

FINAL STUDY PLAN FOR MUMMICHOG MARK-RECAPTURE IN THE LOWER PASSAIC RIVER

Prepared by the
U.S. Fish and Wildlife Service
New Jersey Field Office
4 E. Jimmie Leeds Road, Suite 4
Galloway, New Jersey 08205

on behalf of the

DIAMOND ALKALI NATURAL RESOURCE TRUSTEES

U.S. Department of the Interior
U.S. Fish and Wildlife Service
and,
U.S. Department of Commerce
National Oceanic and Atmospheric Administration

May 17, 2021

Executive Summary

The lower Passaic River (LPR), flowing through Bergen, Essex, Hudson, and Passaic Counties in New Jersey, is contaminated through the past and ongoing release of hazardous substances at or from the Diamond Alkali Superfund Site (DASS), including 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), polychlorinated biphenyls (PCBs), chlorinated pesticides, polycyclic aromatic hydrocarbons (PAHs), and heavy metals. The DASS Natural Resource Federal Trustees – the U.S. Department of the Interior, acting by and through the United States Fish and Wildlife Service, and the U.S. Department of Commerce, acting by and through the National Oceanic and Atmospheric Administration (collectively, the “Federal Trustees”), acting under their authority as natural resource trustees pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), are conducting a natural resource damage assessment (NRDA) to determine and quantify the natural resources injured and services lost in the LPR, which is part of the DASS, due to the release of those hazardous substances. The final Natural Resource Damage Assessment Plan (DAP) provides additional detail regarding the environment in this area, the presence of hazardous substances, the role of the Federal Trustees, and the plan for moving forward with the NRDA (Federal Trustees 2020a).

The LPR provides habitat for freshwater and estuarine fish species of multiple feeding guilds. Fish surveys conducted over the course of one year in 2009 and 2010 identified 45 fish species throughout the lower 17.4 miles of the Passaic River (Windward 2019). The Federal Trustees intend to conduct both field and laboratory studies to evaluate injuries to fish in the LPR due to exposure to hazardous substances, and also support the quantification of any such injury.

Pursuant to the DAP, the Federal Trustees have developed this ***Final Study Plan for Mummichog Mark-Recapture in the Lower Passaic River*** (Final Study Plan), for a fish injury assessment effort. This Final Study Plan describes a field study the Federal Trustees intend to undertake to meet the following objectives:

1. measure spatial and temporal scales of mummichog dispersal in the LPR to determine, and as appropriate, quantify injury caused by exposure to hazardous substances;
2. determine the absolute abundance of mummichog in the LPR to determine, and as appropriate, quantify injury caused by exposure to hazardous substances; and
3. quantify mummichog productivity in the LPR to determine, and as appropriate, quantify injury caused by exposure to hazardous substances.

This study will support efforts to evaluate and quantify potential injury to mummichog fish in the LPR. The Federal Trustees may propose additional work to supplement this effort in the future.

The Federal Trustees made a draft of this Study Plan available for review and comment for a

period of 30 calendar days, ending April 14, 2021. The Federal Trustees did not receive any public comments during this time period.

Table of Contents

1.0	Background.....	1
2.0	Introduction.....	2
3.0	Public Review and Participation.....	2
	Study Purpose and Objectives	2
4.0	Methods.....	3
4.1	Study Location	3
4.2	Study Organism.....	3
4.3	Field Tagging and Recapture	3
4.4	Tag-recapture Models	4
5.0	Quality Assurance/Quality Control.....	7
5.1	Project Management.....	7
5.2	Data Generation and Acquisition	7
5.3	Data Quality Objectives	7
6.0	Literature Cited	9

1.0 Background

In 1983, environmental sampling by the State of New Jersey and the U.S. Environmental Protection Agency (EPA) at and near the Diamond Alkali Company facilities, located on the Passaic River at 80-120 Lister Avenue in Newark, New Jersey, revealed high levels hazardous substances including 2,3,7,8-tetrachlordibenzo-*p*-dioxin (TCDD), polychlorinated biphenyls (PCBs) chlorine pesticides, polycyclic aromatic hydrocarbons (PAHs), heavy metals and other hazardous substances in the soil and groundwater. TCDD, PCBs, metals, PAHs and various pesticides were also found in sediment of the Passaic River. Additional sampling revealed hazardous substances throughout Newark Bay and its tributaries, the Hackensack River, the Arthur Kill and Kill Van Kull tidal straits. Subsequently, in September 1984, the EPA through its authorities under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), designated the area as the Diamond Alkali Superfund Site (EPA ID# NJD980528996) (DASS).

CERCLA also stipulates that “*natural resources*” (i.e., land, fish, wildlife, biota, air, water, groundwater, drinking water supplies, and other such resources managed by or otherwise controlled by the United States, any state or local government) be restored to the state that they were at before being adversely impacted, or lost due to the release of a hazardous substance. To this end, CERCLA authorizes Natural Resource Trustees, in the instant matter currently designated as the U.S. Department of the Interior (DOI), acting by and through the U.S. Fish and Wildlife Service (USFWS) and the U.S. Department of Commerce, acting by and through the National Oceanic and Atmospheric Administration (NOAA), hereinafter referred to as the “Federal Trustees,” to act on behalf of the public for the purpose of preparing an “*injury*” claim to recover “*damages*” from potential responsible parties necessary to restore or replace injured natural resources. In accordance with the Natural Resource Damage Assessment (NRDA) regulations (43 C.F.R. Part 11), the Federal Trustees developed a [Natural Resource Damage Assessment Plan](#) (DAP) (Federal Trustees 2020a) that presents an array of potential studies to identify the scope and scale of injury and service losses to natural resources. This ***Final Study Plan for Mummichog Mark-Recapture in the Lower Passaic River*** (Final Study Plan), is one such study. Ultimately, this and other studies are intended to help the Federal Trustees determine and quantify injuries to natural resources, and select the appropriate scope and scale of restoration projects to restore natural resources.

The DAP identified biological injuries to fish as an area the Federal Trustees planned to investigate to determine and quantify potential injury, and understand exposure pathways. As a means of evaluating DASS-related injury to fish species, the Federal Trustees propose to conduct both field and laboratory studies to determine potential adverse effects on fish due to exposure to hazardous substances in the lower Passaic River (LPR).

2.0 Introduction

In accordance with the DAP, the Federal Trustees have developed this Final Study Plan as part of their fish injury assessment effort. Given the goals of the NRDA, and the currently-planned [mummichog fish toxicity study](#) released in 2020 (Federal Trustees 2020b), the Federal Trustees have determined that it is appropriate to conduct further investigations on the life history traits of mummichog in the LPR to more comprehensively evaluate and accurately quantify potential injury to lower trophic level fish.

This Final Study Plan describes a tag and recapture field study to establish the spatial and temporal dispersal, as well as absolute abundance and productivity, of mummichog (*Fundulus heteroclitus*) fish in the LPR. This study will inform future injury quantification, damages determination, and restoration planning in the LPR.

3.0 Public Review and Participation

Public participation and review are an integral part of any NRDA. Public comments help the Federal Trustees plan and conduct a NRDA that is scientifically valid, cost effective, and that incorporates a broad array of perspectives. The Federal Trustees made a draft of this Study Plan available for review and comment for a period of 30 calendar days, ending April 14, 2021. The Federal Trustees did not receive any public comments during this time period.

Study Purpose and Objectives

The purpose of this study is to inform the Federal Trustees' assessment of injury to fish caused by the release of hazardous substances from the DASS, and to guide their future efforts to evaluate contaminant exposure pathways and natural resource injuries, as defined in the Natural Resource Damage Assessment regulations (43 C.F.R. Part 11). The results of this study will also be used to help determine the nature and scope of future studies conducted in accordance with the DAP.

The objectives of this study are to:

1. measure spatial and temporal scales of mummichog dispersal in the LPR to determine, and as appropriate, quantify injury caused by exposure to hazardous substances;
2. determine the absolute abundance of mummichog in the LPR to determine, and as appropriate, quantify injury caused by exposure to hazardous substances; and
3. quantify mummichog productivity in the LPR to determine, and as appropriate, quantify injury caused by exposure to hazardous substances.

4.0 Methods

4.1 Study Location

Mummichog will be captured from the portion of the Passaic River that constitutes the 17.4-mile tidal portion from RM 0 to Dundee Dam (RM 17.4), and potentially other tributaries where suitable mummichog habitat is found.

The Raritan River will serve as an urban reference river for this study, where equivalent tagging and recapture efforts will be conducted.

4.2 Study Organism

As described by Abraham (1985), mummichog, also known as Atlantic killifish, are not commercial or sport fish; however, their distribution and abundance make them important in nearshore and estuarine food webs. They are among the most common killifishes on the Mid-Atlantic coast, and although rarely taken in full seawater, they are tolerant of salinity and temperature fluctuations. Mummichog attain sexual maturity and spawn during their second year. They have a semilunar spawning periodicity during the spawning season; eggs incubate in air and are not submerged until the next spring tide after they are laid. Young mummichog remain on the marsh for 6-8 weeks, then begin to move off with the tides, with the adults. Mummichog are able to subsist on wide variety of prey including diatoms, amphipods, insect larvae, and detritus.

4.3 Field Tagging and Recapture

Beginning in the spring/summer of 2021, mummichog will be baited and trapped in tidal creeks along the LPR using wire mesh traps. Trapping will occur for one to two days, until at least 75 fish are captured at each location. Collected fish will be tagged, measured (to the nearest ± 1.0 mm; total length), and kept in an aerated cooler until released at a single location (denoted Distance 0) for each initial trapping site. Mummichog mortality due to the tagging method has been shown to be minimal (Teo and Able 2003b; Able *et al.* 2006; Jensen *et al.* 2019).

Mummichog fish will be batch marked with wire tags, then subsequently recaptured at pre-determined temporal and spatial intervals. While, in theory, mummichog can be labeled with an individual ID, the fish would need to be dissected to remove the tag and read the ID number. Thus, dissection would result in rapid depletion of the tagged population and limit the study duration. Given this, wire tagging and recapture methods will follow the methods of Teo and Able (2003a) and Jensen *et al.* (2019). In brief, batches of mummichog at each site of the LPR will be tagged using 1.1 mm long $\times$ 0.28 mm diameter coded wire tags. Tags will be injected into the dorsal musculature using a handheld multishot tag injector, and tag placement will be verified using a handheld wand detector (Northwest Marine Technology).

Recaptures, or repeated sampling, of tagged mummichog will occur at fixed intervals, located 5 to 90 m from the release site. In order to maximize expected recaptures from a fixed amount of sampling effort (*i.e.* number of traps), spacing among adjacent recapture locations will be shorter (5 to 10 m) near the release location, and wider and farther away. Recapture sites will be sampled successively over time, from one to as long as 330 days post-release, depending on the continued presence of tagged individuals in the recapture samples.

To recapture tagged mummichog, three traps will be placed on the bottom at the edge/ marsh interface at each location. Trapping periods will be as similar as possible to ensure that total fishing effort is consistent among locations within each study site. For each location, recaptures of tagged individuals will be recorded using the handheld wand scanner and measured (± 1.0 mm; total length). All untagged mummichog will also be counted and recorded. All recaptured mummichog will be released at the site of capture to avoid introducing confounding density-dependent factors or altering dispersal patterns.

Adjustments may be necessary during fish tagging and recapture efforts to best accomplish the objectives of the study. The Federal Trustees and Field Team Leader may make *in situ* decisions regarding sample numbers and locations based on unforeseen circumstances in the field. Any such decisions, and explanation for necessary changes, will be described in the Report of Assessment.

4.4 Tag-recapture Models

Absolute Abundance

Absolute abundance of mummichog will be determined using a mark-recapture field method and the Schumacher-Eschmeyer Model, a robust variant of the Schnabel Model (Schnabel 1938). The Schumacher-Eschmeyer Model applies a linear regression to obtain an estimate of the slope ($1/N$), and thus an estimate of the population size. First published by Schumacher and Eschmeyer (1943), and subsequently summarized by Krebs (1989), the regression model uses the following equation:

$$N = \frac{\sum_{t=1}^s (C_t M_t^2)}{\sum_{t=1}^s (R_t M_t)}$$

where

- N = population estimate in numbers of fish;
- s = total number of samples
- t = sample number, ranging from first (t_1) to last (t_n)
- C_t = total number of individuals caught in sample t
- R_t = number of individuals already marked (recaptures) when caught in sample t
- M_t = number of previously marked individuals in the population before time t th sample is taken

Variance of the Schumacher estimator is derived from the slope of the regression (Sokal and Rohlf 1995; Zar 1996), calculated from the mark-recapture data with the following equation:

$$\text{Variance of } \left(\frac{1}{N}\right) = \frac{\sum(R_t^2/C_t) - \left[(\sum R_t M_t)^2 / \sum C_t M_t^2\right]}{s - 2}$$

where s = number of samples included in the summations.

The standard error of the slope of the regression is calculated using the following equation:

$$\text{Standard Error of } \left(\frac{1}{N}\right) = \sqrt{\frac{\text{Variance of } (1/N)}{\sum(C_t M_t^2)}}$$

and the 95% confidence limits of $1/N = 1/N \pm t(\text{Standard error})$.

Productivity

A separate mark-recapture field protocol, and subsequent spatial model, will be used to estimate mummichog productivity. For a population assumed to be at equilibrium (neither growing nor shrinking), productivity is equal to mortality, which is the mathematical complement of survival. Generally, mortality and dispersal are confounded in mark-recapture analyses since a tagged animal that leaves the study area is indistinguishable from one that has died. However, a spatial capture-recapture model will be used to estimate mortality, as well as dispersal, for batch-marked mummichog. This is important since failing to account for dispersal and its changes over time leads to positively biased estimates of mortality (and therefore negatively biased estimates of maximum age), incorrectly assuming that fish not recaptured later in the study died, when they may have actually moved beyond the study area. The methodology of this model, as applied and published by Jensen *et al.* (2019), is described below.

Specifically, the model will assume the expected number of recaptured individuals, pooled across traps within each site-sampling period, at location i at time t , $E(R_{i,t})$, is related to the number of individuals tagged, survival and dispersal processes, and availability to recapture:

$$E(R_{i,t}) = N_0 S^t D_{i,t} \lambda \quad (1)$$

where $E(R_{i,t})$ = expected number of recaptured individuals at location i at time t
 N_0 = initial number of marked individuals
 S = daily survival rate
 $D_{i,t}$ = relative density of marked individuals at location i and time t (determined by the dispersal model described below)
 λ is a scalar representing the availability of marked individuals to the sampling gear.

Dispersal will be modeled as a relative frequency ‘distribution of dispersal distances’ (DDD) in continuous space (Paradis *et al.* 2002, Flostrand *et al.* 2009) using 3 candidate dispersal models:

$$\text{Half Normal: } D_{i,t} = \sqrt{\frac{2}{\pi\sigma_t^2}} \exp\left(-\frac{x_i^2}{2\sigma_t^2}\right) \quad (2)$$

$$\text{Exponential: } D_{i,t} = \frac{1}{\sigma_t} \exp\left(-\frac{x_i}{\sigma_t}\right) \quad (3)$$

$$\text{Half Cauchy: } D_{i,t} = \frac{2}{\pi\sigma_t\left[1+\left(\frac{x_i}{\sigma_t}\right)^2\right]} \quad (4)$$

where $D_{i,t}$ is the relative density of marked individuals at i and time after release t
 x_i is the distance between i and the release site
 σ_t is the dispersal parameter at t

Scientific literature supports the theory that dispersal distributions should expand over time as individuals move away from the release site. Because the parameter controlling dispersal distance (*i.e.*, the variance for the half-normal distribution) should approach an asymptote, movements in and around home-range centers are governed by an Ornstein-Uhlenbeck biased random walk process, whereas movements between centers (transitions) are described by a stochastic state-switching process. These dynamic dispersal distributions will be quantified in addition to the simple constant dispersal model. Model structures will be quantified in 3 ways:

- (1) as an independent dispersal term estimated at each time t ;
- (2) as a random effect where the dispersal term at each time t is a random value drawn from a lognormal hyper-distribution describing average dispersal; and
- (3) as a 2-parameter asymptotic function of t (Michaelis-Menten).

To account for potential overdispersion (*i.e.* more variability in counts than would be expected from a Poisson distribution), count data will be modeled using a negative binomial distribution, which estimates an additional variance parameter. For each fitted model, the estimated daily survival and maximum age will be calculated. Maximum age can be calculated from daily survival following Hoenig (1983):

$$A_{max} = \exp\left(\frac{1.46 - \log M}{1.01}\right) \quad (5)$$

where A_{max} = Maximum age
 M = mortality rate = $(-365) \times \log S$
 S = the daily survival rate estimated based on Eq. (1)

Modelling will be implemented in R (v3.5.1, R Core Team 2018) using the Template Model Builder package (Kristensen *et al.* 2016) to perform maximum likelihood estimation. Data will

be analyzed for each sampling location separately to allow for comparison. Akaike's information criterion (AIC) will be used to select the most parsimonious model structure.

5.0 Quality Assurance/Quality Control

A detailed Quality Assurance Project Plan (QAPP) is being developed, in collaboration with the field contractor for this study. The QAPP will be consistent with the project management, data generation and acquisition, assessment and oversight, and data validation and usability objectives defined in Appendix A of the final DAP (Federal Trustees 2020a), and will be included in the Report of Assessment.

5.1 Project Management

The U.S. Fish and Wildlife Service (USFWS) is managing this study on behalf of the Federal Trustees. The project management organization for this Final Study Plan is consistent with that presented in Appendix A of the DAP (see Exhibit A-1, Federal Trustees 2020a). The Field Team Leader/Principal Investigator will report directly to the USFWS Assessment Managers. The Quality Assurance (QA) Coordinator at Industrial Economics, Incorporated (IEC) will oversee Quality Assurance and Quality Control (QC) of the study, including whether specified QA/QC procedures are followed as described. The QA Coordinator will discuss any identified issues with the Field Team Leader/Principal Investigator and the USFWS Assessment Managers as the need arises.

5.2 Data Generation and Acquisition

It is important ensure that data of sufficient and known quality are generated through the implementation of this study. The Field Team Leader/Principal Investigator will submit written Standard Operating Procedures (SOPs) detailing respective methods and QC procedures. The USFWS Assessment Managers will review and approve the SOPs, and the QA Coordinator will review aspects related to QC. The approved SOPs will be kept on file.

Modifications to the approved SOPs will be documented in the final study report describing the field collection activities and laboratory results. Minor modifications will be made at the discretion of the Field Team Leader/Principal Investigator. For more significant modifications, the USFWS Assessment Managers will be consulted before modifications are implemented.

5.3 Data Quality Objectives

Data quality objectives (DQOs) are statements including narrative and quantitative criteria that specify the quality and quantity of data to be collected to support a project's goals. The methods and procedures for this study are being developed to achieve the DQOs quickly, safely, and cost-effectively (Exhibit 1).

Exhibit 1 Data Quality Objectives

STEP	DESCRIPTION
Step 1: State the Problem	Contaminants from upland industrial facilities (e.g., Diamond Alkali chemical manufacturing plant) have been released to the DASS. Potential injuries to fish resulting from these releases have not been quantified.
Step 2: Identify the Decision(s)	A mummichog toxicity investigation is currently being conducted to assess injury to mummichog due to contaminants currently in the LPR in advance of scheduled remedial dredging of the lower eight miles of the LPR. Additional data on dispersal, absolute abundance, and productivity will be necessary to quantify injury to mummichog in the LPR.
Step 3: Identify the Inputs to the Decisions	Mummichog dispersal, absolute abundance, and productivity will be calculated based on mark-recapture studies in the LPR.
Step 4: Define Study Boundaries	The LPR is the study area and the Raritan River is the reference area for the purposes of this Final Study Plan.
Step 5: Develop Decision Rules	Input tag-recapture field results into statistical models to calculate dispersal, absolute abundance, and productivity. Use these results, along with results of the toxicity investigation, to assess, and as appropriate, quantify potential injury to mummichog in the LPR compared to the Raritan River.
Step 6: Specify Tolerable Limits on Errors	Appropriate sampling techniques will be utilized to obtain an optimum sample quantity and to identify sampling locations that will meet study objectives. Data review will be performed by the QA Coordinator. Full data packages will be preserved for future review as needed.
Step 7: Optimize Sampling Design	Locations and numbers of samples will be based on a review of existing data combined with professional judgement.

6.0 Literature Cited

- Able KW, Hagan SM, Brown SA. 2006. Habitat use, movement, and growth of young-of-the-year *Fundulus* spp. In southern New Jersey salt marshes; comparisons based on tag/recapture. *J Exp Mar Biol Ecol* 335:177–187.
- Abraham BJ. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic)–mummichog and striped killifish. U.S. Fish and Wildlife Service Biological Report 82(11.40).
- Federal Trustees. 2020a. Natural Resource Damage Assessment Plan for the Diamond Alkali Superfund Site, prepared by the federal natural resource trustees. U.S. Department of Commerce, National Oceanic and Atmospheric Administration; U.S. Department of the Interior, U.S. Fish and Wildlife Service. Final. January 2020.
- Federal Trustees. 2020b. Final Study Plan, Fish Injury of the Lower Passaic River, Diamond Alkali Superfund Site Natural Resource Damage Assessment. Final. July 2020.
- Flostrand LA, Schweigert JF, Daniel KS, Cleary JS. 2009. Measuring and modelling Pacific herring spawning-site fidelity and dispersal using tag-recovery dispersal curves. *ICES J Mar Sci* 66: 1754–1761.
- Hoenig JM. 1983. Empirical use of longevity data to estimate mortality rates. *Fish Bull* (Wash, D.C.) 82: 898–903.
- Jensen OP, Martin CW, Oken KL, Fodrie, FJ, López-Duarte PC, Able KW, Roberts BJ. 2019. Simultaneous estimation of dispersal and survival of the gulf killifish *Fundulus grandis* from a batch tagging experiment. *Marine Ecology Progress Series*. 624:183–194.
- Krebs CJ. 1989. *Ecological Methodologies*. Harper and Row, New York, NY. 654 p.
- Kristensen K, Nielsen A, Berg CW, Skaug H, Bell BM. 2016. TMB: Automatic differentiation and Laplace approximation. *J Stat Softw* 70: 1–21.
- Paradis E, Baillie SR, Sutherland WJ. 2002. Modeling largescale dispersal distances. *Ecol Modell* 151: 279–292.
- Schnabel ZW. 1938 The Estimation of the Total Fish Population of a Lake. *The American Mathematical Monthly* 45(6): 348-352.
- Schumacher FX and Eschmeyer RW. 1943. The estimation of fish populations in lakes and ponds. *Journal of the Tennessee Academy of Science* 18: 228–249.
- Sokal RR and Rohlf FJ. 1995. *Biometry: The Principles and Practice of Statistics in Biological Research*. 3rd Edition, W.H. Freeman and Co., New York.

Teo SLH, Able KW. 2003a. Growth and production of the mummichog (*Fundulus heteroclitus*) in a restored salt marsh. *Estuaries* 26:51–63.

Teo, SLH., Able, KW. 2003b. Habitat use and movement of the mummichog (*Fundulus heteroclitus*) in a restored salt marsh. *Estuaries* 26, 720–730.

Windward Environmental, L.L.C. (Windward). 2019. Lower Passaic River Study Area Baseline Ecological Risk Assessment. Final. Prepared for USEPA Region 2 as part of the 17-mile LPRSA Remedial Investigation/Feasibility Study. Windward Environmental LLC, Seattle, WA.

Zar JH.1996 Biostatistical Analysis. 3rd Edition, Prentice Hall.