisheries Management*, *16*, 693–727.

Nicolas, J.-M. (1999). Vitellogenesis in fish and the effects of polycyclic aromatic hydrocarbon contaminants. *Aquatic Toxicology*, *45*, 77–90.

Nilsson, G. E., Östlund-Nilsson, S., Penfold, R., & Grutter, A. S. (2007). From record performance to hypoxia tolerance: Respiratory transition in damselfish larvae settling on a coral reef. *Proceedings of the Royal Society of London B: Biological Sciences*, *274*, 79–85.

O'Connor, J. J., Lecchini, D., Beck, H. J., *et al.* (2015). Sediment pollution impacts sensory ability and performance of settling coral-reef fish. *Oecologia*, 1–11.

Peebua, P., Kruatrachue, M., Pokethitiyook, P., & Kosiyachinda, P. (2006). Histological effects of contaminated sediments in Mae Klong River Tributaries, Thailand, on Nile tilapia, *Oreochromis niloticus*. *Science Asia*, *32*, 143–150.

Petersen, W., Willer, E., & Willamowski, C. (1997). Remobilization of trace elements from polluted anoxic sediments after resuspension in oxic water. *Water, Air, and Soil Pollution*, *99*, 515–522.

PIANC (2009). *Dredging Management Practices for the Environment: A Structured Approach* (pp. 62). Permanent International Association of Navigation Congresses, Report No. 100, Brussels, Belgium.

Pirotta, E., Laesser, B. E., Hardaker, A., Riddoch, N., Marcoux, M., & Lusseau, D. (2013). Dredging displaces bottlenose dolphins from an urbanised foraging patch. *Marine Pollution Bulletin*, *74*, 396–402.

Popper, A. N., & Hastings, M. C. (2009). The effects of anthropogenic sources of sound on fishes. *Journal of Fish Biology*, *75*, 455–489.

Popper, A. N., Hawkins, A. D., & Fay, R. R., *et al.* (2014). *Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI, ASA S3/SC1.4 TR-2014* (pp. 1–73). Cham, Switzerland: Springer International Publishing.

R Development Core Team (2014). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from www.R-project.org

Rainbow, P. S. (1995). Biomonitoring of heavy metal availability in the marine environment. *Marine Pollution Bulletin*, *31*, 183–192.

Rainbow, P. S. (2007). Trace metal bioaccumulation: Models, metabolic availability and toxicity. *Environment International*, *33*, 576–582.

Redding, J. M., Schreck, C. B., & Everest, F. H. (1987). Physiological Effects on Coho Salmon and Steelhead of Exposure to Suspended Solids. *Transactions of the American Fisheries Society*, *116*, 737–744.

Reid, S. M., Fox, M. G., & Whillans, T. H. (1999). Influence of turbidity on piscivory in largemouth bass (*Micropterus salmoides*). *Canadian Journal of Fisheries and Aquatic Sciences*, *56*, 1362–1369.

Reine, K. J., & Clarke, D. G. (1998). *Entrainment by hydraulic dredges – A review of potential impacts*, Technical Note DOER-E1 (pp. 1-14). U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS.

Reine, K. J., Clarke, D., & Dickerson, C. (2014). Characterization of underwater sounds produced by hydraulic and mechanical dredging operations. *The Journal of the Acoustical Society of America*, *135*, 3280–3294.

Reine, K. J., Clarke, D., Dickerson, C., & Wikel, G. (2014). *Characterization of underwater sounds produced by trailing suction hopper dredges during sand mining and pump-out operations* (pp. 1–96). U.S. Army Corps of Engineers, Engineer Research and Development Center, Technical Report ERDC/EL TR-14-3.

Reine, K. J., Dickerson, D. D., & Clarke, D. G. (1998). *Environmental windows associated with dredging operations* (pp. 1–14). U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS, Technical Note DOER-E1.

Rosenthal, R. (1979). The file drawer problem and tolerance for null results. *Psychological Bulletin*, *86*, 638–641.

Seelye, J. G., Hesselberg, R. J., & Mac, M. J. (1982). Accumulation by fish of contaminants released from dredged sediments. *Environmental Science & Technology*, *16*, 459–464.

Sellin, M. K., Snow, D. D., & Kolok, A. S. (2010). Reductions in hepatic vitellogenin and estrogen receptor alpha expression by sediments from an agriculturally impacted waterway. *Aquatic Toxicology*, *96*, 103–108.

Servizi, J. A., & Martens, D. W. (1987). Some effects of suspended Fraser River sediments on sockeye salmon (*Oncorhynchus nerka*). *Canadian Special Publication of Fisheries and Aquatic Sciences*, *96*, 254–264.

Servizi, J. A., & Martens, D. W. (1992). Sublethal responses of Coho Salmon (*Oncorhynchus kisutch*) to suspended sediments. *Canadian Journal of Fisheries and Aquatic Sciences*, *49*, 1389–1395.

Simpson, S. L., Batley, G. E., & Chariton, A. A. *et al.* (2005). *Handbook for sediment quality assessment* (pp. 117). Bangor, NSW: CSIRO.

Simpson, S. D., Purser, J., & Radford, A. N. (2015). Anthropogenic noise compromises antipredator behaviour in European eels. *Global Change Biology*, *21*, 586–593.

Smith, M. E., Coffin, A. B., Miller, D. L., & Popper, A. N. (2006). Anatomical and functional recovery of the goldfish (*Carassius auratus*) ear following noise exposure. *Journal of Experimental Biology*, *209*, 4193–4202.

Smith, M. E., Kane, A. S., & Popper, A. N. (2004). Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*). *Journal of Experimental Biology*, *207*, 427–435.

Speas, D. W., Walters, C. J., Ward, D. L., *et al.* (2004). Effects of intraspecific density and environmental variables on electrofishing catchability of brown and rainbow trout in the Colorado River. *North American Journal of Fisheries Management*, *24*, 586–596.

Steuer, J. J. (2000). *A mass-balance approach for assessing PCB movement during remediation of a PCB-contaminated deposit on the Fox River*. Water Resources Investigations Report. US Geological Survey, Reston, VA, USA.

Suedel, B. C., Kim, J., Clarke, D. G., & Linkov, I. (2008). A risk-informed decision framework for setting environmental windows for dredging projects. *Science of the Total Environment*, *403*, 1–11.

Sved, D. W., Roberts, M. H., & Van Veld, P. A. (1997). Toxicity of sediments contaminated with fractions of creosote. *Water Research*, *31*, 294–300.

Sweka, J. A., & Hartman, K. J. (2001). Effects of turbidity on prey consumption and growth in brook trout and implications for bioenergetics modelling. *Canadian Journal of Fisheries and Aquatic Sciences*, *58*, 386–393.

Sweka, J. A., & Hartman, K. J. (2003). Reduction of reactive distance and foraging success in smallmouth bass, *Micropterus dolomieu*, exposed to elevated turbidity levels. *Environmental Biology of Fishes*, *67*, 341–347.

Syms, C., & Jones, G. P. (2000). Disturbance, habitat structure, and the dynamics of a coral-reef fish community. *Ecology*, *81*, 2714–2729.

Tao, S., Liu, C., Dawson, R., Long, A., & Xu, F. (2000). Uptake of cadmium adsorbed on particulates by gills of goldfish (*Carassius auratus*). *Ecotoxicology and Environmental Safety*, *47*, 306–313.

Thomsen, F., McCully, S. R., Wood, D., White, P., & Page, F. (2009). *A generic investigation into noise profiles of marine dredging in relation to the acoustic sensitivity of the marine fauna in the UK waters: PHASE 1 Scoping and review of key issues*. Lowestoft, UK: Aggregates Levy Sustainability Fund/Marine Environmental Protection Fund.

Ueno, D., Alaee, M., Marvin, C., *et al.* (2006). Distribution and transportability of hexabromocyclododecane (HBCD) in the Asia-Pacific region using skipjack tuna as a bioindicator. *Environmental Pollution*, *144*, 238–247.

USACE (1983). *Dredging and dredged material disposal*. EM 1110-2-5025. Washington, DC: Office of the Chief of Engineers.

Utne, A. (1997). The effect of turbidity and illumination on the reaction distance and search time of the marine planktivore *Gobiusculus flavescens*. *Journal of Fish Biology*, *50*, 926–938.

Utne-Palm, A. (1999). The effect of prey mobility, prey contrast, turbidity and spectral composition on the reaction distance of *Gobiusculus flavescens* to its planktonic prey. *Journal of Fish Biology*, *54*, 1244–1258.

Utne-Palm, A. (2002). Visual feeding of fish in a turbid environment: Physical and behavioral aspects. *Marine and Freshwater Behaviour and Physiology*, *35*, 111–128.

VBKO (2003). *Protocol for the Field Measurement of Sediment Release from Dredgers. A practical guide to measuring sediment release from dredging plant for calibration and verification of numerical models*. Report produced for VBKO TASS project by HR Wallingford Ltd & Dredging Research Ltd Issue 1:83 pp. Oxfordshire, UK.

Venables, W. N., & Ripley, B. D. (2002). *Modern applied statistics with S* (4th ed.). New York, NY: Springer. ISBN 0-387-95457-0.

Vicquelin, L., Leray-Forget, J., Peluhet, L., *et al.* (2011). A new spiked sediment assay using embryos of the Japanese medaka specifically designed for a reliable toxicity assessment of hydrophobic chemicals. *Aquatic Toxicology*, *105*, 235–245.

Viganò, L., Arillo, A., De Flora, S., & Lazorchak, J. (1995). Evaluation of microsomal and cytosolic biomarkers in a seven-day larval trout sediment toxicity test. *Aquatic Toxicology*, *31*, 189–202.

Vinyard, G. L., & O'Brien, W. J. (1976). Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). *Journal of the Fisheries Board of Canada*, *33*, 2845–2849.

Vogel, J. L., & Beauchamp, D. A. (1999). Effects of light, prey size, and turbidity on reaction distances of lake trout (*Salvelinus namaycush*) to salmonid prey. *Canadian Journal of Fisheries and Aquatic Sciences*, *56*, 1293–1297.

Watson, R., Revenga, C., & Kura, Y. (2006). Fishing gear associated with global marine catches: II. Trends in trawling and dredging. *Fisheries Research*, *79*, 103–111.

Wenger, A. S., Fabricius, K. E., Jones, G. P., & Brodie, J. E. (2015). Effects of sedimentation, eutrophication, and chemical pollution on coral reef fishes. In C. Mora (Ed.), *The ecology of fishes on coral reefs* (pp. 145–153). Cambridge, UK: Cambridge University Press.

Wenger, A. S., Johansen, J. L., & Jones, G. P. (2011). Suspended sediment impairs habitat choice and chemosensory discrimination in two coral reef fishes. *Coral Reefs*, *30*, 879–887.

Wenger, A. S., Johansen, J. L., & Jones, G. P. (2012). Increasing suspended sediment reduces foraging, growth and condition of a planktivorous damselfish. *Journal of Experimental Marine Biology and Ecology*, *428*, 43–48.

Wenger, A. S., & McCormick, M. I. (2013). Determining trigger values of suspended sediment for behavioral changes in a coral reef fish. *Marine Pollution Bulletin*, *70*, 73–80.

Wenger, A. S., McCormick, M. I., Endo, G. G., McLeod, I. M., Kroon, F. J., & Jones, G. P. (2014). Suspended sediment prolongs larval development in a coral reef fish. *The Journal of Experimental Biology*, *217*, 1122–1128.

Wenger, A. S., McCormick, M. I., McLeod, I. M., & Jones, G. P. (2013). Suspended sediment alters predator-prey interactions in two coral reef fishes. *Coral Reefs*, *32*, 369–374.

Wenger, A. S., Whinney, J., Taylor, B., & Kroon, F. (2016). The impact of individual and combined abiotic factors on daily otolith growth in a coral reef fish. *Scientific Reports*, *6*, 1–10.

Wilber, D. H., & Clarke, D. G. (2001). Biological effects of suspended sediments: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. *North American Journal of Fisheries Management*, *21*, 855–875.

Wilson, S. K., Burgess, S. C., Cheal, A. J., *et al.* (2008). Habitat utilization by coral reef fish: Implications for specialists vs. generalists in a changing environment. *Journal of Animal Ecology*, *77*, 220–228.

Wilson, S. K., Depczynski, M., Fulton, C. J., Holmes, T. H., Radford, B. T., & Tinkler, P. (2016). Influence of nursery microhabitats on the future abundance of a coral reef fish. *Proceedings of the Royal Society B*, *283*, 1–7.

Witeska, M., Jezierska, B., & Chaber, J. (1995). The influence of cadmium on common carp embryos and larvae. *Aquaculture*, *129*, 129–132.

Wong, C. K., Pak, A. P., & Liu, X. J. (2013). Gill damage to juvenile orange-spotted grouper *Epinephelus coioides* (Hamilton, 1822) following exposure to suspended sediments. *Aquaculture Research*, *44*, 1685–1695.

Wysocki, L. E., Dittami, J. P., & Ladich, F. (2006). Ship noise and cortisol secretion in European freshwater fishes. *Biological Conservation*, *128*, 501–508.

Wyss, A. J. O., Aylin, E., Burks, R. R., Renner, J. F., & Harmon, D. R. (1999). Effects of a Turbo Scouring on Striped Bass Eggs in the Savannah River. In K. J. Hatcher (Ed.), *Proceedings of the Georgia Water Resources Conference (Athens, Georgia, 1999)* (pp. 491–495). Athens, Georgia: Institute of Ecology, the University of Georgia.

Zamor, R. M., & Grossman, G. D. (2007). Turbidity affects foraging success of drift-feeding rosyside dace. *Transactions of the American Fisheries Society*, *136*, 167–176.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

How to cite this article: Wenger AS, Harvey E, Wilson S, et al. A critical analysis of the direct effects of dredging on fish. *Fish Fish*. 2017;18:967–985. https://doi.org/10.1111/faf.12218

Use of an Urban Detention Pond as a Refuge for Endangered and Threatened Fish Species

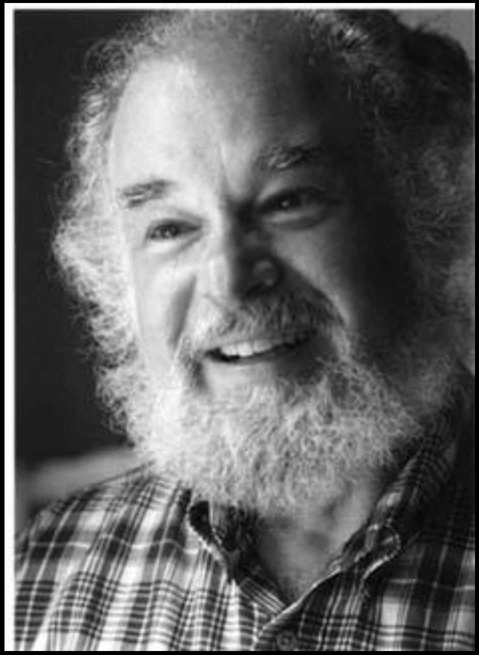
Collaborative Project the following organizations contributed to the work:

Integrated Lakes Management

- Loyola University Dr. John Janssen
- Prairie Crossing Homeowners Association
- Southern Illinois University Dr. Brooks Burr and his graduate students
  Matt Roberts, Adrienne Davis
- Liberty Prairie Foundation
- Illinois Department of Natural Resources
- University of Illinois at Chicago….Dr. Mary Ashley, Fusun Ozer
- USGS   Dr. Jeff Schaeffer
- Illinois Natural History Survey…..Dr. Larry Page
- Max McGraw Wildlife Foundation

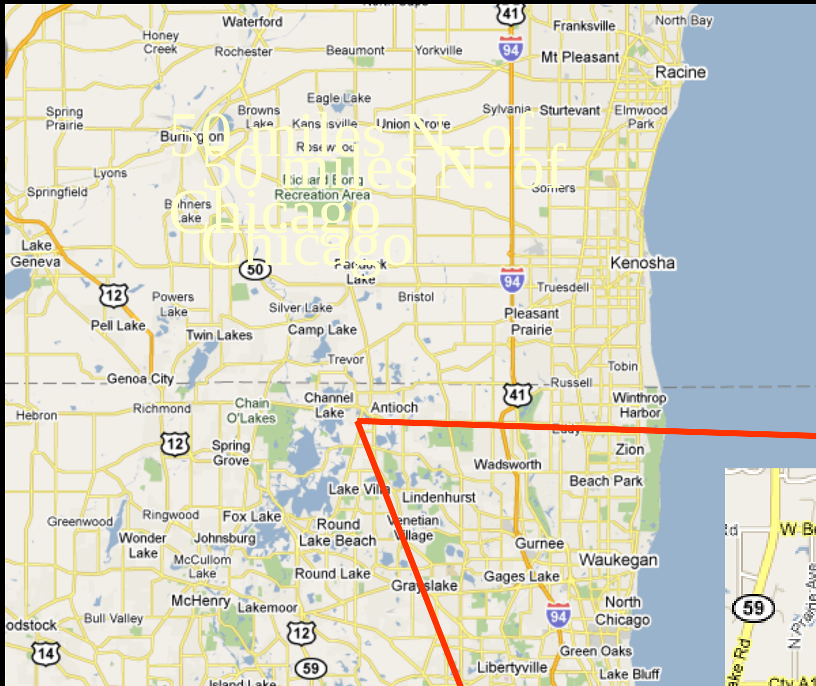
1st Successful Illinois Sanctuary for E/T Fish

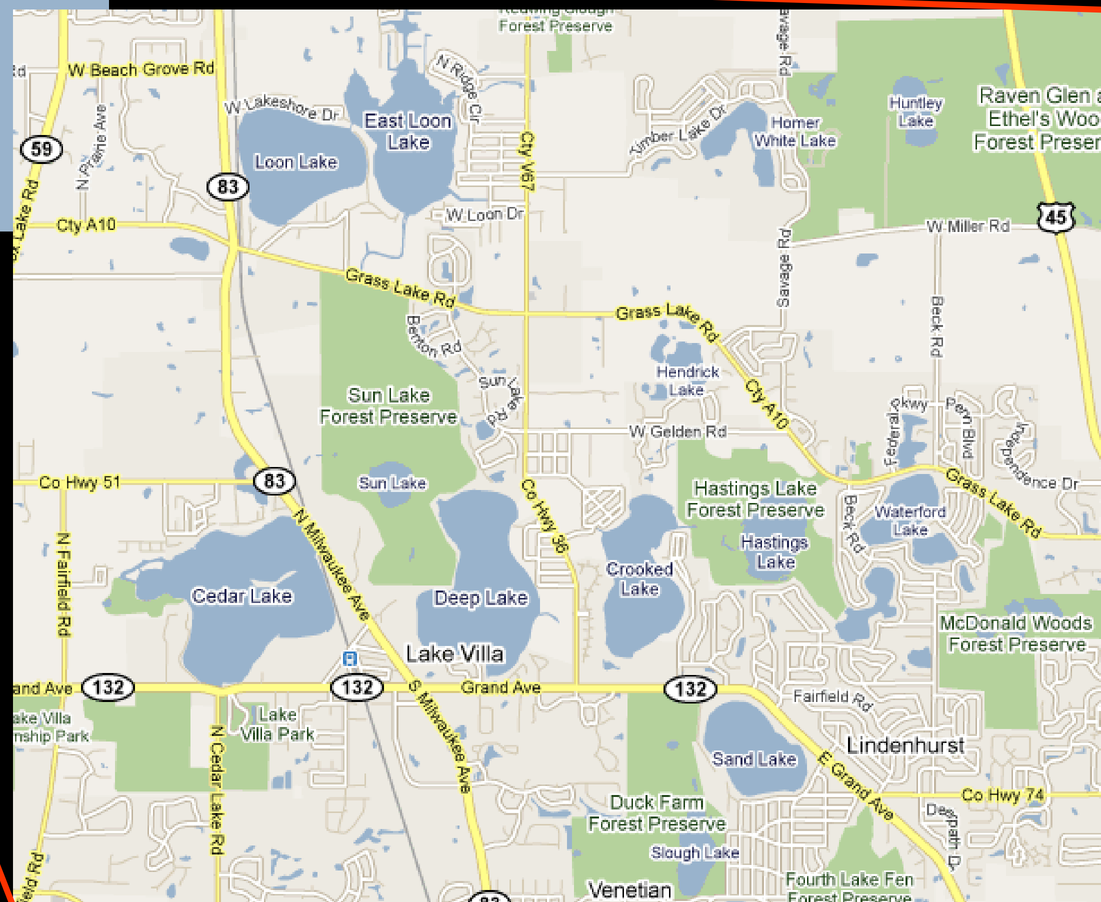
- **Reconciliation Ecology** ***is the science of inventing, establishing and maintaining new habitats to conserve species diversity in places where people live, work or play.***



Michael Rosensweig

- 50 miles N. of Chicago
- Source Lakes : Cedar, Deep
- Fox Lake watershed





Relative land use
•620 acres total
•34 acres water
•45 acres wetland
•100+ acres prairie
•150 + managed landscaping

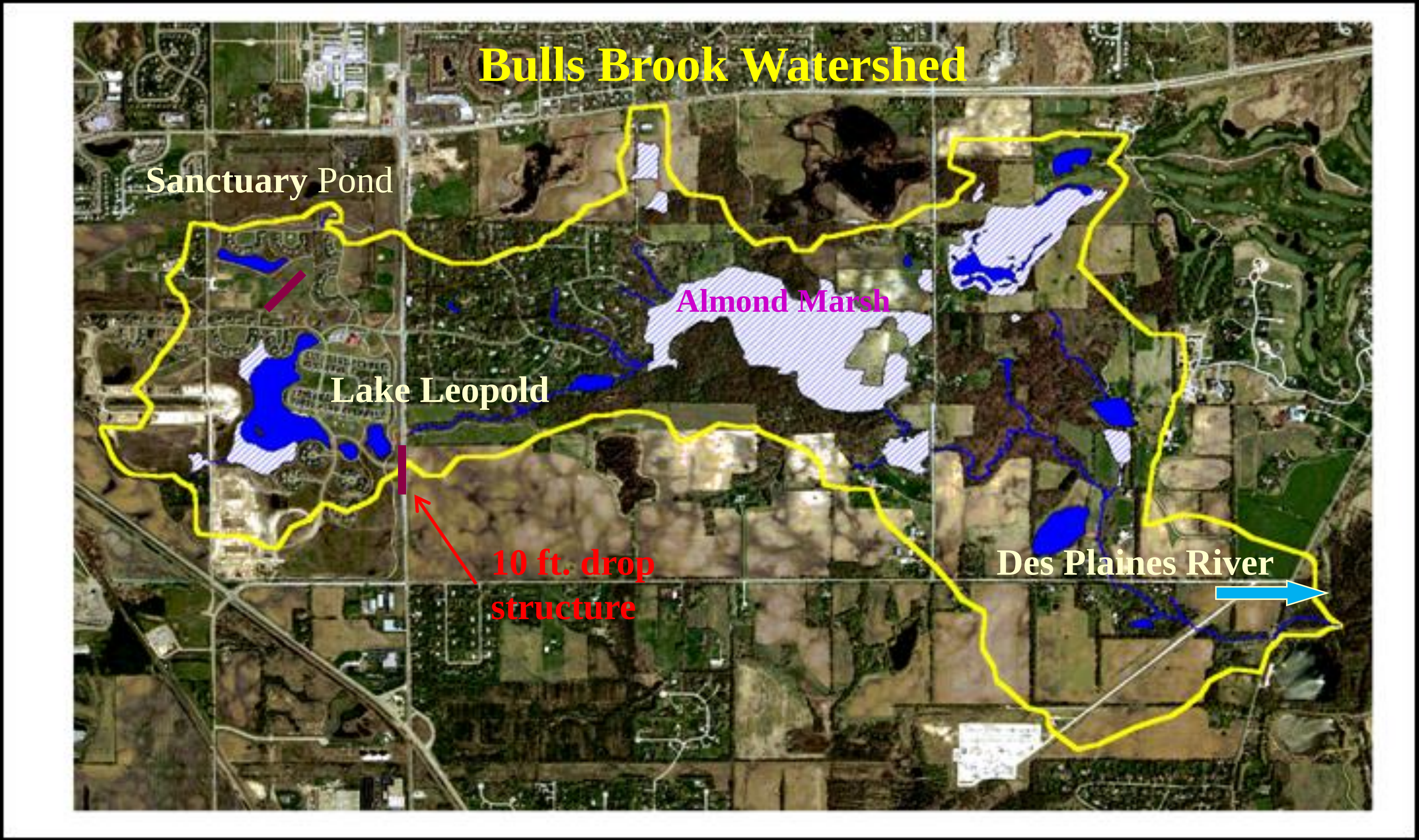
628 Acre Residential Development in Grayslake Illinois

- Energy conserving buildings
- Organic farm on site
- Windmill ; rain gardens
- Use of prairie and wetland landscaping
- Discourage urban lawns
- Have a commitment to biodiversity in their charter
- Two train stations in the immediate proximity
- Charter school with cisterns, solar cells, and other site amenities

* Use of a treatment train to handle urban stormwater…..roofs and roads →grassed swales→ prairies→ wetlands→ detention ponds

Prairie Crossing

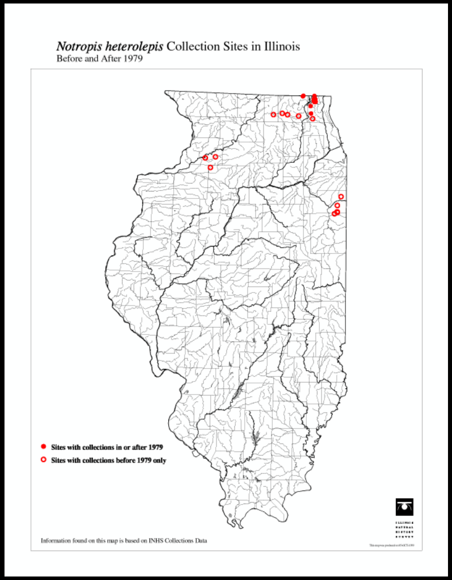
- 2.8 acre Sanctuary Pond
- 28 acre central lake (Lake Leopold)
- headwaters for Des Plaines drainage
- 10 ft. drop structure separates complex from downstream drainage
- emergent and submergent vegetation
- control of sport fishing
- good water quality and clarity
- diverse habitats and substrates
- conservation ethic



Protected from downstream imports (i.e. Carp , etc.)
Allows for export of E/Ts

- Origin of the idea…
- …..Larry Page INHS
- …..Becker (Fishes of Wisconsin)
- …Jim Bland tired of bass , bluegill, and fathead minnow mixes 1940’s origin INHS, Auburn University

- 30 E/T fish species in Illinois
- 3 of the target species had been extirpated from the Des Plaines drainage but were present in isolated lakes on the Fox River drainage
- All 4 of the target species were experiencing range reductions across their N.A. range

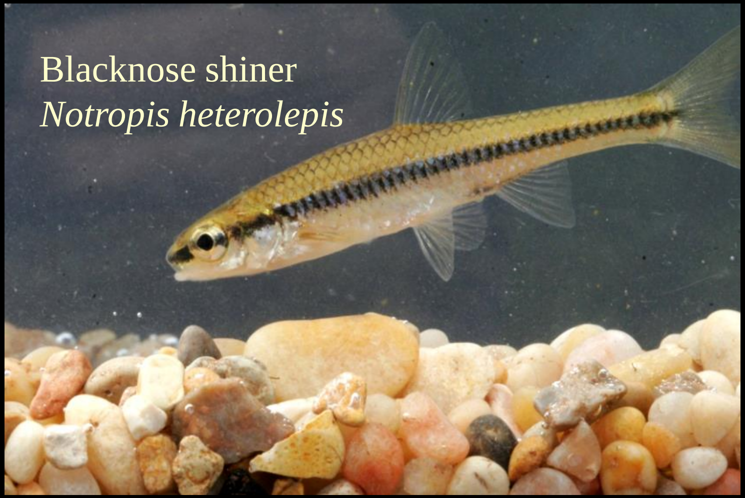


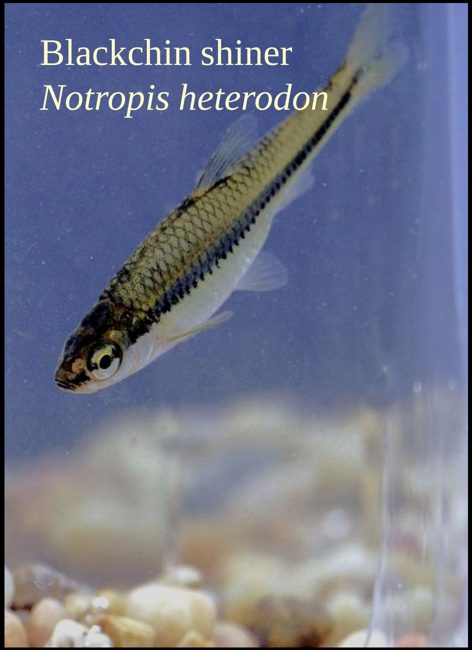
Endangered and Threatened Species

- Blackchin shiner *Notropis heterodon* 200
- Blacknose shiner *Notropis heterolepis* 116
- Iowa darter *Etheostoma exile* 150
- Banded killifish *Fundulus diaphanus* 80

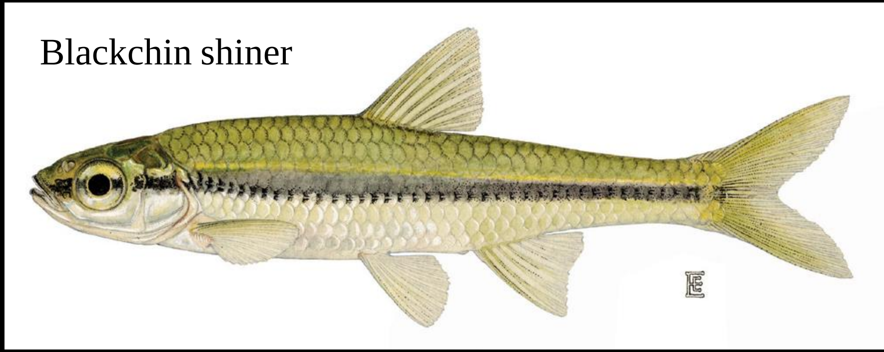
•MVP number and uncertainty
•Restrictions from IDNR on number we could take

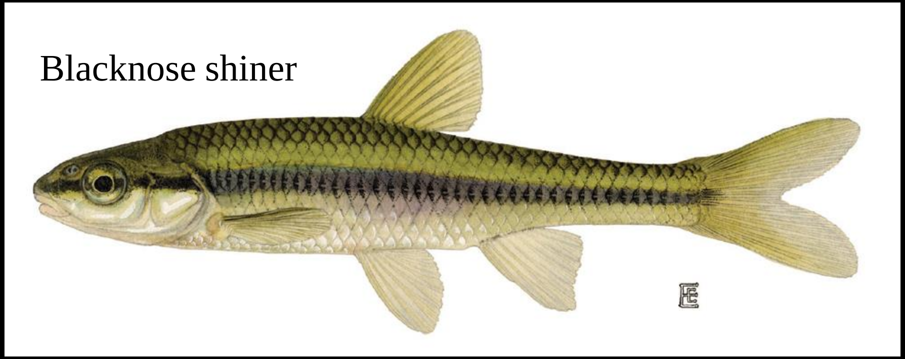
Endangered and Threatened Species





Endangered and Threatened Species





Added unintended bonus…..inadvertently transferred Pugnose shiner. Most seriously endangered of any of the five species.

Compare differences

AFS E/T Transplant Guidelines

Site Screening

- Restrict to historic habitat historic range
- Restrict to protected site management
- Dispersal will be acceptable Des Plaines
- Match to life history requirements new life history study
- Habitat that can support viable populations
- Limit hybridization opportunities

AFS E/T Transplant Guidelines

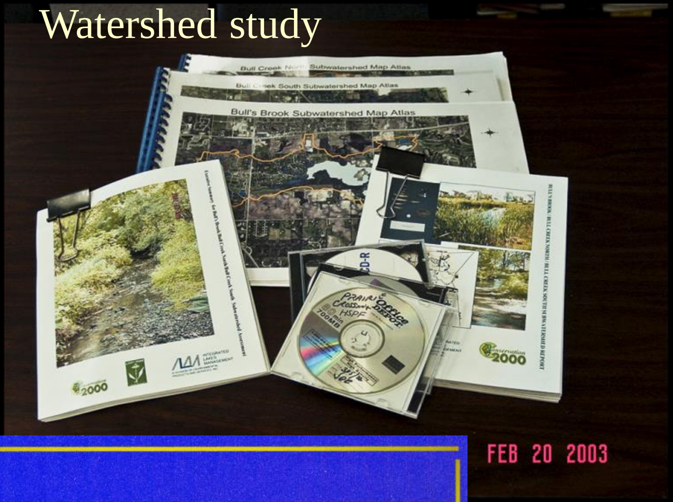
Conducting the Introduction

- Appropriate source….Fox drainage/10 mile
- Examine the taxonomic status…subspecies
- Undesirable pathogens….problematic; limit source water transfer..no quarantine took place
- Numbers and gender distribution….MVP
- Transport methods…..shiner sensitivity and net avoidance
- Conditions for introduction… no predators
- Document translocation… 10 + years of monitoring data

AFS E/T Transplant Guidelines

Post Transplant Activities

- Conduct systematic monitoring
- Restock if warranted…..maybe
- Determine the cause of failures….MVP #'s
- Document findings and conclusions
- Graduate students (2 masters thesis)
- Life history data (1 published life history paper)
- Genetic profiling
- Stocking of Central Lake
- Introduction of predators
- 10 + yrs. Of monitoring
- USGS publication in Fisheries
- Genetics publication in Conservation Genetics



- Results:

- >100,000's blackchin, blacknose shiners & banded killifish

- Documented presence of Iowa darter and pugnose minnow

- 10+ years of biological and chemical monitoring

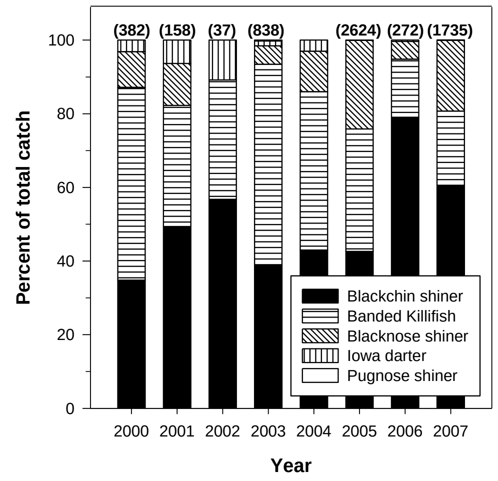
- Follow-on stocking of other regional aquatic sites
  mixed results and importance of monitoring and matching of habitat requirements

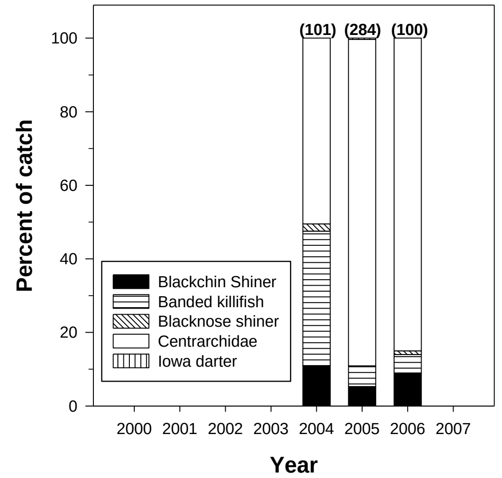
- Movement of fish to Lake Leopold with predators

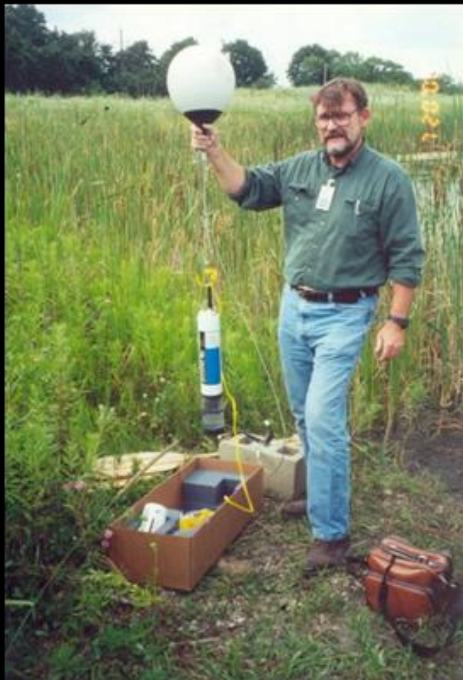
- Validation of genetic ~~heterogeneity~~

- Elaboration of life history data for all 4 species

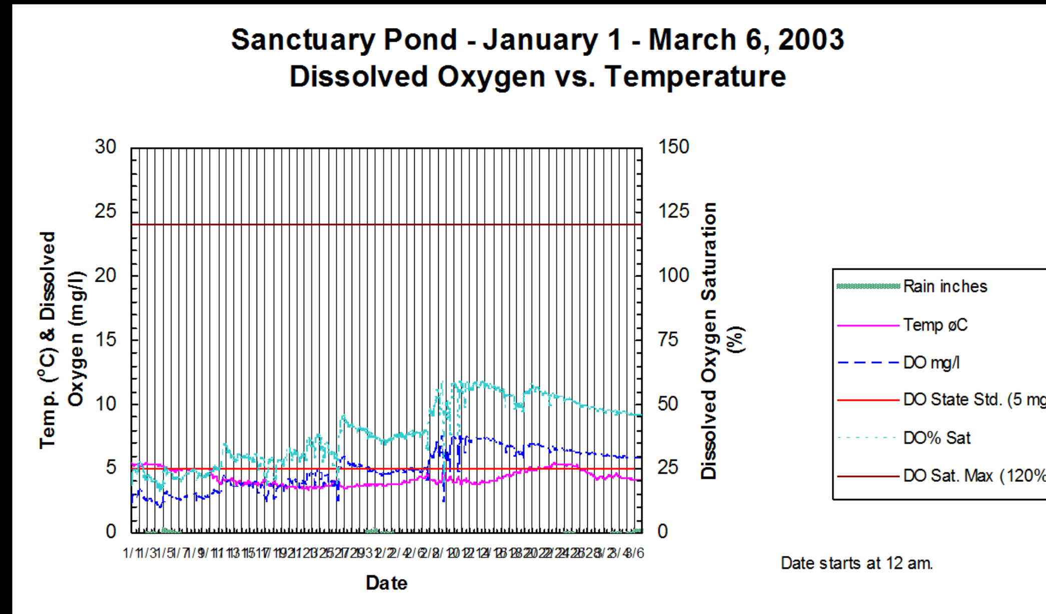
- Technical paper concerning the value of "reconciliation biology"







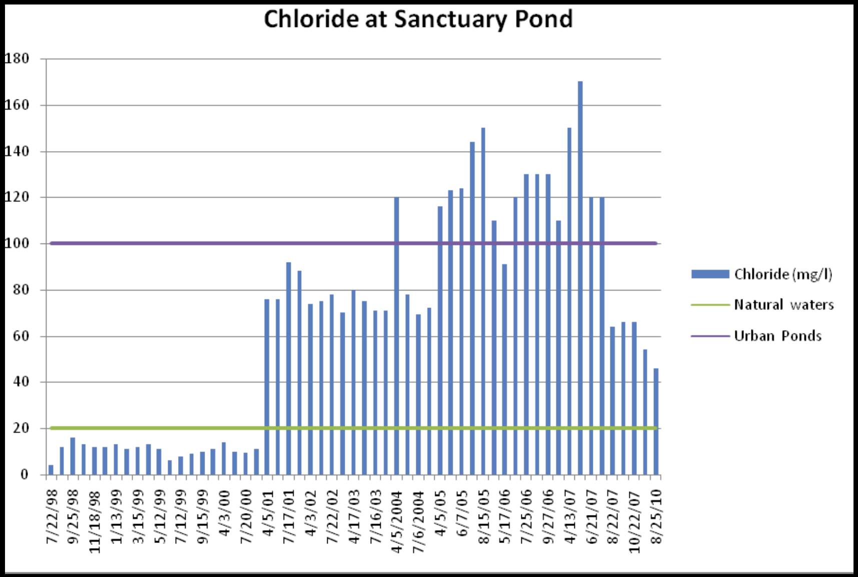
Man with a serious bad hair day



- Work with multiparameter Sonde confirmed that…. Small fish are capable of surviving episodes of little or no oxygen during the winter months

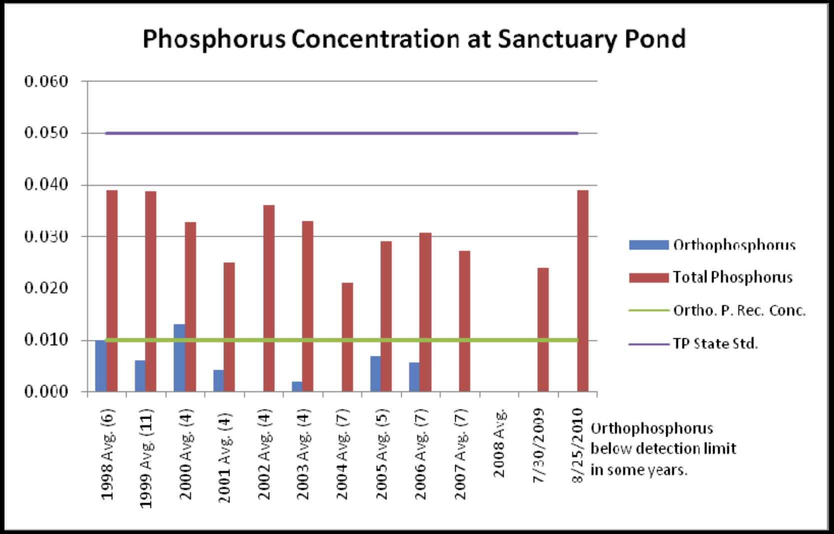
- Water clarity was terrific even in very large and intense storms

Water quality concerns:



- Increase in salt concentration with road salting
- Decrease with substitute deicing compounds

No statistically significant increase in Total P ….
but shifts in algal and rooted aquatic plant communities may be significant in the future



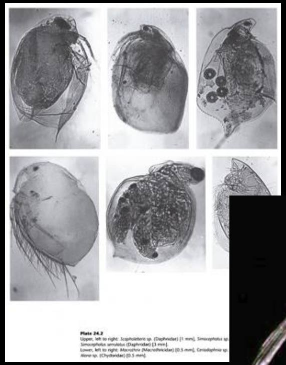
Good News ….shoreline rooted aquatic plants have been allowed to grow with a minimum of directed management

Bad News…. Some shifts toward blue-green algal dominance and continued problems with milfoil and curly-leaf pondweed. Use of milfoil weevils was successful in previous seasons

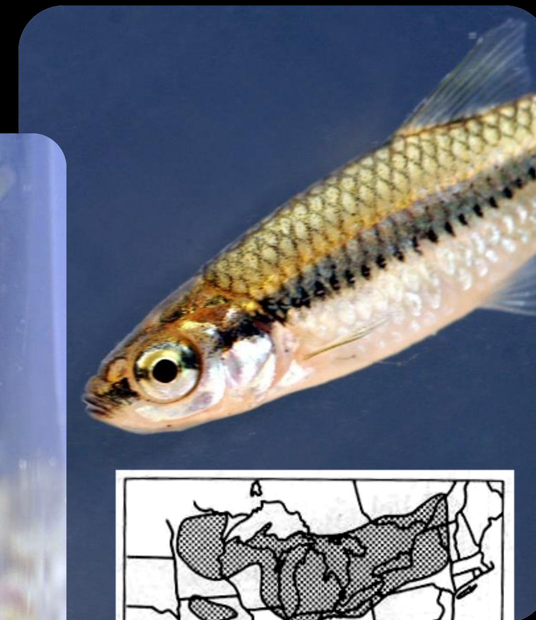
Species profiles
Blacknose shiner, Notropis heterolepis

- Life span : 2 years
- Multiple clutches
- Sexual maturity 1 year
- Opportunistic life history strategy
- Breeding period   April – July
- Boom bust population phenomena (Becker)
- Max size: 56 mm
- Planktivore …. Chydorid water fleas and ostracods
- Rooted aquatic vegetation
- High water clarity
- Diel foraging pattern

- Endangered in Il, Oh, S3 status in In



Species profiles
Blackchin shiner *Notropis heterodon*



- Life span : 2+ years
- Multiple clutches
- Sexual maturity 1 year
- Opportunistic life history strategy
- Breeding period May -August
- Boom bust population phenomena (Becker)
- Max size: 64 mm
- Planktivore ; generalist feeder…. Chydorid , bosminid water fleas , ostracods, dipteran adults?
- Rooted aquatic vegetation + sand substrates
- High water clarity
- Diel foraging pattern (Avoids predation)

- Endangered in Penn, Oh,NY; T in IL, S2 status in IN.

Species profiles
Banded killifish *Fundulus diaphanus*

- Habitat shallow quiet margins of lakes/ponds
- Mid-water feeder despite killi mouth
- Hybridization of subspecies
- Very “hardy” species
- Max size: 64 mm
- Diet : midges, caddis flies, microcrustaceans, ostracods; highly variable opportunistic feeding
- Rooted aquatic vegetation + sand substrates
- High water clarity

- T in IL, E in OH, Secure elsewhere
- Recovery Plan for the Eastern version is underway in Ohio

2 subspecies Fundulus diaphanus diaphanus (Western)
Fundulus diaphanus menona (Eastern killi fish)

Potentially competitive with blackstripe topminnow another killifish

Species profiles
Iowa darter *Etheostoma exile*

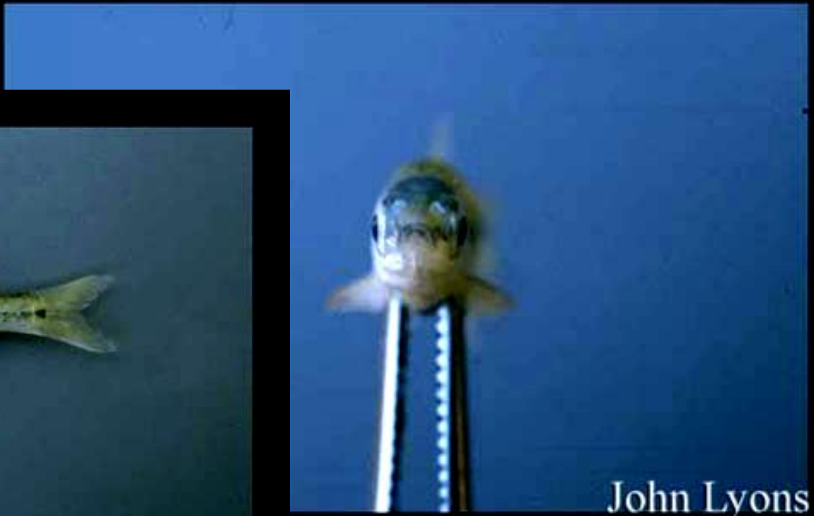
- Slow clear vegetated water of lakes, ponds, streams
- Near shore species in very shallow water
- Max size 66mm
- Life span 4yrs
- "darter " life style
- Diet : planktivore to insectivore
- Widely distributed, locally common
- Probably should not be on E/T list

N.Y. Dept. Cons

Species profiles
Pugnose shiner *Notropis anogenus*

- One of rarest minnows in N.A (G3)
- Range reduced in Canada and U.S.; extirpated from previous known localities
- Turbidity sensitive ??
- Life history: little is known about it
- Rarely exceeds 2" (56 mm)
- Breeding period spring time
- Rooted aquatic vegetation (found in association with algae= Chara and Nitella)
- High water clarity

- Small mouth (almost vertical)
- Decurved lateral line

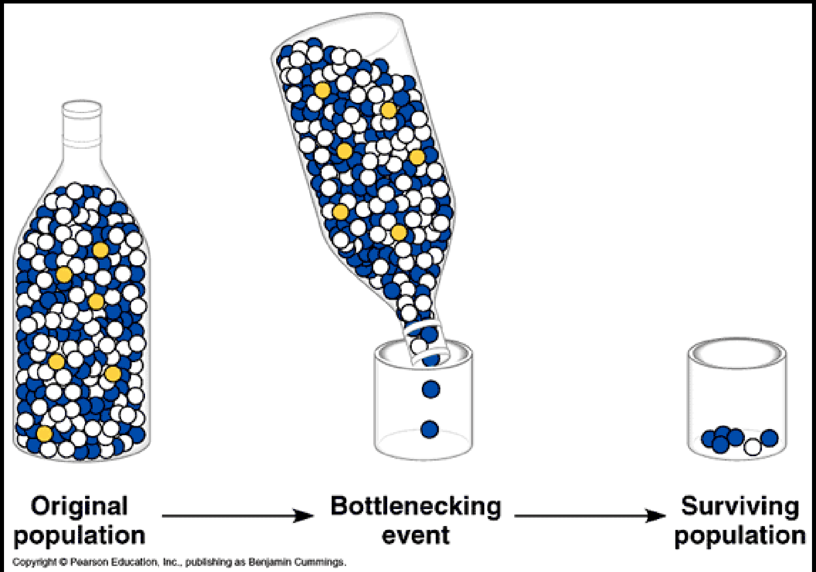


Univ. of Illinois conclusions concerning genetic work:

- Ecological and genetic studies should precede establishment of fish sanctuaries
- There was loss of genetic variability associated with population founder effect DON'T MOVE TRANS POP
- Success of Prairie Crossing project indicates that manmade lakes and ponds may provide suitable habitat for native fishes with qualifications
- Implications for future translocations   MVP=100's

The value and importance of this has been underestimated in the past. New technologies should make genetic analysis much more approachable and it should be routine for any project involving the translocation of fish populations

Founder effect



- Loss of genetic diversity
- New species
- Genetic bottleneck….disappearance

Endangered and Threatened Species

Biggest payoff is that Sanctuary Pond is now being used as a source of fish for stocking across the historic Illinois range for these species. At some later point in time we would hope for delisting of several of the species.

Endangered and Threatened Species

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Lists of Recent or Forthcoming Concerning Prairie E/T Project

- http://www.pchoa.com/outside_home.asp on-line public access web site for Prairie Crossing Home Owners Association. Summary data from 1998 thru 2010 is available as part of an ILM report

- multiple years of fishery and water quality data reports are directly available on-line

- Conservation Genetics Journal Ashley and Ozer publication before the end of the year

- AFS Fisheries Schaeffer et.al. Publication in June

How Do You Spell Success? The Rare Fish Variety, That Is

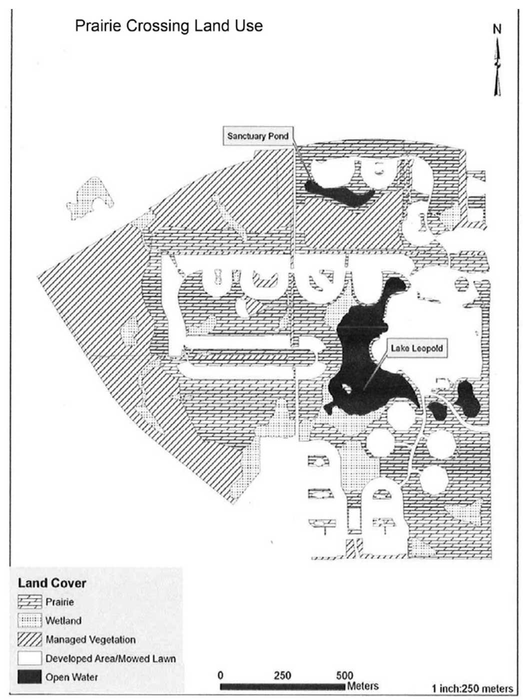
Part I: Grading Success in Rearing Threatened and Endangerd Species

Jim Bland

Adjunct Professor
University of Wisconsin, Milwaukee
School of Freshwater Science

Introduction

I find it surprising that we are still talking about this project despite the fact that it was initiated 15 years ago in 1998. It's appropriate, however, if you feel that the success of environmental projects need to be interpreted over the long run and not with short-duration results. Grading our results, I would call the project largely successful with some qualifications. Our mistakes are probably just as instructive as some of the things that went well. In 1998 we (Jim Bland and Integrated Lakes Management [ILM] staff) were tasked with doing some design work, water quality monitoring, and fish stocking for a residential complex called Prairie Crossing located in Grayslake, Illinois. Prairie Crossing is unique in the country in being one of the first residential developments focused on environmental design and sustainability. The 630-acre development has been configured to retain prairie, wetland, and farmland on site. One lake and three ponds are also part of the complex. Lake Leopold is a 28-acre lake with a maximum depth of 15 feet and Sanctuary Pond is 2.8 acres with a maximum depth of six feet. Applied Ecological Services (AES) was principally responsible for the landscape design elements of Prairie Crossing. Critical to insuring good water quality and high clarity was the incorporation of a concept which AES refers to as a "treatment train." Stormwater is handled by minimizing impervious surfaces, and routing runoff sequentially through grassed swales, prairies, wetlands, and ultimately stormwater detention ponds (Afelbaum et al. 1995). Impervious surfaces include roofs, walkways, roads, and those surfaces that don't let water infiltrate into the soil. Additionally, the homeowners association was "tolerant" of the presence of rooted aquatic plant populations in densities that other associations would find weedy and objectionable. Typical stocking mixes for our region included bass, Bluegill, and Fathead Minnows. However, we did not want to do what was typical. Given its environmental mandate and homeowners' covenant, ILM proposed that Prairie Crossing embark on a project to establish a sanctuary for endangered and threatened (E/T) Illinois fishes.



Toward that end we consulted with Dr. Larry Page, formerly of the Illinois Natural History Survey, and Dr. John Janssen of the University of Wisconsin. Dr. Page's assessment of the Illinois fish fauna and his discussion of rearing ponds is what suggested the project to begin with (Page 1991). Dr. Page also had poor experience with trying to stock E/T species into a situation where predators still existed; for our project he insisted that all potential predators be removed. The Prairie Crossing lake and ponds which were the focus of our project were essentially brand new and thus, hypothetically, there shouldn't have been any fish in them. Much to our surprise, however, Green Sunfish (*Lepomis cyanellus*) had undergone "spontaneous generation" and were present in both Lake Leopold and Sanctuary Pond. It was cost-prohibitive to use fish toxicants in Lake Leopold and thus we decided to stock the upper 2.8-acre pond (later to be called Sanctuary Pond) after we had rotenoned it to remove the Green Sunfish. Fathead Minnows in a minnow cage were used as a bioassay to determine when it was safe to reintroduce fish.

Regional data suggested that Blacknose Shiners (*Notropis heterolepis*), Blackchin Shiners (*Notropis heterodon*), Banded Killifish (*Fundulus diaphanus*), and Iowa Darters (*Etheostoma exile*) had disappeared or were disappearing from the Des Plaines drainage in northeastern Illinois. They also typically occur together and thus problems of competing populations would seem less likely. The Blacknose Shiner is endangered in Illinois while the other three species have a threatened status. All of these species were present in two lakes, Deep Lake and Cedar Lake, in the Fox River drainage. One of the first problems which we encountered was determining how many fish to transfer; we consulted literature to try to determine the minimum viable population (MVP is the minimum number of fish that could be transferred to preserve genetic variability and prevent genetic bottlenecks). Numbers from the literature were not very helpful as they varied from 50 to 1,500. Dr. Janssen, with the cooperation of the Illinois Department of Natural Resources (IDNR), negotiated a figure of 200. While we had a target figure of 200 fish, our collections fell short of that number. Original collection numbers were:

Blackchin Shiner: 200 Iowa Darter: 150
Blacknose Shiner: 116 Banded Killifish: 80

With a small crew of ILM staffers, graduate students, and Dr. Janssen we collected the four species from Deep Lake and Cedar Lake. A 30-foot x 6-foot x 1/8-inch mesh bag seine was used to collect the fish for transfer. Notably both of the shiner species experience net shock very easily; the killifish and the Iowa Darter don't seem to experience the same type of mortality with handling. There are apocryphal stories intimating that killifish can be sent through the mail in wet newsprint! Certainly they are hardier to handle in the net. Fish were transferred to an aerated cooler lined with a black plastic garbage bag. At Prairie Crossing the bag was removed from the cooler and allowed to sit in the water to acclimate temperatures; fish were then removed with an aquarium net, and the black garbage bag flushed to the ground. Minimal amounts of water were thus transferred from one water body to another.

Results

From the outset it was our intention to do three things:

1. Complete a transfer of the E/T species to build their populations within Sanctuary Pond and to subsequently effect transfers to other parts of the Des Plaines drainage; additionally to monitor water quality and pond biology across an extended period of time. All of this to be done in acknowledgement of protocols from the American Fisheries Society.
2. To get detailed life history studies prepared for the two shiners and the Banded Killifish.
3. To get genetic work done to substantiate that variability had been sustained in the receiving ponds.

None of these goals would have been possible were it not for exceptional support from the Prairie Crossing Homeowners Association (PCHA) and their environmental staff. The fish were transferred in the fall of the year and in the subsequent summer it was clear that we had hundreds of thousands of shiners and Banded Killifish in Sanctuary Pond. The Iowa Darters were present in far lower numbers but we had young of the year for all four species. Monitoring of lakes typically involves a standard set of parameters which include ortho- and total phosphorus, ammonia, nitrates, chlorides, chlorophyll a, alkalinity, pH, turbidity, conductivity, and temperature and dissolved oxygen (DO) measured as depth profiles. Both Lake Leopold and Sanctuary Pond were monitored in this way five to six times across the monitoring season. This type of monitoring was continued for both water bodies for over 10 years. Additionally we were able to deploy a multiparameter Sonde that took hourly readings for several sampling seasons for Sanctuary Pond and later for Lake Leopold. After the fish translocation we did seining of Sanctuary Pond approximately four times per year but the seining was not time controlled and no efforts were directed at estimating population size for any of the species. Our collection records do give a description of the relative numbers of each of these species across time and they document breeding success. Rooted aquatic plant populations were identified, densities estimated, and on several occasions were mapped. We were able to do more limited collection and characterization of zooplankton and phytoplankton for Sanctuary Pond. Two years after our first translocation we actively moved a collection of all four species from Sanctuary Pond into Lake Leopold. Lake Leopold was actively managed as a recreational fishery and had a variety of sunfish and bass. The E/T species continue to survive in Lake Leopold and additional records exist for the stream drainage directly downstream from Prairie Crossing.

Our Sonde results were particularly notable. One of the legitimate concerns of the IDNR was the possibility of winter kill or summer kill for the E/T species. The Sonde did document some dramatic loss of DO in the water column and underneath the ice for some winter and summer weather episodes. The low dissolved oxygen in the winter continued for over a month's period of time, however no mortality was evident for any of the four species. Summer reductions in DO were largely diurnal and did not last for extended periods. It appears that these particular species are far more tolerant of low winter DO values than larger fish fauna. Shuter et al. (2012) describes various types of winter survival strategies: "*Lakes that are subject to frequent winter kill events typically support a unique community of fish species that possess a range of specialized behaviors and physiological strategies for tolerating winter oxygen deficit.*" Another significant observation with the Sonde data was the pond and lake response to rain events. Urban detention ponds typically get pretty murky in response to stormwater runoff. By contrast both the Lake and Sanctuary Pond had minimal spikes in turbidity, even when subjected to very large rain events. As follow-up translocations to other lakes and ponds in the Des Plaines drainage were undertaken, even the hint of turbidity seemed enough to kill off both the shiners and the killifish. Less critical but still worrisome was a spike in chloride levels due to winter salting of roadways. Chloride values got as high as 300 parts per million. Prairie Crossing, in response to the elevated chloride levels, incorporated a salt control program.

Shoreline seining was initiated in 1999 but only presence/absence data were recorded in 1999. In 2000 total catches and estimates of effort were recorded but shiners were lumped into a single category (in part because we were concerned about shiner sensitivity to handling). Seining was undertaken four times per season and sufficient numbers collected to develop size/frequency data. Detailed information concerning the results can be found in *Fisheries* (Schaeffer et al. 2012). Field methods have changed across time and more fish were collected for purposes of profiling the population. All four fish species continue to be present in Sanctuary Pond although Iowa Darters have from time to time disappeared from seasonal collections. This is more likely an artifact of collection techniques and the difficulty of collecting in heavy plant growth. Percentage of total catch from 2003 to 2010 is given below.

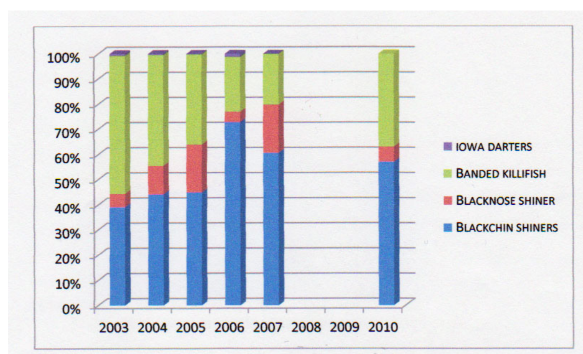


Figure 2 Percentage of Total Catch from 2003 to 2010

General population trends mirror relative population numbers found in other regional lakes. So, Blackchin Shiners are found in larger numbers, Blacknose Shiners in far fewer numbers, Banded Killifish as a substantial presence, and Iowa Darters as a 1% presence. Fish have moved from Sanctuary Pond to Lake Leopold and from Lake Leopold, they have moved down the watershed to Almond Marsh and still further to Bulls Brook just above the junction with the mainstem of the DesPlaines River. While sampling has been limited, fish appear to have spread throughout the Bulls Brook watershed. A significant element for the project is that a ten-foot drop structure exists at the street immediately to the east of Prairie Crossing. Carp and other exotic species cannot make their way into the lakes and ponds of Prairie Crossing. Fish can, however, be exported downstream into the Bulls Brook watershed and the DesPlaines drainage (Figure 3).

In addition to spreading within the immediate watershed there have been approximately six different trials where different combinations of the four species were moved from Sanctuary Pond to other locations within the greater DesPlaines drainage. These trials were not monitored as closely as the original translocation. Shiners were translocated to a zoological society pond but the algal burden of the pond and the presence of sunfish meant that no surviving fish were found in the subsequent season. Transfers to ponds with even a modest amount of turbidity resulted in no survivorship for the shiners. Concerns for those places where the shiners have survived are genetic variability and founder effects. The founder effect describes a condition where the genetic profile is different enough that it has the possibility of creating a new species.

Literature Cited

Afelbaum, S., J.D. Eppich, T.H. Price, and M. Sands. 1995. The Prairie Crossing Project: Attaining Water Quality and Stormwater Management Goals in a Conservation Development. *In* Proceedings of National Symposium on Using Ecological Restoration to Meet Clean Water Act Goals, pp. 33-38. Chicago, Illinois, March 14-16. USEPA Conference.

Page, L.M. 1991. Streams of Illinois .Illinois Natural History Survey Bulletin 34(4): 439-446.

Schaeffer, J.S., J.K. Bland,and J. Janssen. 2012. Use of a Storm water Retention System for Conservation of Regionally Endangered Fish. Fisheries Vol.37 (2): 66-75.

Shuter, B.J.,A.G. Finstad, I.P. Helland, I. Zweimöller, and F. Hölker. 2012. The role of winter phenology in shaping the ecology of freshwater fish and their sensitivities to climate change, Aquatic Sciences Vol. 74(4): 637-657.

Part II: Life History Studies and Conservation Status

Arrangements were made with the Illinois DNR, Southern Illinois University (SIU), and Max McGraw Wildlife Foundation (MWF) to sponsor two graduate students to determine the conservation status and life history profiles of the two shiners and the Banded Killifish (Burr et al. 2005). Dr. Brooks Burr of SIU and Vic Santucci of MWF oversaw the work of Matt Roberts and Adrienne Davis. One of the first finds of their field studies was that the Pugnose Shiner (*Notropis anogenus*) was present in Lake Leopold. Apparently, we had collected some Pugnose along with the other shiners as part of our original translocation. Pugnose consistently showed up in the graduate student collections at Lake Leopold but only in very limited numbers. Life history traits were compared between the original source lakes, Deep Lake and Cedar Lake in Northeastern Illinois, and the Prairie Crossing location in an effort to determine similarities and differences in stocked populations versus natural populations.

Presence/absence records across North America and for Illinois lakes and rivers were reviewed and field sampling undertaken for as many historical Illinois collection sites as possible. In Illinois the Blacknose Shiner was present at only one of 21 historical stream locations and in eight of 12 historical lake sites. The Blackchin Shiner was found in seven of the 18 historical sites; six of these sites are lakes and only a single stream site had a recent record. Extant populations of the Pugnose Shiner were present at four of 10 historical sites. The Pugnose is a particularly difficult species to characterize because of its low numbers, association with high density plant beds, and difficulties with collecting conditions. The graduate students found Banded Killifish at four of 11 historical sites and no new localities were found. Banded Killifish were no longer found in Cook, McHenry, or McClean counties; only Lake County had extant populations. Reductions in ranges thus exist for all of the species in Illinois. Major conservation concerns were the absence of most stream populations for any of these species and the need for active conservation management in the lakes where remnant populations still exist. The following section abstracts the life history and global distribution data compiled by Matt Roberts and Adrienne Davis (Burr et al. 2005).

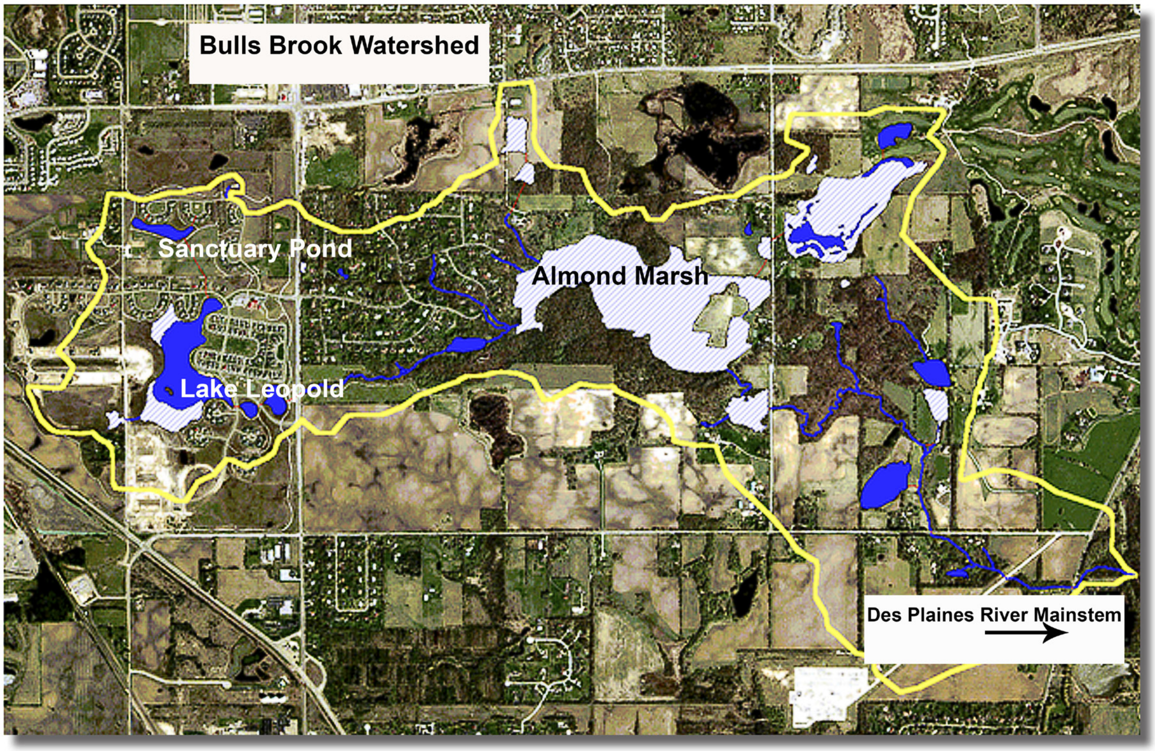


Figure 3. Bulls Brook Watershed and relative location to the DesPlaines River Mainstem. (This figure was left out of the original article in *American Currents*).

Blacknose Shiner *Notropis heterolepis*

The Blacknose Shiner shows a pattern of range reduction along the southern border of its range but it is secure in the northern part of its distribution in Canada and the United States. According to the SIU study, it's typically found in lakes close to shore over sand and in low-to-moderate cover. The species was characterized as having an "*opportunistic life history producing multiple clutches of eggs over a period extending from April to early July*...." Males and females were reproductively mature at 1+ age class; males developed breeding tubercles on the dorsal surface of their pectoral rays from June through October. The mean number of ova present in a clutch was 167. Feeding followed a diel pattern with morning and evening peaks. Their principal diet consisted of zooplankton; mainly chydorid and bosminid water fleas and ostracods. Feeding is heavier in the spring than summer or fall. Life span is short (1+) years and very few individuals survive into a second year, according to field studies conducted by other researchers. Data from Ohio indicate that eggs are scattered over vegetation with no subsequent parental care. The Blacknose was recorded as a fossil from the last glaciations in one ice-dammed lake in northern North Dakota (Newbrey and Ashworth 2004). The Blacknose Shiner is listed as state endangered in Illinois.

Blackchin Shiner *Notropis heterodon*

The Blackchin Shiner showed a 61% reduction in its range across Illinois. The SIU students identified sand and the presence of vegetation from their field sites as important physical components sustaining regional populations. Males and females reach approximately the same size at maturity. Breeding season is from late May through early August and multiple clutches are part of the reproductive pattern. Similar to the Blacknose, the Blackchin was found to be an opportunistic strategist—early maturation, small clutch size, egg diameters, and production of multiple clutches. The Blackchin is also a diel feeder and forages over vegetation, in the open water and at the surface. It is primarily a planktivore, feeding on water fleas and ostracods. It would seem as though the two shiner species should be in competition; their occurrence together is somewhat of a surprise.

Banded Killifish *Fundulus diaphanus*

The most immediate condition that ties all four translocated species together is the requirement for high clarity water and vegetation. A seemingly hardy species, Banded Killifish is resistant to low dissolved oxygen and can withstand a wide variety of temperatures. They can be found over substrates ranging from silt to gravel; the Prairie Crossing ponds and lakes all have a silt substrate. Many of the recreational lakes in northeastern Illinois employ active management to reduce rooted aquatic plant populations and this may have had a bearing on its contracted distribution. It favors shallow, still waters of lakes and ponds. Spawning occurs from late spring to early summer. Adhesive eggs are produced that stick to vegetation. It is described as a generalized feeder and will feed on micro-crustaceans, insect larva, and broad assortment of zooplankton (Becker1983).

Iowa Darter *Etheostoma exile*

The SIU students did not do conservation or life history studies for the Iowa Darter since substantive work had already been done by others. Unlike the other three species, Iowa Darters were still present at DesPlaines sites. Once listed as Endangered, it is currently listed as Threatened in Illinois as a consequence of updated distributional data. The Iowa Darter is one of a handful of darters that can commonly be found in lakes. After its translocation to Prairie Crossing, it was found in all of the Prairie Crossing ponds and as part of the greater Bulls Brook drainage. It lives up to three years, achieves a size of up to 2.75 inches, disperses eggs against the available substrate, and does not protect its young after spawning. Males establish breeding territories in shallow water as water temperatures moderate in early spring. They don't, however, create nests. As with the other Prairie Crossing species, Iowa Darters are able to survive low levels of oxygen. Food sources range from micro-crustaceans, aquatic insect larva to various types of zooplankton. Recent sampling of headwater stream assemblages in Northeastern Illinois has found Iowa Darters as a common occurrence.

Pugnose Shiner *Notropis anogenus*

The Pugnose Shiner is rare throughout its range (Burr et al. 2005). In northeastern Illinois, at the southern limit of its distribution, it is found in only a handful of glacial lakes. SIU students found the Pugnose at five of the 12 sites it had been collected historically. The habitat association of Pugnose Shiners,

(Continued on Page 20)

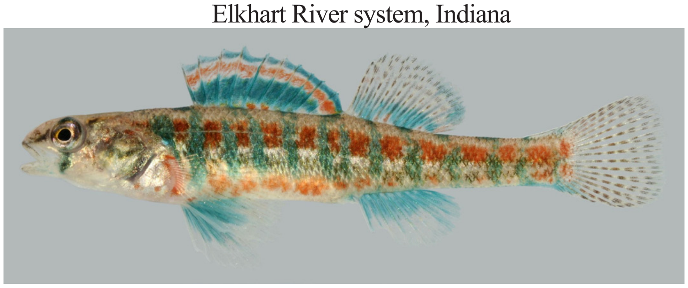
Fishes of Prairie Crossing

Blacknose Shiner Jim Bland

Blacknose Shiner Uland Thomas
Elkhart River system, Indiana

Blackchin Shiner Uland Thomas
Elkhart River system, Indiana

Pugnose Shiner Konrad Schmidt
Crooked Creek, Crow Wing County, Minnesota



Iowa Darter (male) Uland Thomas
Elkhart River system, Indiana

Iowa Darter (female) Uland Thomas
Elkhart River system, Indiana

Banded Killifish Jim Bland

Male Bluehead Chub with close-up of head and tubercles Dustin Smith
Mayo River, North Carolina

dense weed cover, made it hard to collect. Therefore, backpack shocking and nearshore seining have not always been effective in confirming their presence. SIU sampling teams noted that Pugnose also seem to have preferred locations within the larger habitat. They have speculated that the localization within lakes and the association with dense weed beds may have contributed to biases in collection data. Jen Porterfield and Dr. Patrick Ceas of St. Olaf studied the life history traits of the Pugnose Shiner in Minnesota (Ceas 2012). They document a shift from the use of deeper water environments (4 to 6 feet) in early spring to nearshore shallows (3 to 4 feet) where aquatic vegetation is abundant. They also infer from feeding studies that Pugnose feed on both filamentous algae and micro-crustaceans. Year 2 females and males are sexually mature by mid-may while Year 1 males were sexually mature by July and thus represent potential spawning later in the summer. Scientists from Canada are doing microsatellite DNA profiles for different populations. Preliminary results distinguish significant differences between western stocks and eastern stocks. Canada has also prepared a recovery plan for this species (Lyons 2012)

Literature Cited

Becker, G.C.1983. *Fishes of Wisconsin*. University of Wisconsin Press. 1,052 pp.

Burr, B.M.,V.J. Santucci, M.E. Roberts, A.M. Davis, and M.R. Wiles. 2005. Conservation status and life history characteristics of the blacknose shiner *Notropis heterolepis*, blackchin shiner *Notropis heterodon* (Cyprinidae),with conservation evaluations of the pugnose shiner *Notropis anogenus* (Cyprinidae), and banded killifish *Fundulus diaphanus* (Fundulidae), in Illinois. Max McGraw Wildlife Foundation, Final Report.

Ceas, P., and J. Porterfield. 2012. Life histories of the northern longear sunfish (*Lepomis megalotis peltastes*) and pugnose shiner (*Notropis anogenus*) in Minnesota, with examinations of other rare non-game fishes. Final Report. Minnesota State Wildlife Report T-32-R-1.

Illinois Department of Natural Resources. 2011. Checklist of Endangered and Threatened Animals and Plants of Illinois. Illinois Endangered Species Protection Board.

Lyons, J. Editor. 2012. *Fishes of Wisconsin* E-book.. Wisconsin Department of Natural Resources, Madison and U.S. Geological Survey, Middleton, Wisconsin. http://www.fow-ebook.us

Newbrey, M.G., and A.C. Ashworth. 2004. A fossil record of colonization and response of lacustrine fish populations to climate change, Canadian Journal of Fisheries and Aquatic Sciences 61(10): 1807-1816.

Roberts, M.E, B.M. Burr, M.R. Whiles, and V.J. Santucci, Jr. 2006. Reproductive Ecology and Food Habits of the Blacknose Shiner, *Notropis heterolepis,* in Northern Illinois, American Midland Naturalist 155: 70-83

Part III: Preserving Genetic Variability: The Real Measure of Successful Translocations

The last part of this story has taken perhaps the longest time. The results are important however for anyone looking to effect translocations of imperiled fish fauna. Dr. Mary Ashley of the University of Illinois Chicago Circle and her graduate student, Fuson Ozer, performed microsatellite analysis of the two shiner species. Microsatellites are short sequences of DNA that repeats themselves frequently; they are used as molecular markers. Fish samples were taken from the source lakes, Cedar Lake and Deep Lake in the Fox River drainage, and from the receiving lake and pond, Lake Leopold and Sanctuary Pond (Upper Pond in their publication). Initial genetic analysis occurred between 2001 and 2005, after the breeding season. Given a generation time of 1- to- 2 years, these samples were taken between two and seven generations post-translocation. Success would require that genetically diverse and representative populations were created in the sanctuary lake/pond. Preliminary results were hopeful; however, more detailed analysis determined that there were short-falls in the project (Ashley and Ozer 2013).

The research objectives of the UIC team were: 1) compare microsatellite profiles between the source lake and the sanctuary lake/pond; 2) assess levels of divergence between Blackchin Shiners and Blacknose Shiners and insure that hybridization was not taking place; 3) quantify levels of genetic losses if in fact there were losses; 4) test whether close kin (siblings) occurred in the sample; and 5) estimate the effective size for sampled populations for microsatellite studies.

Microsatellite data showed that the two species are quite distinct and there was no evidence of hybridization in either the source or translocated samples. Moderate levels of heterozygosity were sustained by both species as part of the translocation. When thinking about heterozygosity you might think about the alternate traits on Mendel's pea plants. If a dominant and recessive trait exists at one gene allele site we speak of it as heterozygous. On a population level if animals have low heterozygosity they may be at risk; examples include Cheetahs and Black-footed Ferrets. High levels of heterozygosity imply that genetic variability has been preserved. For the Prairie Crossing project many alleles observed in the source populations were not observed in the translocated populations, indicating that some genetic diversity had not been preserved. Surprising also was the finding that full sibs (brothers and sisters) occurred with half sibs (cousins) within the source lake samples. This has the effect of reducing the effective population size of the reintroduced stock.

The loss of genetic diversity implies that taking fish from Sanctuary Pond or Lake Leopold for additional reintroductions risks the possibility of genetic bottlenecks (populations eventually die back) or founder effects (we're busy creating new species). In the future we may do additional translocations from Cedar Lake and Deep Lake into Sanctuary Pond and/or Lake Leopold. In the short-run however, Dr. Ashley has suggested that any stock for reintroductions come directly from the original source lakes. It is also implied that we took too few fish from the source lakes for the creation of the sanctuaries. As we collect fish, Dr. Ashley would also suggest that we cast a larger net, i.e., look to sample a broader range of environments in the lake so that we are not sampling close relatives (sibs). In the initial translocation we were not able to obtain the 200 fish per species that was our target. According to Ashley and Ozer (2013): *"While this study does not preclude the use of small, man-made ponds and lakes in management plans, it does suggest that to maintain both heterozygosity and allelic diversity, sanctuary populations will need to be established using several hundred fish from multiple sites, compared to 200 or fewer collected from single sites, as used for the Prairie Crossing sanctuary."*

Literature Cited

Ashley,M., and F. Ozer. 2013. Genetic evaluation of remnant and translocated shiners *Notropis heterodon* and *Notropis heterolepis.* Journal of Fish Biology 82:1281-1296.

The George Maier Fund is now accepting grant requests

The George Maier Fund
A fund dedicated to the study of killifish
Oviparous Cyprinodontiform Fishes of the Class
Actinopterygii, Order Cyprinodontiformes.

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Request for Applications (RFA) No. GMF A-13 Please refer to this number in all correspondence

Key Dates:
Application Deadline: Applications are due by December 31, 2013 Grant Awards: Grants will be awarded no later than January 31, 2014.

Relevant Procedures:
GMF P-1 Grant Proposal Requirements
Proposals not in accordance with this document will not be evaluated. Copies of this procedure are available via e-mail request to the address noted below.

2013 Grant Summary:

Total Available Funding:	$7,500
Length of Project Period:	Up to 2 years
Estimated Number of Awards:	Up to three

(3)a.Multiple grants for lesser amounts may be considered whose sum is equal to or less than the maximum amount.

Charles A. Nunziata — Chairman, 2011-2015
Anthony Terceira Ph.D — Secretary

Contact Charles Nunziata at epiplaty@tampabay.rr.com document copies.

Does lake dredging affect biodiversity?

Evaluating biodiversity levels of fish at various stages of the dredging process in freshwater lakes.

By:

Robert W. Schwerdtfeger Jr.

An Undergraduate Thesis

Submitted in Partial Fulfillment for the Requirements of

Bachelor of Arts

In

Environmental Science: Conservation and Ecology

Carthage College

May 2016

Does lake dredging affect biodiversity?

Evaluating biodiversity levels of fish at various stages of the dredging process in freshwater lakes.

Robert W. Schwerdtfeger Jr.

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Abstract

Fish are important higher trophic level organisms whose presence in lakes can be used to help determine the health of an ecosystem. However freshwater fish populations have declined over the past few decades primarily due to exploitation and degradation of habitat. One process that is done in an attempt to restore freshwater lake habitat is dredging. However not much study has been done on the long term effects of lake dredging and we are unsure if the process is beneficial to freshwater fish in the long term. This study focuses on biodiversity levels in three freshwater lakes, one of which was undergoing the dredging process and one that had already undergone the dredging process, in northern Illinois and south central Wisconsin. Fish were collected through traditional angling methods and biodiversity was looked at through measures of Species Richness, Shannon Diversity Index rating, and the average size of Sunfish was also calculated for each lake and compared. Results show that lakes that have been dredged and undergone recovery has a statistically higher Shannon Diversity Index rating, and average sunfish size when compared to a lake that has never been dredged. The lake that has been dredged also has a higher species richness rating than the lake that has never been dredged. From the results of this study we can see that there is a significant difference in the biodiversity levels when comparing a lake that has never been dredged and a lake that has been dredged previously.

Introduction

Fish are unique organisms that occupy the higher trophic levels of freshwater lakes. Their presence and abundance is important to the health of freshwater lakes in a variety of ways. They also play an important role in the food web of aquatic ecosystems, for example they help transfer nutrients from lower trophic levels to themselves and other organisms such as birds and humans. Piscivore fish also help keep nuisances in lakes such as algal blooms in check by feeding on the smaller fish who eat the macroinvertebrates and other algae's that keep the nuisance algae's in check. Freshwater fish are also important in the field of aquaponics because they provide a nutrient source for the plants being grown in these environments. The importance of these unique organisms makes them indispensable.

Fish fill an important economic role as well. Thousands if not millions of people spend money every year on fishing licenses, fishing gear, guides, charter boats, and other services centered around freshwater fishing. Some states like Florida benefit greatly from the freshwater fishing industry. In 2011 Florida had 1.2 million freshwater anglers that accounted for 25.7 million days fishing combined. These anglers spent roughly 1 billion dollars, generating an economic impact of $1.7 billion, which supported more than 14,040 jobs in the state of Florida alone (Commission, 2015).

However, fish populations have taken a dip in the past few decades due to a variety of factors including overfishing, anthropogenic disturbances and the introduction of non-native species (Strayer & Dudgeon, 2010). The American Fisheries Society Endangered Species Committee compiled a list in 2008 that listed imperiled, endangered, threatened, vulnerable and extinct freshwater and diadromous fishes of North America. Diadromous fish are fish that spend portions of their life cycles in both freshwater and saltwater (Anadromous Fish, 1994). Through their research they saw that the number of species on the list has increased 92% over the past 20 years since last compiling a list in 1989. The most notable increase with over a quarter of the increase amount belonging to the Cyprinidae, or minnow family (Jelks et al., 2008). As of December of 2015, the U.S. Fish and Wildlife Service has 162 records of endangered fish species throughout the United States (Service, 2015). The World Wildlife Fund and the Living Planet Index Research puts the main causes of this increase in threatened species to be exploitation, and degradation of habitat ("Living Planet index," 2015). The decline in these fish populations puts a higher need on conservationists to protect and ensure the health of existing populations and ecosystems.

Freshwater lakes that house these fish are also under threat. Only 0.007% of water on earth resides in freshwater lakes (USGS, 2015). The uniqueness of this ecosystem is continued with its inhabitants, freshwater ecosystems are home to at least 100,000 species out of approximately 1.8 million species (Dudgeon et al., 2006). Everything from aquatic insects, freshwater fish, mollusks, and macrophytes can be found in freshwater lakes. These organisms fill different niches throughout varying trophic levels in the aquatic system. Residing in the upper aquatic trophic levels are the fish. Fish fill varying roles, everything from filter feeding Asian carp, to piscivore fish like the Northern Pike.

While lakes are unique ecosystems that are rich in biodiversity, they are also used for many human recreational activities. People use lakes for activities like boating, skiing, swimming, fishing, and many other activities. Communities that reside on lakes also profit from them, a study performed by Lansford in Texas found that a property in Texas had a base premium of $59,826 for lakefront property regardless of house size or location (Lansford, 1995). Since communities get such benefit from having a healthy lake ecosystem in them, they tend to take measures to try to maintain the ecosystem in a condition that is considered good for the earlier stated recreational activities.

To do so, communities tend to stock fish, monitor fish populations, weeds, chemicals, and other bacteria levels in order to ensure that the lake can be used for recreational activities. Sometimes though, a treatment may do more harm than good for a system. For example, the chemical Rotenone is used as a sort of do over button for aquatic systems, the chemical kills almost all living things in the system. This is usually done in order to contain an invasive species. This large scale disturbance has been studied enough and we know that after a while the lake will be suitable for life again, but some large scale disturbances have not been studied as well.

Lake dredging is a large scale anthropogenic disturbance, commonly just referred to as dredging. Dredging is a process in which a company uses machines to remove sediment from the bottom of a body of water. While most times dredging is done in rivers, it is also done in lakes (EPA, 2015). Lake Dredging is a very expensive and time-consuming process.

Due to the decreasing populations of freshwater fish over the course of the past few decades (Jelks et.al, 2008) it is more important now to focus on effective conservation efforts. However, with little or no research being done on the long term effects of lake dredging on biodiversity levels in freshwater systems, especially in northern Illinois and south central

Wisconsin, we are unsure if this method of "restoration" is effectively leaving the community at a healthier level in the long term. By better understanding the long term impact of lake dredging on biodiversity levels in freshwater lakes we can promote better forms of biodiversity conservation, whether that be dredging or another option.

Literature Review:

Lakes:

Coming in many forms, lakes are a very unique environment that reside on our planet. They can be freshwater or saltwater, some even have a mixture of both salt and fresh water known as brackish water. While most of our planet is covered in salt water oceans, freshwater lakes and rivers are unique in such a way that we as humans need them for life as we know it to exist. This unique makeup is only made more irreplaceable when you look at the percentages of how much water on earth is present in freshwater lakes. According to the United States Geological Survey, or USGS, only 2.5% of the water on Earth is Freshwater (USGS, 2015). From this only 1.2% of that 2.5% is Surface water or other freshwater (USGS, 2015), meaning that only 0.03% of the water on earth is surface or other freshwater. From that, as quoted earlier, only 0.007% of the water on earth resides in freshwater lakes.

All types of lake ecosystems are unique systems that can support a wide array of biological life. Both systems can have a high biodiversity index, or a low biodiversity index depending on the conditions that the system is in. Biodiversity is defined by the Convention on Biological Diversity as "the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems" (Biodiversity, 2014).

Lake Dredging*:*

There are two different methods of dredging that are used in order to fully remove the sediment from the body of water. Hydraulic dredging is one process, in this process pipes are usually laid down by barges throughout the water system that are all connected and lead back to a sediment drying area (EPA, 2015). The pipes utilize a pump and effectively work like a giant vacuum to remove sediment. The sediment is then pumped to the sediment drying area, this area is usually offsite and acts as a retention pond where the wet sediment is stored and left to dry out. (EPA, 2015). Another form of dredging is mechanical dredging, this process varies a lot from the hydraulic dredging. Mechanical dredging involves lowering water levels in the body of water and physically going in with heavy machinery, like bulldozers and backhoes, to remove the sediment. Mechanical dredging can also be done by having a machine, like a backhoe, on a floating platform like a barge and removing the sediment like that. This is done if it is impossible to lower the lake water levels. The sediment removed in this process is also then transferred to a sediment drying area (EPA, 2015). After the sediment is dried in the retention pond, depending on the quality of the sediment and the organic content of the sediment, the material can be used as filler for landscaping purposes or as a fertilizer on farmland (EPA, 2015).

Disturbances:

Lake Dredging however is, in essence, an ecological disturbance. While the term disturbance has many definitions it is important to define what classifies as an ecological disturbance. An ecological disturbance is any relatively discrete event in time that disrupts ecosystems, community, or population structure and changes resources, substrate availability, or the physical environment (White, 1985). Dredging is a removal of sediments or detritus from the lake. Lake Dredging is not a natural disturbance though. Lake dredging is classified under more specific definition of disturbances known as anthropogenic disturbances.

Both natural and anthropogenic disturbances are still disturbances and they differ only in the causes of the disturbances. While a natural disturbance is exactly that, something that naturally happens such as a flood, heavy rain, or natural damming of a river, anthropogenic disturbances are things that are not natural. To be exact, the term anthropogenic means human caused, so an anthropogenic disturbance is a disturbance caused by humans. Examples of an anthropogenic disturbance in an aquatic ecosystem that is not lake dredging are situations in which a dam is built on a river. This interferes with the natural flow of the river and can also interfere with the natural flooding cycle of rivers downstream from the dam (International

Rivers, 2016). While both types of disturbance, natural or anthropogenic, can be bad, too little disturbance can be just as detrimental to an ecosystem as too much disturbance.

Succession:

In a freshwater ecosystem the most common type of succession is called a hydrosere (Succession, 2011). A hydrosere is a process of aquatic succession that can only occur when the aquatic ecosystem remains undisturbed throughout the entirety of the successional process (Succession, 2011). This process is outlined in figure 1 below which shows the general process of hydrosere (Succession, 2011).

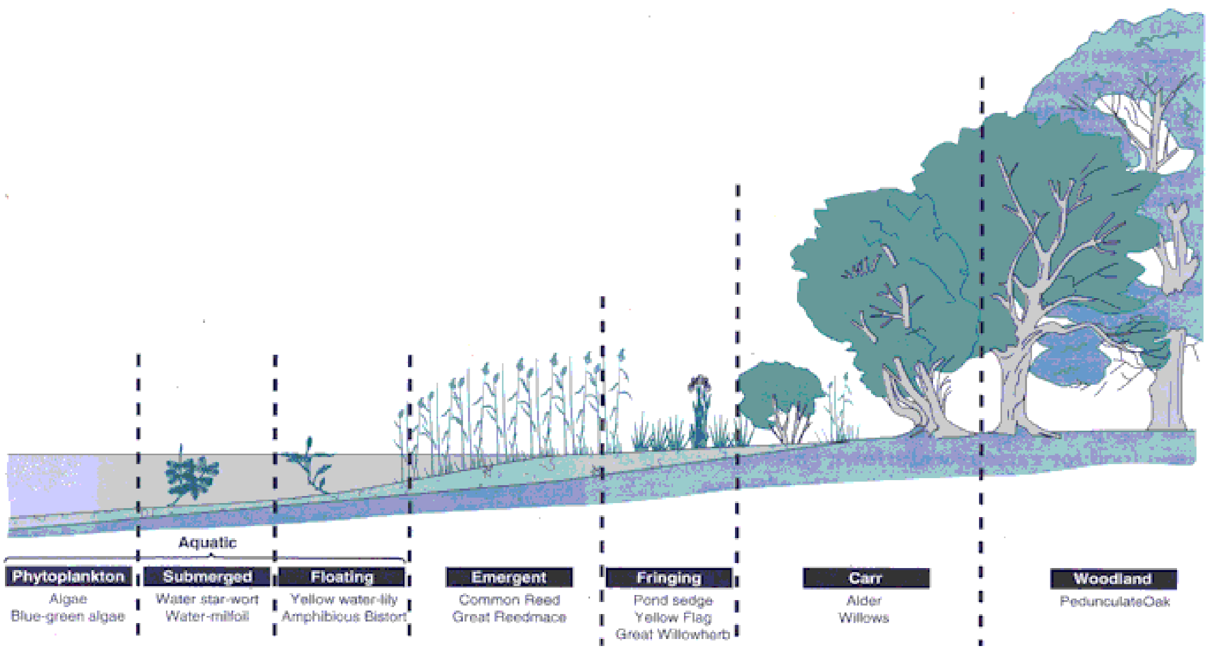

Figure 1.) *A diagram showing the vegetation stages that are commonly associated with freshwater succession in a shallow lake (*Nagle, 2000).

While succession occurs when there is no ecological disturbance to the aquatic ecosystem, we know that disturbances do happen in aquatic ecosystems. If the process of succession is disturbed by either an anthropogenic or natural disturbance then the environment will follow the process of secondary succession (Succession, 2011). Secondary succession is defined as “the ecological succession that occurs on a preexisting soil after the primary succession has been disrupted or destroyed due to a disturbance that reduced the population of the initial inhabitants” (Secondary Succession). The disturbance leaves room for rooted plants to take hold in the shallow areas of the body of water and that allows reeds to grow in thick and dead soil. (Succession, 2011). In figure 2, which can be found below, it shows a rough transition of the process of secondary succession over time.

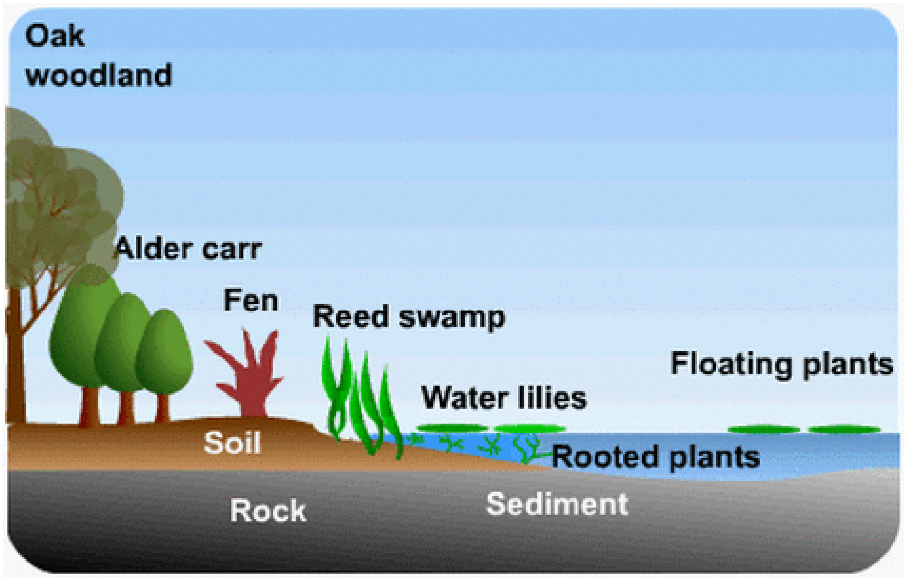

Figure 2.) *Illustration showing the different stages in which secondary succession occurs after a disturbance. Rooted plants change the micro-environment, allowing reeds, fen, and carr to grow in. Figure obtained from Successions, 2011.*

Purpose of Study.

The purpose of this study is to determine if lake dredging had a positive or negative long term impact on the biodiversity levels of freshwater lakes. While keeping in mind that all bodies of water are unique, a few different methods were used in order to determine the overall health of the lakes. It was predicted that the lake that has been dredged will have a higher Shannon diversity index rating than the lake that has not been dredged. This is thought to be because of the purpose of dredging being to improve the overall quality of the lakes. It was also predicted that the lake that was undergoing dredging at the time of the study would have the lowest Shannon Diversity index rating. This was thought due to the idea that if an area is currently being impacted by a disturbance it would be at a low point in diversity, because different forms of life are not being allowed to fully establish before being disturbed. Lastly to help determine the health of lakes it was predicted that the lake that has been dredged will support a larger, size wise, and more numerous population of a common fish species that is found in all three lakes.

The idea behind this hypothesis is that if an unhealthy lake can lead to stunting of fish species (Minnesota DNR, 2016) then a healthy lake should be able to support a larger size wise population of fish.

Methods

Study Sites:

Three different lakes were sampled, two lakes are located in Northern Illinois, one in McHenry County (GPS: 42.3842^o N, 88.3678^o W) and the other in Lake County (GPS: 42.3866876^o N, 88.1995302^o W), and one in south central Wisconsin in Sauk County (GPS: 43.5650^o N, 89.8200^o W).

The first lake, representing one a lake that has never been dredged, was Pistakee Lake in Lake County Illinois (Figure 3). This lake is located along what is known as the Chain of Lakes. The max depth listed is 31 feet and the lake has an average depth of 6 feet (Angler Web, 2014). The fish species listed as present in the lake are Largemouth Bass, Smallmouth Bass, Bluegill, Black Crappie, White Crappie, Freshwater Drum, Muskellunge, Northern Pike, and Walleye (Angler Web, 2014). Comments made on fishing sites also put catfish as a species present in the lake (Angler Web, 2014).

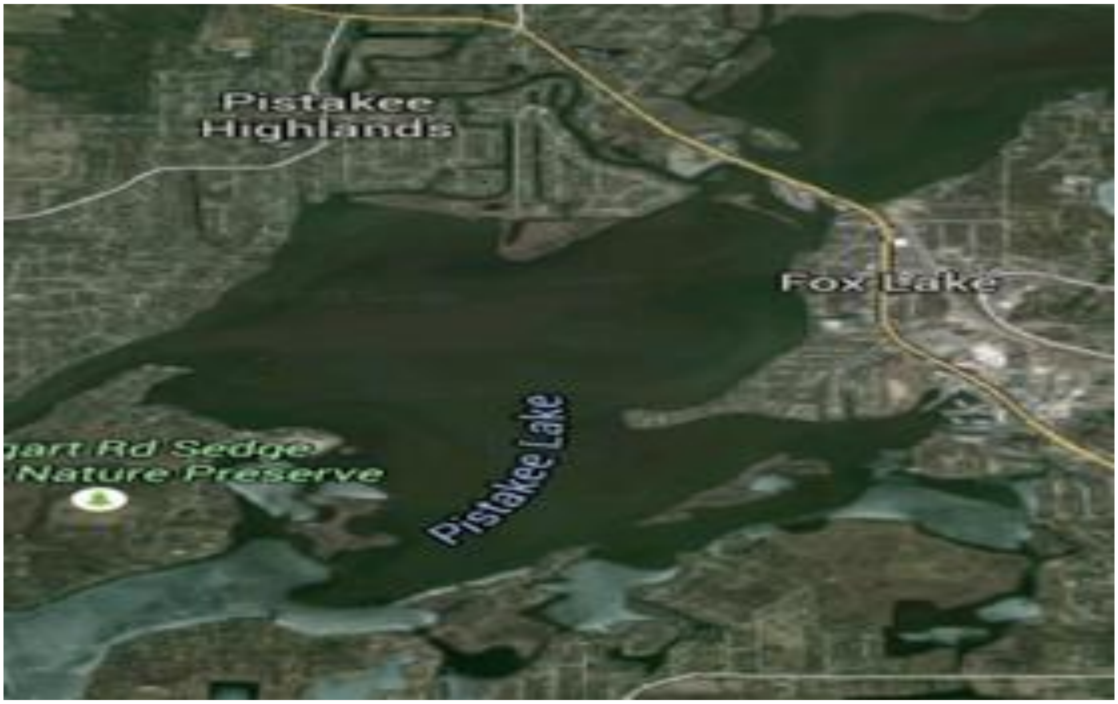

Figure 3. *A Google Map overview of Pistakee Lake located in Lake County Illinois. This Lake was the sample site representing a lake that has never undergone dredging.*

The second lake, representing a lake that is currently being dredged is Wonder Lake in McHenry County Illinois (Figure 4). This lake was chosen due to the opportunity to study a lake while it is being dredged. The average depth of Wonder Lake is listed at 6 ft with a max depth of 16ft. Wonder Lake was also used as a model lake in which the other lakes to be found for this study were sought to have similar characteristics as this lake, such as surface area, average depth, and max depth. Fish Species in this lake are assumed to be similar to Pistakee Lake but a current list of species is not currently known (WLMPOA, 2015).

Figure 4. *A Google Map Overview of Wonder Lake, located in McHenry County Illinois. This lake was the sample site representing a lake that is undergoing the dredging process.*

The third lake, representing a lake that has been dredged and has undergone recovery, is Mirror Lake in Sauk county Wisconsin, see Figure 5. The lake has an area of 139 acres, a mean depth of 8 feet, and a max depth of 19 feet. Fish species listed as present in the lake include Panfish which are species of sunfish and also crappie, Largemouth Bass, Northern Pike, Walleye and White Perch (Resources, 2015). Mirror Lake was dredged in 2008 after a council vote of 16-0 in favor of the process decided to dredge the lake (Kupfer, 2008).

Figure 5. *A Google Map overview of Mirror Lake, located in Sauk County Wisconsin. This lake was the sample site representing a lake that has undergone dredging and had time to recover.*

Data Collection:

Data was collected over the course of the summer of 2015 starting in late May until mid-August on the weekends. At Wonder Lake and Pistakee Lake, angling was done for set periods of time, of 3 hours, for an equal number of times. Times were classified as Morning, Midday or Evening. Morning was considered between the times of 8:00-11:00 AM. Midday was considered between 12:00-3:00PM. Afternoon was considered 4:00-7:00PM. All times were in the Central Time zone. Wonder lake and Pistakee Lake were always fished on the same day, never fishing at one without going to the other the same day. Times were rotated through for both lakes for times fished. For example, for week 1 Wonder Lake was fished in the morning, and Pistakee in the Midday. The second week Wonder Lake was fished Midday, and Pistakee the Afternoon. The third week Wonder Lake was fished in the afternoon, and Pistakee was fished in the morning and so on in this style of rotation.

Wonder Lake/Pistakee Lake:

Data was collected using traditional angling methods. A variety of open spool reels were used, varying from "Ultra-lite" style to Heavy Rods. Line strength also varied depending on pole, the smallest line used had a 5 lbs test on it with the strongest having a 20 lbs test. A variety of lures were used as well in an attempt to catch fish of varying niches. Types of lures used included top water buzz baits, rooster tails/spinners, spoons, divers of varying depth ranges, plugs, and soft plastic baits. Only artificial baits were used and no live bait was used while collecting data. This was done to eliminate differences in chemicals or foods used in the baits to attract certain species of fish. After fish were caught their common name was recorded, example Largemouth Bass, Smallmouth Bass, Bluegill/Sunfish, Carp etc., in a notebook that was used for every sampling time. The length of each fish was taken as well and recorded to the nearest half inch. This was done due to time constraints and difficulties associated with working in a time effective way in order to ensure the survival of the fish. After the data was recorded all fish were released back into the water in which they were caught close to the spot in which they were hooked. Fishing was done from both the shore and from boats in Wonder Lake. Trying to keep an equal number of times for each method, trying best to alternate times. For example one week if it was shore fishing the next was from a boat, then the next from shore. If weather was not permitting then boat fishing was not done. During cases of rain or storms poles were set out using pole holders and had bells placed on them in order to tell when something was hooked. If storms were really severe sampling was not done or cut short.

Mirror Lake:

Data from Mirror Lake was collected by Will Harrison over the summer months of 2015. Fish were collected using traditional angling methods. Supplies used included a Shakespeare Ultra Lite rod, night crawlers with a 1/16oz jig and a Shakespeare fiber glass light medium rod with a hook and a plastic night crawler that was pumpkinseed in color. Fish were identified by sight and prior knowledge of the species present in the lake. When fish were caught they were recorded for their size in inches to the nearest half inch, their species, the date in which they were caught and the time frame in which they were caught including AM or PM.

Statistical Analysis:

Data was collected and entered first into a Microsoft excel document for analysis and to make preliminary graphs.

Microsoft Excel was used as a tool to calculate average size in inches of sunfish for each lake. It was also used to calculate the Shannon Diversity index (SDI) for each lake using two different methods. Method 1 for calculating Shannon diversity index was the standard practice way. Using the equation ((Pi*(LN[Pi]))) for each species where "Pi" is the proportion of individuals from the total sample population. For example if 25 largemouth bass were caught and in total 100 fish were caught the equation would be ((25/100)*(LN[25/100])). Then the numbers generated for each species in a lake are added together to create a sum number, that number is then multiplied by negative one (-1) to get a positive index number, this number is the Shannon Diversity Index for the lake.

Method 2 for calculating SDI was similar to Method 1 but varied slightly. Method 2 calculated the SDI of each lake using the same equation as above, but instead of using the entire sample population in the calculations the SDI was calculated for each day that was spent sampling at each lake. These indices were then averaged to come up with an average SDI for each lake. Doing this method also allowed for statistics to be run on the data set. Standard error was also found for these averages.

For comparison of the data, t-tests were run using Microsoft excel in order to compare the lakes to one another. The comparisons are as follows, Pistakee Lake vs. Wonder Lake, Pistakee Lake vs. Mirror Lake, and Wonder Lake vs. Mirror Lake. T-tests were also run in order to compare the average size in inches of sunfish of all three lakes. The comparisons of the T-tests were the same as the comparisons of the lakes. All t-tests were run assuming two-tailed, unequal variance. Standard error was also calculated using Microsoft excel for all averages.

Results

A total of 491 combined fish were sampled from the three lakes. 134 fish were caught in Pistakee Lake which has been dredged, 108 fish were caught in Wonder Lake which was undergoing dredging at the time of sampling, and 249 fish were caught in Mirror Lake which has undergone dredging previously and has undergone a recovery period (Table 1). The most common fish caught was the sunfish, which included species such as Green Sunfish, Blue Sunfish, and Pumpkinseed, these were combined due to the difficulty in proper identification due to the hybridization of the species. Overall the sunfish was the most caught fish in all three lakes. The most species were caught in Wonder Lake, followed by Mirror Lake and lastly Pistakee Lake. Figure 6 shows the species richness for each sample site. Shannon Diversity Index was calculated two ways and was found to be the highest in Wonder Lake in method 1 (Figure 7) and Mirror Lake in method 2 (Figure 8).

Table 1. *A summary table showing the total number of each type of fish caught in each lake, including the total number of fish caught in each lake.*

Type of Fish	Pistakee Lake	Wonder Lake	Mirror Lake
Largemouth Bass	29	27	41
Smallmouth Bass	0	5	8
Sunfish	77	37	147
Crappie	14	0	28
Northern	0	6	4
Perch	0	0	21
Walleye	8	5	0
Bullhead	0	5	0
Carp	0	11	0
Catfish	6	12	0
Total	134	108	249

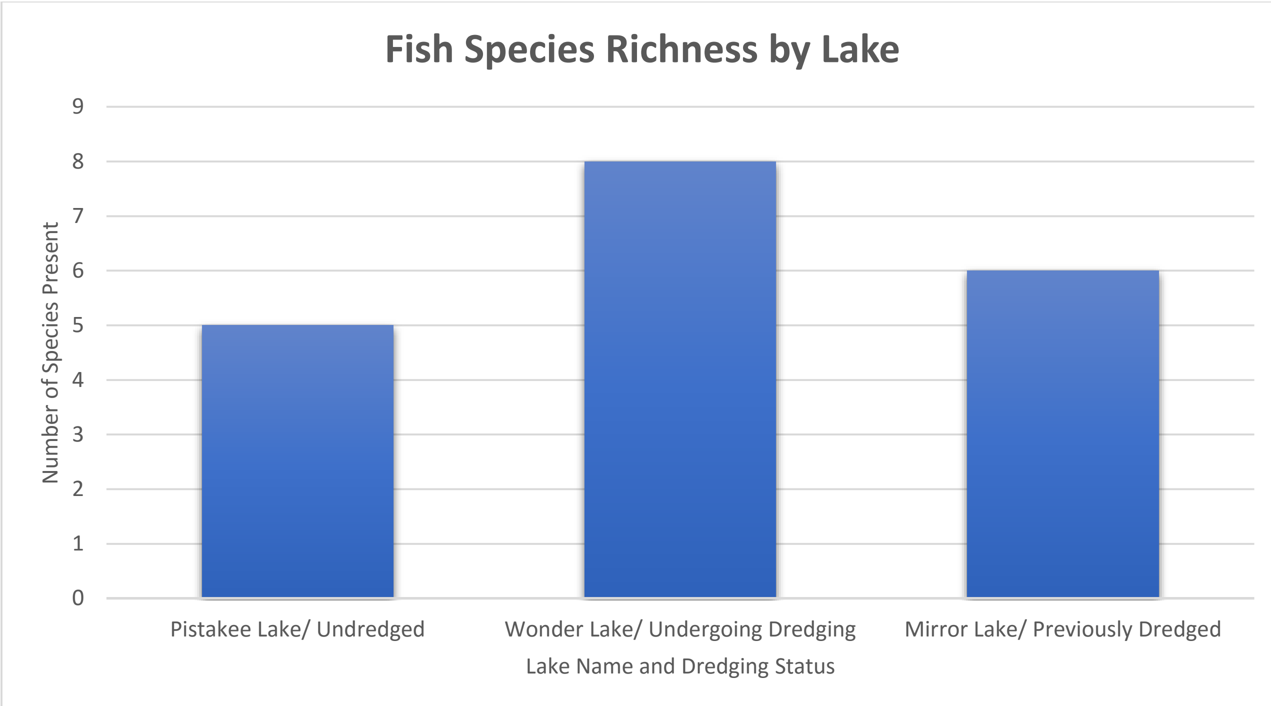

Figure 6. *Calculated species richness in each lake. Species richness was calculated as the number of species that were caught in each lake.*

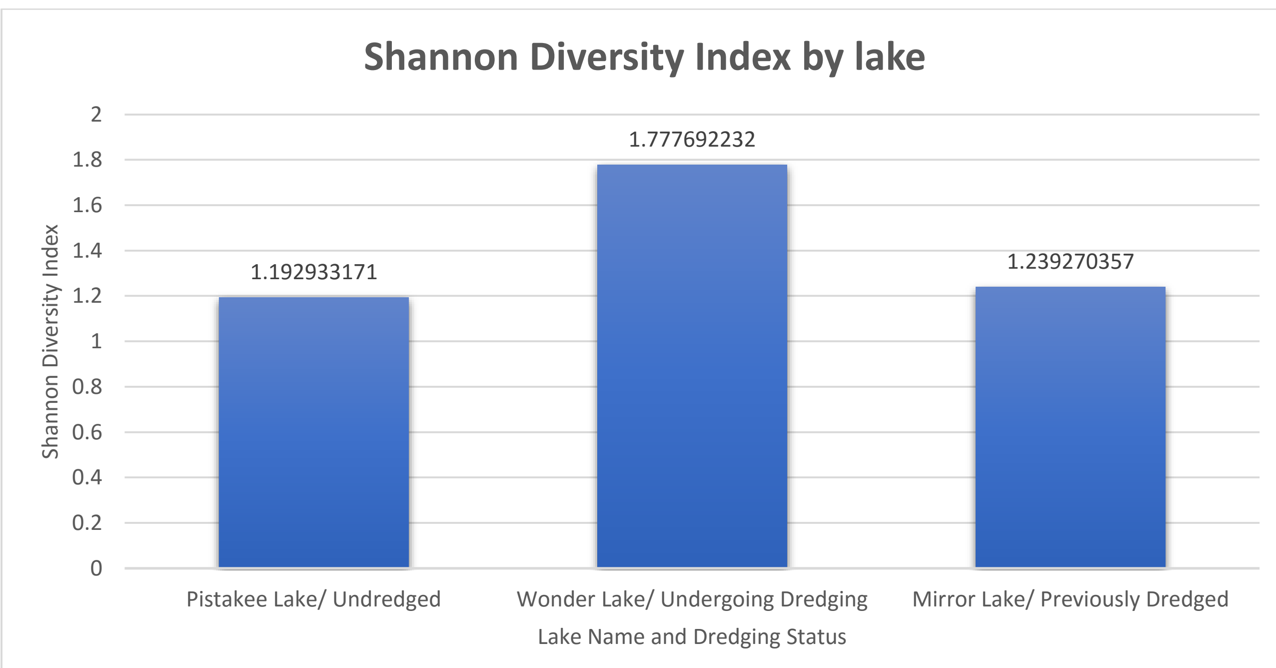

Figure 7. *Shannon Diversity Index of each lake. Calculated from the entire sample population (Method 1.*

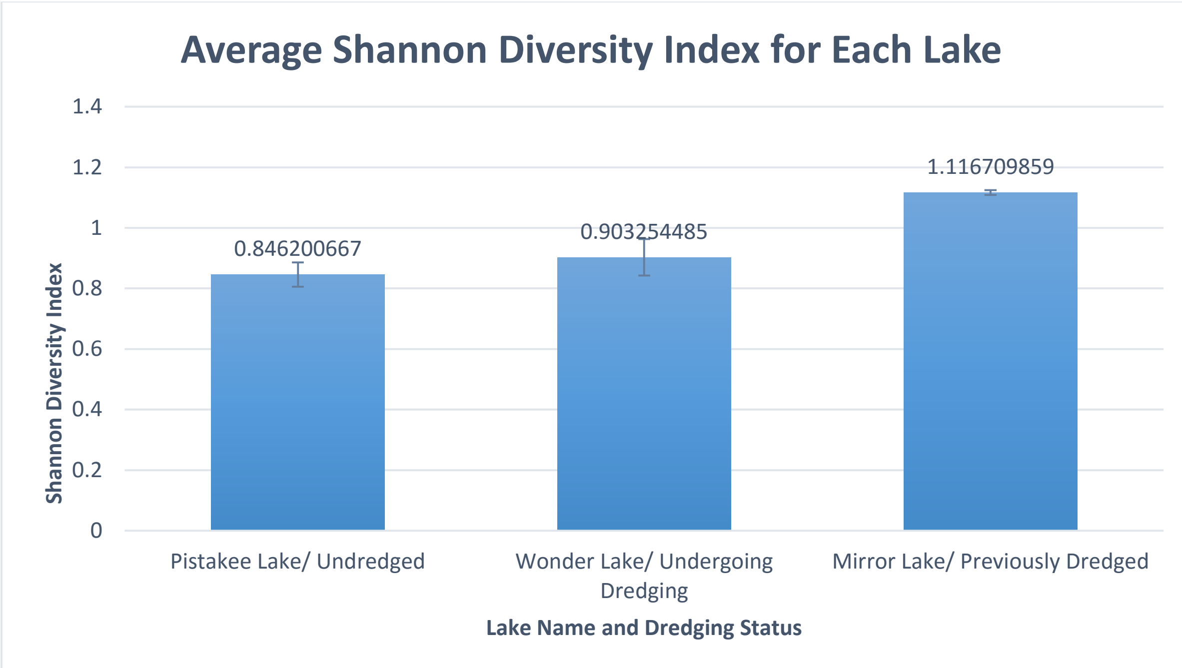

Figure 8. *Daily average Shannon Diversity index by lake (Method 2). Error bars = +/- standard error.*

Table 2. *Statistical analysis results of T-Test between lakes average Shannon Diversity Index.*

Lake Comparison	P Value
Pistakee/Wonder	0.3828
Pistakee/Mirror	0.0387
Wonder/Mirror	0.1959

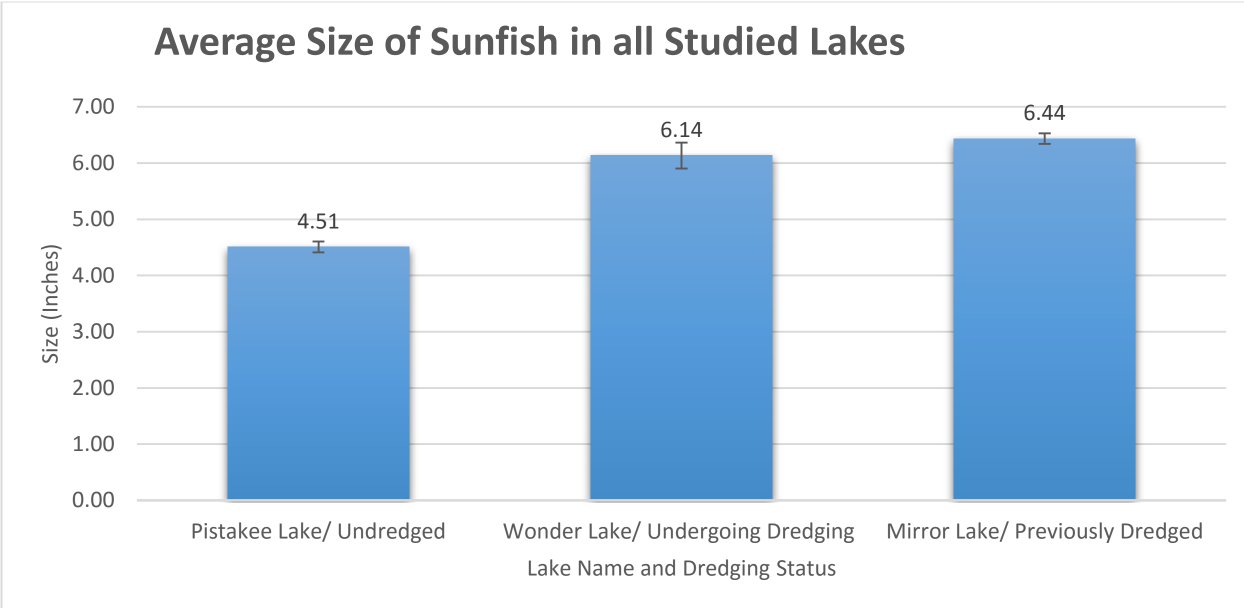

Figure 9. *The average size of sunfish for each lake (error bars = +/- standard error) (Pistakee Lake N=77, Wonder Lake N=37, and Mirror Lake N=147)*

Table 3. *Table showing the T-test results for lake comparisons of Sunfish size.*

Lakes	P Value
Pistakee/Wonder	<0.001
Pistakee/Mirror	<0.001
Wonder/Mirror	0.23317824

Discussion

The data shows that species richness was highest in Wonder Lake, followed by Mirror Lake, and Pistakee Lake had the lowest species richness rating with species richness ratings of 8, 6, and 5 respectively (Figure 6). While species richness was not the biodiversity rating originally intended to be used in this study, it is good to take into consideration when looking at the number of reported species in each lake. Pistakee Lake had 9 reported species, Wonder Lake had 8 assumed species present, and Mirror Lake had 6 reported species. While looking at these numbers in comparison to the species richness ratings we can see that the species caught in

Mirror Lake represent all species that are assumed to be present in the lake. Whereas Pistakee Lake and Mirror Lake do not have all assumed species represented.

This could be due to a variety of reasons, for example the Muskellunge, *Esox masquinongy*, is a large sport fish that is usually stocked but are hard to maintain in larger populations outside of their native habitats when there is a lack of prey species such as Walleye, *Sander vitreus*. (Eslinger, Dolan, & Newman, 2010) Another reason could simply be that while these lists are usually accurate the fish missing from the sample populations in both lakes could all just have very small populations in the lake and therefore the chances of catching them, even with so many hours spent fishing, were just too slim in order to catch them on rod and reel. Another point to consider is that while a variety of times were used for sampling times, night times, 8:00pm to 7:00am, were left untouched in this study. This leaves room open for fish that are more active at times that were not sampled, including night, and avoid being caught during this study. This adds another level of error to be taken into consideration when looking at the diversity levels and species richness of the lakes in this study.

Similarly, when looking at the Shannon Diversity index for each lake, that was calculated using method 1 (Figure 7) we see that Wonder Lake had the highest SDI with an index rating of 1.78. Mirror Lake was second highest again with a SDI rating of 1.239, and lastly Pistakee Lake had the lowest SDI rating with an index rating of 1.19. When looking solely at the non-dredged and dredged lakes, Pistakee and Mirror respectively, we can see that Mirror Lake has a higher diversity rating than Pistakee Lake. While looking solely at this rating it would seem that, with all other factors being as close as possible for this study, the long-term effect of lake dredging leads to an increase in Shannon Diversity Index rating.

However when looking at the t-test results of and the Shannon Diversity Index values calculated using method 2 (Table 2 and Figure 7) we see that Mirror Lake has the highest average SDI measure with a SDI of 1.1167. Wonder lake in turn using this method had the second highest SDI with 0.9033 and Pistakee Lake one again had the lowest with and SDI of 0.8462. After running T-tests to compare these averages we can see that Mirror Lakes SDI rating is significantly greater than Pistakee Lake ($P=0.0387$) (Table 2). While the Shannon Diversity rating for Mirror Lake is significantly greater than in Pistakee Lake, we also see that the difference between Pistakee Lake and Wonder Lake is not significant ($P=0.38$), and the difference between Wonder Lake and Mirror Lake is not significant (P=0.1959) (Table 2). When taking into consideration the parameters of this study we can suggest that Lake dredging has a positive effect on the Biodiversity levels overtime in lakes in which it is done.

Interestingly, using both methods of calculating the Shannon Diversity Index, Mirror Lake has a higher diversity rating than Pistakee Lake, in the case of method 2 it is significantly greater in fact (P=0.0387). This finding supports our primary hypothesis that a lake that has been dredged will have a significantly greater Biodiversity rating when compared to a lake that has not been dredged.

However our second hypothesis, that the lake that is undergoing dredging at the time of sampling will have the lowest Shannon Diversity Index rating when compared to the other two lakes, was not supported. We see that Wonder Lake in fact, when using method 1, had the highest Shannon Diversity Rating (SDI=1.78) of all of the lakes. Wonder Lake also has the highest species richness rating of all of the lakes as well (Figure 6). While these findings do not support our hypothesis they do leave room for future studies into the topic of disturbances that occur over an extended period of time and Biodiversity levels during the time of the disturbance.

When looking at our third hypothesis, that a common fish found in all 3 lakes, will be significantly larger on average in the previously dredged lake, Mirror Lake, when compared to the lake that has never been dredged, Pistakee Lake, we see that our data supports this hypothesis (Figure 9 and Table 3). The common fish used was sunfish, as it was the most abundant species in all three lakes. When comparing the lake that has never been dredged, Pistakee Lake, to the lake that has been previously dredged, Mirror Lake, we can see that the average size of sunfish was 6.44 inches in Mirror Lake, and 4.51 inches in Pistakee Lake (Figure 9). This difference between Mirror Lake and Pistakee Lake in average size was significant ($P<0.01$). The P-value was actually extremely low, with the T-test reporting it as $5.4x10^{-32}$ (Table 3). The difference between Wonder Lake (undergoing dredging) and Pistakee lake (never dredged) was significant as well ($P<0.01$). However the difference between Wonder Lake (undergoing dredging) and Mirror Lake (previously dredged) was found to not be significant (P=0.23). This means that while the difference between the previously dredged lake, Mirror Lake, and the lake that has never been dredged, Pistakee Lake, as well as between the lake undergoing dredging, Wonder Lake, and the lake that has never been dredged, Pistakee Lake, are significant, there is still room for more research to look into the relationship between lakes being dredged and lakes that have already been dredged. However our primary concern was the relationship between the non-dredged lake and the dredged lake and the difference between those have been found to be significant.

<u>Future Directions:</u>

While the findings of this support support the hypothesis that biodiversity levels and average fish size of sunfish, which acted as a common species with a high population in each lake, increase when looking at a dredged lake vs a non-dredged lake, it is important to remember that this was a small scale time frame study and that more studies need to be done to come up with a better understanding of the biological and ecological effects of lake dredging.

Future versions of this study could expand in multiple areas which could include an increase in the amount of samples taken. While the sampling in this study was adequate for this experiments purposes, to get more information and better detail about the exact effect of lake dredging on biodiversity levels, a larger sample population would be required. If possible, sampling an entire lakes' population would be the best case scenario for studying the effects but in a field study that possibility is highly unlikely.

Another improvement that could be made would be to follow a single lake throughout the history of the dredging procedure, starting from before a dredging process beings, to during the dredging process, until an extended period of time after the dredging has stopped, in order to better understand the effects of lake dredging on an individual ecosystem.

Lastly, while the lakes in this study were the best possible options that were available to the researcher if it is possible to find more identical lakes that would only improve the study. Things to keep in mind while looking for the lakes are geological history, average depth, max depth, surface area, shoreline development, and species known to be present. While finding a single lake to follow throughout the course of Lake dredging for this experiment would be ideal, if these areas are met by multiple lakes as well as one being dredged and one having been dredged and undergone a recovery period and one having never been dredged. Then finding lakes that are most identical in those areas would better improve the results of this study.

Another improvement would be to use a variety of collection methods that include more than just angling. Examples of different sampling methods commonly used would be a fyke or trap net, cast nets, gill nets, electrofishing, or even using underwater observation (Portt et.al, 2006)

Implications of Study:

The data supports the hypothesis that biodiversity levels and average fish size increase significantly when comparing a lake that has not been dredged to a lake that has been dredged and undergone a recovery period. Combining this knowledge with the other benefits that come about from the process of lake dredging, such as increased home and property value (Lansford, 1995), increased water quality (EPA, 2015), and income from selling the sediment that is removed from the lake for profit. Lake dredging appears to be a worthwhile process. This data and any future studies that show similar results can be used to support decisions to dredge lakes, and can show communities that not only is it beneficial from an economic standpoint as well as an ecological and biological standpoint.

Conclusion

While lake dredging may seem to be a highly disruptive process for a lake to undergo, according to this study's findings, the benefits of it seem to outweigh the cost and immediate damage of it. Our data support the idea that Biodiversity levels, as calculated by both a flat Shannon Diversity Index rating, and an averaged Shannon Diversity Index rating, as well as average fish size of a common populous species between lakes, increase significantly from a lake that has not been dredged to a lake that has undergone dredging and has had time to recover from the process. While our findings leave room for future studies into this relationship and the relationship between lakes that are currently undergoing dredging and lakes that have been dredged, our findings support the hypothesis that there is a significant connection between higher biodiversity levels in lakes that have been dredged, compared to those that have not been dredged.

References

"ANADROMOUS FISH." *ANADROMOUS FISH*. National Conservation Training Center, 17 June 1994. Web. 10 Mar. 2016.

"Biodiversity." *Encyclopedia of Earth*. Ed. John Lloyd. N.p., 15 Sept. 2014. Web. 23 Oct. 2015.

Commission, F. F. a. W. C. (2015, 2015). Value of Freshwater Fishing in Florida. *Economic Value of Freshwater Fishing.* Retrieved from http://myfwc.com/conservation/value/freshwater-fishing/

Dodson, Stanley I. *Introduction to Limnology*. New York: McGraw-Hill, 2005. Print.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z.-I., Knowler, D. J., Leveque, C., . . . Sullivan, C. A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews of the Cambridge Philosophical Society, 81*(2), 163-182. doi:10.1017/s1464793105006950

"Environmental Impacts of Dams." *International Rivers*. International Rivers, n.d. Web. 11 Mar. 2016.

Eslinger, L. D., Dolan, D. M., & Newman, S. P. (2010). Factors Affecting Recruitment of Age-0 Muskellunge in Escanaba Lake, Wisconsin, 1987-2006. *North American Journal of Fisheries Management, 30*(4), 908-920. doi:10.1577/m09-114.1

Jelks, H. L., Walsh, S. J., Burkhead, N. M., Contreras-Balderas, S., Diaz-Pardo, E., Hendrickson, D. A., . . . Warren, M. L. (2008). Conservation Status of Imperiled North American Freshwater and Diadromous Fishes. *Fisheries, 33*(8), 372-407. doi:10.1577/1548-8446-33.8.372

Kupfer, Trevor. "Dredging Starts on Mirror Lake." *Wiscnews.com*. N.p., 25 June 2008. Web. 01 May 2016.

Lansford, H. N., Jones, L. L. (July 1st, 1995). Marginal Price of Lake Recreation and Aesthetics. Journal of Agricultural and Applied Economics, Vol. 27, No. 01.http://ageconsearch.umn.edu/handle/15347.

"Lake Dredging." *Lake Dredging* (1998): n. pag. *Illinois EPA*. Environmental Protection Agency. Web. 19 Apr. 2015.

Living Planet index. (2015). *Living Planet Index.* Retrieved from http://wwf.panda.org/about_our_earth/all_publications/living_planet_report/living_planet_index2/

Nagle, G. (2000). Advanced Geography. Oxford: Oxford University Press.

"Pistakee Lake." Angler Web. Angler Web, n.d. Web. 10 May 2015. <http://www.anglerweb.com/fishing_spots/pistakee-lake>.

Resources, W. D. o. N. (2015). Mirror Lake. Retrieved from http://dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=1296000&page=facts

Service, U. S. F. a. W. (2015). List of Endangered Fish Species in the United States.

Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society, 29*(1), 344-358. doi:10.1899/08-171.1

Commission, F. F. a. W. C. (2015, 2015). Value of Freshwater Fishing in Florida. *Economic Value of Freshwater Fishing.* Retrieved from http://myfwc.com/conservation/value/freshwater-fishing/

Dodson, Stanley I. *Introduction to Limnology*. New York: McGraw-Hill, 2005. Print.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z.-I., Knowler, D. J., Leveque, C., . . . Sullivan, C. A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges.

Biological reviews of the Cambridge Philosophical Society, 81(2), 163-182. doi:10.1017/s1464793105006950

"Environmental Impacts of Dams." *International Rivers*. International Rivers, n.d. Web. 11 Mar. 2016.

Jelks, H. L., Walsh, S. J., Burkhead, N. M., Contreras-Balderas, S., Diaz-Pardo, E., Hendrickson, D. A., . . . Warren, M. L. (2008). Conservation Status of Imperiled North American Freshwater and Diadromous Fishes. *Fisheries, 33*(8), 372-407. doi:10.1577/1548-8446-33.8.372

Kupfer, Trevor. "Dredging Starts on Mirror Lake." *Wiscnews.com*. N.p., 25 June 2008. Web. 01 May 2016.

Lansford, H. N., Jones, L. L. (July 1st, 1995). Marginal Price of Lake Recreation and Aesthetics. Journal of Agricultural and Applied Economics, Vol. 27, No. 01.http://ageconsearch.umn.edu/handle/15347.

"Lake Dredging." *Lake Dredging* (1998): n. pag. *Illinois EPA*. Environmental Protection Agency. Web. 19 Apr. 2015.

Living Planet index. (2015). *Living Planet Index.* Retrieved from http://wwf.panda.org/about_our_earth/all_publications/living_planet_report/living_planet_index2/

Nagle, G. (2000). Advanced Geography. Oxford: Oxford University Press.

"Pistakee Lake." Angler Web. Angler Web, n.d. Web. 10 May 2015. <http://www.anglerweb.com/fishing_spots/pistakee-lake>.

Portt, C.B., G.A. Coker, D.L. Ming, and R.G. Randall. 2006. A review of fish sampling methods commonly used in Canadian freshwater habitats. Can. Tech. Rep. Fish. Aquat. Sci. 2604 p.

Resources, W. D. o. N. (2015). Mirror Lake. Retrieved from http://dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=1296000&page=facts

Service, U. S. F. a. W. (2015). List of Endangered Fish Species in the United States.

"SHANNON DIVERSITY INDEX." *Shannon Diversity Index*. National Institute of Standards and Technology, n.d. Web. 7 Mar. 2015.

Strayer, D. L., & Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society, 29*(1), 344-358. doi:10.1899/08-171.1

"Succession.", 2011, *Freshwater Biomes*. N.p., n.d. Web. 20 Apr. 2015.

"Sunfish Management." *Minnesota Department of Natural Resources*. Minnesota DNR, 2016. Web. 01 Apr. 2016.

"Wonder Lake Master Property Owners Association, M.P.O.A. WLMPOA.ORG." *Welcome... | Official Website of the Wonder Lake Master Property Owners Association, M.P.O.A. WLMPOA.ORG*. Wonder Lake Master Property Owners Association, n.d. Web. 7 Mar. 2015.

White, P.S., and S.T.A. Pickett, 1985, Natural disturbance and patch dynamics; an introduction. Pages 472 in S.T.A. Pickett and P.S. White, eds. The ecology of natural disturbance and patch dynamics. Academic Press, Orlando, FL. Web. 15 Apr. 2016.

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Genetic evaluation of remnant and translocated shiners, *Notropis heterodon* and *Notropis heterolepis*

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Population and conservation genetics of two freshwater fish species, *Notropis heterodon* and *Notropis heterolepis*, were evaluated in north-eastern Illinois, U.S.A., where both species have severely declined. Fishes were sampled from two remnant populations occurring in small glacial lakes (source samples) and from two man-made ponds that had been stocked with fishes from those same lakes (sanctuary samples). The goal was to obtain information that would help inform conservation programme planning to reintroduce sanctuary fishes to areas where both species are extirpated. Microsatellite data showed that the two species were genetically quite distinct and there was no evidence of hybridization in either source or sanctuary samples. Within each species, source and sanctuary samples had moderate levels of heterozygosity and were not significantly different from each other. Many alleles observed in the source samples, however, were not detected in the sanctuary samples, indicating that translocation had resulted in reduced allelic diversity of the sanctuary samples. Sibship analysis indicated that full and half sibs occurred within source-lake samples, thus reducing the effective population size of the reintroduced stock. Taken together, these results suggest that source-lake stocks rather than sanctuary stocks are more appropriate for future reintroductions of both species in their native range, unless sanctuary populations can be established with hundreds of fishes. Also, fishes should be harvested from multiple locations in source lakes to avoid over-representation of family groups.

Key words: fish sanctuaries; genetic variability; microsatellites; reintroduction; sibship.

INTRODUCTION

Many freshwater fish habitats have been severely degraded through human activities. Deforestation and catchment erosion have changed the headwater regions of streams and siltation has destroyed the breeding habitats of many species that require well-oxygenated waters. Agricultural practices, pesticides, fertilizers, sewage and chemical pollutants add additional stresses to freshwater fish populations. Impoundments, canalization and diversion of streams and construction of dams create barriers to natural dispersal pathways of fishes and restrict gene flow. Introduced exotic

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species also pose a serious threat to many native fish species (Vrijenhoek *et al*., 1985; Vrijenhoek, 1998).

Decline of native fishes has been particularly dramatic in most of the mid-western U.S.A. In Illinois, for example, 25% (*c*. 50 species) of the native fish fauna have either been completely extirpated or have been placed on endangered, threatened or watch lists (Burr, 1991). In 1998, a sanctuary for endangered and threatened fishes was established at Prairie Crossing, a housing development site in Grayslake, Illinois. The sanctuary was established under the guidance of the Illinois Department of Natural Resources by Integrated Lakes Management Inc., a local environmental consulting company, and the Liberty Prairie Foundation, a private operating foundation. Four naturally co-occurring state endangered and threatened species, the blackchin shiner *Notropis heterodon* (Cope 1865), the blacknose shiner *Notropis heterolepis* Eigenmann & Eigenmann 1893, the banded killifish *Fundulus diaphanus* (LeSueur 1817) and the Iowa darter *Etheostoma exile* (Girard 1859) were transplanted to a detention pond at Prairie Crossing.

Here, a study on the conservation genetics of the two *Notropis* species from their source and sanctuary populations is described. The genus *Notropis*, belongs to the minnow (Cyprinidae) family and is one of the largest genera in the world (Dowling & Brown, 1989) with more than 100 described *Notropis* species in the U.S.A. *Notropis* spp. are commonly called shiners; they are short-lived, small species that may exhibit more rapid and detectable population changes in response to changes in habitat and water quality than longer-lived, larger species. *Notropis* spp. may be especially sensitive to reductions in dissolved oxygen levels, increased turbidity and changes in pH (Matuzsek *et al*., 1990). Members of the black-lined shiner group, which includes the pugnose shiner *Notropis anogenus* Forbes 1885, bridle shiner *Notropis bifrenatus* (Cope 1867), *N. heterolepis* and *N. heterodon* are sensitive to habitat changes and their presence or absence is useful for environmental monitoring (Matuzsek *et al*., 1990; Carlson, 1997).

Both shiner species transplanted to Prairie Crossing, *N. heterolepis* and *N. heterodon*, were formerly widespread and common in the Laurentian Great Lakes and upper Mississippi River basins, but have suffered severe declines, especially in the southern parts of their ranges. In Illinois, they have been extirpated from much of their former range and are currently restricted to a few glacial lakes in the north-eastern part of the state (Nÿboer *et al*., 2006). Both species are small (35–50 mm total length), short-lived (2–3 years) and inhabit clean, sandy or gravel bottom and organic debris substrata as well as dense beds of aquatic vegetation.

To establish the native fish sanctuaries at Prairie Crossing, transplanted individuals were captured from Deep Lake (42° 25′ 20″ N; 88° 04′ 00″ W) and Cedar Lake (42° 25′ 20″ N; 88° 05′ 30″ W) in Lake County, Illinois, two glacial lakes that are part of the Fox River catchment. The lakes at Prairie Crossing, Lake Leopold (42° 19′ 40″ N; 88° 00′ 40″ W) and Upper Pond (42° 20′ 00″ N; 88° 00′ 43″ W), are small, man-made lakes that lay in the catchment of the Des Plaines River, and are *c*. 10 km south-east of the source lakes. Upper Pond drains into Lake Leopold. All four species successfully reproduced following translocation and several hundred individuals of each species occur in Upper Pond. In 2000, fishes were transferred from Upper Pond to Lake Leopold to establish a second population. Unlike Upper Pond, predator fishes such as bluegill *Lepomis macrochirus* Rafinesque 1819, largemouth bass *Micropterus* *salmoides* (Lacépède 1802) and green sunfish *Lepomis cyanellus* Rafinesque 1819 are present in Lake Leopold. The ultimate goal of establishing these sanctuary populations was to supply stocks for reintroduction into areas where they have been extirpated.

The establishment of native fish sanctuaries in artificial, man-made lakes is a novel conservation approach, and, if successful, could be a management option for many small, threatened freshwater fish species. Success would require that a genetically diverse and representative population become established in the sanctuary lakes. Even if a relatively large number of individuals are translocated, however, only a sub-sample of these individuals will survive and reproduce. Furthermore, source lakes may be sampled at one or a very few locations on a single day. If related individuals are found in close proximity, as has been shown for some salmonids (Hansen *et al*., 1997; Carlsson *et al*., 1999; Fraser *et al*., 2005), there may be a risk of sampling individuals representing only a few families, further reducing the genetic diversity of the founding stock.

The research objectives of this study were to: (1) compare levels of microsatellite genetic variability of the source and sanctuary samples of both species; (2) assess levels of genetic divergence between the two species and detect hybridization, if it occurred, in either source or sanctuary samples; (3) assess genetic differentiation among the native and translocated samples; (4) quantify levels of genetic losses, if any, in association with sampling and translocation; (5) test whether close kin (siblings) occurred within samples; (6) estimate effective population size (N_e) for sampled populations from the microsatellite data. Overall, these objectives were aimed at determining whether sanctuary-lake populations, established by translocating fishes from native habitat to man-made environments, can result in genetically viable stocks for future reintroductions.

MATERIALS AND METHODS

SAMPLING

Specimens of *N. heterodon* and *N. heterolepis* were collected from native populations in Cedar Lake and Deep Lake (source samples) and from man-made lakes, Lake Leopold and Upper Pond (sanctuary samples), which harbour translocated populations (Fig. 1). Cedar Lake has a surface area of 122 ha and Deep Lake 91 ha. Lake Leopold and Upper Pond are much smaller, with Lake Leopold having a surface area of 13 ha and Upper Pond 1·1 ha. Upper Pond drains into Lake Leopold but an intermittent channel and a vertical overflow prevents upstream movement of fishes from the larger lake. In 1998, Upper Pond was stocked with *c*. 200 *N. heterodon* individuals and 116 *N. heterolepis* individuals. In 2000, up to 200 individuals of both species from Upper Pond were introduced into Lake Leopold. Sampling for genetic analysis was conducted between 2001 and 2005, after the breeding season which runs from April to June. Given a generation time between 1 and 3 years reported for other shiners (Harrell & Cloutman, 1978; Matthews & Heins, 1984; Cloutman & Harrell, 1987), these samples were taken between two and seven generations post-translocation, and were comprised only of individuals recruited after translocation. Adult fishes were collected using a 1·8 m × 9·1 m bag seine (3·6 mm mesh). Sample sizes are shown in Table I, and were limited by collection permits and low success in catching fishes. Dense vegetation, steep slopes and soft sediments reduced seine efficiency, and fishes may have had localized distributions within the lakes. All specimens were preserved in 95% ethanol upon collection.

FIG. 1. Map of Prairie Crossing showing sanctuary lakes, Upper Pond and Lake Leopold. Small map of Illinois shows approximate location of Prairie Crossing (★) and the two source lakes, Cedar Lake and Deep Lake (■).

GENETIC ANALYSIS

Total genomic DNA was extracted from muscle tissue using DNEasy Kit (Qiagen Inc.; www.qiagen.com). Nine microsatellite primers developed for Cape Fear shiner *Notropis mekistocholas* Snelson 1971 (Burridge & Gold, 2003; Saillant *et al*., 2004) were used for this study: *Nme 5B10*, *Nme 18C2*, *Nme 6A7*, *Nme 25C8*, *Nme18A6*, *Nme 2D5*, *Nme 2B10*, *Nme 4F4* and *Nme 30F12*. PCRs were performed in 10 μl total volumes, composed of the following: 50 ng μl^{-1} genomic DNA, 10× *Taq* buffer (Promega Corporation; promega.com), 0·6 μl of 10 μM deoxynucleotide triphosphate (dNTP) (Perkin-Elmer; perkinelmer.com), 1–2·5 mM $MgCl_2$, 0·16 μM reverse primer, 0·04 μM M13-tagged forward primer, 0·16 μM fluorescently labelled (NED, FAM, VIC and TET) probe and 0·15 units of *Taq* DNA polymerase (Promega Corporation). The thermocycling profile was 94° C for 3 min, followed by 35 cycles of denaturation at 94° C for 30 s, 30 s annealing and 72° C extension for 1 min and a final extension at 72° C for 5 min. Microsatellite genotyping was conducted

TABLE I. Sample size (n) and sampling dates for populations of *Notropis heterodon*. Descriptive statistics for microsatellite loci, including number of alleles (n_A), observed (H_O) and expected (H_E) heterozygosities, allelic richness (A_R; based on 15 individuals) and private allelic richness (P_{AR}) in source and sanctuary populations of *N. heterodon*

Population (n) (sampling dates)		Microsatellite loci									
		Nme2B10	*Nme2D5*	*Nme4F4*	*Nme5B10*	*Nme6A7*	*Nme18A6*	*Nme18C2*	*Nme25C8*	*Nme30F12*	Mean
Cedar Lake ($n = 45$) (2003, 2005)	n_A	7	2	12	7	15	8	12	9	10	9·1
	H_O	0·955	0·800	0·923	0·667	0·778	0·654	0·727	0·654	0·952	0·790
	H_E	0·835	0·720	0·857	0·578	0·886	0·845	0·835	0·567	0·881	0·778
Deep Lake ($n = 57$) (2003, 2005)	n_A	7	1	16	3	9	5	7	9	16	8·1
	H_O	0·923	0·826	1·00	0·353	0·529	0·810	0·800	0·778	0·870	0·765
	H_E	0·749	0·812	0·701	0·559	0·657	0·829	0·760	0·683	0·843	0·733
Source lakes pooled	A_R	8·2	7·8	7·8	3·9	11·5	8·5	7·5	6·8	10·2	8·1
	P_{AR}	1·6	0·8	3·7	0·9	5·9	2·6	2·6	1·8	3·8	2·6
Upper Pond ($n = 47$) (2001, 2005)	n_A	7	2	13	4	9	5	5	7	8	6·6
	H_O	0·957	0·833	0·960	1·00	0·333	0·667	0·500	0·545	0·944	0·749
	H_E	0·726	0·809	0·674	0·500	0·278	0·697	0·406	0·601	0·733	0·603
Lake Leopold ($n = 24$) (2001, 2005)	n_A	7	2	12	5	8	5	6	8	8	6·8
	H_O	1·000	0·733	1·000	0·556	0·500	0·833	0·533	0·737	1·000	0·766
	H_E	0·720	0·858	0·656	0·630	0·569	0·819	0·529	0·662	0·840	0·698
Sanctuary lakes pooled	A_R	7·5	8·6	4·4	4·8	6	8·2	7·7	7·6	7·8	6·9
	P_{AR}	0·9	1·6	0·3	1·8	0·4	2·2	2·8	2·6	1·5	1·6

on an automated ABI 3730 DNA analyser with Genescan 500-LIZ size standard and genotypes were scored using GeneMapper software (Applied Biosystems; www.appliedbiosystems.com).

Exact tests of linkage disequilibrium (LD) between pairs of loci and deviations from Hardy–Weinberg equilibrium (HWE) were tested using Fisher's method and permutation, implemented in Genepop 4.1 (Raymond & Rousset, 1995), with 1000 dememorizations, 100 batches and 1000 iterations. Significance was determined by applying Bonferroni corrections for multiple tests. Genetic variability levels, including mean number of alleles, observed (H_O) and expected (H_E) heterozygosities, were calculated using FSTAT 2.9.3.2 (Goudet, 2001) and Genalex 6.1 (Peakall & Smouse, 2006). Allelic richness and private allelic richness values were assessed using HP-Rare 1.0 (Kalinowski, 2005). For this analysis, genotype data for the source and sanctuary samples were pooled, as the proportion of missing data at the loci *Nme2D5* and *Nme5B10* was limiting the analyses. Wilcoxon sign-rank tests were used to determine if differences in measurements of genetic variation were significantly different between samples. Inbreeding levels were estimated by calculating F_{IS} using Genepop.

Population differentiation was evaluated using conventional (F_{ST}) values and a Bayesian clustering approach. Significance of pair-wise F_{ST} values between samples were tested by permutation (10 000 iterations) using FSTAT. Bayesian assignments were conducted using the programme Structure 2.2 (Pritchard *et al*., 2000) to investigate the genetic structure between the two *Notropis* species as well as the genetic structure within each species; it uses Monte-Carlo Markov Chain (MCMC) approach to assign individuals into genetic clusters. Structure simulations were run for $K = 1$ to $K = 10$ clusters, assuming an admixture ancestry model without using the origin of populations (USEPOPINFO = 0). The simulations were run with a burn-in period of 10 000 and MCMC iterations of 100 000, after convergence of MCMCs. The K value was inferred by comparing the log-likelihood values obtained for each K, and selecting the smallest K before the log-likelihood values level off, as recommended by Pritchard *et al*. (2000). Structure analysis was conducted on all samples (both species) together and separately on samples from each species. Principal co-ordinate analyses (PCA) was conducted using Genalex 6.1 (Peakall & Smouse, 2006) using Nei's distance matrix for multilocus data and standard covariance method.

To determine whether the sampling method using single-day seine collections resulted in collection of close kin, a sibling analysis of each sample was conducted using a likelihood approach of sibship reconstruction as described by Wang (2004) and Wang & Santure (2009), implemented in the computer programme COLONY 2.0.2.0 (Jones & Wang, 2010). Although the mating pattern of *N. heterolepis* and *N. heterodon* is not known, it has been reported that most of the *Notropis* species exhibit broadcast spawning (Johnston, 1992). Therefore, each sample was analysed using the polygamous mating system option and the full-likelihood option. COLONY was run using the observed allele frequencies for each species and error rate due to allelic drop-out and erroneous sizing of alleles of 0 and 0·001, respectively.

The sibship assignment (SA) method of Wang (2009) was used to infer N_e because it has been shown to be more accurate than the heterozygote excess (HE) or LD method and does not assume random mating and an isolated population closed to immigration (Wang, 2009). Values of N_e from SA were estimated using COLONY assuming non-random mating. The 95% c.i. was obtained from bootstrapping.

RESULTS

The microsatellite loci used in this study were moderately polymorphic, and none of the eight samples showed significant deviations from HWE. Overall, F_{IS} values per sample ranged between −0·123 and 0·054, indicating no or very low levels of inbreeding. None of the loci showed LD in either species. Similar levels of genetic variation were observed in both species (Tables I and II). The average number of alleles per locus in *N. heterodon* and *N. heterolepis* was 7·6 and 7·8, respectively. The H_E and H_O levels were not significantly different between the two species (both $P > 0·05$) (Tables I and II). The overall F_{ST} value between *N. heterodon* and *N. heterolepis* was 0·123. Structure analysis determined that two genetic clusters existed and clearly assigned the members of each species into their own cluster.

NOTROPIS HETERODON

For *N. heterodon* samples, the number of alleles observed in the source lakes was higher than that of the sanctuary lakes (Table I). Cedar Lake had a total of 82 alleles (mean per locus 9·1), significantly more than Upper Pond (67, mean 6·6) and Lake Leopold (61, mean 6·8), the two sanctuary lakes ($P < 0·05$). Deep Lake had a total of 73 alleles (mean 8·1), which was also higher than both sanctuary lakes, but not significantly higher. Allelic richness in the pooled source samples ranged from 3·9 to 11·5 (mean per locus 8·4) and from 4·4 to 8·6 (mean per locus 6·9) in the pooled sanctuary samples (Table I), but were not significantly higher in the source samples ($P > 0·05$). Similarly, the private allelic richness values were not statistically different in the source and sanctuary samples ($P > 0·05$).The H_O and H_E levels were similar and not statistically different in the source and sanctuary samples ($P > 0·05$; Table I), with the only exception that Cedar Lake had significantly higher expected heterozygosity than Upper Pond. There were 31 rare alleles (frequency $< 0·1$) in the samples from Cedar Lake, of which 19 (61%) were not observed in the sanctuary-lake samples. Similarly, 24 alleles were observed in Deep Lake samples and 13 (54%) were not detected in sanctuary samples. There were also 12 alleles that were not detected in source fish samples but observed in sanctuary samples.

The F_{ST} values between the two source samples as well as source and sanctuary samples were small and statistically non-significant (Table III). Structure analysis detected two genetic clusters when the fishes from the source and sanctuary samples were analysed together (Fig. 2), but the clusters did not reflect the origin of the individuals, with each cluster containing individuals from both source and sanctuary lakes. There was also a sizeable group of individuals from both the source and the sanctuary lakes that showed mixed ancestry. The PCA analysis indicated differentiation of the Upper Pond and Lake Leopold individuals along co-ordinate 2 [Fig. 3(a)]. Deep Lake individuals showed the highest overlap with individuals from Cedar and Prairie Crossing Lakes.

Sibship analyses using COLONY software indicated that full sibs occurred in six of the eight samples, including all the samples from source lakes (Table IV). The sample with the highest proportion of full sibs was the Cedar Lake 2005 sample, where eight of the 12 individuals were assigned to one of the three full-sib families. It is likely that some of the full-sib families were nested within half-sib families but the markers did not provide enough resolution to identify half sibs with confidence. Estimates of N_e using the SA method (Wang, 2009) were consequently very low, ranging from 7 to 20. The HE method of estimating N_e was not useful, ranging from 0 to >2 million.

TABLE II. Sample size (n) and sampling dates for populations of *Notropis heterolepis*. Descriptive statistics for microsatellite loci, including number of alleles (n_A), observed (H_O) and expected (H_E) heterozygosities, allelic richness (A_R; based on 19 individuals) and private allelic richness (P_{AR}) in source and sanctuary populations of *N. heterolepis*

Population (n) (sampling dates)		Microsatellite loci									
		Nme2B10	*Nme2D5*	*Nme4F4*	*Nme5B10*	*Nme6A7*	*Nme18A6*	*Nme18C2*	*Nme25C8*	*Nme30F12*	Mean
Cedar Lake ($n=64$) (2003, 2005)	n_A	9	5	11	4	13	10	8	7	12	8·8
	H_O	1·000	1·000	0·958	0·533	0·621	0·674	0·750	0·667	0·951	0·795
	H_E	0·727	0·500	0·873	0·569	0·828	0·800	0·782	0·774	0·817	0·741
Deep Lake ($n=36$) (2003, 2005)	n_A	8	7	6	4	6	17	6	11	10	8·3
	H_O	1·00	N/A	0·941	0·500	0·563	0·708	0·654	0·767	0·885	0·752
	H_E	0·779	N/A	0·881	0·406	0·824	0·737	0·712	0·764	0·885	0·748
Source lakes pooled	A_R	6·4	3·0	12·8	8·0	11·6	6·2	8·8	7·9	11·1	8·4
	P_{AR}	1·4	3·0	4·0	5·0	5·3	1·3	3·7	1·1	5·0	3·3
Upper Pond ($n=20$) (2001, 2005)	n_A	9	9	5	2	2	8	3	10	8	6·2
	H_O	1·000	N/A	0·947	0·474	0·571	0·684	0·600	0·900	0·788	0·745
	H_E	0·732	N/A	0·827	0·515	0·710	0·768	0·641	0·767	0·725	0·710
Lake Leopold ($n=44$) (2001, 2005)	n_A	6	9	4	5	6	9	7	8	8	6·9
	H_O	0·944	1·000	1·000	0·571	0·538	0·500	0·727	0·611	0·722	0·663
	H_E	0·701	0·500	0·890	0·602	0·784	0·650	0·727	0·610	0·738	0·632
Sanctuary lakes pooled	A_R	6·6	2·0	11·1	4·7	8·2	5·7	5·3	7·9	7·1	6·5
	P_{AR}	1·5	2·0	2·3	1·7	2·0	0·7	0·3	1·0	1·0	1·4

TABLE III. Pair-wise F_{ST} values of *Notropis heterodon* (lower matrix) and *Notropis heterolepis* (upper matrix in bold). The comparison marked (*) was statistically significant ($P < 0.01$) after Bonferroni correction

	Cedar	Deep	Upper Pond	Leopold
Cedar	–	**0·018**	**0·014**	**0·025***
Deep	0·038	–	**0·028**	**0·032**
Upper Pond	0·042	0·019	–	**0·010**
Lake Leopold	0·070	0·015	0·025	–

NOTROPIS HETEROLEPIS

As with *N. heterodon*, more alleles were found in the source lakes than the sanctuary lakes for *N. heterolepis* (Table II). For example, Cedar Lake had a total of 79 alleles, 23 more than Upper Pond and 17 more than Lake Leopold. Cedar Lake samples had 29 rare alleles (frequency < 0·1), 17 (58%), none of which were found in sanctuary samples. As a result, the mean number of alleles in the Cedar Lake sample was significantly higher than both sanctuary samples ($P < 0.05$ for Cedar Lake and Lake Leopold and $P < 0.05$ for Cedar Lake and Upper Pond comparisons). The allelic richness values in source and sanctuary samples ranged from 3·0 to 12·8 (mean per locus 8·4) and 2·0 to 11·1 (mean per locus 6·5), respectively. Both the allelic richness and private allelic richness values are significantly higher in the source samples ($P < 0.05$) (Table II). Expected heterozygosity in Cedar Lake individuals was also significantly higher than in the Upper Pond samples ($P < 0.05$) (Table II). None of the other comparisons of genetic variability between samples of *N. heterolepis* were significantly different, although Deep Lake fish also had more alleles (75) than fish in the sanctuary lakes. Sixteen of the 19 (84%) rare alleles observed in Deep Lake samples were not detected in sanctuary samples. Nine alleles were found in sanctuary samples but not in source samples.

The level of genetic differentiation between Cedar Lake and Lake Leopold for *N. heterolepis* was moderate but significant based on the pair-wise F_{ST} value (0·025; Table III). Comparisons of pair-wise F_{ST} values indicated that the sanctuary populations were genetically more similar to Cedar Lake *N. heterolepis* than Deep Lake *N. heterolepis* (Table III). Structure analysis detected no genetic clusters within

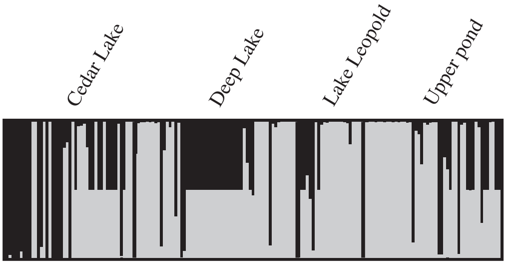
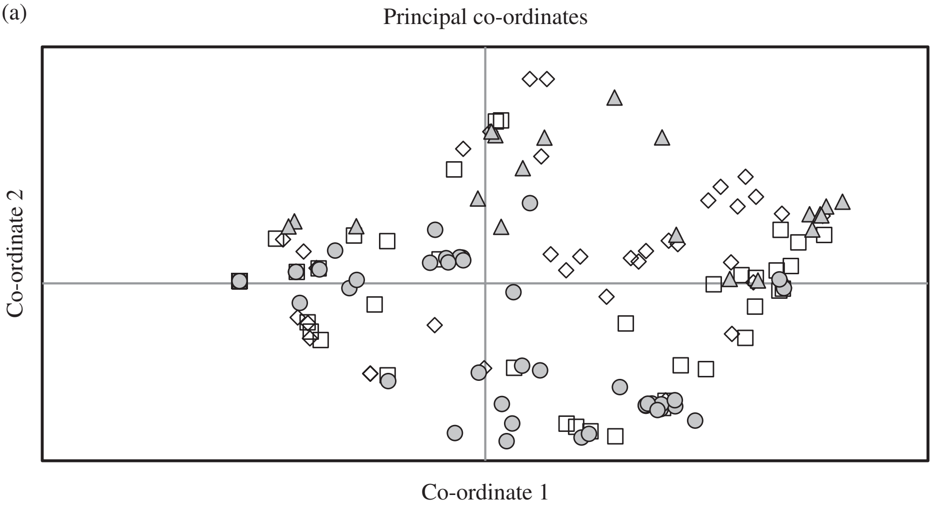


FIG. 2. Bayesian clustering of *Notropis heterodon* individuals from source and sanctuary populations. The coefficients of membership are plotted on the x-axis. ■, individuals belong to genetic cluster 1; □, individuals belong in genetic cluster 2. ▌, separate the sample sets of each lake.

(a)



(b)

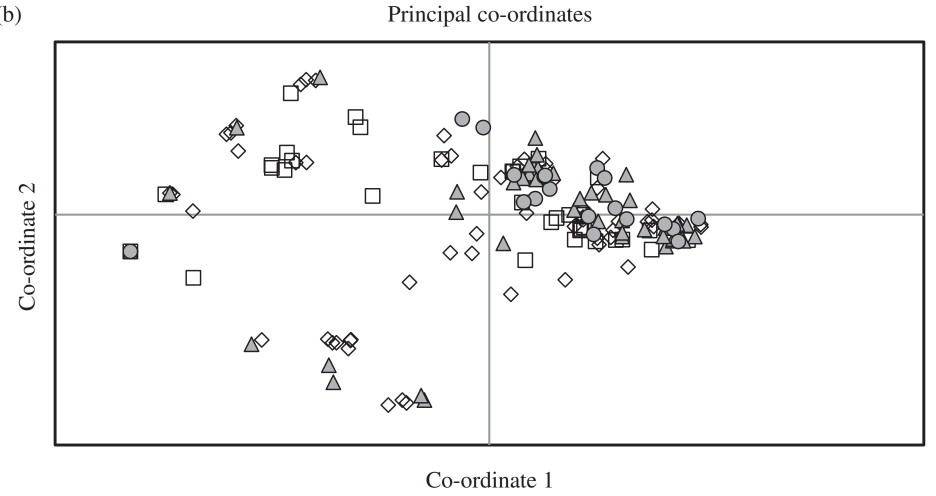


FIG. 3. Principal component analysis of (a) *Notropis heterodon* and (b) *Notropis heterolepis* from the source (open symbols) and sanctuary (shaded symbols) populations. Individuals from: Cedar Lake (◇), Deep Lake (□), Lake Leopold (△) and Upper Pond (○).

N. heterolepis ($K = 1$). PCA also showed no clustering of individuals from source and sanctuary populations of *N. heterolepis* [Fig. 3(b)].

Similar to *N. heterodon* results, the COLONY results indicated the presence of full sibs within five of the six samples for *N. heterolepis*, although, generally, a smaller proportion of individuals in each sample were assigned as a member of a sibship (Table V). The sample with the highest proportion of full sibs was the Deep Lake 2005 sample, where eight of 35 the individuals were assigned to one of the four full-sib families. Estimates of N_e using the SA method (Wang, 2009) were also very low for *N. heterolepis*, ranging from two to 19 (Table V). As with *N. heterodon*, the HE method did not provide useful estimates of N_e.

TABLE IV. Results of sibship analysis for samples of *Notropis heterodon*

Sample	n	Full sibs	Full-sib families	N_e
Cedar Lake 2003	23	8	4	20 (11–41)
Cedar Lake 2005	12	8	3	7 (3–23)
Deep Lake 2003	17	6	3	15 (7–35)
Deep Lake 2005	19	4	2	10 (5–26)
Lake Leopold 2001	8	0	0	10 (4–215 × 10^3)
Lake Leopold 2003	13	0	0	15 (7–42)
Lake Leopold 2005	27	7	3	11(6–26)
Upper Pond 2005	19	2	1	15 (8–34)

n, number of individuals in each sample; full sibs, number of individuals assigned to be a full sib of another individual in the sample with inclusion probability > 0·90; full-sib families, the number of full-sib families with members assigned with inclusion probability > 0·90; N_e (95% C.I.) is the effective population size calculated by the sibship assignment method (Wang, 2009).

DISCUSSION

Conservation programmes that involve reintroductions are labour-intensive and costly and therefore should only be undertaken if studies on the ecology and genetics of the species suggest that they will have high probability for success. Source populations for reintroductions that already have reduced genetic diversity may be problematic, limiting the reintroduced population's potential for adaptive evolution. This study was undertaken to evaluate future reintroduction goals to re-establish populations of *N. heterodon* and *N. heterolepis*, two threatened fish species that have exhibited substantial declines in range and abundance. Presumably, neutral microsatellite markers were used for assessing genetic variation in source and sanctuary populations.

By definition, neutral markers, such as microsatellites, do not directly measure adaptive or ecologically important variation, and results from these markers must be interpreted in their proper context. For example, reduced levels of neutral genetic variability may not correlate with genetic variation in ecologically important

TABLE V. Results of sibship analysis for samples of *Notropis heterolepis*

Sample	n	Full sibs	Full-sib families	N_e
Cedar Lake 2003	28	2	1	15 (8–31)
Cedar Lake 2005	33	6	3	19 (10–38)
Deep Lake 2005	35	8	4	12 (21–41)
Lake Leopold 2001	5	0	0	2 (4–30)
Lake Leopold 2003	11	2	1	7 (3–21)
Upper Pond 2005	39	8	3	6 (11–26)

n, number of individuals in each sample; full sibs, number of individuals assigned to be a full sib of another individual in the sample with inclusion probability > 0·90; full-sib families, the number of full-sib families with members assigned with inclusion probability >0·90; N_e (95% C.I.) is the effective population size calculated by the SA method (Wang, 2009).

quantitative traits (McKay & Latta, 2002; Knopp *et al*., 2007). Populations with the highest levels of genetic diversity in neutral markers may not necessarily be the best genetic source for restorations or translocations (McKay *et al*., 2005). Nevertheless, microsatellites provide estimates of evolutionary patterns and processes from multiple highly variable loci. They can provide important information for conservation management, including inferences of population size, population structure, demographic history, levels of inbreeding, hybridization and resolving taxonomic uncertainties (Frankham, 2010). Here, microsatellite variation in remnant populations of *N. heterodon and N. heterolepis*, as well as sanctuary populations established in man-made lakes, was used to evaluate their potential as appropriate candidates for translocations. Analyses were intended to discern population structure and levels of genetic variation before and after translocation, detect hybridization or inbreeding and to estimate the effective population sizes.

Notropis heterodon and *N. heterolepis* are morphologically and ecologically very similar and they naturally co-occur in Cedar and Deep Lakes. Although they show many similarities in their habitat preferences and many other life-history traits, the results indicate that they are genetically distinct. Cedar Lake and Deep Lake are relatively large lakes that provide different habitat choices for *Notropis*, whereas Lake Leopold and Upper Pond are much smaller lakes, with more limited habitat that could increase the likelihood of hybridization. The results of the genetic analysis show that there is no evidence for hybridization between the two species in either source or sanctuary lakes.

Although declining populations may suffer loss of genetic variation, the results suggest that microsatellite variation observed in the remnant populations of *N. heterodon* and *N. heterolepis* were in the range typically seen in freshwater fish species. A comprehensive review by DeWoody & Avise (2000) on 49 freshwater fish species reports that an average species possesses 7·5 alleles per microsatellite locus and an average heterozygosity level of 0·46. The mean number of alleles per locus per population observed in source populations of both species (*N. heterodon*: 8·1 and 9·1; *N. heterolepis*: 8·3 and 8·8 in Cedar Lake and Deep Lake; Tables II and III) was slightly higher than this average for freshwater species. The average number of alleles per locus in sanctuary populations was slightly below the average (*N. heterodon*: 6·6 and 6·8; *N. heterolepis*: 6·2 and 6·9 in Cedar and Deep Lake). Both the mean H_O and H_E of source and sanctuary populations of *N. heterodon* and *N. heterolepis* were higher than the average for freshwater fishes (Tables II and III).

Genetic studies conducted on two other *Notropis* species, both federally endangered, can be compared to the results reported here. A study on genetic diversity using eight microsatellite loci in the Topeka shiner *Notropis topeka* (Gilbert 1884) reported levels of allelic diversity and heterozygosity for wild populations in Six Mile Creek in South Dakota, Mound Creek in Minnesota and Sugar Creek in Missouri. All three populations showed lower levels of genetic variation compared with the present study populations (Anderson & Sarver, 2008). Another study conducted by Saillant *et al*. (2005) on two wild populations of *N. mekistocholas* found relatively high levels of genetic variation at 22 microsatellite loci and suggest that the genetic differentiation between the two sampled populations could have arisen since the construction of a dam in the early 1900s.

While numerous genetic studies have been conducted on reintroduced freshwater fishes, most involve reintroductions and supplemental stocking of commercial and game fishes and therefore are not directly relevant to the conservation of threatened non-game native fish species. One recent study on the endangered spring endemic watercress darter *Etheostoma nuchale* Howell & Caldwell 1965 found that a population established by translocation of 200 founders maintained levels of microsatellite genetic variation similar to that of the source population (Fluker *et al*., 2010). On the other hand, a captive population of the endangered *N. mekistocholas* had significantly lower genetic variation (number of alleles, allelic richness and gene diversity) at microsatellite loci when compared to the population from which the captive stock was constituted (Saillant *et al*., 2005).

In this study, consistently lower levels of allelic diversity in sanctuary compared with source populations of both *Notropis* species were observed, and in several cases these differences were statistically significant. Source populations harboured more alleles than sanctuary populations. In particular, many rare alleles were not observed in sanctuary populations. It is likely that some of the rare alleles do exist in the sanctuary populations, but were not detected due to insufficient sampling. Even so, there appears to have been a substantial loss of allelic diversity in the sanctuary populations of both species. Fishes possessing rare alleles were never transferred to Prairie Crossing populations, or they were transferred but did not successfully reproduce. In any case, it is evident that genetic drift during translocation changed the allelic composition of the sanctuary populations. These differences are not revealed by reduced heterozygosity levels; both H_O and H_E values were, in most cases, similar in source and sanctuary populations. This is not unexpected, however, because rare alleles contribute little to overall heterozygosity. The findings described above for *N. mekistocholas* together with those reported here for *N. heterolepis* and *N. heterodon* suggest that it may be common to lose allelic diversity when establishing captive populations of small freshwater fishes.

A possible explanation for the loss of allelic diversity during translocation may involve spatially restricted sampling. One issue that has not been adequately addressed with regards to freshwater fishes is whether sampling methods will harvest a random sample of unrelated individuals, or, alternatively, harvest some closely related individuals. The latter might be the case if there are stable associations of kin, as has been shown for at least some salmonids (Hansen *et al*., 1997; Carlsson *et al*., 1999; Fraser *et al*., 2005), but not yet tested, as far as is known, for Cyprinidae or other small, non-game freshwater fishes. These micro-geographic associations of related individuals might result simply from restricted dispersal of cohorts from spawning areas or active aggregation of kin. The sampling approach used here, which involved seining a small portion of shoreline, resulted in the collection of at least some full sibs. Thus, some families were over-represented. This reduced the N_e of the translocated samples. Indeed, estimates of N_e were extremely low (2–20; Tables IV and V), and unrealistic for even small lake populations. This indicates that micro-geographic genetic structure exists even within small lakes and ponds, at least for these two species. If this is a common occurrence, it suggests that harvesting fishes for conservation should include sampling at multiple sites and on multiple occasions to obtain genetically representative stock and to avoid erosion of genetic variability.

It may seem surprising that some alleles were observed in sanctuary but not in source populations of both species. The source-lake samples examined in this study, however, are not the actual founders of the sanctuary-lake populations, so the true founders must have carried alleles not detected in the more recent sample. The original source fishes were collected from different areas of the source lakes for translocations, whereas samplings for this genetic study was limited by permit requirements and low success in catching fishes, and was spatially restricted due to limited physical access to source lakes.

Although sibship analysis demonstrated the presence of family groups within samples, analyses of genetic structure over larger spatial scales produced mixed results. The F_{ST} value between the two source populations was non-significant for *N. heterodon* but significant, although small, for *N. heterolepis*. Neither the Bayesian clustering nor the PCA results suggested that *N. heterodon* and *N. heterolepis* populations of Cedar Lake and Deep Lake populations form distinct genetic clusters (Fig. 3) and suggested that some gene flow between populations of the two source lakes is occurring. This is not surprising as Cedar Lake drains into Deep Lake.

The findings reported here have important implications for the conservation of *N. heterodon* and *N. heterolepis*, and for conservation management of other threatened freshwater fishes. High genetic variation levels with no evidence for inbreeding within Cedar Lake and Deep Lake fish demonstrate that these stocks are good sources for further reintroductions or translocations of *N. heterodon* and *N. heterolepis* in their native range. These results, however, argue against temporally and spatially restricted sampling of source lakes. Indeed, mixing of fishes from these lakes could be considered as there is little evidence for genetic differentiation between Cedar Lake and Deep Lake fish stocks and they have probably experienced recent gene flow. While the sanctuary populations exhibited similar levels of heterozygosity to source populations, allelic diversity was reduced, suggesting that the effective population sizes of the translocated samples were not large enough to prevent founder effects and loss of alleles. While this study does not preclude the use of small, man-made ponds and lakes in management plans, it does suggest that to maintain both heterozygosity and allelic diversity, sanctuary populations will need to be established using several hundred fishes collected from multiple sites, compared to 200 or fewer collected from single sites, as used for the Prairie Crossing sanctuary. While abundant in numbers, fishes in the sanctuary lakes do not appear to fully represent the genetic diversity of the source lakes.

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References

Anderson, C. M. & Sarver, S. K. (2008). Development of polymorphic microsatellite loci for the endangered Topeka shiner, *Notropis topeka*. *Molecular Ecology Resources* **8**, 311–313.

Burr, B. M. (1991). The fishes of Illinois: an overview of a dynamic fauna. *Illinois Natural History Survey Bulletin* **34**, 417–427.

Burridge, C. P. & Gold, J. R. (2003). Conservation genetic studies of the endangered Cape Fear shiner, *Notropis mekistocholas* (Teleostei : Cyprinidae). *Conservation Genetics* **4**, 219–225.

Carlson, D. M. (1997). Status of the pugnose and blackchin shiners in the St. Lawrence River in New York, 1993-95. *Journal of Freshwater Ecology* **12**, 131–139.

Carlsson, J., Olsen, K., Nilsson, J., Øverli, Ø. & Stabell, O. (1999). Microsatellites reveal fine-scale genetic structure in stream-living brown trout. *Journal of Fish Biology* **55**, 1290–1303.

Cloutman, D. G. & Harrell, R. D. (1987). Life history notes on the whitefin shiner, *Notropis niveus* (Pisces: Cyprinidae), in the Broad River, South Carolina. *Copeia* **1987**, 1037–1040.

DeWoody, J. A. & Avise, J. C. (2000). Microsatellite variation in marine, freshwater and anadromous fishes compared with other animals. *Journal of Fish Biology* **56**, 461–473.

Dowling, T. E. & Brown, W. M. (1989). Allozymes, mitochondrial DNA and levels of phylogenetic resolution among four minnow species (*Notropis*: Cyprinidae). *Systematic Zoology* **38**, 126–143.

Fluker, B. L., Kuhajda, B. R., Lang, N. J. & Harris, P. M. (2010). Low genetic diversity and small long-term population sizes in the spring endemic watercress darter, *Etheostoma nuchale*. *Conservation Genetics* **11**, 2267–2279.

Frankham, R. (2010). Challenges and opportunities of genetic approaches to biological conservation. *Biological Conservation* **143**, 1919–1927.

Fraser, D. J., Duchesne, P. & Bernatchez, L. (2005). Migratory charr schools exhibit population and kin associations beyond juvenile stages. *Molecular Ecology* **14**, 3133–3146.

Hansen, M. M., Nielsen, E. & Mensberg, K. L. D. (1997). The problem of sampling families rather than populations: relatedness among individuals in samples of juvenile brown trout *Salmo trutta* L. *Molecular Ecology* **6**, 469–474.

Harrell, R. D. & Cloutman, D. G. (1978). Distribution and life history of the sandbar shiner, *Notropis scepticus* (Pisces: Cyprinidae). *Copeia* **1978**, 443–447.

Johnston, C. E. & Page, L. M. (1992). The evolution of complex reproductive strategies in North American minnows (Cyprinidae). In *Systematics, Historical Ecology, and North American Freshwater Fishes* (Mayden, R. L., ed), pp. 600–621. Stanford, CA: Stanford University Press.

Jones, O. R. & Wang, J. (2010). COLONY: a program for parentage and sibship inference from multilocus genotype data. *Molecular Ecology Resources* **10**, 551–555.

Kalinowski, S. T. (2005). HP-RARE 1.0: a computer program for performing rarefaction on measures of allelic richness. *Molecular Ecology Notes* **5**, 187–189. Available at http://www.montana.edu/kalinowski/KalinowskiReprints/2005_HP-Rare_MolecularEcologyNotes.pdf

Knopp, T., Cano, J. M., Crochet, P. A. & MerilÃ, J. (2007). Contrasting levels of variation in neutral and quantitative genetic loci on island populations of moor frogs (*Rana arvalis*). *Conservation Genetics* **8**, 45–56.

Matthews, M. M. & Heins, D. C. (1984). Life history of the redfin shiner, *Notropis umbratilis* (Pisces: Cyprinidae), in Mississippi. *Copeia* **1984**, 385–390.

Matuzsek, J. E., Goodier, J. & Wales, D. L. (1990). The occurrence of Cyprinidae and other small fish species in relation to pH in Ontario Lakes. *Transactions of the American Fisheries Society* **119**, 850–861.

McKay, J. K. & Latta, R. G. (2002). Adaptive population divergence: markers, QTL and traits. *Trends in Ecology and Evolution* **17**, 285–291.

McKay, J. K., Christian, C. E., Harrison, S. & Rice, K. J. (2005). "How local Is local?"-A review of practical and conceptual issues in the genetics of restoration. *Restoration Ecology* **13**, 432–440.

Nÿboer, R. W., Herkert, J. R. & Ebinger, J. E. (2006). *Endangered and Threatened Species of Illinois: Status and Distribution*, Vol. **2**. Springfield, IL: Illinois Endangered Species Protection Board. Available at http://dnr.state.il.us/ORC/WildlifeResources/theplan/PDFs/2%20From%20Threatened%20&%20Endangered%20Species%20of%20Illinois.pdf

Peakall, R. & Smouse, P. E. (2006). GENALEX 6: genetic analysis in Excel. Population genetic software for teaching and research. *Molecular Ecology Notes* **6**, 288–295.

Pritchard, J. K., Stephens, M. & Donnelly, P. (2000). Inference of population structure using multilocus genotype data. *Genetics* **155**, 945–959.

Raymond, M. & Rousset, F. (1995). Genepop (Version-1.2) – population-genetics software for exact tests and ecumenicism. *Journal of Heredity* **86**, 248–249.

Saillant, E., Patton, J. C., Ross, K. E. & Gold, J. R. (2004). Conservation genetics and demographic history of the endangered Cape Fear shiner (*Notropis mekistocholas*). *Molecular Ecology* **13**, 2947–2958.

Saillant, E., Patton, J. C. & Gold, J. R. (2005). Genetic variation, kinship, and effective population size in a captive population of the endangered Cape Fear shiner, *Notropis mekistocholas*. *Copeia* **2005**, 20–28.

Vrijenhoek, R. C. (1998). Conservation genetics of freshwater fish. *Journal of Fish Biology* **53**, 394–412.

Vrijenhoek, R. C., Douglas, M. E. & Meffe, G. K. (1985). Conservation genetics of endangered fish populations in Arizona. *Science* **229**, 400–402.

Wang, J. (2004). Sibship reconstruction from genetic data with typing errors. *Genetics* **166**, 1963–1979.

Wang, J. (2009). A new method for estimating effective population sizes from a single sample of multilocus genotypes. *Molecular Ecology* **18**, 2148–2164.

Wang, J. & Santure, A. W. (2009). Parentage and sibship inference from multilocus genotype data under polygamy. *Genetics* **181**, 1579–1594.

Electronic Reference

Goudet, J. (2001). *FSTAT, a Program to Estimate and Test Gene Diversities and Fixation Indices,* Version 2.9.3.2, Updated from Goudet 1995. Available at http://www.unilch/izea/softwares/fstat.html/